Designing mineral supplementation of forage programs for beef cattle

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Abstract

Mineral supplementation programs in the cow-calf/stocker industry range from plain salt/sulfur blocks to highly formulated free-choice mineral supplements containing organic and inorganic sources of minerals. Choice of a mineral supplementation program that provides the greatest return on investment is important in a competitive marketplace. Many variables must be considered when designing the mineral supplement. Environmental condition, management practices, forage type, animal genetics, and physiological state of production make every production system different with respect to needs for mineral supplementation. However, to prevent tremendous complexity in managing mineral supplementation programs, average environments, forage mineral supplies, animal characteristics, and production levels are generally used as a starting point. In unique situations, formulations can be altered to account for variances from the norm. However, care must be taken to avoid critical negative mineral-to-mineral interactions that are known to exist. It is not uncommon to create a completely new problem when changing a mineral supplement program to fix an old problem. Choice of supplement ingredients is also critical to ensure adequate mineral absorbability. In addition, the mineral supplement providing the best mixture of mineral salts to meet production needs is of little value if consumption is not adequate. These issues are discussed with respect to forage supply of minerals meeting animal requirements.

Key Words: Minerals, Feed Supplements, Beef Cattle, Forage

Introduction

Forage production is the foundation of the beef cattle industry. Beef cattle may derive 85% of their diet from forage, with the remaining 15% being derived from supplements and(or) feedyard diets. Many forage crops are produced on agricultural lands not suited for other crops, and beef cattle make efficient harvesters of these economically important commodities. However, forage alone does not provide a complete feed for cattle (Greene, 1997). In order to maintain long-term production, mineral supplementation is needed. Mineral supplementation for grazing cows is required for optimal reproduction, immunity, lactation, and growth (Corah and Ives, 1991; Ansotegui et al., 1994; Greene, 1997). Development of mineral supplements to meet grazing cattle's requirements often becomes a difficult and challenging problem due to 1) changes in animal requirements with stage and level of production, 2) differences in forage supply of minerals, and 3) methods to supply cost-effective supplemental minerals that ensure adequate intake and bioavailability. This article describes these factors with respect to matching the grazing animal's requirements to mineral supply from forage and supplements.

Discussion

Mineral Requirements of Cattle

Table 1 shows the mineral requirements of beef cattle. Prediction of specific dietary requirements is difficult to assess in grazing environments because of several factors. The major factors dictating the dietary requirement include mineral utilization from forages, mineral interactions, and stage and level of production.

Macromineral Requirements. The Ca and P requirements of grazing cattle are dependent on stage and level of production (NRC, 1996). Major changes occur in Ca requirements during the transition from gestation to lactation. Although Ca requirements increase at calving, hypocalcemia is not a major practical problem in beef cows. Calcium deficiency is not a significant problem in growing calves. Phosphorus is the mineral that provides the greatest return on investment when supplemented (McDowell, 1996). It is the most deficient mineral throughout the world for grazing livestock. Phosphorus plays an intimate role in energy metabolism, causing an energy deficiency in phosphorus-deficient animals (Greene et al., 1985). Consequently, a significant reduction in production and reproduction occurs in the presence of a P deficiency. Unlike Ca, P deficiency is likely when cattle graze non-P-fertilized forages and native ranges. Phosphorus is usually adequate when cattle graze P-fertilized grasses.

The Mg requirements for growing, pregnant, and lactating cattle are .10, .12, and .20%, respectively (NRC, 1996). The change in requirement from gestation to lactation occurs very rapidly and is the cause of a metabolic disorder, grass tetany, in cows grazing cool-season forages (Mayland et al., 1990). This malady does not seem to be as prominent in cows grazing less-productive warm-season perennial pastures or native range even though dietary Mg levels may be below .2%. The lush-growth cool-season perennial forage is high in K. Potassium has been shown to reduce Mg absorption in the ruminant stomach (Greene et al., 1983; Fontenot et al., 1989). Additionally, cattle of British and Continental breeding are more often diagnosed with the grass tetany syndrome than those of Zebu breeding (Greene et al., 1989). Consequently, Mg supplementation should be increased for lactating cows of British and Continental origin when they are grazing cool-season perennial or annual forages.

