TRACE MINERAL NUTRITION IN BEEF CATTLE

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Introduction

Minerals can be divided into two main categories, 1) macro-minerals and 2) micro or trace minerals. Macro minerals are minerals that are needed/required in relatively large amounts in comparison to micro or trace elements which are needed/required in relatively small amounts. In general macro minerals are required at concentrations greater than 100 ppm of the diet and are often expressed as a percentage of the diet while trace minerals are required at concentrations less than 100 ppm (McDowell, 1992; NRC, 1996). Macro minerals such as phosphorus, potassium, sulfur, magnesium, sodium, and chloride and trace minerals such as copper, zinc, iodine, manganese, selenium, cobalt, and iron are considered essential for beef cattle (NRC, 1996). Macro minerals have important physiological functions in beef cattle and therefore must be supplemented to beef cattle diets when forages or rations are deficient or have the incorrect proportions of macro minerals. If not supplied in the correct amounts and ratios, specific metabolic diseases and/or toxicities can be produced. However, several of the mineral imbalances commonly observed in beef cattle are due to imbalances in trace minerals. To promote normal tissue growth, homeostasis, enzyme function, cell regulation, and immune function, it is imperative that trace minerals be maintained within narrow concentrations within the body (McDowell, 1989, 1992; Underwood and Suttle, 1999). Trace mineral deficiencies, toxicities, and imbalances require the animal to metabolically compensate for the nutrient deviation (McDowell, 1989, 1992; Underwood and Suttle, 1999). In doing so, certain metabolic diseases can be produced and overall animal performance can be depressed (McDowell, 1989, 1992; Underwood and Suttle, 1999). Due to the magnitude of this topic – Mineral Nutrition in Beef Cattle, this review will focus primarily on trace minerals involved in beef cattle production. Focusing this review on trace minerals involved in beef cattle production by no means indicates that macro minerals (phosphorus, calcium, potassium, etc) are not important in beef cattle production. In fact the macro minerals play a significant role in beef cattle production. However, the majority of mineral questions/problems observed in the field seem to focus around trace minerals. Therefore, the intent of this review is to: 1) give a general description of the function of trace minerals in beef cattle 2) discuss the impact of trace minerals on performance parameters in beef cattle, and 3) discuss factors that can potentially affect trace mineral requirements in beef cattle. For an in depth review of both macro and trace minerals see the textbooks written by McDowell, (1992) and Underwood and Suttle, (1999).

Q. Why should I be interested in supplementing minerals to my cowherd?

Minerals play a vital role in forage digestion, reproductive performance, the immune system, and the development of bones, muscle, and teeth. An inadequate intake of minerals and vitamins may result in 1) reduced forage intake; 2) lower reproductive efficiency; 3) poor disease immunity; 4) slower daily gains, and 5) poorer feed conversion. Sub clinical trace mineral deficiencies occur more frequently than recognized by most livestock producers. This may be a larger problem than an acute mineral deficiency, because the rancher does not see specific symptoms that are characteristic of a trace mineral deficiency. With a sub clinical deficiency, the animal grows or reproduces at a reduced rate, uses feed less efficiently and operates with a depressed immune system (McDowell, 1989, 1992; Underwood and Suttle, 1999). Texas A&M researchers believe trace element deficiencies may impact production in better-managed herds even more than previously recognized. Table 1 shows the six macro-minerals and seven trace minerals that cattle require.

Table 1. Minerals Cattle Need	
Macro Minerals	**Trace Minerals**
Calcium	Copper
Phosphorus	Zinc
Magnesium	Manganese
Salt	Cobalt
Potassium	Iodine
Sulfur	Iron
	Selenium

Q: Why should I be concerned about trace minerals for my cow herd?

Supplementing minerals to beef cattle has been shown to have positive effects on reproduction, immune status, disease resistance and feed intake. Trace minerals are needed for vitamin synthesis, hormone production, enzyme activity, collagen formation, tissue synthesis, oxygen transport, energy production, and other physiological processes related to growth, reproduction and health. The requirement for trace minerals is often based upon the ability of the animal to maintain a desired level of performance. Table 2 shows the trace mineral requirements for growing and finishing cattle, and cows.

