Cost-Effective Mineral Supplementation Programs for Beef Cattle

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Introduction

The fact that mineral requirements for beef cattle are spoken of in terms of parts-per-hundred or parts-per-million of the diet implies that nutritionists possess precise knowledge on the level of each mineral needed in beef cattle diets for optimal performance. While it is true that the results of frank mineral deficiencies and toxicities have been described in detail, this perception is untrue from the standpoint that very little quantitative information is available to describe mineral requirements of beef cattle for a given physiological state or level of production. Wasting diseases, hair loss, depigmented hair, skin disorders, non-infectious abortion, diarrhea, loss of appetite, bone abnormalities, tetany, low fertility, and pica have all been attributed to dietary mineral deficiencies or excesses in beef cattle diets (McDowell and Valle, 2000). The likelihood that a particular beef operation will ever encounter one of these profound symptoms is vanishingly small. Rather, less obvious (i.e., sub-clinical) mineral intake problems are far more likely. The lack of quantitative descriptions relating mineral intake to performance makes it very difficult to evaluate and treat instances of sub-clinical deficiency or toxicity (Figure 1). This review will attempt to distinguish between facts and perceptions regarding mineral nutrition of beef cattle and to make suggestions on cost-effective supplementation practices.

Five Common Perceptions about Mineral Nutrition

Depth of Knowledge. Many beef producers assume that scientific understanding of mineral nutrition of beef cattle is largely complete. The truth is that nutritionists have much to learn about dietary mineral interactions, the capability of beef cattle to store minerals in body tissue, and fine-tuning mineral requirements. An interesting case in the literature illustrates this point. Arthington et al. (1995) reported that a herd of Angus-based beef cows presented with classical symptoms of copper deficiency (i.e., depigmented hair). Tests later revealed that the forage the cows were consuming was very high in molybdenum (Mo) and that liver copper status of the cows was deficient. Cows were treated with copper oxide boluses for a period of 106 days, which restored liver copper status to near normal levels relative to unsupplemented controls. Additionally, hair coats were restored to normal appearance (Larson, 2001). Reproductive performance by cows was unaffected by copper supplementation and calf weight gains decreased in response to copper supplementation of dams (Arthington et al., 1995). In this case, copper deficiency clearly existed prior to treatment; moreover, the deficiency was corrected by treatment. A lack of response to supplemental copper by the cows and a negative response by the calves indicates that mineral nutrition is more complicated than currently appreciated.

Nutritional Wisdom of Cattle. There is a fairly common perception among beef producers that beef cattle can somehow sense when their diets are deficient in a particular mineral. The root of this perception is that mineral-deprived cattle have been observed attempting to eat bones, dirt, and wood (i.e., perform pica). Furthermore, it was assumed that pica was an attempt by cattle to ingest mineral elements that were deficient in their diets, thereby controlling their own mineral intakes (Marston, 1999). These assumptions are inaccurate. Cattle do not have the capability to balance their own diets. Much evidence in the literature shows that most mammals exhibit little nutritional wisdom and that animals will select a palatable but poor quality diet in preference to an unpalatable, nutritious diet, even to the point of death (McDowell, 1995). Palatability, and not metabolic demand, is the factor controlling the amount and frequency of mineral consumption by beef cattle (Marston, 1999).

Reproductive Failure. Reproductive performance by beef cows that is slightly below par is frequently attributed to sub-clinical deficiencies of a variety of trace minerals. Although this may be true in isolated cases, Corah et al. (1998) indicated that trace mineral deficiencies are probably not a common cause of reproductive failure. Trace mineral deficiencies appear more likely to occur in high-producing herds and are more likely to affect calf health than dam growth or reproduction. These dams appear to be lactating to full potential but nevertheless exhibit reproductive failure or health problems that are otherwise unexplainable (Corah et al., 1998). Figure 1 illustrates the subtlety with which trace mineral deficiency can influence the health and performance of cows and calves (Wikse, 1992). Physiological functions are progressively affected by deficiencies. For example, loss of pigmentation occurs with intakes of Cu that are sufficient for pregnancy maintenance and hemoglobin formation. Pregnancy is not maintained by intakes of Cu that prevent anemia. Furthermore, the disruption to Fe metabolism caused by Cu deficiency does not occur until after most other clinical signs have appeared (Mills, 1987).

Required Mineral Elements. From time to time, the popular press will tout the value of a novel mineral element to beef production (e.g., boron, chromium, vanadium, etc). The natural assumption is that cattle have a bona fide requirement for these minerals. In some cases, however, the National Research Council has not established one (NRC, 1996). Currently, there are 23 mineral elements recognized as having significance to beef cattle nutrition: calcium (Ca), phosphorous (P), sodium (Na), magnesium (Mg), potassium (K), cobalt (Co), copper (Cu), iron (Fe), zinc (Zn), manganese (Mn), iodine (I), selenium (Se), aluminum (Au), molybdenum (Mo), sulfur (S), chlorine (Cl), chromium (Cr), fluorine (F), lithium (Li), silicon (Si), vanadium (V), nickel (Ni), arsenic (As), and lead (Pb). Relatively few of the elements on this list are likely to be of practical consequence, as deficiencies or toxicities of the others occur with extreme rarity (MacPherson, 2000). The NRC (1996) has established dietary requirements or maximum tolerable levels for 16 mineral elements in beef cattle diets (Table 1). Those mineral elements which have a reasonably likelihood of being deficient in diets of forage fed cattle are Ca, P, Na, Mg, Mn, Zn, Co, Cu, I, and Se (Table 2). In addition, S, Fe, and Mo should be monitored because of their antagonistic interactions with copper (Marston, 1999).

Consistency of Mineral Intake. Another common perception among beef cattle producers is that mineral intake must be constant in order to avoid production problems; however, it is known that mammals conserve, to varying degrees, most required mineral elements in their tissues and fluids. What is unknown at this time is the degree to which individual minerals elements are conserved and how long it takes an animal to manifest a deficiency problem once intake of a particular mineral ceases (McDowell and Valle, 2000). Greene (2000) provides an interesting commentary on this issue:

> Stocker calves purchased for backgrounding on native or small grain forages for 120 to 150 days before entering the feedlot many not show any deficiency signs if no mineral supplement is supplied. If a forage mineral deficiency does exist, it may not be recognized due to body stores of the potentially deficient mineral and performance may not be affected. If, however, calves enter the backgrounding program with depleted body stores of a potentially deficient mineral, animal performance and health may be impaired. 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.

A sound mineral nutrition program is critical to the success of any beef cattle operation. There seems, however, to be a tendency to supply mineral supplements to match the appetite of beef cattle with no regard to the animal's capability to conserve these elements in tissue and fluid. There is clear evidence to support the contention that body mineral reserves can be mobilized in time of need; moreover, deficiencies can take long periods of time to manifest themselves (McDowell and Valle, 2000). It is also known that an animal's appetite for minerals is not an indication of mineral status (McDowell, 1995). This evidence could be used to argue that mineral supplements should be delivered only to meet a targeted level of daily intake. If over-consumption of free-choice mineral supplement occurs (e.g., a two-week supply of mineral is consumed in one week), additional mineral can be withheld until an appropriate amount of time has elapsed to match the targeted intake level (e.g., two weeks). Similarly, under-consumed free-choice mineral supplements may need to be altered to improve palatability (Hale and Olson, 2000).