Sodium and Cl are electrolytes that regulate cellular osmotic pressure, Na^+/ K^+ pump activity, and acid-base balance (Underwood and Suttle, 1999). These minerals must be supplied daily and are closely regulated via kidney/hormonal systems (White et al., 1978). Forage Na is often below animal requirements and supplementation is necessary. Cattle will crave salt and consume it in excess when it is provided free-choice. It is the base of many free-choice mineral supplements.

Potassium deficiency is not likely to occur in cattle grazing actively growing forages, but it can create a problem if it is too high (> 2.5%). The problem is due to a reduction in Mg availability in cows (Greene et al., 1983). However, this problem does not affect calves grazing forages high in K (> 2.5%). Dead plant material is low in K (Greene et al., 1987) and below animal requirements.

Sulfur is more often too high instead of too low in grazing animal diets. In some production environments S can be high in the water. The major problem with consuming S at levels higher than requirements is the antagonist effect of S plus Mo on Cu availability.

Micromineral Requirements. These requirements do not change with stage or level of production (NRC, 1996), with the exception of Mn, for which the requirement doubles from growing calves to gestating and lactating cows and heifers. Cobalt is required for the synthesis of vitamin B_{12} by the ruminal microbial population. A dietary concentration of .1 ppm Co usually provides adequate Co for rumen function. In the United States, cobalt deficiencies are not widespread and occur most often in the tropical regions of the country (McDowell, 1996).

Copper requirements are set at 10 ppm (NRC, 1996) and vary depending on other dietary components. In the reducing environment of the rumen, Mo and S form thiomolybdates when excesses of these elements are fed. Thiomolybdate complexes Cu at both the gastrointestinal and tissue level, rendering it unavailable to the animal (Suttle,1991). Additionally, elevated dietary concentrations of Fe also act to exacerbate a Cu deficiency. A survey of nine Midwestern states conducted by Montana State University (Greene et al., 1998b) showed that liver Cu concentrations are generally deficient in grazing beef cattle for optimum performance and immune response. Significant genetic variation also exists to increase the demand for dietary Cu. Ward et al. (1995) indicated that Simmental and Charolais cows were more likely to display signs of a Cu deficiency than Angus cows. Woolliams et al. (1986) showed that selection of ram lambs for four generations could reduce Cu deficiency in these animals. The low Cu status of ruminants derives from 1) a low forage Cu concentration, 2) an elevated concentration of known Cu antagonist, or 3) a combination of these two.

Iodine requirements are set at .5 ppm, and this element functions to regulate metabolism. A widespread deficiency of this element does not exist, but deficiencies do occur in specific regions of the country. Iodine can be supplemented by the use of iodized salt. It is often supplemented in the organic form, ethylenediaminedihydroiodide, in therapeutic doses. The use of organic I as a therapeutic agent is regulated by FDA.

Iron deficiency does not occur very often in grazing beef cattle in the United States. It is not uncommon to find dietary Fe concentrations well over two times the requirement in forages. Excess dietary Fe has detrimental effects on the bioavailability of Cu. Regardless of these facts, it is not uncommon to find Fe salts added to free-choice mineral supplements at 1% or higher as a coloring agent. This practice is not justified except to meet the perception of producers that a good mineral has to be red in color. Feed manufactures include FeO in free-choice mineral supplements as a marketing tool. Although FeO is not very absorbable, additional Fe can potentially act to exacerbate an already low Cu status in cattle.

Manganese is often supplemented to cattle to prevent any deficiencies that may exist. However, little information is available on the specific needs of Mn supplementation to grazing calves. Manganese content of forages is variable and usually higher than cattle requirements. Identification of a Mn deficiency is difficult to determine due to the inconspicuousness of the deficiency symptoms.

Although deficiencies of Se severe enough to cause clinical signs of white muscle disease are scarce in grazing cattle, subclinical deficiencies do occur and often affect production efficiency and health. Forages produced in certain geographical regions are extremely low in Se, whereas forages produced in other regions can act as Se accumulators. Due to the rather small window of safety, excess Se supplementation should be avoided unless known deficiencies occur. Currently, FDA allows up to .3 ppm dietary Se to be fed.