Table 2. Trace mineral requirements for beef cattle

mg of mineral required per kg of dry matter consumed		
Mineral	Growing-Finishing Cattle	Cows
Cobalt	0.1	0.1
Copper	10	10
Iodine	0.5	0.5
Iron	50	50
Manganese	20	30
Selenium	0.1	0.1
Zinc	30	30

How did we discover that trace minerals were necessary for livestock?

Copper, molybdenum and sulfur:

- The necessity of copper for cattle was first established in the 1930's with the discovery in Florida that cattle that had a wasting disease were deficient in cobalt, iron, and copper. Researchers in Northern Europe described this wasting disease by animals as having diarrhea, loss of appetite, and anemia (McDowell,1992).
- In the late 1930's, scientists in England described a severe scouring disease of cattle called "teart" that was caused by ingestion of forage with high levels of molybdenum (McDowell,1992). Later scientists discovered that large doses of copper sulfate could prevent this condition. Still later it was shown that molybdenum limited the retention of copper in the body, especially in the presence of adequate amounts of inorganic sulfate in the diet (water?; McDowell,1992). It was this discovery that led to numerous studies on the relationship among copper, molybdenum, and sulfate. We can summarize these interrelationships as:

1. Molybdenum in the presence of sulfate reduces the deposition of copper in organs and increases the excretion of copper in the urine.
2. An increase of dietary copper reduces molybdenum deposition in the liver.
3. When the copper to molybdenum ratio of forages in the presence of adequate sulfate was less than 2.8 to 1, then copper deficiency is evident. A copper to molybdenum ratio of no less than 4:1 has been proposed to ensure that the copper requirement will be met.
4. High levels of dietary zinc and iron depress copper absorption and tend to increase the requirements. High dietary levels of zinc (100 ppm) reduce liver copper storage.
5. Cattle can die from copper poisoning; these animals may experience nausea, vomiting, salivation, abdominal pain, convulsions, paralysis, and death. The usual cause is improperly formulated supplements or diets.

Zinc:

- Zinc is widely distributed through the body, but animals have a limited ability to store zinc in a form that can be mobilized to prevent a deficiency in cattle. The highest concentrations of zinc were found in the following order: pancreas, liver, pituitary gland, kidney, and adrenal gland (McDowell,1992). Additional reports have shown that the testicles and accessory sex glands contain high concentrations of zinc (McDowell,1992).
- It is suspected that zinc was applied as an ointment for skin lesions by several cultures, including the Egyptians.
- In 1960 scientists discovered that a skin disorder of cattle could be cured with zinc therapy.
- Loss of appetite is one of the first signs of deficiency in calves, a bowing of the hind legs and stiffness of the joints was noted.
- In laboratory animals, severe zinc deficiency has resulted in offspring with impaired learning ability.
- Additional clinical signs of a zinc deficiency in cattle include: inflammation of the nose and mouth with submucous hemorrhages, unthrifty appearance, rough hair coats, stiffness of the joints with swelling of the feet and fetlocks, cracks in skin of coronary bands around the hooves, and dry scaly skin on the ears (McDowell,1992).
- In grazing animals, a marginal zinc deficiency results in subnormal growth, fertility, low serum zinc values, and decreased resistance to infection and stress (McDowell,1992)..

Selenium:

- During the 1930's selenium was identified as the toxic element in some forages that caused animals to lose hair, nails, and hooves. Selenium is now known to be required by food animals and humans. Consumption of feedstuffs containing both toxic and deficient concentrations of selenium present a problem for grazing livestock (McDowell,1992).
- Marco Polo in his travels in western China (ca. 1295) described a syndrome resulting from the ingestion of seleniferous plants. He reported that when horses ate this poisonous plant, hooves dropped off (McDowell,1992).
- In 1860 an army surgeon in South Dakota also described a fatal disease in horses grazing near Fort Randall. The horses exhibited extreme tenderness and inflammation of the feet, accompanied by loss of hair from the mane and tail.
- Some speculate that many horses of the U.S Calvary commanded by General Custer exhibited selenium toxicity during the summer of 1876.
- Pioneers on the northern Great Plains in the 1890s also described selenium toxicity of their livestock. They associated the disease with alkali seeps and waters of high salt content. It became known as alkali disease (McDowell,1992).

