Trace Mineral Programs and Pasture Quality

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Introduction

Pasture and supplemental feed inputs represent the lion's share of a beef producer's annual expenses and are an ideal starting place for initiating hard-nosed cost control measures. When environmental variation is combined with ever-changing animal nutrient requirements and pasture quality indices, lower feed costs represent a moving target that can only be bull's-eyed with appropriate planning and constant evaluation. An excellent starting place for many operations intent on reducing production costs is an evaluation of the existing pasture mineral supplement program.

An understanding of mineral nutrition requires a solid appreciation of the complexities and interactions which occur between the trace elements as affected by numerous factors (such as soil and environment) and conditions (animal and microbial requirements, ruminal conditions, etc.). Consequently, no class of nutrients has caused as great a confusion among beef producers as the trace minerals. The trace mineral levels found in many commercially available supplements today is a good case in point. Unfortunately, element levels in a mineral supplement are often used as a marketing tool and usually the higher the level, the better perceived the supplement is. Meeting 100% of the animal's requirement with no consideration for the contributions from the trace elements originating from the diet or grazed forage base could potentially lead to toxic levels that create more problems than was originally intended to solve.

Practically every recent review of trace minerals has focused entirely upon animal requirements, trace mineral antagonisms, bioavailability and the subsequent effects of deficiency (or excess) upon immunity, reproduction and performance, with very little discussion of those factors which may potentially affect trace mineral content and variation in forages. The objectives of this paper are to: 1) define the function of trace minerals in plants and how they compare to animal requirements, 2) discuss the effects of forage quality on trace element content and forage intake, 3) discuss the factors which affect absorption of trace minerals by plants, and 4) review techniques for determination of whole plant mineral status.

Plant vs Animal Trace Mineral Requirements

As observed with animals, there are essential trace minerals for specific physiological functions by plants. Gardner et al. has previously outlined the basic function and use of the various elements by plants (Table 1). In general, the elements are assimilated by plants for four primary physiological purposes: 1) basic structure, 2) energy storage and transfer, 3) ionic charge balance and 4) activation of enzymes and electron transport. When expressed as a percent of total weight, plants are composed of approximately 94% carbohydrates (45, 6 and 43% carbon, hydrogen and oxygen, respectively). The remaining 4.5% (less 1.5% nitrogen) comprises the fraction which is potentially available for meeting the grazing ruminant's mineral requirements.

The relative mineral requirements between plants and the various classes of beef cattle[15] are compared in Table 2 with the various elements prioritized in terms of likely deficiency in beef cattle. The relative placement of the various elements helps illustrate the general framework that nutritionists and veterinarians face when attempting to either diagnose a potential deficiency or formulate a supplement to complement the forage type being grazed. For the most part, the levels of the various elements found in plants are relatively comparable in terms of magnitude to those levels identified for attaining cattle requirements. The important question which requires consideration is "Whose mineral requirement is lowest, the animal or the plant?" Situations will exist whereby levels of soil elements are sufficient for plants and yet deficient for beef cattle. Conversely, there are those elements required solely for plants. When deficit, forage yields may be affected with no apparent effect on beef cattle.

Impact of Advancing Maturity on Forage Quality and Intake

Most forage species decline in nutritive value over the course of a growing season. The plant's priorities for allocating nutrients for specific functions changes as it matures. Early season or vegetative growth finds the plant supplying nutrients for enhanced leaf growth area to encourage photosynthetic activity for maximum

Table 1. Function and use of nutrient elements by plants[a]