Mineral Status in the Four-State Area

Adequate Minerals. Macro-minerals are those elements that are required in relatively large amounts in the diets of beef cattle: Ca, P, Na, K, Mg and S. Macro-minerals that are not likely to be deficient in the diets of forage-fed cattle in the four-state area include Ca, K, and S. Although major changes occur in Ca requirements during the transition from gestation to lactation, hypocalcemia is not a common problem in beef cows. Neither is it typical in growing calves (Greene, 2000). Similarly, K 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%; Greene, 2000; McDowell and Valle, 2000). Potassium interferes with Mg availability in the diets of cows (see later discussion of grass tetany); however, it reportedly does not affect calves (Greene, 2000). Sulfur deficiencies are extremely rare in the Midwest (Table 3). In fact, it is more often present in excessive levels in beef cattle diets. This can be problematic because S, together with Mo and Fe, can reduce availability of dietary copper (Suttle, 1991).

Trace minerals are classified as such because they are required in only trace amounts in beef cattle diets: Co, Cu, I, Fe, Mn, Se, and Zn. Requirements for most trace minerals do not change with level of production (NRC, 1996). Those that are typically not deficient in the four-state area include Co, I, Fe, and Mn (Tables 4 and 5; Mortimer et al., 1999). In the United States, Co and I deficiencies are not widespread and occur most often in the tropical regions of the country and in the Great Lakes region, for Co and I respectively (Greene, 2000). Iron deficiency is extremely rare in grazing beef cattle; it is not uncommon to find dietary Fe concentrations well over two times the requirement in forages (Tables 4 and 5). In spite of the known Fe status of area forages and the antagonistic effects of Fe on copper metabolism, it is not uncommon to find Fe added to free-choice mineral supplements at a relatively high level to serve as a coloring agent. This practice is simply a marketing tool designed to appeal to the notion that a good mineral supplement has to be red in color. Iron oxide (FeO) is typically used for this purpose. Although FeO is not readily available to cattle as an iron source, it can exacerbate an already low Cu status in cattle (Greene, 2000). Lastly, manganese content of forages, although variable, is usually higher than the dietary requirement of beef cattle (Tables 2, 3, 4 and 5). Identification of an Mn deficiency is difficult to determine due to the inconspicuous nature of symptoms (Greene, 2000).

Problem Minerals. Macro-minerals that have a reasonable likelihood of being deficient in the diets of forage-fed cattle in the four-state area include P, Na, and Mg. Phosphorus is the mineral that provides the greatest return on investment when supplemented (McDowell, 1995; Greene, 2000). It is also the most deficient mineral throughout the world for grazing livestock (McDowell, 1995; Greene, 2000; McDowell and Valle, 2000). Phosphorus plays a pivotal role in energy metabolism; deficiencies can cause immediate repercussions in terms of performance. Phosphorus deficiency is most likely to occur when cattle graze cultivated forages that have not been fertilized with P or graze native forages. Phosphorus is usually adequate when cattle graze phosphorus-fertilized forages (Greene, 2000). An additional fact that bears mentioning is that many popular byproduct feeds in the Midwest are quite high in P. Cattle that are supplemented with these feeds may not require additional P (Hale and Olson, 2000; see later discussion of byproduct feeds).

Forage Na is often below animal requirements and supplementation is essential; however, cattle crave salt and will consume it in excess when it is provided free-choice (Greene, 2000). Another element that is an occasional cause for concern is Mg. The Mg requirement becomes dramatically higher in postpartum cows. This rapid change in requirement has been implicated as the cause of grass tetany. Grass tetany is a metabolic disorder that occurs in cows grazing lush cool-season forages. It is not as prominent in cows grazing warm-season perennial pastures or native range, even though dietary Mg levels may be below the requirement (Table 1). Lush cool-season perennial forages are high in K. Potassium has been shown to reduce Mg absorption in the ruminant stomach (Greene, 2000). Magnesium deficiency can be difficult to avoid or correct in these circumstances because the most common Mg source, magnesium oxide, is very bitter. Mineral supplements offered to cattle that are at risk for grass tetany may need to be blended with molasses, grains, or oil seeds to stimulate adequate consumption (Hale and Olson, 2000).

Trace minerals that may be deficient in the four-state area include Cu, Se, and Zn. Surveys by Mortimer et al. (1999) of tall fescue samples collected in the Midwest indicated only 26% were adequate in Cu, 4% in Se, and 15% in Zn. Among native forage samples, 18% were adequate in Cu and 24% were adequate in Se and Zn. A majority of the samples collected were marginal in terms of copper content (73 and 82% for fescue and native grass, respectively), indicating that frank Cu deficiencies in the forage were uncommon. Of greater importance was the fact that minerals known to antagonize copper (i.e., Fe, S, and Mo) were high or marginally high in 7 to 40% of the samples. Copper deficiency problems in the four-state area are most likely to occur because of the presence of antagonistic minerals in the diet rather than extremely low intakes of Cu. Significant genetic variation also exists to increase the demand for dietary Cu. Ward et al. (1996) noted that Simmental and Charolais cows were more likely to display signs of a Cu deficiency than Angus cows.

Severe Se deficiency is not common in the four-state area (Figure 2); however, Mortimer et al. (1999) indicated that 96% of tall fescue samples and 77% of native forage samples were marginally low or deficient in Se. In spite of these facts, care should be exercised when beef cattle diets are supplemented with this mineral. The margin of difference between a Se-adequate diet and a diet that has toxic levels of Se is extremely narrow (Table 1). Moreover, the Food and Drug Administration does not allow dietary Se concentrations above 0.3ppm (Greene, 2000). Selenium fed at 100 ppm in the diet can cause reduced weight gain, feed conversion, and packed cell volume and 40 ppm for 12 days can cause feed refusal (Marston, 1999).

Local forages often to do not meet Zn requirements of beef cattle (Tables 2, 3, 4, and 5), thus Zn is a critical component of trace mineral supplements. When supplementing Zn intake of beef cattle, care must be taken to prevent potential negative interactions by including higher than normal levels of Zn in the diet. Elevated Zn intake stimulates production of a compound called metallothionein that functions to transport Zn across the intestinal wall and to facilitate its storage in the liver. Metallothionein also binds Cu, more strongly than Zn, and increased levels of metallothionein can exacerbate Cu deficiency (Greene, 2000).