- In the 1950s, selenium was reported to be beneficial for livestock and shown to prevent liver necrosis in swine and muscular dystrophy in calves (McDowell,1992).
- Selenium is closely linked to vitamin E; both protect biological membranes from degeneration. Lack of these nutrients results in tissue breakdown.
- Selenium deficiency in ruminants is called white muscle disease which is a degeneration of striated muscles. Animals with it have generalized weakness, stiffness, and muscle deterioration. Animals have difficulty standing.

- There are a couple of clinical patterns. There is a congenital type of muscular dystrophy in which calves are stillborn or die within a few days after sudden physical exertion such as nursing and/or running. It is usually observed in calves between 1 – 2 months of age.
- Poor reproductive performance also is a symptom of selenium deficiency and includes retained placenta. Work from Ohio showed that the incidence of retained placentas was reduced when cows were injected with a combination of selenium and vitamin E (McDowell,1992).
- Alkali disease generally happens when animals graze forages with selenium in the range of 5 to 40 ppm. Certain selenium accumulating plants have between 100 and 9,000 ppm selenium.
- Animals suffering from selenium toxicity have loss of appetite, lack of thriftiness, cirrhosis of the liver, loss of hair, lameness, and elongated hooves (McDowell,1992).

Manganese:

- Manganese is involved in many of the same processes as zinc and copper, although the original research that identified Mn as an essential trace element was based on measurements of reproductive parameters (Orent and McCollum, 1931; Kemmerer et al., 1931). Hidiroglou (1975) reported that Mn uptake was greater in the ovine Graafian follicle and corpus luteum when compared to other reproductive tissues. This author suggested that Mn may be essential for normal ovarian function. As Maas (1987) indicated, Mn deficiency has been associated with the anestrus condition in cattle.
- Manganese has also been identified as an essential component in bone and cartilage formation and growth. Leach (1971) noted that Mn is essential in the activation of glycotranferases that are partly responsible for mucopolysaccharide synthesis. Manganese is also involved in lipid and carbohydrate metabolism. Therefore, Mn deficiency can potentially lead to a decrease in overall animal growth (Prasad, 1984).

Cobalt:

- Cobalt (Co) was shown to be essential for ruminats in 1935 when it was found to correct a disorder characterized by reduced appetite and weight loss (Underwood, 1971). In 1948, Co was shown to be an essential component of vitamin B_{12} (cobalamin). Under normal situations, domestic ruminants are not dependent on a dietary source of vitamin B_{12} because ruminal microorganisms are capable of synthesizing vitamin B_{12} from Co (NRC, 1996). The efficiency at which Co is utilized by vitamin B_{12}-producing rumen microorganisms is low. Smith (1987) reported that the amount of dietary Co converted to vitamin B_{12} in the rumen ranged from 3-13% of intake. Furthermore, rumen microorganisms shunt Co to inactive vitamin B_{12}–like compounds that are unavailable to the animal (Gawthorne, 1970; NRC, 1996). Vitamin B_{12} is an essential part of certain enzymes involved in metabolic reactions. Most of the cobalamins occur in two coenzyme forms, adenosylcobalmin and methylcobalmin (McDowell, 1992; NRC 1996). Cyanocobalamin is converted within cells to either methylcobalmin – a coenzyme for methyltransferase, or adenosylcobalmin-the coenzyme for mutase (McDowell, 1992). Methylmalonyl CoA mutase is an enzyme involved in the metabolism of propionate to succinate via the conversion of L-methylmalonyl-CoA to succinyl-CoA (Smith, 1987;

McDowell, 1992; NRC, 1996). 5-methyltetrahydrofolate homocysteine methyltransferase is also a vitamin B_{12}-dependent enzyme that is heavily involved in one-carbon and methionine metabolism (Smith, 1987; McDowell, 1992; NRC, 1996).

Q: What are the symptoms of a copper or zinc deficiency?

Table 3 summarizes the potential effects of a copper and/or zinc deficiency in both cows and bulls. The main effects of copper and zinc deficiencies are a reduction in reproductive efficiency; delayed estrus, decreased conception rates, and increased dystocia. Zinc deficiency may also be related to footrot, although there has been no direct evidence linking zinc deficiency to footrot in the literature.