Zinc requirements of 30 ppm are often not met for grazing cattle. Table 2 shows average forage Zn concentrations from 17.8 to 32.5 ppm. In evaluating forage Zn concentrations from various production environments, tremendous variation exists. To prevent possible production losses, an available supplemental source of Zn is recommended. Zinc is intimately involved with animal health. As a consequence, supplementation of Zn for its therapeutic properties is often practiced in feeding cattle. However, care must be taken to prevent potential negative interactions by including higher than normal levels of Zn in the diet. Elevated Zn intake stimulates metallothionein synthesis for Zn transport across the intestine and storage in the liver. Metallothionein binds Cu more strongly than Zn, and increased levels of metallothionein can exacerbate a Cu deficiency.

Mineral Composition of Forages

Forage mineral composition is dependent on many factors, including soil characteristics (Brady, 1974), stage of plant growth (Greene et al., 1987), climatic conditions, and fertilization practices (Mayland et al., 1990). Soils are different with respect to the minerals found in the soil matrix.

Sandy soils often allow minerals to leach more easily from the growing surface than heavier clay soils. Soil acidity also affects the availability of soil minerals for uptake by roots and subsequent translocation to plant tissues. The controlling factor that can potentially alter forage mineral composition more than any other practice is fertilization. However, from an economic standpoint, forages should be fertilized to meet the growth characteristics of the plant and then, when minerals are deficient, supplementation to the animal should be practiced. Greene et al. (1987) showed that actively growing plant tissue had much higher concentrations of P, Mg, and K than nonactively growing plant tissue. Any environmental factors (e.g., rainfall or temperature) that affect plant growth will alter the ability of the plant to translocate minerals from the soil to plant tissues and thereby alter mineral composition. Micromineral concentration of forages across growing seasons is generally less variable than macromineral concentrations. A number of data sets exist in independent laboratories to characterize forage mineral concentrations for different forage types and growing seasons, but very few of these data sets are published. A few known data sets were compiled (Table 2), and mineral composition was averaged across similar forage types.

Legume forages contain over twice the amount of Ca as grasses and are more than adequate to meet animal requirements. The data suggest that Zn is the most deficient trace mineral in legumes, with an average value of 23 ppm. The average Cu concentration for legumes is adequate for meeting most animal requirements. Selenium concentration of legume forage was higher than that of warm-season grasses. However, it must be noted that forage Se concentrations change considerably depending on soil Se levels.

Warm-season grasses included in Table 2 suggest that most grazing animal mineral requirements will be met except for Cu and Zn. All data sets presented in the warm-season grasses category in Table 2 were below cattle requirements for Cu and Zn, with the exception of the five millet samples presented by Kappel et al. (1985). Additionally, Cu composition of some warm-season grasses will not meet the lactation requirement of cows and will depend on soil Cu concentrations. Mineral composition of cool-season grasses is not drastically different from that of warm-season grasses, and Cu and Zn again are found to be the most limiting trace minerals (Table 2).

Native grasses provide a much greater challenge in developing mineral supplementation programs than fertilized forages. In the Greene et al. (1998a) and Corah and Dargatz (1996) data sets, and in another data set (K. Mills, Exell-Key Grain Co., unpublished data), P, Mg, and K are much lower than data reported for fertilized grasses. Livestock grazing native forages must be supplemented extensively with P in order to meet requirements. Native forage Mg meets requirements for gestation, but not lactation. However, there are not many reported cases of a Mg deficiency in livestock grazing native forage. Similar to fertilized grasses, native pastures are often deficient in Zn and Cu.

The data presented in Table 2 provide basic information on the potential need for specific mineral supplementation. Although many of the data sets used in compiling the information contained significant sample sizes, the information is limited due to variation and ranges found in the data. Additionally, the data presented do not address the absorbability of minerals from the forages. Underwood and Suttle (1999) indicate that data are too limited to predict mineral absorbability from forages. Consequently, there are too many confounding factors (e.g., soil type, fertilization methods, absorbability, and rainfall) that make it impossible to apply average values from the data sets to a specific pasture or range. Predicting forage mineral composition is difficult due to the large variation observed. When developing or "fine-tuning" a mineral supplement, a forage sampling and analysis scheme for the specific production environment is recommended.

