Mayland, H.F. 1999. Plant Nutrient Content and Animal Health Issues. p. 67-80. Proceedings 34th Annual Meeting Pacific Northwest Animal Nutrition Conference. 12-14 October 1999. Portland, OR.

Plant Nutrient Content and Animal Health Issues

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ABSTRACT

The list of mineral elements necessary for livestock growth is similar to that for plants. It includes K, Ca, Mg, P, S, Cl in relatively large concentrations, as well as the trace minerals Co, Cu, Fe, Mn and Zn. Animals, but not plants, also require Na, Se, and I. Several interactions important to animal health exist. High concentrations of K will reduce Mg and Ca uptake by plants and animals increasing the risk of grass tetany in animals. Interactions of Cu, Mo, and S reduce bioavailability of Cu to animals. High concentrations of S reduce bioavailability of Se to animals.

MINERALS AND ANIMAL HEALTH

Reid and Horvath (1980) and Harris et al. (1989) discuss the influence of herbage minerals on palatability and digestion of forages. Palatability affects total dry matter intake including mineral intake. Total intake and interactions among several of the minerals may greatly impact the bioavailability of the minerals (Ammerman et al., 1995). The following discussion about mineral elements and their effects on animal health is based on paper by Grace and Clark (1991), and McDowell (1992). The points made in the discussion must be considered together with the information given in Table 1 on ruminant mineral requirements. All mineral elements, whether essential or nonessential, can adversely affect an animal if included in the diet at excessively high levels (Gough et al., 1979 and NRC, 1980).

Calcium and Phosphorus

Milk fever or parturient paresis, is characterized by low blood Ca (<1.0 mmol L^{-1}). This disorder occurs during late pregnancy and onset of lactation. It may occur even at high levels of Ca (4.4 g kg^{-1} DM) in the diet. Animals must be treated parenterally with Ca for several days. Calcium:Phosphorus ratio of 2:1 (wt:wt) is ideal, but 8:1 has been tolerated. Animal nutritional guides generally discuss ratios of Ca:P rather than absolute dietary concentrations.

With today's environmental concerns, it is mandatory that we especially consider current levels of P used in animal feeds. The increasing concentrations of P appearing in water supplies have resulted in identifying P as an important pollutant that may contribute to eutrophication in receiving waters.

Magnesium

Hypomagnesemic grass tetany is probably the most important metabolic problem in ruminants (Fontenot, et al.,1989, Mayland, 1988). It is characterized by low blood plasma Mg concentrations (<0.4 mmol L^{-1}) and most assuredly by low urinary Mg concentrations (< 0.8 mmol L^{-1}). Although 2 g Mg kg^{-1} DM is adequate to meet the Mg requirements in most situations, cows and ewes near parturition may need extra Mg (10 to 30 g Mg cow-day^{-1}, 2 to 3 g Mg ewe-day^{-1}).

Magnesium absorption by ruminants is reduced by high concentrations of herbage N and K and low concentrations of readily fermentable carbohydrates. The risk of grass tetany increases exponentially when the herbage K/(Ca+Mg) increases above 2.3 (expressed as moles of charge basis). Prudent use of N and K fertilizers is warranted in order to minimize the risk of grass tetany (Mayland and Wilkinson, 1989). Aluminum in acid soil solutions may also inhibit Ca and Mg uptake by cool-season grasses. This interaction will reduce plant Ca + Mg uptake, and enhance ruminant susceptibility to grass tetany.

Potassium

Very high levels of K are beginning to appear in forages used in feeding dairy cows. These high levels occur because: rations may have additional mineral K added, field producing hay or silage have fertilizer K added and more K may be applied via the manure produced by animals in confined feed lots. The net effect is that we are cycling more and more K on small areas. Forages grown on these fields take up K in concentrations greatly beyond that needed for plant growth.

Potassium levels of 28 g kg^{-1} DM in herbage (Tables 1, 2) provide near maximum herbage yield. However, increases in soluble soil K will reduce uptake of both Ca and Mg by plants, even at solution K levels that result in less than maximum forage yield. Smith et al (1985) reported that Mg concentrations leveled out at 1.9 g kg^{-1} DM when herbage contained ≥25 g K kg^{-1} DM. The Ca concentration continued to decrease to a low of 6 g kg^{-1} DM as forage K increased to 65 g K kg^{-1} DM. High herbage K levels also depressed Mg and Ca absorption by ruminants. Prudent applications of fertilizer K and manure are required to meet plant growth requirements, and maintain bioavailability of Mg and Ca uptake by plants and absorption by animals.