Table 3. Symptoms of a copper or zinc deficiency in beef cattle

Mineral	Cow	Bull
Copper	Delayed estrus	Decreased libido
	Embryonic death	Decreased spermatogenesis
	Decreased conception	
	Delayed puberty	
	Decreased ovulation Immunity	
Zinc	Increased dystocia	Impaired growth Delayed puberty
	Abnormal estrus Immunity	Decreased testicular size Decreased libido

Q: What are examples of other trace mineral deficiencies?

The following table provides a summary of the effects of manganese, iodine, selenium and iron deficiencies in beef cattle.

Table 4. Symptoms of trace mineral deficiencies in beef cattle

Mineral	Deficiency symptoms	Other Comments
Manganese	• Impaired reproductive performance (silent heats), • Skeletal deformities, • Shortened tendons in new born, • Reduced birth weight.	High dietary calcium, potassium or phosphorus increase manganese excretion in the feces, presumably by reducing manganese absorption Excessive dietary iron depresses manganese retention in calves
Iodine	• Weak or stillborn calves • Calves born hairless,	Be careful if using organic iodine (EDDI). Prolonged use at high levels

	• Impaired fertility • Retained placenta • Increased susceptibility to soft tissue infection • Foot rot • Lump jaw	can cause elevated temperature, dry coughing, runny noses and eyes. Young calves show symptoms first. By law, feed mills can not exceed allowed levels of organic Iodine.
Selenium	• White muscle disease • Reduced disease resistance • Retained placenta • Weak or dead calves • Chronic diarrhea	High dietary or water sulfate seems to interfere with selenium absorption. By law, feed mills can not exceed allowed levels of Selenium.
Iron	• A problem in young animals only • Anemic animals are listless and have poor feed intake and weight gain • Greater sickness and mortality caused by depressed immune system	250-500 ppm Fe in diet has been implicated as causing Cu depletion from body. Iron toxicity (1000 ppm) causes diarrhea, poor gains and lowered feed intake

Q: What factors can influence trace mineral metabolism in cattle?

Despite the involvement of certain trace minerals in animal production and disease resistance, deficiencies of trace minerals have not always reduced performance or increased the susceptibility of domesticated livestock species to natural or experimentally-induced infections (Spears, 2000). There are many factors that could affect an animal's response to trace mineral supplementation such as the duration and concentration of trace mineral supplementation, physiological status of an animal (i.e. pregnant vs. non pregnant), the absence or presence of dietary antagonists, environmental factors, and the influence of stress on trace mineral metabolism (Baker et al., 2003). For the purpose of this portion of the review, five areas deserve attention when discussing potential factors that may affect the trace mineral requirements of ruminants: breed, gestational status, stress, trace mineral antagonists, and age.

Breed Effects:

Although species differences in trace mineral metabolism have long been recognized, only recently have differences been noted between breeds within a species. Differences in trace mineral metabolism between breeds of dairy cattle have been reported. In an experiment by Du et al. (1996), Holstein (n=8) and Jersey (n=8) primiparous cows and Holstein (n=8) and Jersey (n=8) growing heifers were supplemented with either 5 or 80 ppm of copper for 60 days. At the end of the 60 day experiment, Jerseys had higher liver copper concentrations relative to Holsteins across both treatments. Furthermore, liver copper concentrations increased more rapidly and were higher in the Jerseys supplemented with 80 ppm of copper compared to Holsteins supplemented with 80 ppm of copper by day 60 of the experiment. Overall serum ceruloplasmin oxidase activity (a copper-dependent enzyme involved in iron transport) was higher in Jerseys than Holsteins. Additionally, Jersey cows and heifers had higher liver iron and lower liver zinc concentrations than did Holstein cows and heifers at day 60 of the experiment. These data indicate that Jerseys and Holsteins metabolize copper, zinc, and iron differently.

Ward et al. (1995) conducted a metabolism study in which Angus (n=8) and Simmental (n=8) steers were placed in metabolism crates to monitor apparent absorption and retention of copper. At the end of the six-day metabolism experiment, plasma copper concentrations and apparent absorption and retention of copper were higher in Angus relative to Simmental steers. The authors indicate, from their data as well as from others, that Simmental cattle may have a higher copper requirement than Angus cattle and that these different requirements may be related to differences in copper absorption in the gastrointestinal tract between breeds. Furthermore, it has also been suggested that these breed differences in copper metabolism may not be due solely to differences in absorption, but also to the manner in which copper is utilized or metabolized post-absorption. Gooneratne et al. (1994) reported that biliary copper concentrations are considerably higher in Simmental cattle than in Angus cattle. It is apparent that differences in copper metabolism exist between Simmental and Angus cattle both at the absorptive and post-absorptive levels.