Method of Mineral Supplementation

Meeting the mineral requirement for grazing cattle often becomes a challenge. Identification of minerals not being supplied in adequate quantities by the diet is necessary. Compounding this endeavor is the various mineral interactions/imbalances that occur. Additionally, the decision on method of mineral supplementation must be made.

Minerals can be provided by either an indirect or direct route (McDowell, 1996). Indirect methods of mineral supplementation include using mineral-containing fertilizers, altering soil pH, and encouraging the establishment of certain forage species that are known to be adequate in minerals of concern. Increasing soil pH can influence the uptake of certain minerals, such as Se and Mo, but it decreases the uptake of Cu and Co (McDowell, 1996). From Table 2, it is evident that different forage species have the propensity to supply different concentrations of minerals to grazing animals. The P and K content of forages can be increased in environments where climate conditions exist to promote growth and uptake of soil minerals.

Foliar application of Mg and some trace minerals (Cu, Co, and Zn) can increase the consumption of these minerals by cattle (Robinson et al., 1989; McDowell, 1996). Valle et al. (1993) showed that foliar application of Se increased Se intake. However, mineral fertilization should be only practiced to improve production characteristics of the forage. Mineral fertilization is not an efficient method of increasing the intake of minerals to animals. After fertilization with mineral to maximize soil fertility for forage growth, if forage mineral supply is still inadequate alternate methods to increase mineral intake will be more economical.

Direct methods of mineral supplementation include adding minerals to the water, oral drenching, injection, ruminal boluses, force-feeding in protein/energy feeds, and free-choice supplementation. Oral drenching of minerals is an effective way of providing minerals to cattle, but it is not very practical. Orally drenched minerals will pass through the digestive tract rapidly with little time allowed for absorption. Continual drenching on multiple days will be more effective than a one-time dose, but it is extremely labor-intensive in a commercial production system and is not recommended as a method of providing minerals to cattle. Injection of Cu and Se has been used to increase the status of these minerals but it is not an effective method. Copper glycinate was used as an injectable source several years ago but has since been removed from the marketplace. Selenium injections will increase the status of this mineral, but the response is not long-lasting. Oral dosing of trace mineral boluses is an acceptable method of providing specific trace minerals. This method is not recommended for macromineral supplementation due to the large amount of mineral required in the bolus. When a specific trace-mineral deficiency is diagnosed, this route of administration allows for the direct supplementation of the deficient mineral, especially Cu, Co, I, and Se. Rogers et al. (1996) showed an increase in I, Se, and Co by using a ruminal bolus containing these minerals. MacPherson (1983) showed that Cu status was increased in cows given oral doses of CuO needles. Copper oxide needles are small rods that lodge in the reticulum and are flushed through the reticular-omasal oriface to the abomasum over a period of time. After the CuO rods enter the acid environment of the abomasum, they lodge in the abomasal folds and are dissolved, releasing Cu for absorption in the small intestine. The above methods of supplementation require handling animals and physically administering the mineral supplement. However, each animal will receive the prescribed dose of mineral being administered.

Supplementation of minerals in water or a supplement will result in more animal-to-animal variation in the amount of mineral consumed compared to other methods. As early as the 1940s, P supplements were being successfully added to water as a source of P (Black et al., 1943) to eliminate severe P deficiencies of southern Texas cow herds. Additionally, recommendations have been made to add $CuSO_4$ to water tanks as a method to rapidly increase Cu status of Cu-deficient cows. However, these methods are fruitless if cattle have access to other sources of water.

Providing minerals in protein/energy feeds will ensure consumption but intake variation will exist. The protein/energy feeds will be a good carrier for mineral salts but will also provide mineral themselves. Feeding 1 kg of natural protein (e.g., cottonseed meal or soybean meal) supplement to grazing cows daily can supply 25% of the cows' P requirement. However, protein/energy feeds are not needed year round and cannot economically be used as a long-term method of providing minerals.