Elements	Symbol	Approximate Concentration in Dry Matter	Function
		%	
Carbon	C	45	**Basic structure**- Carbohydrates are the building blocks for plant structure and are a source of metabolic energy. By weight, about 45, 6, and 43% of a plant is composed of carbon, hydrogen and oxygen, respectively.
Oxygen	O	45	
Hydrogen	H	6	
Primary Nutrients			**Energy Storage and Transfer Energy**
Nitrogen	N	1.5	- essential constituent of amino acids, amides, nucleotides and is essential to cell division, expansion and therefore, growth.
Phophorus	P	.2	- structure component of a number of vital compounds: ADP, ATP, NAD, NADH, membrane integrity
Sulfur	S	.1	- component of certain amino acids, enzymes and vitamins
Secondary Nutrients			**Charge Balance**
Calcium	Ca	.5	- component of cell wall; essential for cell division and growth
Magnesium	Mg	.2	- center of chlorophyll and essential for hundreds of enzymatic reactions
Potassium	K	1.0	- used by co-factors, maintenance or osmotic potential and water uptake
Trace Nutrients		ppm	**Enzyme activation and electron transport**
Boron	B	20	- influence cell development and inhibits starch formation at the active site of phophorylation
Chlorine	Cl	100	- essential for transformation of oxygen in photosystem II
Cobalt	Co		- formation of Vitamin B12 in symbiotic and free-living N-fixing organisms
Copper	Cu	6	- component of chloroplast enzyme plastocyanin and several oxidases
Iron	Fe	100	- constituent of electron transport enzymes
Manganese	Mn	50	- activates several enzymes - fatty acid and nucleotide synthesis
Molybdenum	Mo	0.1	- plant requirements for Mo is lower than for any of the other mineral nutrients except nickel; involved with nitrite and nitrate reductase
Selenium	Se		
Sodium	Na		- required as a microelement in certain species having the C4 photosynthetic pathway
Zinc	Zn	20	- component in several different enzymes

[a]Compiled from Gardner[8] and Marschner[10]

Table 2. A gross comparison of mineral requirement for plants and animals[a]

Element	Plants: Marginal tissue level	Plants: Range	Likely animal deficiency	Beef cattle stage of production[b]: Grow/ finish	Gestating cow	Lactating cow	Observed animal: Field deficiency	Field toxicity
Sodium,%	NR	.01-high	High	.06-.08	.06-.08	.10	+	
Chlorine,%	<.01	.01-high		--	--	--	+	
Macro-mineral								
Phophorus,%	.1-.2	.14-.30		.2-.3	.2-.3	.2-.3	+	
Magnesium,%	.20			.10	.12	.20	+	
Calcium,%	.04-.10	.03-3.0		.2-.4	.2-.4	.2-.4	+	
Sullfur, %	.025-.10	.12-.30		.15	.15	.15	+	
Trace Mineral								
Zinc,ppm	10-50	30-100		30	30	30	+	
Copper,ppm	5-10			10	10	10	+	
Cobalt,ppm	.08			.10	.10	.10	+	
Iodine,ppm	NR			.50	.50	.50	+	
Selenium,ppm	NR	wide		.10	.10	.10	+	+
Iron,ppm	100	wide		50	50	50	Rare	
Potassium,%	1.0	1.5-3.0		.60	.60	.70	?	
Manganese,ppm	10-20	50-150		20	40	40		
Molybdenum,ppm	.2-.5	3-100		--	--	--	0	+
Silicon,ppm	?(Low)	300-200000					?	+
Boron,ppm	10-50		Low					

[a]Adapted from Van Soest[22]
[b]National Research Council, 1996

uptake of energy and nutrients for growth. During the reproductive stage, the nutrient flow is directed towards the development of a rigid stem "girder network" needed for support of the seed head and for the eventual distribution of seed.

The mineral levels found in plants normally parallel the digestibility pattern and decline with the maturity of forage as cellular content and metabolic tissues diminish (Figure 1). Consequently, one would correctly surmise from Table 1 that the mineral levels found over the growing season in plants and, more specifically, the plant parts correspond with the element's specific function. For example, trace elements which are components of various enzyme systems would be expected to be located in active metabolic tissue such as the leaf (Table 3). Consequently, with advancing maturity and a resulting decline in the leaf:stem ratio, there is a decline in cobalt, copper, iron and zinc levels.

Once absorbed by plants, the internal movement of trace elements may be characterized as mobile, variably mobile or immobile. The extent of the element's mobility has consequences from the standpoint of diagnosing the sufficiency of an element and for determining if and when a supplemental mineral program is necessary. Elements, such as those required for certain enzyme systems, are metabolized and translocated to sites of active growth or during the latter stages of senescence, while others are immobile throughout most of the growing season. Mobile elements such as nitro-