An extensive study comparing the mineral status of Angus, Braunvieh, Charolais, Gelbvieh, Hereford, Limousin, Red Poll, Pinzgauer, and Simmental breeds consuming similar diets has also been conducted (Littledike et al., 1995). This work compared not only copper, but also zinc and iron status between all previously mentioned breeds of cattle. In adult cattle, it was shown that Limousin liver copper concentrations were higher than all other breeds, except for Angus. This same trend was not seen for zinc and iron; with very little breed differences observed except for lower liver zinc concentrations in Pinzgauer when compared to Limousin. Serum zinc and copper concentrations did not differ by breed.

Gestational Status:

Although little data has been published examining the effects of gestational status on trace mineral metabolism in cattle, several experiments have been conducted using laboratory animals and humans that indicate trace mineral metabolism is altered during pregnancy. Research has indicated that zinc concentrations increase in bovine conception products (placenta, placental fluids, and fetus) as the fetus grows (Hansard et al., 1968). Studies using rats have shown that the overall maternal body stores of copper and zinc increase during pregnancy and then decrease during lactation. Mean zinc total body stores at the start of pregnancy were recorded at 5,260 μg of zinc versus 5,810 μg of zinc at day 15 of pregnancy. By day 14 of lactation, maternal body stores of zinc had decreased to 5,640 μg of zinc, which was still considerably higher than at the onset of pregnancy (Williams et al., 1977). These same trends were observed with copper. In a recent experiment by Vierboom et al. (2002), pregnant cows and sheep absorbed and retained zinc to a greater degree than non-pregnant cows and sheep. These data indicate that certain physiological and/or metabolic parameters are altered in pregnant cows and ewes consuming an alfalfa-based diet that enhance the apparent absorption and retention of certain trace minerals.

The aforementioned data indicate that copper and zinc metabolism is altered in pregnant vs. non-pregnant animals. Further research is required to determine the metabolic mechanisms that enable pregnant animals to alter copper and zinc metabolism as well as an animal's specific metabolic requirement for both maintenance and fetal development. In addition, research to determine the effects of gestational status on the metabolism of other trace minerals as well as if breed differences exist relative to trace mineral metabolism and gestational status is needed.

Stress:

As mentioned earlier, trace minerals such as copper and zinc are involved in immune response. Deficiencies and/or imbalances of these elements can alter the activity of certain enzymes and function of specific organs thus impairing specific metabolic pathways as well as overall immune function.

Stress and its relationship to the occurrence of disease has long been recognized. Stress is the nonspecific response of the body to any demand made upon it (Selye, 1973). Stressors relative to animal production include a variety of circumstances such as infection, environmental factors, parturition, lactation, weaning, transport, and handling. Stress induced by parturition, lactation, weaning and transport has been shown to decrease the ability of the animal to respond immunologically to antigens that they encounter. Furthermore, research has indicated that stress can alter the metabolism of trace minerals. Stress in the form of mastitis and ketosis has been shown to alter zinc metabolism in dairy cattle. Orr et al. (1990) reported an increase in urinary copper and zinc excretion in cattle inoculated with IBRV. Furthermore, Nockels et al. (1993) reported that copper and zinc retention was decreased in steers injected with ACTH (a stressor), in conjunction with feed and water restriction. These studies, in conjunction with several others, indicate that stress in the form of an infection (IBRV), a metabolic disorder (ketosis), or deprivation of feed and (or) water can increase copper and zinc depletion from the animal.