The most widely used direct method of feeding minerals to grazing cattle is free-choice mineral supplements. Development of palatable free-choice mineral supplements is as much an art as it is a science. Formulation of the supplement to supply minerals in the exact ratios is useless if the supplement is not consumed in adequate quantities. Intake of free-choice mineral supplements is variable from animal to animal. Some cattle will overconsume and others will underconsume the supplement. Regulation of consumption is the greatest problem to overcome when providing minerals free choice. Cattle will consume NaCl in excess. Consequently, it is often used as the base for free-choice supplements. Other inorganic mineral salts are not as palatable, especially P and Mg, and tend to reduce the consumption of free-choice supplements. When providing a complete free-choice mineral supplement, all other sources of NaCl should be removed from the pasture. Other sources of Na (e.g., forage, water, and soil) can reduce the free-choice consumption of the mineral supplement. Palatability of the free-choice mineral can be enhanced by the addition of other feedstuffs such as protein or energy feeds, molasses, and flavor enhancers. Generally, the formulation of free-choice mineral supplement is prepared for a target intake of between 56 and 114 g $\cdot$ animal^{-1} $\cdot$ d^{-1}.

Formulation of Free-Choice Supplements

Formulation strategies for free-choice mineral supplements can become complex due to differences in forage mineral availability, interactions among minerals, and difficulty in assessing mineral status of animals. Ideally, free-choice mineral supplement changes with stage of animal production and forage mineral composition, but this is not practical from a management standpoint. The easiest free-choice mineral supplement to manage is to supply the same supplement year-round to all classes of grazing cattle, but this will not work when trying to meet the mineral needs of grazing cattle at specific times. Obviously, a compromise between the ideal and most easily managed is a choice to be made by individual producers. Commercial suppliers of free-choice mineral supplements would be overwhelmed if expectations were to formulate free-choice mineral supplements to meet specific herd requirements for specific forage growth characteristics. However, commercially available free-choice minerals are generally developed for specific geographical areas to meet 100 to 125% of the average herd's requirement given that it is housed in an average environment. Unfortunately, every production herd is either above or below the average. Many commercial companies provide a valuable service to customers by altering their base mineral package to accommodate specific mineral needs of a herd. It is the recommendation of the author that managers of larger herds work with nutritionists to formulate supplements that meet production needs at different times of the year and then have these formulations competitively bid. This procedure can be economical and at the same time provide a better-balanced supplement for the herd. However, the question of what the formula should contain continues to surface.

Formulations can be as simple as plain salt and(or) sulfur blocks to as complex as addressing each macro- and micro-mineral to include different combinations of mineral sources. Cattle should not be given free access to sulfur blocks because this mineral is more often found to be high rather than low in the diet. In some cases, plain salt may be the most economical program for the production environment. For example, stocker calves being purchased for backgrounding on native or small grain forages for 120 to 150 d before entering the feedyard may not show any deficiency signs if no mineral supplement is supplied. If a dietary mineral deficiency does exist, a deficiency may not be recognized due to body stores of the potentially deficient mineral. Performance (weight out – weight in) may not be affected, causing mineral supplement to be an extra expense. However, if calves entered the backgrounding program with little body stores of a potentially deficient mineral, animal performance and health may be impaired if only plain salt is supplied. Consequently, free-choice mineral supplements are often used as an insurance program. In some cases, the free-choice mineral supplement may be more valuable as a carrier for ionophores than as a source of mineral. The above scenario is not true for a cowherd that will be housed in the same environment long-term. If mineral deficiencies occur for a long enough time throughout the year, plain salt will not be adequate, and movement toward a mineral supplement containing all minerals from varying sources will be needed.

The following are some general recommendations to follow when designing a free-choice mineral supplement containing 15 to 30% salt as the base ingredient. These recommendations are based on mineral requirements and forage mineral concentrations presented in this manuscript:

For unfertilized grasses, use 12 to 16% Ca, 8 to 12% P, and 2 to 4% Mg as the base supplement.

For fertilized warm-season forages, use 12 to 16% Ca, 4 to 8% P, and 2 to 4% Mg.