Factors Affecting Mineral Content of Forages and Feedstuffs. Variability in the trace mineral content of common feedstuffs is much greater than is variability of protein and energy content. This is true even when making allowances for sampling error, soil contamination, and analytical error (Berger, 1995). Adams (1975) reported that there were 1.4 and 5.0 fold differences between samples of legume-grass forages for TDN and crude protein, respectively. In contrast, those differences were 46, 260, 44, and 38 fold for Cu, Fe, Mn, and Zn, respectively, for the same forages. Moreover, Greene (2000) reported that trace mineral concentrations in forages are generally less variable than macro-mineral concentrations. A common belief is that feedstuffs grown in a particular geographical region will have similar trace mineral profiles. This is untrue in most cases; trace mineral concentrations in forages and other feeds are affected by five interdependent factors: 1) plant species, 2) soil characteristics, 3) soil fertility, 4) stage of plant maturity, and 5) climatic conditions (Greene, 2000).

Legumes tend to be higher in Ca, K, Mg, Cu, Zn, Fe, and Co than grasses. In contrast, grasses tend to be higher in Mn and Mo than legumes when grown on the same soil (Berger, 1995). Differences in mineral content between plant species highlight the importance of maintaining diversity in pasture species composition. Pasture and range plants do not necessarily mirror minerals in the soil. Plants react to inadequate supplies of minerals in the soil either by reducing the concentration of deficient soil minerals in their own tissue, by reducing growth, or by doing both (Greene, 2000). Soil mineral profiles that optimize plant growth may yield feeds that are deficient in trace minerals from an animal requirement perspective. For instance, soil concentrations of I, Se, and Co required for optimal plant growth are well below the requirements of beef cattle (Berger, 1995). Mineral concentration in soils has a great effect on soil pH, which in turn has a major impact on mineral uptake by plants (Berger, 1995; Greene, 2000). For example, Mo uptake increases as soil pH increases. Cobalt, Zn, and Cu uptake by plants is decreased as soil pH increases (Berger, 1995).

Environmental factors that influence plant growth will change the capability of plants to translocate minerals from the soil to plant tissues (Greene, 2000). During early growth of the plant, there is a rapid uptake of mineral elements. Mineral content declines as plants mature due to a natural dilution process and translocation of nutrients to the root system. As photosynthetic material increases, DM production outstrips mineral uptake, resulting in a decline in mineral concentration (Underwood, 1981; McDowell and Valle, 2000). Leaves and seed heads will be lost as the plant begins to senesce. Consequently, the mineral concentration of the standing herbage can also decreases due to a change in leaf to stem ratio. Copper, Zn, Fe, Co, and Mo are the trace minerals most affected by plant maturity (Underwood, 1981)

One of the most important issues with regard to mineral nutrition of beef cattle is the capability to predict mineral availability from feedstuffs. Unfortunately, there is a conspicuous lack of data available to predict the biological availability of minerals from forages (McDowell and Valle, 2000; Greene, 2000). Perhaps more than any other factor, this hinders the development of truly cost-effective mineral supplementation programs in the United States.

Special Issues

Certain aspects of mineral nutrition of beef cattle merit special commentary in this paper. They have the distinction of either being fairly unique to the four-state area or being popular topics in the media: diets based on byproduct feeds, trace-mineral antagonism, and chelated minerals.

Byproduct Feeds. We are fortunate in the four-state area to have grain and oilseed milling byproducts available for use as ruminant feedstuffs. Many are inexpensive sources of protein and energy compared with corn and soybean meal; nearly all are characterized by atypical mineral profiles. Processing of grains and oilseeds has the effect of removing some nutrients from the eventual byproduct while concentrating others. Several popular byproduct feedstuffs (e.g., wheat middlings, corn gluten feed, and distiller's grains) are characterized by Ca to P ratios of substantially less than the optimum of 1.2:1 (NRC, 1996). In order to manage these feedstuffs appropriately, mineral supplements must be tailored to supply much more Ca than is typical for commercial preparations. Calcium to P ratios greater than 18:1 are common for mineral supplements designed to be fed in conjunction with these byproducts.

High concentrations of sulfur also characterize certain byproduct feeds (i.e., corn gluten feed and distiller's grains). Sulfur is a potent antagonist of dietary copper; moreover, sulfur toxicity can become a concern when cattle are offered diets high in these byproducts. Moderate to high dietary sulfur intake has the potential to cause polioencephalomalacia (PEM) in ruminants (Gould et al., 1997). The clinical and pathological signs are similar to thiamine deficiency and PEM is often accompanied by thiamine deficiency. This led investigators to propose that high levels of sulfur in the body interfere with normal thiamine metabolism; however, in many cases thiamine activity is was not altered in the presence of high sulfur intake, even though PEM symptoms were present. Recently, it has been demonstrated that sulfur in the rumen can cause PEM directly, independent of disturbances of ruminal metabolism (McAllister et al., 1992). Rumen microbes normally produce hydrogen sulfide. Under conditions of high dietary sulfur intake, the capacity for microbial production of hydrogen sulfide increases. Hydrogen sulfide is highly toxic and when present in rumen gas that is eructated and inhaled, may cause brain lesions resulting in PEM symptoms (Larson, 2001). When feeding high-sulfur byproducts, care must be taken not to exceed the maximum tolerable concentration of sulfur in the complete diet (Table 1).

Soybean hulls, wheat middlings, corn gluten feed, rice bran, and distiller's grains are typically high in trace minerals relative to most forages; notably, Cu, Se, Fe, and Zn are present in much greater quantities (NRC, 1996). Trace mineral intakes require careful balancing when diets contain high proportions of these byproducts. In particular, potential mineral antagonisms must be identified and dealt with to avoid problems.

Trace Mineral Antagonism. In the reducing environment of the rumen, Mo and S form compounds called thiomolybdates when excesses of these elements are consumed. Thiomolybdate binds Cu at both the gastrointestinal and tissue level, rendering it unavailable to the animal (Suttle, 1991). Additionally, elevated dietary levels of Fe also act to exacerbate Cu deficiency. A survey of nine midwestern states conducted by Montana State University showed that liver Cu concentrations were generally deficient in grazing beef cattle for optimum performance and immune response (Greene, 2000). Presumably, this circumstance is caused not only by low copper intakes via forage (Tables 3, 4, and 5) but also by the presence of Cu antagonists. Copper intake must be adjusted to account for dietary content of Mo, S, and Fe. Suttle (1981) produced equations to predict the availability of Cu (ACu) in grass, grass silage, hay, cereals, and brassica crops:

- Grass: ACu (%) = 5.72 – 1.297[S] – 2.785loge[Mo] + 0.227([Mo] x [S])
- Silage: ACu (%) = 10.6 – 6.65loge[S]
- Hay: ACu (%) = 8.9 – 0.70$\log_e$Mo – 2.61$\log_e$[S]
- Brassica Crops: ACu (%) = 0.042 – 0.0096[Mo] x [S]

Alternatively, copper intake can be adjusted using the following principle: for each 1 ppm of Mo in a total ration (DM basis), the amount of Cu available should be discounted by 8 ppm. Thus, if the total ration has 1 ppm of Mo and 20 ppm Cu, available Cu is considered to be 12 ppm (Marston, 1999). The author of this paper is unaware of quantitative adjustment factors for other mineral antagonisms.