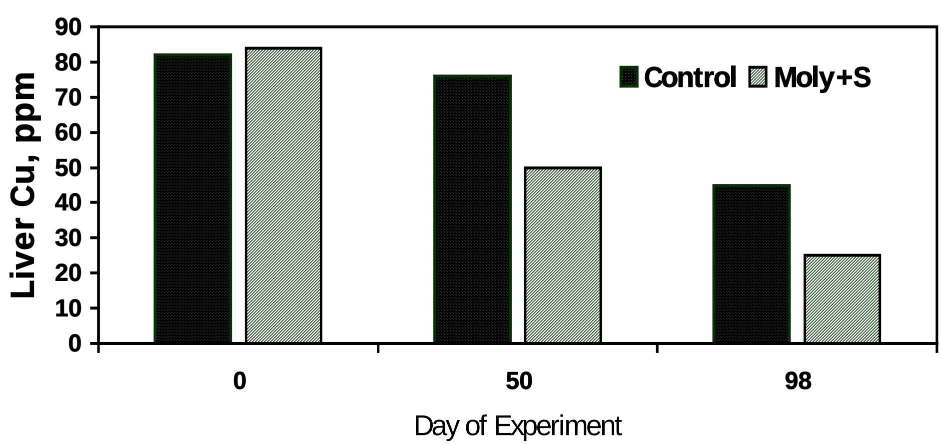
Trace Mineral Antagonists:

Many element-element interactions have been documented (for an in depth review of potential element-element interactions see Puls, 1994). These include zinc-iron, copper-iron, copper-sulfur, copper-molybdenum, and copper-molybdenum-sulfur interactions and interactions between elements and other dietary components. Peres et al. (2001) used perfused jejunal loops of normal rats to characterize the effects of the iron:zinc ratio in the diet on mineral absorption. When the iron:zinc ratio in the diet was held below 2:1, no detrimental effects on absorption were observed. However, once concentrations were increased to yield a ratio between 2:1 and 5:1, zinc absorption was decreased. Similar effects have also been seen for copper absorption, with depressed copper uptake in the presence of excess iron. Liver copper concentrations of Heifers receiving approximately 500 ppm of iron were drastically reduced (form 134.0 ppm to 5.6 ppm) after receiving the high iron diet for 16 weeks, whereas liver copper concentrations of control heifers receiving 4 ppm copper decreased at a much slower rate (Phillippo and Humphries, 1987).

Q: Are there minerals that can reduce the utilization of copper and zinc?

The best known of mineral interactions that can cause a reduction in copper absorption and utilization is the copper-molybdenum-sulfur interaction. It has been shown that an excess of sulfur, molybdenum, and iron in the diet can interfere with the utilization of copper and may result in deficiency symptoms even though the levels of copper in the diet are adequate. However, even molybdenum or sulfur alone can have antagonistic effects on copper absorption. Suttle (1974) reported that plasma copper concentrations were reduced in sheep with increasing concentrations of dietary sulfur from either an organic (methionine) or inorganic (Na_2SO_4) form. In another experiment, Suttle (1975) demonstrated that hypocupraemic ewes fed copper at a rate of 6 ppm of copper, with additional sulfur or molybdenum, exhibited slower repletion rates than sheep fed no molybdenum or sulfur. However, when both molybdenum and sulfur were fed together, copper absorption and retention was drastically reduced. Current research would support these findings and suggest that in addition to independent copper-sulfur and copper-molybdenum interactions, there is a three way copper-molybdenum-sulfur interaction that renders these elements unavailable for absorption and/or metabolism due to the formation of thiomolybdates (Suttle, 1991). This concept is demonstrated by the work of Arthington et al. (1996) who showed that copper levels in the liver were significantly reduced when molybdenum and sulfur were supplemented to beef cattle (Figure 1).

Figure 1. Change in liver copper concentration when cattle were supplemented with Molybdenum and Sulfate (adapted from Arthington et al., 1996)



Ward (1978) also investigated the independent effect of molybdenum on copper absorption and concluded that elevated molybdenum intake reduces copper availability and can lead to a physiological copper deficiency. This was attributed to a copper-molybdenum complex which forms in the rumen that cannot be broken down and absorbed. Based on this and previous experiments, it appears that the ratio of the antagonistic elements seems to be more important than the actual amounts. Miltimore and Mason (1971) reported that if copper:molybdenum ratios fall below 2:1, copper deficiency can be produced. Huisingh et al. (1973) further concluded, in their attempt to produce a working model of the effects of sulfur and molybdenum on copper absorption, that both sulfur (in the form of sulfate or sulfur-containing amino acids) and molybdenum reduce copper absorption due to the formation of insoluble complexes. They also noted that sulfur and Mo interact independently and suggested that they may share a common transport mechanism.