However, K levels in dry, mature, or winter grass (standing or cut, but left in field) may be inadequate for cattle requirements. Minimum critical levels for animals may be in the range of 5 to 10 g kg^{-1} DM. Plant K levels may fall below this level because of K weathering and leaching from the curing forage. During summer, 20 g K kg^{-1} DM may be desired to reduce heat stress in cattle.

Sulfur

Nitrogen:Sulfur ratios of 12:1 are recommended for ruminants. Blind staggers (polioencephalomalacea) may be caused by ruminant animal ingestion of excess sulfate sulfur. This occurs when ruminant organisms reduce SO_4 to the toxic H_2S form.

Nitrates

Nitrate (NO_3^-) accumulates in plant tissue because of luxuriant uptake of soil nitrate when plant metabolism of N is slow or even stopped. The condition is promoted by cool weather, drought or physiological stress that slows growth. Upon ingestion by animals, plant nitrate is initially reduced to nitrite (NO_2^{-1}) in the rumen and then to other nitrogenous forms like ammonia (NH_3) and ammonium (NH_4^+). Upon ingestion and absorbtion, nitite complexes with blood hemoglobin to form a brownish colored methemoglobin which is toxic (Mayland and Cheeke, 1995). Ruminants may be conditioned to small increases in forage NO_3^-. Nevertheless, forages containing 3400 to 4500 mg N kg^{-1} DM as NO_3^- should be considered potentially toxic.

The uptake and accumulation of NO_3^{-1} by grasses was demonstrated by Smith et al. (1985). They reported that when total N in grass increased from 30 g kg^{-1} to 66 g kg^{-1} DM, NO_3-N increased linearly from 0.1 to an excess of 1.4 g kg^{-1}. Prudent use of N fertilizer is warranted.

Cobalt, Copper, Fluorine, and Iodine

Cobalt requirements for sheep are about twice those for cattle. Lambs are most sensitive to Co deficiency. Copper availability is reduced in the presence of increased Mo, S, and Fe intake (Grace and Clark,1991). The formation of thiomolybdates in the gut, reduce the absorption of Cu by the animal. Dietary Cu intake should be decreased in those areas where herbage Mo levels are extremely low. Copper requirements for cattle are about twice those for sheep. Dietary fluorine levels of 1 to 2 mg F kg^{-1} DM, although not required by animals, are beneficial for high tooth and bone density. Concentrations of 4 to 8 mg F kg^{-1} DM will cause brown staining of tooth enamel and concentrations greater than 8 mg F kg^{-1} DM will reduce tooth and bone density and increase tendency for breakage. Drinking water is the primary source of F. High F is most often associated with thermal water. Animal performance can be good on pastures containing 0.3 mg iodine kg^{-1} DM. However, the northern half of the USA and Canada is generally I deficient. Salt (NaCl) is a common carrier of I for both human and domestic livestock. Dietary intakes of 1 to 2 mg I kg^{-1} DM must be considered in the presence of goitrogenic herbage like *Brassicas*.

Manures from confined animal feeding operations often have large residuals of feed additives. The most notable of these are Cu and Zn. Copper toxicity to sheep may be a potential problem if excessive rates of high Cu manure are applied to pastures where sheep graze. Poultry litter absorption on the surface of grass leaves could result in high availability of Cu for consumption by grazing livestock.

Selenium

Selenium is unique (Oldfield et al., 1994) in that it may occur in high to toxic (to animals) levels in herbage grown on Cretaceous geological soils, especially in the Central Plains of North America. In other areas, herbage Se concentrations may be inadequate for animal requirements. Dietary Se requirements range from 0.03 to as much as 1.0 mg Se kg^{-1} DM. The amount depends upon the class of animal and dietary levels of Vitamin E, S, and other factors. The effect of Se is complemented to some extent by that of Vitamin E. High levels of dietary S will counter the availability of Se to ruminants. Whole blood Se concentrations should be > 250 nmol L^{-1}.

Selenium is the only mineral whose supplementation is regulated. Effective 13 September 1993, the US Food and Drug Administration (Food and Drug Administration, 1993) permitted an increase of 0.1 mg Se kg^{-1} (as sodium selenite or sodium selenate) in complete feeds for animals. The use of Se boluses is not permitted. The USA Congress and the President suspended the FDA action until 31 December 1995 (Gloyd, 1994). Thus, during 1995, animal and fowl feeds could contain 0.3 mg Se kg^{-1} and the osmotic Se bolus for cattle could be used as a source of Se. The current status is that none of the controls consider the level of Se in naturally occurring feed stuffs. Selenium deficiency causes white muscle disease, ill thrift, and reduced fertility in animals. Alkali disease and acute toxicosis as selenosis, may occur when animals ingest excess Se (> 5 mg kg^{-1} DM).