Chelated Minerals. Chelated minerals are those bound, or chelated, to an organic molecule. They are distinct from traditional mineral sources in which the mineral of interest is bound to an inorganic ion such as an oxide or sulfate. Chelated (organic) minerals) carry a neutral charge which reportedly enables them to be absorbed and metabolized 300 to 500% more efficiently than are inorganic minerals (Marston, 1999); however, studies comparing the biological availability of organic and inorganic minerals have reported contrasting results. Ward et al. (1993), Wittenburg et al. (1990), and Olson et al. (1999) found no differences between bioavailability of organic and inorganic minerals. In contrast, Kincaid et al. (1986) and Nockels et al. (1993) reported that chelated copper was more available to cattle than inorganic copper. Kropp (1990) reported that feeding chelated minerals to first-calf cows 30 d before the breeding season caused more animals to exhibit estrus and conceive after the first service than did feeding inorganic minerals. Similarly, Swenson et al. (1998) reported a shorter postpartum interval for cows supplemented with organic sources of Cu, Zn, Mn, and Co compared with sulfate forms of the trace minerals. Olson et al. (1999) reported that supplementing the same minerals as Swenson et al. (1998) reduced reproductive performance of first-calf cows compared to unsupplemented cows. Muehlenbein et al. (2001) found that both chelated and inorganic Cu sources increased liver Cu levels in cows, but neither source improved the health or growth of the calves or increased total pregnancy rates of the cows. The control cows in the study by Muehlenbein et al. (2001) were Cu deficient at calving but rebred at a high level and produced calves with normal growth and health.

In retrospect, some authorities on mineral nutrition have agreed that chelated minerals have a higher bioavailability than their inorganic counterparts and recommend they be included as a portion of supplemental trace mineral when known deficiencies exist and a rapid change in mineral status is needed (Greene, 2000). Others experts do not share this view. MacPherson (2000) stated that claims about chelates have not been substantiated by unequivocal scientific evidence. Citing studies in which inorganic and chelated minerals were compared at the same feeding rates, MacPherson (2000) claimed that no consistent productive benefit of chelates has been demonstrated. He added that chelates have the added disadvantage of being considerably more expensive than traditional inorganic mineral sources.

Evaluating Mineral Status

Feedstuffs and Forages. Mineral profiles of feedstuffs and forages offered to beef cattle must be developed in order to insure that mineral deficiencies, toxicities, or antagonisms do not impair production. This practice should be a matter of routine. As discussed previously, mineral content of crop residues and pastures can fluctuate widely from month to month. Furthermore, harvested forages and grains will have different mineral profiles from year to year. Dietary mineral analyses provide useful information on the mineral status of beef cattle, if representative samples of all feeds can be obtained. Actual chemical analyses need to be performed, rather than indirect estimation, and should include those elements that are required for normal metabolic function as well as those with antagonistic relationship to other minerals (e.g., Mo, S, and Fe). Tabular values and feed tags should not be relied on for estimating trace element intakes (Kincaid, 2000).

Periodic sampling of grazable forages is a special feed testing circumstance because of the need to repeat it as often as the forage changes its nutritional character (i.e., monthly, during the growing season). It is known that beef cattle are highly selective about the pasture forage species that they choose to eat. When given a choice, animals will select a higher quality forage in terms of protein, energy, calcium and phosphorus (Corah and Arthington, 1995) The issue of selectivity raises a question with regard to pasture sampling. Is it possible to accurately profile the mineral intake of grazing cattle by simply hand-clipping forage samples?

Mayland and Lesperance (1977) compared the mineral content of hand-clipped samples chosen at random with the mineral content of freshly grazed ruminal contents. They reported that animal-selected samples were generally not different from hand-clipped samples in Mg, Ca, K, Mn, Fe, and Mo; however, animal-selected samples were higher than hand-clipped samples in Na, P, Zn, and Co. Randomly collected pasture samples, in this case would have underestimated animal intake of Na, P, Zn, and Co. Corah and Arthington (1995) used a similar procedure to collect animal-selected samples; however, they collected hand-clipped samples from specific locations where cattle were observed to graze. Samples were clipped 1 to 3 inches from the ground to avoid contaminating the sample with soil. Results indicated that animal-selected samples were not different from hand-clipped samples in terms of Fe, Cu, Zn, and Mn (Table 6). These studies can be interpreted to suggest that hand-clipped forage samples collected from locations where cattle have been observed to graze can accurately depict the dietary profile of most important trace minerals. With the exception of Co and macro-minerals, clipped forage samples can be a useful and relatively inexpensive tool to gauge the mineral status of grazing cattle. The author recommends collecting pasture forage samples where cattle are observed to graze during the evening and morning over a period of several days. Samples should be composited and placed in a clean container, free of soil and other contaminants, and chilled until mineral analyses can be conducted.

Animals. Mineral status of beef cattle can also be evaluated by measuring mineral reservoirs within the body. Procedures associated with directly measuring mineral status can be costly and time consuming; as such, they should not be undertaken lightly. The most common reason to directly assess the trace mineral status of beef cattle is because performance is below expectation and no other explanations for the performance problem are apparent (Kincaid, 2000). There are several tissue and fluid pools in the body that have been proposed to reflect mineral status of individual animals: blood and blood components, serum enzymes, liver, milk, urine, hair, wool, and hoofs.

Kincaid (2000) reported that there are several limitations to blood analyses. Red blood cells in cattle have a life span of about 160 days (Schlam, 1980). Practically, this means that concentrations of some trace minerals in plasma change very slowly. Homeostatic control mechanisms can limit changes in concentrations of some trace minerals in plasma until endogenous reserves are substantially depleted (Miller, 1975). Corah and Arthington (1995) recommended that blood or blood components be used only as a preliminary screening tool for mineral deficiency. They noted that the utility of blood as an indicator of mineral status was limited for certain trace elements, such as Cu and Se. Conversely, certain enzymes present in blood serum may be reasonable indicators of Cu and Se status.

The liver is the tissue pool that best represents the status of trace elements in cattle. Ideally, biopsy samples should be taken before and after treatments are applied in order to gauge the efficacy of treatment (McDowell, 1992). Other tissues do not consistently reflect trace mineral status (Kincaid, 2000). Analyses of minerals in milk and urine are seldom useful in mineral assessment because most cations (i.e., positively charged ions like Na, Ca, Fe, and Mg) in milk are actively transported into the mammary gland and concentrations are regulated (Miller, 1975). Anions (e.g.,negatively charged ions like Mo and I) in milk are exceptions and reflect dietary intake (Miller et al., 1975; Wittenburg and Devlin, 1988). Selenium and Iodine levels in milk and urine could have a role in indicating excess intakes if reference values were ever established. Conversely, minerals content of hair, wool, and hoofs lack reference standards, are too slowly responsive to intakes, and can be easily contaminated (Kincaid, 2000).