Mineral to mineral interactions are not the only possible inhibitors of mineral absorption. Other dietary components can also inhibit or enhance the amount of mineral that is absorbed. Protein, as might be expected from the discussion involving sulfur-containing amino acids, is an example of a dietary component that can affect mineral metabolism. Snedeker and Greger (1983) reported that high protein diets significantly increase apparent zinc retention. In contrast, diets high in sulfur-containing amino acids have been shown to decrease copper absorption, most likely due to the formation of insoluble copper-sulfur and potentially copper-molybdenum-sulfur complexes (Robbins and Baker, 1980).

In his review, O'Dell (1984) also noted the potential for carbohydrate source to affect copper absorption. This is attributed to phytate as well as oxalate concentrations in the diet. Fiber can also act as a mineral trap due to its relatively large negative charge that serves to bind the positively charged divalent metal cations rendering them unavailable for absorption (van der Aar et al., 1983).

Age:

Animals have also been shown to have varying mineral needs depending on their age. Trace mineral requirements have been reported to vary with age of dairy cattle (NRC, 2001). Wegner et al. (1972) reported that dairy cattle in their second to fifth lactations had higher serum zinc concentrations than either first lactation or bred heifers. This change in mineral needs over time is most obvious in young growing animals.

Q: How do I troubleshoot a potential trace mineral deficiency?

Step One--Other Factors: The first step in identifying trace mineral deficiencies is to attempt to rule out other more directly contributing factors that can be the cause of decreased animal performance. For example, if average cow body condition scores are below a five (moderate), chances are far greater that decreases in reproductive performance and/or immune competence are a result of energy/protein deficiency rather than a trace mineral deficiency. Secondly, be sure that proper management of free-choice trace mineral feeding is offered. For example, are the cattle being offered a continuous supply of fresh, dry mineral? Are they consuming the mineral at the recommended level?

Step Two--Forage and Water Trace Mineral Concentrations. Know the trace mineral contribution of the available feedstuffs. Collect forage samples, being careful to select forage that the animals are actually grazing or consuming. Perform a standard trace mineral evaluation of the forage. Also, do not forget to analyze the drinking water, especially in drought-type conditions. Sulfate can play an antagonistic role in both copper and selenium availability. Excessive levels of iron may also depress the utilization of copper. Your local feed representative or Extension agent can help you with forage and water sampling. A complete protein, energy, and mineral analysis of your forage or water will cost between $30 to $60/sample.

Step 3--Herd Trace Mineral Status: In some instances it may be important to confirm or disprove a potential trace mineral deficiency by examining trace mineral status through blood and/or liver collection. Liver samples provide the most reliable indicator of actual animal stores of copper and selenium. This is a fairly expensive option (~$40/sample) because of the number of samples required. Consider this option carefully before proceeding.

When comparing grasses to legumes grown in the same location, legumes tend to be higher in Ca, Cu, Zn and Co than grasses (Greene et al. 1998). Distribution of the mineral in the plant, chemical form, and mineral interactions can also influence bioavailability. Table 5 describes average mineral content for grasses, grass-legume and legume hay samples collected in Montana, Texas and Arkansas.

Table 5. Average mineral content of forages from Montana, Texas and Arkansas (Paterson, unpublished data; Herd, 1997 and Davis et al., 1999).

State	Forage type	Ca	P	S	Cu	Zn	Mo
Montana --		***-------***	***% ---------***		***---------***	***mg/kg***	***-------***
	Grass hay	***0.62***	***0.16***	***0.14***	***5.2****	***18.2****	***1.5***
	Grass-legume hay	**0.85**	**0.21**	**0.19**	**7.0***	**19.2***	**0.81**
	Legume hay	**1.40**	**0.24**	**0.26**	**8.8***	**21.4***	**1.2**
Texas	**Native range**	**0.48**	**0.10**	**0.13**	**5.0***	**21.0***	
Arkansas	**Mixed grass hay**	**0.59**	**0.29**	**0.22**	**10.2**	**24.3***	