Ultra-trace elements

The elements Al, As, Cr, Ni, Si, V, Sn are presumed essential for ruminants although research data are not available. If required, the dietary concentrations must be extremely low. Using the definition of essentiality for plants; one might also add Ba, Br, F, Rb, and Sr. We have measured <0.5 mg Cd kg^{-1} DM and 0.5 to 6 mg F kg^{-1} DM in grass herbage.

Silicon

Plant Si uptake and subsequent deposition in leaf-cell wall and leaf perimeters provides physical support to the plant. Silicon deposits also reduce susceptibility to insect and fungal attack and may also affect animal preference (Shewmaker et al., 1989). Silicon reduces digestibility of forage by 1) acting as a varnish on the plant cell wall and reducing accessibility to rumen microflora, 2) complexing with trace elements like Zn and reducing their availability to rumen microflora, or 3) complexing with some of the enzymes that are integrally involved in rumen metabolism.

Urolithiasis

Male sheep or cattle are more prone to kidney stones when the dietary Ca:P is less than 2:1, or when ingested silicon is high and water intake is limited. Supplementing Ca will reduce the incidence of this problem only if the stones are analyzed as containing high concentrations of P. Providing adequate and quality drinking water will reduce the incidence of silicosis.

Soil Contamination

Mineral element concentrations of analyzed herbage samples may be significantly biased by the presence of dust or soil adhering to the material. Such contamination is reflected by sample Fe concentrations > 250 to 500 mg kg^{-1} DM (Mayland and Wilkinson, 1989). Soil contamination on herbage may elevate the intake of Fe, Mn, Se, Co, and other elements above the true elemental composition of the herbage. Direct soil ingestion by animals may also affect the intake of some mineral elements (Mayland et al., 1977).

SUMMARY

Discussions of mineral nutrition of forages must include the mineral element needs of forages and animals. Plants require six macronutrient (N, K, Ca, Mg, P, and S) in concentrations exceeding 1 g kg^{-1} DM. They also require seven micronutrients (B, Cl, Cu, Fe, Mn, Mo, and Zn) in concentrations ranging from 0.1 to 100 mg kg^{-1} DM. Some ultratrace elements like Ni, Co, Si, and Na may also be needed by cool-season grasses.

Grazing and dry-lotted animals require eight macronutrients. This list includes the same six needed by plants plus Na and Cl. Animals require some of the same micronutrients as plant (Cu, Fe, Mn, Mo, and Zn) plus Co, I and Se. Animals may also require ultratrace quantities of Cr, Li, and Ni.

Nutrient levels adequate for plant growth may not be adequate for animal growth and good health. Also,

mineral interactions occur at the soil-plant level, but occur more frequently at the animal level.

Often the forage diet will contain nutrient levels considered adequate, but the bioavailability of some minerals may be reduced because of interactions between S and Se; Cu and Zn; K and Mg; and among Mo, Cu, and S; Split applications of K fertilizer will minimize the impact of high K levels on Mg availability to plant and subsequently to animals.

Forages in some geographic areas contain sufficient mineral nutrients to maintain herbage growth, but there may be an insufficient amount of Cu, Mg, Se (not needed by plants), or Zn to meet animal requirements. For example, tall fescue is well adapted to many areas of the USA. Soils in these areas contain little plant-available Se and plants growing on them may not take up sufficient Se to meet animal requirements.

Knowledge of mineral element requirements of both cool-season grass and grazing animals provides essential information for both forage and animal production.

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Table 1. Nutrient element concentrations in cool-season grasses in relation to ruminant requirements (see discussion for interactions).†

Element	Cool season grasses		Dietary requirements‡	
	Critical minimum§	Normal range	Sheep	Cattle
	------------------- g kg^{-1} DM -------------------			
Calcium, Ca	< 2	3 - 6	3 - 4	3 - 4
Chlorine, Cl	0.3 - 1.2	1 - 5	1	2
Magnesium, Mg	1	1 - 3	1	2
Nitrogen, N	25 - 35	20 - 40	10 - 15	10 - 15
Phosphorus, P	2 - 3	2 - 4	2	1 - 3
Potassium, K	20 - 30	20 - 50	3	8
Silicon, Si	n.r.¶	2 - 20	n.r.	n.r.
Sodium, Na	n.r.	<1 - 3	1	1 - 2
Sulfur, S	2 - 3	1 - 3	1 - 2	1 - 2
	------------------- mg kg^{-1} DM -------------------			
Boron, B	< 3	5 - 15	n.r.	n.r.
Copper, Cu	4	5 - 30	5 - 6	7 - 10
Fluorine, F	n.r.	1 - 20	n.r.	n.r.
Iron, Fe	< 50	50 - 150	40	40
Manganese, Mn	20	30 - 100	25	25
Molybdenum, Mo	<0.1.	0.1 - 2	<0.1	<0.1
Zinc, Zn	10 - 14	15 - 60	25	25
	------------------- μg kg^{-1} DM -------------------			
Cobalt, Co	n.r.	50 - 300	100	60
Chromium, Cr	n.r.	200 - 1000	Trace	Trace
Iodine, I	n.r.	40 - 800	500	500
Nickel, Ni	-	200 - 1000	100-800	100-800
Selenium, Se	n.r.	10 - 500	30-200	40-300