An obvious question to ask when attempting to evaluate the trace mineral status of a herd is how many individual animals must be sampled to develop an accurate picture of the entire group. The correct answer depends on the goal of the inquiry. To estimate the average concentration of plasma Cu in a herd of 200 cows, with 95% confidence and within a 0.5 standard deviation of the mean, 15 animals must be sampled. If the goal is to determine the proportion of a population that might be Cu-deficient, and if the proportion is suspected to be less than 25%, 119 animals must be sampled. Finally, if the goal is to determine whether any animals are Cu-deficient in a herd of 200, to be 95% certain of detecting 1% prevalence, 155 animals must be sampled (Kincaid, 2000). Obviously, more precise answers require greater inputs of labor and capital.

Mineral Supplementation Methods

Indirect Methods. Indirect methods of mineral supplementation include using mineral-containing fertilizers on forage crops, altering soil pH via phosphorus application, and encouraging the establishment of forage species that are likely to be adequate in minerals of concern (McDowell, 1996). Mineral fertilization is not an efficiently method of increasing the intake of minerals by grazing animals. Forages should be fertilized to meet the growth characteristics of the plant and then, if certain minerals are still deficient, direct supplementation of the animal’s diet should be practiced (Greene, 2000).

Direct Methods. Direct methods of mineral supplementation include adding minerals to drinking water or feed, oral drenching, injection, ruminal boluses, and free-choice supplementation. Supplementation of minerals in water or a supplement will result in more animal-to-animal variation in the amount of mineral consumed compared to direct dosing. Adding minerals to water is only feasible if cattle do not have access to alternative water sources (Greene, 2000). MacPherson (2000) indicated that addition of mineral supplements to feed or water is the method of choice for animals maintained in confinement. Variation in intake is reduced relative to free-choice supplementation and the addtional labor requirement and expense are relatively small. 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. Injection of Cu and Se has been used to increase the status of those minerals but the response is not long lasting. In contrast, oral dosing of mineral boluses is a practical method of providing cattle with specific trace minerals (Greene, 2000).

The most widely used method of feeding minerals to cattle is through free-choice supplements (Greene, 2000). Even though grazing livestock have been found not to balance their mineral needs perfectly when consuming a free-choice mineral supplement, there is usually no other practical way of supplying mineral needs under grazing conditions (McDowell, 1995). To encourage optimum usage, mineral supplements are best positioned close to watering points and one mineral feeder should be available for every 25-40 animals (MacPherson, 2000). Beef producers should also be aware of the fact that drinking water that is naturally high in mineral salts will decreases mineral supplement intake. Where the salt content of water is high, mineral supplements should not be based on sodium chloride and should instead be reformulated with other palatability stimulators such as cottonseed meal and molasses. Physical form of the free-choice mineral supplement also influences consumption. Intake is often 10% less when provided in block versus loose form (McDowell, 1995).

Mineral Supplements

Selecting a Commercial Mineral Supplement. When planning a mineral supplementation program, four criteria need to be addressed: 1) specific mineral requirements of the animal, 2) relative biological availability of mineral sources, 3) daily intake, and 4) concentration of minerals in the diet (Marston, 1999). Environmental conditions, management practices, forage type, animal genetics, and physiological state make every production system unique with respect to mineral needs. Each mineral in the diet and in supplements must be carefully evaluated for amount, bioavailability, and possible interactions with other minerals. Without this attention to detail, it is not uncommon to create a completely new problem when changing a mineral supplement program to fix an existing problem (Greene, 2000). Commercially available mineral supplements are usually developed for specific geographical areas to meet 100 to 125% of peak animal requirements. McDowell (1992) provided a list of characteristics of efficacious free-choice mineral supplements:

1. A minimum of 6 to 8% phosphorus is required. In areas where forages are consistently lower that 0.2% phosphorus, 8 to 10% is preferred.

2. The calcium-to-phosphorus ratio should not be substantially over 2:1.

3. Supplements should contain at least 50% of the animal's requirement for cobalt, copper, iodine, manganese, and zinc.

4. Mineral sources with high relative bioavailability (e.g., sulfate salts) should be used whenever possible, while avoiding mineral sources that contain potentially toxic or antagonistic elements (e.g., fluorinated phosphates).

5. The product must be sufficiently palatable to promote consumption at targeted levels.

6. Manufacturers should be licensed, reputable, and provide quality-control guarantees as to the accuracy of the mineral supplement label.

7. The product should have an acceptably uniform particle size that allows adequate mixing and prevents undue settling during storage.

8. Products should be formulated for specific regions, animal classes, levels of animal productivity, and environments in which they will be fed.

9. For most locations, it would be appropriate to include selenium, unless toxicity problems have been observed. Iron should be included in temperate region mixtures, but often iron and manganese can be eliminated in regions where the soil is acidic. In certain areas where parasitism is a problem, iron supplementation may be beneficial.

Greene (2000) suggested that development of cost-effective free-choice mineral supplements is as much an art as it is a science; moreover, he proposed that the following modifications to the guidelines of McDowell (1992) might be of benefit in customizing free-choice mineral supplements that contain 15 to 30% salt as the base ingredient:

1. For unfertilized grasses, 12 to 16% calcium, 8 to 12% phosphorus, and 2 to 4% magnesium should form the basis of the supplement.

2. For fertilized warm-season forages, 12 to 16% calcium, 4 to 8% phosphorus, and 2 to 4% magnesium should form the basis of the supplement.

3. For cool-season perennial and annual forages, 12 to 16% calcium, 0 to 4% phosphorus, and 6 to 10% magnesium should form the basis of the supplement.

4. Sulfur, except in the form of sulfate salts, and Fe should not be added to any free-choice mineral supplement unless known deficiencies exist.

5. When grazing unfertilized, dormant forages, the addition of K to free-choice supplements may be advantageous.

6. Copper content of free-choice mineral supplements should be increased to between 0.15 and 0.25% of the complete product (target intake of 2 to 4 oz per animal per day).

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

The most serious drawback to free-choice mineral supplementation is variation in animal intake (McDowell, 1992). Regulation of consumption is another great obstacle to overcome in making free-choice mineral supplements truly cost-effective (Greene, 2000). Mineral supplements should be mixed with hand-fed energy or protein supplements whenever possible to reduce this variability. When it is not practical to do so, it might be helpful to consider mineral intakes that are characteristic of various feeding regimens (Arthur, 2000). With such information, it may be possible to adjust the palatability of free-choice mineral supplement to encourage consumption.

1. Under normal circumstances, intake of a complete free-choice mineral supplement should be about 2 oz per head per day.