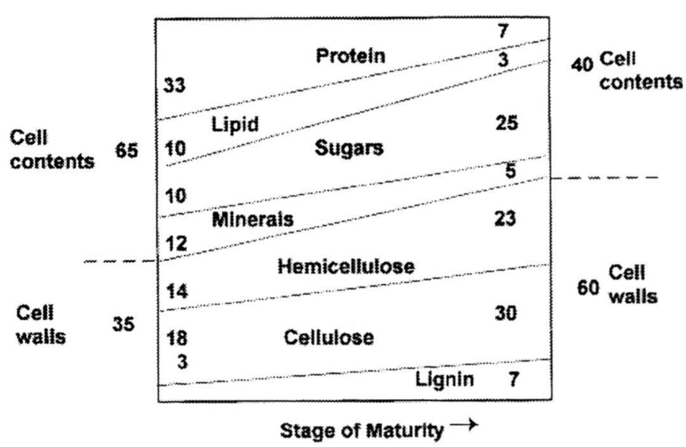

Figure 1. Effect of maturity on the chemical composition of grasses. (Adapted from Beever *et al*[4])

Table 3. Generalization of mineral content as affected by forage characteristics[a]

Mineral	Stage of growth	Plant parts	Species differences	Mobility inside plants
Phosphorus	P level declines as plants increase in size and advance towards maturity	No consistent difference between leaf vs stem fractures	Temperate > Tropical species	Mobile
Magnesium	Mg level declines as plants increase in size and advance towards maturity	Differences exist between leaf and stem	Temperate > Tropical species	Variably mobile
Copper	Cu level declines as forage matures (due to decrease in % of leaf)	Leaves tend to contain greater Cu content than stem	Tropical < Temperate grass Temperate > Tropical legumes	Variably mobile
Zinc	As forage matures, there is an increase in the proportion of stem	Leaves tend to contain greater Zn content than stem	Temperate forages tend to contain slightly less Zn than tropical Grasses tend to contain less than legumes.	Variably mobile
Manganese	In most reported studies, Mn concentration remains relatively constant	No consistent relationship between the Mn content of the leaf and stem fractions	Generally contain similar concentration when Mn level in grass is less than 60 ppm. However, grasses contain more Mn than legumes when grass Mn concentration exceeds 60 ppm.	Immobile
Selenium	?	?	Grasses (both temperate and tropical) contain higher concentration of Se than legumes	--

[a]Compiled from Minson[14]

gen, phosphorus and potassium cycle to the sites of metabolic activity in the plant while immobile elements such as calcium, boron, manganese and molybdenum move into growing plant tissues and remain until the plant part dies and falls off.

One must understand the limitations which exist when interpreting and applying the results of a forage analysis to a production situation. Correctly estimating the approximate level of forage intake is a critical first step for insuring intended trace mineral levels are being met. Generally, forage intake is a function of the structural volume, and therefore the cell wall content of the forage and is dependent upon the rate at which organic matter is removed from the rumen. In turn, the removal rate is a function of the fermentation rate, the rate of particle size reduction and the rate of passage of these forage particles from the rumen. Most often, mature forages do not have sufficient amounts of nitrogen for normal ruminal microbe fermentation. Consequently, digestion is limited by the rate at which nitrogen can be released from the forage and recycled via the blood and saliva. Table 4 provides some guidelines for estimating forage dry matter intake for dry, gestating and lactating beef cows and heifers.

The uncertainty of the manually collected samples not being representative of what livestock are presently selecting for consumption is another limitation of hand-collected forage samples. Forage selectivity essentially takes three forms which include site selection, plant species selection and plant parts selection. As a rule of thumb, beef cattle given adequate availability of forage will tend to select a diet two to three percentage units higher in crude protein than a clipped forage sample. This is illustrated in work by Arthington[2] which demonstrated an increase from two to almost five percentage units in crude protein content from forage selected

Table 4. Forage intake of beef cows and heifers as affected by stage of production, forage quality, and supplement type[a]

	Stage of Production	
Roughage type	Dry gestating (% body weight)	Lactating (% body weight)
Low-quality roughages		
Unsupplemented	1.5	2.0
Protein supplement	1.8	2.2
Energy supplement	1.5	2.0
Average-quality roughages		
Unsupplemented	2.0	2.3
Protein supplement	2.2	2.5
Energy supplement	2.0	2.3
High-quality roughages		
Unsupplemented	2.5	2.7
Protein supplement	2.5	2.7
Energy supplement	2.5	2.7