For cool-season perennial and annual forages, use 12 to 16% Ca, 0 to 4% P, and 6 to 10% Mg as the base supplement.

Do not add sulfur except in the form of trace mineral salts to any free-choice supplement unless known deficiencies exist.

For unfertilized, dead plant material, K addition to the free-choice supplement may be advantageous.

Do not add Fe to free-choice supplements unless known deficiencies exist.

Increase Cu intake during the last third of pregnancy to between .15 to .25% of the supplement with a target intake of 56 to 114 g$^{\cdot}$ animal$^{-1\cdot}$ d^{-1}.

When formulating for trace minerals, formulate Co, Cu, I, Mn, and Se to provide 75 to 125% of the requirement.

When known antagonists are present, adjust supplemental minerals accordingly, being careful not to exacerbate the problem by creating another antagonistic response.

Choose trace mineral sources for the formulation that are biologically available.

Identification of biologically available minerals for use in mineral formulations is a challenge. Ellis et al. (1988) characterized mineral salts with respect to the percentage of mineral element and the relative bioavailability. The oxide forms of Cu, Zn, and Fe are not recommended for use in free-choice supplements because of their low availability. The question of whether organic sources of minerals should be used in the free-choice supplement also is an issue. Chelates, proteinates, and complexes generally have a higher bioavailability than their inorganic counterparts (Greene et al., 1998b), but they also have a greater cost. The author recommends these sources of minerals as a portion of the trace mineral when known deficiencies exist and a rapid change in mineral status is needed.

There are many methods of supplying minerals to cattle after supplementation requirements are identified. For production environments of greater than 1,000 cows or 2,500 stocker calves, it can be economically beneficial to develop a program targeted for the specific ranch by formulating and competitively bidding a ranch mineral. For smaller herds, the purchase of commercially available mineral supplements following guidelines given in this manuscript will be most economical. In cases in which individual cows/calves can be treated and specific deficiencies identified, individual dosing with boluses may be cost-effective.

Implications

Mineral deficiencies often cause hidden production losses in reproduction, health, and growth of grazing cattle. To identify specific minerals that may be a problem, start with determining mineral intake. Forage and water mineral analysis is critical for determining intake. After intake deficiencies are identified, development of cost-effective supplementation programs that meet the needs of individual producers is required.

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Notes

1. Reference to a company or trade name does not imply endorsement or approval by the Texas Agric. Exp. Sta.
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Table 1. Mineral requirements of beef cattle[a]

Mineral	Growing cattle	Cows/heifers Gestating	Cows/heifers Lactating
Calcium[b], %	.40 to .80	.16 to .27	.28 to .58
Phosphorus[b], %	.22 to .50	.17 to .22	.22 to .39
Magnesium, %	.10	.12	.20
Potassium, %	.60	.60	.60
Sodium, %	.06 to .08	.06 to .08	.10
Sulfur, %	.15	.15	.15
Cobalt, ppm	.10	.10	.10
Copper, ppm	10	10	10
Iodine, ppm	.50	.50	.50
Iron, ppm	50	50	50
Manganese, ppm	20	40	40
Selenium, ppm	.10	.10	.10
Zinc, ppm	30	30	30

[a]NRC, 1996.

[b]Calcium and P requirement (% of DM intake) decreases with increasing weight, increases with rate of gain and increases with level of milk production.

Table 2. Mineral composition of various forages averaged across several data sets[a]