2. When feeding dry hay, mineral intakes typically drop to 0.5 to 0.6 oz per head per day.

3. When feeding silage, mineral intakes drop to 0.9 to 1.0 oz per head per day

4. With hard water (total dissolved solids > 2000ppm), mineral intakes drop to 0.3 to 0.4 oz per head per day

Developing Custom Mineral Supplements. Planning and building custom mineral supplements for grazing cattle is a difficult and challenging process due to 1) changes in animal requirements with stage and level of production, 2) seasonal differences in forage mineral content, and 3) limited methodology to supply cost-effective supplemental minerals to cattle. The approach of most manufacturers of mineral supplements is to formulate the product to meet 100 to 125% of the animal's requirement at its highest stage of production, within a given region. This approach is valid in that it provides customers with convenience and it minimizes the likelihood of deficiencies. A disadvantage of this approach is that it may supply mineral elements in excess of the requirement for a large part of the production cycle, effectively causing the producer to pay for supplement that is not needed. Another disadvantage is that there are several confounding factors (e.g., soil type, fertilization methods, and rainfall) that make it difficult to apply average regional mineral values to a specific pasture or range. When developing or fine-tuning a mineral supplement, a forage sampling and analysis scheme for the specific production environment is recommended (Greene, 2000).

When there is no information available on mineral status of feeds and forages for a given region, then producers have little choice but to invest in comprehensive mineral supplements. In contrast, producers who develop databases that describe forage mineral content on a monthly basis can develop specialized mineral mixes. A database of this nature could be constructed with a investment of $900 to $1800 over a period of 3 years, assuming that one forage sample was collected and analyzed each month for 36 months and that individual analyses for mineral content cost between $25 and $50. Custom mineral supplements can be significantly less expensive due to the fact that they contain only the minerals that are lacking in forages and other feeds in the diet (McDowell and Valle, 2000). In Columbia, ten cattle experiments were designed to evaluate feeding complete commercial supplements versus feeding supplements formulated to contain a minimum number of minerals that had previously been established as deficient on the basis of forage and animal-tissue analyses (Laredo et al., 1989). The cattle fed specifically-tailored mineral supplements performed equally with cattle fed a comprehensive, commercially prepared mineral supplement. Furthermore, the custom mineral was delivered with a total cost savings of 42% over the commercial mineral. Greene (2000) recommended that managers of larger herds work with nutritionists to formulate mineral supplements that are customized to complement the mineral content of the basal diet and the production cycle and then to have these formulations competitively bid.

Literature Cited

Adams, R. S. 1975. Variability in mineral and trace mineral content of dairy cattle feeds. J. Dairy Sci. 58:1538.

Arthington, J. D., R. L. Larson, and L. R. Corah. 1995. The effects of slow-release copper boluses on cow reproductive performance and calf growth. Prof. Anim. Sci. 11:219.

Arthur, A. J. 2000. Trace Minerals for Beef Cattle. http://www.agr.gov.sk.ca./DOCS/livestock/beef/feeds_and_nutrition/traceminerals.asp

Berger, L. L. 1995. Factors affecting the trace mineral composition of feedstuff. http://www.saltinstitute.org/STM-6.html.

Corah, L. R. and J. D. Arthington. 1995. Determining the trace mineral status of a beef cow herd. Agri-Practice 16(4):11.

Corah, L. R., D. A. Dargatz, and C. W. Peters. 1996. NAHMS forage survey: trace mineral analysis of 352 forage samples collected in 18 states. J. Anim. Sci. 74(Suppl. 1): 202.

Corah, L. R., C. L. Wright, and J. A. Arthington. 1998. Applied aspects of vitamin E and Trace mineral supplementation. Comp. Cont. Edu. Prac. Vet. 20(7):866.

Gould, D. H., B. A. Cummings, and D. W. Hamar. 1997. In vivo indicators of pathologic ruminal sulfide production in steers with diet-induced polioencephalomalacia. J. Vet. Diagn. Invest. 9:72.

Greene, L. W. 2000. Designing mineral supplementation of forage programs for beef cattle. J. Anim. Sci. 78(E-Suppl.):E13.

Kincaid, R. L., R. M. Blauwiekel, and J. D. Cronrath. 1986. Supplementation of copper as copper sulfate or copper proteinate for growing calves fed forages containing molybdenum. J. Dairy Sci. 69:160.

Kincaid, R. L. 2000. Assessment of trace mineral status of ruminants: a review. J. Anim. Sci. 78(E-Suppl.):E20.

Kropp, J. R. 1990. Reproductive performance of first-calf heifers supplemented with amino acid chelate minerals. In: Oklahoma Anim. Sci. Res. Rep. 41 pp 35-43. Oklahoma State Univ., Stillwater.

Laredo, M. A., C. F. Gonzalez, J. A. Carillo, and L. R. McDowell. 1989. Mineral supplementation of beef cattle in an Andean region of Colombia. Nutr. Rep. Intl. 39:1069.

Larson, R. L. 2001. Personal communication.

MacPherson, A. 2000. Trace-mineral status of forages. In: D. I. Givens, E. Owen, R. F. E. Axford, and H. M. Omed (Eds) Forage Evaluation in Ruminant Nutrition. CABI Publishing, New York, pp. 345-371.

Marston, T. T. 1999. Trace mineral supplementation in beef cattle II. Comp. Cont. Edu. Prac. Vet. 21(2 Supplement):S70.

Mayland, H. F. and A. L. Lesperance. 1977. Mineral compostion of rumen fistula samples compared to diet. J. Range Manage. 30:388.

McAllister, M. M., D. H. Gould, and D. W. Hamar. 1992. Sulfide-induced polioencephalomalacia iin lambs. J. Comp. Pathol. 106:267.

McDowell, L. R. 1985. Free-choice mineral supplementation and methods of mineral evaluation. In: Nutrition of Grazing Ruminants in Warm Climates, Academic Press, Inc. San Diego, pp 383-407.

McDowell, L. R. 1992. Minerals in Animal and Human Nutrition. Academic Press, San Diego.

McDowell, L. R. 1996. Feeding minerals to cattle on pasture. Anim. Feed Sci. Technol. 60:247.

McDowell, L. R. and G. Valle. 2000. Major minerals in forages. In: D. I. Givens, E. Owen, R. F. E. Axford, and H. M. Omed (Eds) Forage Evaluation in Ruminant Nutrition. CABI Publishing, New York, pp. 373-397.

Miller, W. J. 1975. New concepts and developments in metabolism and homeostasis of inorganic elements in dairy cattle: a review. J. Dairy Sci. 58:1549.

Miller, J. K., E. W. Swanson, and G. E. Spalding. 1975. Iodine absorption, excretion, recycling, and tissue distribution in the dairy cow. J. Dairy Sci. 58:1578.

Mills, C. F. 1987. Biochemical and physiological indicators of mineral status in animals: copper, cobalt, and zinc. J. Anim. Sci. 65:1702.

Mortimer, R. G., D. A. Dargatz, and L. R. Corah. 1999. Forage analyses from cow/calf herds in 23 states. Beef 97, National Animal Health Monitoring Service.