[a]Hibberd and Thrift[9]

by ruminally fistulated steers relative to hand-clipped samples. Relative to the clipped sample, the Cu, Zn and Mn content in the masticate from the ruminally cannulated cattle changed -8, +4.4 and -13.3%, respectively. This occurrence was not expected in light of the previous discussion regarding the association of these trace elements in the leaf component of the plant. The availability of minerals is quite variable inside the ruminal environment.[16] Generally, minerals in forages are thought to consist of three fractions: 1) a fraction (consisting of Mg, K, P, and Cu) that is very soluble and released rapidly, 2) a fraction that is released slowly over a period of hours as the forage cell wall and (or) protein is degraded, and (3) some elements where the fraction is not released.[20]

Factors Which Affect the Uptake of Minerals by Plants

With the exception of sunlight, the soil is responsible for support and nourishment of the plant with moisture and nutrients for growth. Soils consist of organic material and minerals and are classified by particle size as sand, silt and clay. Sandy soil ranges in particle size from 0.05 to 2 millimeters (mm), silt from .002 to .05 mm and clay particles are less than .002 mm. Sandy soil types consist primarily of larger sized particles and possess less water and oxygen retaining capacity than clay soils, presumably because of the larger surface area each small particle has in relation to size.

Soil nutrients, regardless of soil origin or type, are derived from the weathering of inorganic minerals (parent material) and biodegradation of organic matter. Parent material, soil depth, topography and previous vegetation are the major factors which have a profound impact on the productivity potential of soils. Moreover, the type of parent material (bedrock) present has a profound effect on the density of nutrients available, and thus the plant's capacity for productivity. During the weathering process, some extremely small, negatively charged particles, referred to as colloids, are formed. Consequently, colloids are able to attract the positively charged ions (cations) such as potassium, sodium, hydrogen, calcium and magnesium and repel the negatively charged ions (anions) such as chlorides, nitrates, sulfates and phosphates. Accordingly, the more colloids a soil has the better it can attract cations.

A physical or chemical proximity between the root and the available ions, at the proper time of a plant's stage of growth, is necessary for the assimilation of the elements inside the plant. According to Pearson and Ison,[18] the factors which affect the concentration of the ion at the root/soil interface and the speed from which the plant incorporates the element include: 1) the amount of available element in the soil, 2) the buffering capacity of the soil, and finally, 3) the transport of the specific ion through the soil. The nutrient status of plants is determined to a greater extent by the relative availability of the nutrients rather than the absolute quantity of ions present in the soil medium *per se.* Quite often a deficiency will manifest itself as a reduction in forage yield rather than having a pronounced reduction in the content of the deficient element in the plant.[22]

Soil pH is a primary factor which influences availability of the various elements for plants. As shown in Figure 2, soil pH influences ion solubility and hence the availability of nutrients for plant use. Generally, grasses do best at a pH range from 6.0 to 6.5, although certain grasses do well at low pH partly because of their adaptation to acid soils and reduced competition from other, less adapted grass species. Table 5 illustrates the various factors which influence the absorption efficiency of selected minerals. Under particular soil conditions or environmental conditions, the availability of an ion may be either enhanced or antagonized by the presence of other ions.[13] For example, the presence of calcium will accelerate the uptake of potassium, sulfate and phosphates. On the other hand, phosphorus interferes with zinc and iron uptake, and yet enhances magnesium absorption (Blevins, personal communication). The effects of fertilization on subsequent trace element levels in plants depends upon the existing soil mineral supply. Increased plant growth resulting from fertilization may actually dilute the concentrations of the trace elements present.

Unless confronted with a classic textbook example of an acute mineral toxicity or deficiency, any visible