Forage	No. of samples	Ca, %	P, %	Mg, %	K, %	Cu, ppm	Zn, ppm	Mn, ppm	Se, ppm	Mo, ppm	Fe, ppm	S, %	Source
Legumes													
Alfalfa/alfalfa mix	69		.25			7.4	19.1	51.0	.320	2.10	202	.26	Corah and Dargatz, 1996
Berseem	12	1.57		.25	1.69	25.1	30.8	30.9	.240	.40	268	.18	Brown et al., 1988
Subclover	12	1.28		.25	1.25	28.4	37.3	44.5	.210	.33	352	.18	Brown et al., 1988
Average		1.43	.25	.25	1.47	12.4	23.0	47.6	.295	1.65	230	.24	
Warm-season grasses													
Bahia	13	.34		.28	1.61	5.9	30.1	292.1	.070	.32	217	.15	Brown et al., 1988
Bahia	41	.40	.48	.32	1.60	8.5	29.4	139.9	.086				Kappel et al., 1985
Average		.39	.48	.31	1.60	7.9	29.6	176.5	.082	.32	217	.15	
Bermudagrass	125	.48		.27	1.80	4.6	29.0	52.2	.140	.44		.30	Brown et al., 1988
Bermudagrass	n=[b]	.43	.21	.17	1.54	6.4	23.4	86.0			115	.34	Greene et al., 1998
Bermudagrass	27	.38	.45	.22	1.78	8.0	35.0	111.1	.164				Kappel et al., 1985
Bermudagrass	36		.21			8.5	22.4	125.0	.200	.90	122	.22	Corah and Dargatz, 1996
Average		.43	.21	.17	1.54	6.3	24.3	83.9	.155	.54	115	.33	
Millet	13	.63		.67	2.60	6.5	28.3	124.8	.070	1.28	454	.16	Brown et al., 1988
Millet	5	.60	.66	.40	2.69	15.3	43.3	90.0	.076				Kappel et al., 1985
Average		.62	.66	.60	2.63	8.9	32.5	115.1	.072	1.28	454	.16	
Corn	40	.22		.19	.84	4.0	24.5	83.4	.040	.24	111	.07	Brown et al., 1988
Corn silage	56	.30	.32	.21	1.11	5.9	21.4	51.8	.050				Kappel et al., 1985
Average		.27	.32	.20	1.00	3.5	22.7	65.0	.046	.24	111	.07	
Sorghum	18	.31		.39	2.00	4.9	37.5	63.8	.040	.41	156	.09	Brown et al., 1988
Sorghum silage	21	.36	.32	.34	1.47	5.2	22.1	60.8	.061				Kappel et al., 1985
Sudan	27		.21			7.5	24.4	57.1	.217	1.40	364	.33	Corah and Dargatz, 1996
Average		.34	.26	.36	1.71	6.1	27.2	60.1	.119	1.00	281	.23	
Cool-season grasses													
Fescue	26		.27			6.2	17.8	122.0	.063	.99	100	.22	Corah and Dargatz, 1996
Fescue	28	.35	.33	.26		4.6							Tully, 1992
Fescue endophyte	28	.40	.35	.27		4.3							Tully, 1992
Average		.38	.32	.27		5.0	17.8	122.0	.063	.99	100	.22	
Oat-Wheat	42	.42	.31	.16	3.60	12.3						.41	Hardt et al., 1991
Oats	128	.55	.20	.14	2.70		27.0						Chirase et al., 1988
Oats-Rye	31	.53	.47	.23	3.30	5.8	23.0	84.6	.082				Kappel et al., 1985
Ryegrass	319	.52		.23	3.56	6.8	24.9	93.5	.100	1.10	193	.18	Brown et al., 1988
Cereal	17		.21			5.5	15.1	69.4	.185	1.30	148	.17	Corah and Dargatz, 1996
Average		.52	.26	.20	3.34	7.2	25.0	91.6	.102	1.11	191	0.18	

Native grasses													
Native	n = [c]	.48	.10	.12	.91	5.0	21.4	49.7			205	.13	Greene et al., 1998
Native	536		.11	.11	.90	11.0	30.0	62.0				.14	Mills[d]
Native	30		.17			6.4	18.3	103.6	.247	1.50	352	.31	Corah and Dargatz, 1996
Average		.48	.10	.12	.91	5.7	22.5	51.6	.247	1.5	206	.14	

[a]Average values were calculated by weighting the mineral composition by the number of samples analyzed in each data set.
[b]n = Ca, 7,745; P, 7,881; Mg, 7,965; K, 7,975; Cu, 858; Zn, 874; Mn, 852; Fe, 560; S, 548.
[c]n = Ca, 4,020; P, 3,918; Mg, 4,052; K, 4,037; Cu, 3,741; Zn, 3,723; Mn, 3,743; Fe, 3,044; S, 222.
[d]D K. Mills, Exell-Key Grain Co., unpublished data.