Muehlenbein, E. L., D. R. Brink, G. H. Deutscher, M. P. Carlson, and A. B. Johnson. 2001. Effects of inorganic and organic copper supplemented to first-calf cows on cow reproduction and calf health and performance. J. Anim. Sci. 79:1650.

NRC. 1996. Nutrient Requirements of Beef Cattle, 7th Revised Edition. National Academy Press, Washington, D.C.

Nockels, C. F., J. DeBonis, and J. Torrent. 1993. Stress induction affects copper and zinc balance in calves fed organic and inorganic copper and zinc sources. J. Anim. Sci. 71:2539.

Olson, P. A., D. R. Brink, D. T. Hickok, M. P. Carlson, N. R. Schneider, G. H. Deutscher, D. C. Adams, D. J. Colburn, and A. B. Johnson. 1999. Effects of supplementation of organic and inorganic combinations of copper, cobalt, manganese, and zinc above nutrient requirement levels on postpartum two-year-old cows. J. Anim. Sci. 77:522.

Hale, C. and K. C. Olson. 2000. Mineral supplements for beef cattle. University of Missouri Technical Guide G-2081.

Schlam, O. W. 1980. Blood and blood-forming organs. In: H. E. Amstutz (Ed.) Bovine Medicine and Surgery II. Pp 791. American Veterinary Publication, Santa Barbara, CA.

Suttle, N. F. 1981. Predicting the effects of molybdenum and sulphur concentrations on the absorbability of copper in grass and forage crops to ruminants. In: J. Howell, J. M, Gawthorne, and C. L. White (Eds) Trace Elements in Man and Animals – 4. Australian Academy of Science, Canberra, Australia, pp. 545-548.

Suttle, N. F. 1991. The interactions between copper, molybdenum, and sulfur in ruminant nutrition. Annu. Rev. Nutr. 11:121.

Swecker, W. S. Jr., D. E. Eversole, C. D. Thatcher, and D. J. Blodgett. 1991. Selenium supplemenation of gestating beef cows on selenium-deficient pastures. Agri-Practice 12(2):25.

Swenson, C. K., R. P. Ansotogui, E. J. Swenson, J. A. Paterson, and A. B. Johnson. 1998. Trace mineral supplementation effects on first-calf beef heifer reproduction, milk production and calf performance. Proc. West. Sec. Amer. Soc. Anim. Sci. 49:327.

Underwood, E. J. 1981. The Mineral Nutrition of Livestock. Commonwealth Agricultural Bureaux, Slough, England.

Ward, J. D., J. W. Spears, and E. B. Kegley. 1993. Effect of copper level and source (copper lysine vs copper sulfate) on copper status, performance, and immune response in growing steers fed diets with or without supplemental molybdenum and sulfur. J. Anim. Sci. 71:2748.

Ward, J. D., J. W. Spears, and G. P. Gengelbach. 1996 Differences in copper status and copper metabolism among Angus, Simmental, and Charolais cattle. J. Anim. Sci. 73:571.

Wikse, S. 1992. The relationship of trace element deficiencies to infectious diseases of beef calves. Proc., 1992 TX Beef Cattle Short Course. Pp. 1 – 8.

Wittenburg, K. M. and T. J. Devlin. 1988. Effects of dietary molybdenum on productivity and metabolic parameters of lactating ewes and their offspring. Can. J. Anim. Sci. 68:769.

Wittenburg, K. M., R.J. Boila, and M. A. Schariff. 1990. Comparison of copper sulfate and copper proteinate as copper sources for copper-depleted steers fed high molybdenum diets. Can. J. Anim. Sci. 70:895.

Figure 1. The effect of trace-mineral deficiency on health and performance of cows and calves (Adapted from Wikse, 1992)

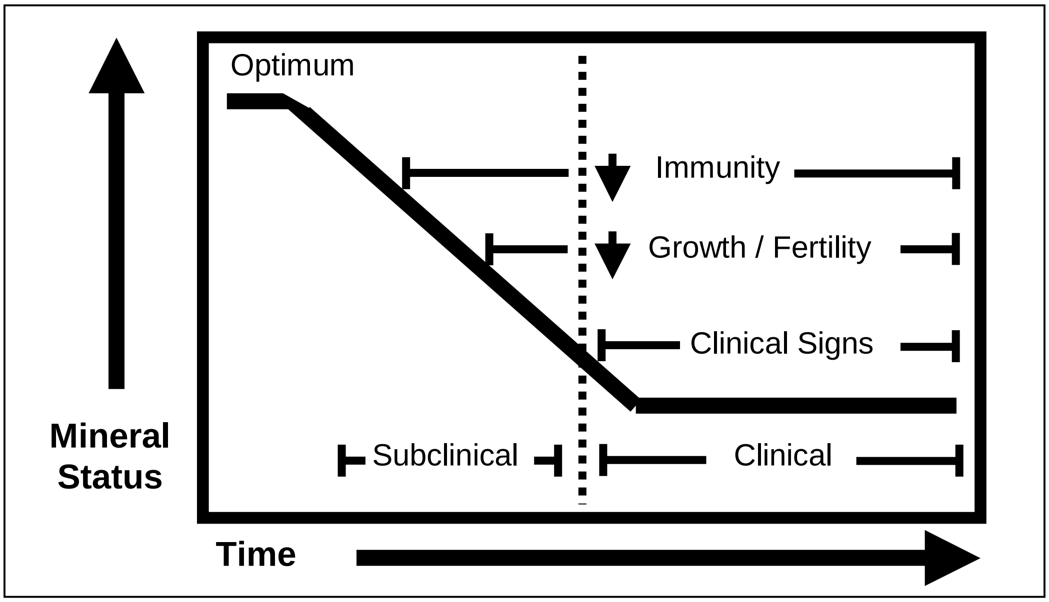

Figure 2. Selenium content of U.S. forage and cereal crops (adapted from Swecker et al., 1991)