† Herbage data are generalized from Gough et al. (1979), Jones and Thomas (1987), Mayland (unpublished), and Reid et al. (1970). Animal data are generalized from, Grace and Clark (1991), Jones and Thomas (1987), NRC (1984, '85, '89). F, while not required by animals is beneficial to bones and teeth.

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

§ Growth is reduced when test values are less than those shown for plants at vegetative to boot stage.

¶ n.r. - not required for C-3 grasses or animal nutrition.

Table 2. Forage composition ($\bar{x} \pm s$) of hay and silage types analyzed by the Northeast DHIA Forage Lab, Ithaca, New York, during the period 1 May 91 to 30 Apr 92 (published with permission of P.K. Sirois, Forage Lab. Manager).

	Hay		Silage	
	Legume	Grass	Legume	Grass
No samples [†]	2287	2061	2608	1257
	------- g kg^{-1} DM -------			
Calcium	14.3 ± 2.9	6.1 ± 2.3	13.8 ± 2.7	7.0 ± 2.6
Magnesium	2.9 ± 0.7	2.0 ± 0.6	2.7 ± 0.5	2.1 ± 0.6
Phosphorus	2.6 ± 0.5	2.3 ± 0.6	3.1 ± 0.5	2.8 ± 0.6
Potassium	23.4 ± 5.3	18.9 ± 5.2	28.8 ± 5.8	24.1 ± 6.8
Sulfur	2.8 ± 0.6	2.2 ± 0.9	2.9 ± 1.1	2.3 ± 0.7
Chlorine	4.7 ± 1.8	4.4 ± 2.9	5.8 ± 2.2	5.4 ± 2.1
	------- mg kg^{-1} DM -------			
Sodium	71 ± 74	370 ± 740	360 ± 430	460 ± 870
Iron	330 ± 3600	171 ± 174	350 ± 376	624 ± 2030
Zinc	24 ± 9	31 ± 17	27 ± 7	34 ± 17
Copper	9 ± 5	10 ± 6	9 ± 3	10 ± 5
Manganese	37 ± 21	79 ± 52	44 ± 22	74 ± 46
Molybdenum	2.3 ± 1.5	1.2 ± 0.8	1.8 ± 0.8	1.6 ± 0.9
Nitrate as N	90 ± 70	110 ± 140	140 ± 140	110 ± 140
	------- g kg^{-1} DM -------			
Total Nitrogen	30.6 ± 4.2	17.6 ± 4.8	32.5 ± 4.8	21.8 ± 5.3
Protein solubility	324 ± 51	290 ± 49	543 ± 86	471 ± 105
ADF	324 ± 45	379 ± 36	358 ± 52	396 ± 46
NDF	418 ± 62	615 ± 64	453 ± 68	599 ± 75
Ash	85 ± 8	64 ± 11	94 ± 16	79 -
Nonstructural Carbohydrates	272 ± 51	182 ± 5	230 ± 47	167 ± 53
Relative feed value [‡]	145 ± 28	91 ± 13	129 ± 28	92 ± 17

† Number of samples for dry matter (DM), Ca, Mg, P, K, acid detergent fiber (ADF), neutral detergent fiber (NDF), and nonstructural carbohydrates (NSC). Remaining data are for ≤35% of that number. Fifty-five percent of samples originated from New York, 25% from other northeastern states, and 20% from other areas of the U.S. Data are reported on dry matter basis.

‡ These values are relative to a forage having 530 g kg^{-1} NDF and 410 g kg^{-1} ADF having RFV = 100.

Interpretive Summary.
Animals require the same mineral elements for growth and reproduction as do plants. In additional, animals also require Na, Se, and I. Optimum ranges of these essential minerals have been established. Of increaseing concern are the interactions that occur between some of these elements. For example, K reduces the bioavailability of Mg and Ca and can be a significant factor in the increased occurrence of grass tetany (hypomagnesemia) in the U.S. Another example is the effect of Mo and S on reducing the bioavailability of Cu. Sulfur is also known to reduce the bioavailability of Se. Knowledge of these interactions helps in diagnosing dietary mineral deficiencies and toxicities.