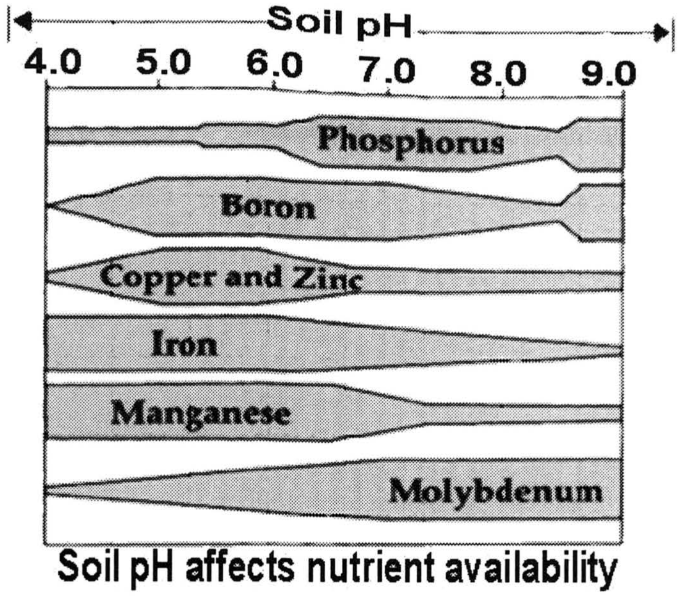

Figure 2. Effects of soil pH on trace element availability[a] (Ball *et al*[3]).

evidence (such as animal appearance and sub-optimal performance) may be quite easily confused with symptoms related to underfeeding or parasitism. Therefore, it becomes imperative to understand the limitations of the various methods available which can provide an early and accurate diagnosis. Unfortunately, documented forage mineral levels across grazing seasons are lacking for specific regions and normally not available when diagnostic support is needed most. When few reliable data are available regarding a specific area, some general information obtained via a soil survey or local FCS and Cooperative Extension personnel may provide some additional clues into potential livestock deficiencies across specific range sites. Mortimer et al[15] conducted a broad survey of mineral content in 709 different forage types from 678 cow/calf operations in 23 states (Table 6). The only trace element which appeared to be consistently deficient (< 20 ppm) across forage type was zinc. Although the ratio of Cu:Mo was greater than 4.5:1 in all cases, all of the forage types contained appreciable levels of the antagonistic elements which impact

Table 5. Factors which affect absorption efficiency of selected minerals by plants[a]

Mineral	Forage species/type	Stage of growth	Nutrient content	Presence of other elements and compounds
Phosphorus (P)	True availability in grass and legume varies considerably	--	Absorption/excretion not altered by increasing protein level in the diet	Apparent absorption of P is related to Ca retention. Phytate may limit availability in mature forage when P is low.
Magnesium (Mg)	Mg in forage has a high potential availability in grasses:possibly lower for legumes	Mg absorption in rapidly growing forages is lower	Absorption appears to be depressed by high levels of crude protein, NH_3 and NH_4 in diet and low soil O_2 conditions	High levels of K, Ca, Mn, H+ (low pH) and a low ratio of Na/K will increase incidence of grass tetany
Copper (Cu)	Large differences in Cu concentration between species. Temperate legumes contain more Cu than temperate grasses	Cu concentrated in leaves relative to stem. As forage matures there is a decrease in the concentration of Cu.	--	Mo, S, Cd, Fe, and Zn Effects most marked when soils high in Fe are combined with forages high in S.
Zinc (Zn)	Because of associated Ca levels, availability is likely higher in grasses vs legumes	--	--	High levels of Ca

[a]Compiled for Minson[14]

Table 6. A summary of forage analysis from cow-calf herds in 23 states[a]

Forage type	No. Samples	% of forage samples deficient[b] <4ppm Cu	<20ppm Mn	<20ppm Zn	Cu/Mo Ratio	<100ppm Se	Copper antagonist, % of forage samples ideal[c] 50-200 Fe	<1 Mo	.15-2% S
Alfalfa	196	.51	1.53	34.2	11.28	23.98	65	30	23
Brome	20	0	0	80	12.54	45.00	50	50	35
Bermuda	112	0	0	8.04	39.22	52.68	83	82	13
Fescue	73	1.37	0	38.36	17.13	78.04	82	49	38
Orchardgrass	34	5.88	0	44.12	15.71	67.65	74	53	44
Sudan	61	1.64	0	31.15	22.10	31.15	51	49	13
Cereal	46	0	2.17	45.65	23.40	52.17	72	65	39
Native	38	0	0	36.84	17.63	39.47	71	63	21
Silage/ Silage grass	31	0	0	32.26	26.88	32.26	61	65	16
Overall	709	.71	.56	33.29	15.66	43.44			

[a]Compiled from Mortimer et al[15]
[b]Mineral values that were identified from the literature by the authors which would likely contribute to a mineral disorder.
[c]Percentage of samples which are ideal or below the established antagonistic levels for those elements which impact the bioavailability of copper.

copper bioavailability (Mo, S and Fe). One could conclude from the results of this survey that the likelihood of a marginal mineral disorder is quite high. Two, five-year summaries of average mineral levels and standard deviations for forages analyzed at Pennsylvania[1] and at Kansas[11] (Table 7) indicated major variation even within a small region.