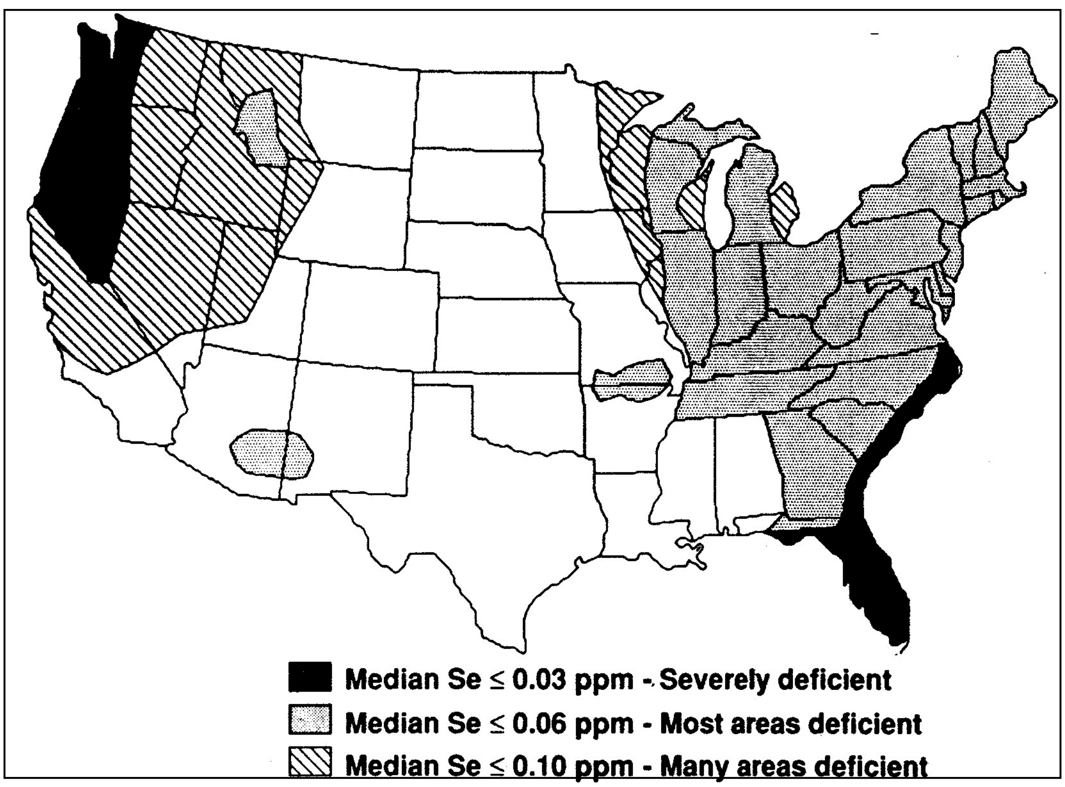

Table 1. Mineral requirements and maximum tolerable levels for beef cattle (adapted from NRC, 1996 and Greene, 2000).

Mineral	Units	Growing and Finishing Cattle	Gestating and Dry Cows	Lactating Cows	Maximum Tolerable Level
Calcium	%	0.40 to 0.80	0.16 to 0.27	0.28 to 0.58	-
Chromium	ppm	-	-	-	1000.00
Cobalt	ppm	0.10	0.10	0.10	10.00
Copper	ppm	10.00	10.00	10.00	100.00
Iodine	ppm	0.50	0.50	0.50	50.00
Iron	ppm	50.00	50.00	50.00	1000.00
Magnesium	%	0.10	0.12	0.20	0.40
Manganese	ppm	20.00	40.00	40.00	1000.00
Molybdenum	ppm	-	-	-	5.00
Nickel	ppm	-	-	-	50.00
Phosphorus	%	0.22 to 0.50	0.17 to 0.22	0.22 to 0.39	-
Potassium	%	0.60	0.60	0.60	3.00
Selenium	ppm	0.10	0.10	0.10	2.00
Sodium	%	0.07	0.07	0.10	-
Sulfur	%	0.15	0.15	0.15	0.40
Zinc	ppm	30.00	30.00	30.00	500.00

Table 2. Trace-mineral classification for 352 forage samples collected from 18 states (adapted from Corah et al., 1996)

	Level (%)			
Trace Element	Adequate	Deficient	Marginal	Very High
Copper	36.0	14.2	49.7	-
Manganese	76.0	4.7	19.3	-
Zinc	2.5	63.4	34.1	-
Cobalt	34.1	48.6	17.3	-
Iron	62.8	8.4	17.0[a]	11.7[a]
Molybdenum	42.2	-	48.6[a]	9.2[a]

[a] Causes interference with other elements

Table 3. Trace mineral classification for 709 forage samples from 23 states (adapted from Mortimer et al., 1999)

	Animal Requirement				Copper Antagonism	
Element	Deficient (%)	Marginal (%)	Adequate (%)	MTL[a] (%)	Marginal (%)	High (%)
Copper	0.7	66.0	33.3	0	-	-
Manganese	0.6	14.1	85.3	0	-	-
Zinc	33.3	43.7	23.0	0	-	-
Selenium	43.4	26.1	30.2	0.3	-	-
Cu:Mo	15.7	4.8	79.6	-	-	-
Sulfur	6.1	22.0	25.5	2.0	33.6	12.8
Iron	2.8	-	70.5	1.7	18.6	8.0
Molybdenum	-	-	51.5	2.7	40.3	8.2

[a] Maximum tolerable level

Table 4. Trace elements in tall fescue: 73 samples (adapted from Mortimer et al., 1999)

	Copper (ppm)	Manganese (ppm)	Zinc (ppm)	Selenium (ppm)	Cu:Mo (ppm)
Mean ± S. E.	9.3 ± 0.5	151.8 ± 11.4	23.6 ± 1.1	0.08 ± 0.01	17.1 ± 1.9
Classification					
MTL[a] (%)	0	0	0	0	0
Adequate (%)	26.0	97.3	15.1	4.1	80.8
Marginal (%)	72.6	2.7	46.6	17.8	5.5
Deficient (%)	1.4	0	38.4	78.1	13.7
Copper Antagonists					
	Mean ± S. E.	% Ideal	% Marginal	% High	%MTL[a]
Iron (ppm)	153.8 ± 21.7	82.2	6.9	5.5	1.4
Molybdenum (ppm)	1.1 ± 0.1	49.3	46.6	4.1	0
Sulfur (%)	0.2 ± 0.01	38.4	42.5	1.4	0

[a] Maximum tolerable level

Table 5. Trace elements in native grass: 38 samples (adapted from Mortimer et al., 1999)

	Copper (ppm)	Manganese (ppm)	Zinc (ppm)	Selenium (ppm)	Cu:Mo (ppm)
Mean ± S. E.	8.5 ± 0.6	117.3 ± 18.6	24.3 ± 1.6	0.16 ± 0.03	17.6 ± 4.4
Classification					
MTL[a] (%)	0	0	0	0	0
Adequate (%)	18.4	86.8	23.7	23.7	76.3
Marginal (%)	81.6	13.2	39.5	36.8	2.6
Deficient (%)	0	0	36.8	39.5	21.1
Copper Antagonists					
	Mean ± S. E.	% Ideal	% Marginal	% High	%MTL[a]
Iron (ppm)	178.6 ± 33.9	71.1	18.4	5.3	2.6
Molybdenum (ppm)	1.2 ± 0.2	63.2	29.0	7.9	2.6
Sulfur (%)	0.17 ± 0.01	21.1	23.7	7.9	2.6

[a] Maximum tolerable level

Table 6. Trace mineral content of hand-clipped and grazed forage samples (adapted from Corah and Arthington, 1995)

Collection Method	Iron (ppm)	Copper (ppm)	Zinc (ppm)	Manganese (ppm)
Steer Selected	152.7 ± 16.8	10.65 ± 0.56	20.42 ± 0.54	11.32 ± 0.59
Hand-Clipped	154.8 ± 23.7	11.49 ± 0.79	19.50 ± 0.76	12.84 ± 0.84