Use of Forage Samples as an Indicator of an Animal's Mineral Status

There are several methods available which can provide an estimate of mineral status. However, this review will focus primarily on the pros and cons of whole plant sampling. Soil testing has been extensively evaluated as a means of predicting plant levels. Unfortunately, previous research has concluded mineral level in the soil is not indicative of its availability or content in growing plants.[6,19,21] A properly collected forage sample can be quite useful for evaluating the relative trace mineral status of grazing ruminants. Whole plant samples estimate the status of mobile elements since these are likely to be found at reasonable concentrations in new growth regardless of current plant uptake or soil status. Obviously, large grazing areas that consist of numerous species consisting of grasses, forbs and woody species can be problematic.

Improper forage sampling technique can impact profitability and productivity from two different perspectives: 1) a false high analysis which is detrimental to productivity and 2) a false low analysis which results in excessive expense. To avoid this from occurring, it is important to obtain at least 10 forage samples that are representative of the pasture/paddock or from forage harvested from one field (less than 100 tons) at the same cutting and maturity within a 48-hour period. A forage sample obtained from harvested forage should be similar for forage type, field (soil type), cutting date, maturity, variety, weed infestation, type of harvesting equipment, weather experienced during growth and harvest, and finally, storage conditions.

Fick et al[7] has previously summarized some suggested procedures for obtaining a representative sample of forage:

(1) Carefully observe livestock grazing patterns and obtain a sample to represent the animals' diet. Avoid areas where excessive manure has accumulated or from unconsumed areas that has obviously been rejected by animals.
(2) Separate samples from each of the major species should be taken, with estimates for the percentage of each particular species representing the complete sample.
(3) The height of the sample obtained should be representative of plants being consumed.
(4) Take great care in avoiding the possibility of soil-contaminated forage samples.

According to McDowell,[12] elements such as calcium, potassium, phosphorus and molybdenum would not be greatly affected by soil contamination, since soil levels

Table 7. Element content of native grass samples collected during the 1995-1999 growing season in Southwest Kansas[ab]

Item, DM basis	No. of samples	Mean	Standard deviation	Minimum	Maxiumum
Calcium,%	273	0.51	0.20	0.14	1.56
Phophorus,%	274	0.15	0.05	0.06	0.32
Copper, ppm	274	15.1	9.7	2.29	52.7
Iron, ppm	274	306	164	60.6	1320
Molybdenum, ppm	273	1.7	0.95	0.42	6.73
Manganses, ppm	274	41.0	15.2	13.7	104.0
Zinc, ppm	274	34.2	9.8	13.0	81.5

[a]Marston and Yauk[11]
[b]Refer to Table 2 for NRC (1996) animal requirements for comparison.

would be approximately equal to or less than plant material concentrations. On the other hand, soil mineral levels of cobalt, iron, iodine, sodium, manganese and selenium, and to a lesser extent zinc and copper, would be higher than forages. Consequently, even slight contamination "such as caused by splashing rain" could give an erroneously high impression of concentration of these elements.

Conclusions

This paper has reviewed the primary soil and plant factors which affect the trace element content in forage. Only a small fraction of the total minerals present in the soil is available for uptake by the plant. Quite often, there is considerable variation within a geographical region. Because of the multitude of factors that could potentially affect the results of a forage analysis, it is recommended to conduct a routine forage sampling program on a regular basis. In cooperation with a commercial forage testing laboratory (www.SDKLabs.com, SDK Laboratory, Hutchinson, Kansas), a windows-based software program has recently been developed by Kansas State University to assist veterinarians and their clients understand the results of a forage mineral laboratory analysis. Prudent application of the information generated from this program will help insure that appropriate levels of trace elements in the complete mineral complement existing forage levels and are consistent with intended daily intake.

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