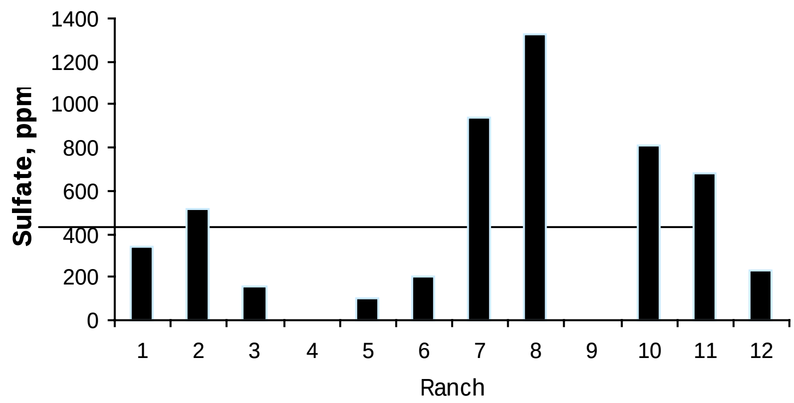
* Requirement for copper (Cu) is 10 ppm and for zinc (Zn) is 30 ppm

Low forage levels of copper coupled with the antagonistic effects of molybdenum requires careful supplementation if you are experiencing any of the symptoms described in Table 3.

Q: What about sampling water?

The following figure (Figure 2) shows the results of a ranch survey conducted in the northeastern part of Montana. As a general rule, copper utilization can be decreased when the amount of sulfate in the water exceeds 500 ppm. This figure suggests that four of the ranches had sulfate levels higher than 500 ppm and trace mineral supplementation needs to be considered. Having livestock water analyzed can tell you much about the potential for causing health problems in your cowherd.

Figure 2. Analyses of water samples for sulfate concentration from 12 Montana ranches



The following table (Table 6) gives an example analysis of a water sample collected from a central Montana ranch.

Table 6. Livestock water quality recommendations and an example of a water sample from central Montana

Item	Recommendation of desired upper limit	Water sample from central Montana	Comments
Nitrate (NO3), ppm	0-44	0	Safe
Calcium, ppm	100	353	Interferes with absorption of other minerals
Magnesium, ppm	50	157	May cause diarrhea
Sulfate (SO4), ppm	500	4049	May interfere with Cu, can cause polio

The nitrate level was considered safe, but the sulfate level was at eight times higher than recommended for cattle.

Q: What about sampling the liver to determine copper status?

The liver is probably the best organ in the body to give an indication of the copper status of the beef animal. The following table (Table 7) shows results from a survey of eight states conducted a few years ago.

Table 7. Percentage of cattle that were classified as deficient or adequate in liver copper

State	No. Cattle	% of cows which were deficient, <30 ppm	% of cows which were adequate, >90 ppm
Colorado	329	30	30
Kansas	257	16	51
Missouri	32	6	63
Montana	182	.2	61
Nebraska	78	55	12
North Dakota	113	92	0
South Dakota	162	65	27
Texas	60	10	62

What these results show is that in Montana, 61% of the cows sampled were considered to have an adequate amount of copper in the liver (>90 ppm) and less than 1% were considered to be severely deficient. The rest of the cows were between 30 and 90 ppm copper. One caution with these results, the cows sampled were from SW Montana and probably do not represent eastern Montana. Based on this survey, eastern Montana cows may have values more similar to western North Dakota and South Dakota. Cows from these two states appear to have a high percentage which would be considered deficient.

Q: **Are there differences in the chemical form of trace minerals on bioavailability?**

Traditionally, supplemental trace minerals have been supplied to livestock in the form of inorganic salts: sulfates, oxides and chlorides, such as copper sulfate or copper chloride. The use of organic trace minerals has increased due to reports of improved feed efficiency, growth, reproduction, and immune response. One study showed that the bio-availability of zinc proteinate was 159% of the bio-availability of zinc sulfate in rats, while another study showed that zinc methionine had 300-400% the potency of zinc sulfate in young channel catfish.
Work by Jerry Spears from North Carolina reviewed the effects of feeding zinc methionine to cattle and reported improved performance, carcass quality, and immune response.

The following table (Table 7), developed by Wayne Greene from Texas A&M, compares the bio-availability of copper, manganese, and zinc from different sources.

Table 7. Relative bioavailability of trace minerals from different sources (adapted from W. Greene et al., 1999)

Mineral	Sulfate-form	Oxide-form	Carbonate	Chloride-form	Organic- form (Complexed chelate,etc.)
Copper	100	0	-	105	130
Manganese	100	58	28	-	176
Zinc	100	-	60	40	159-206

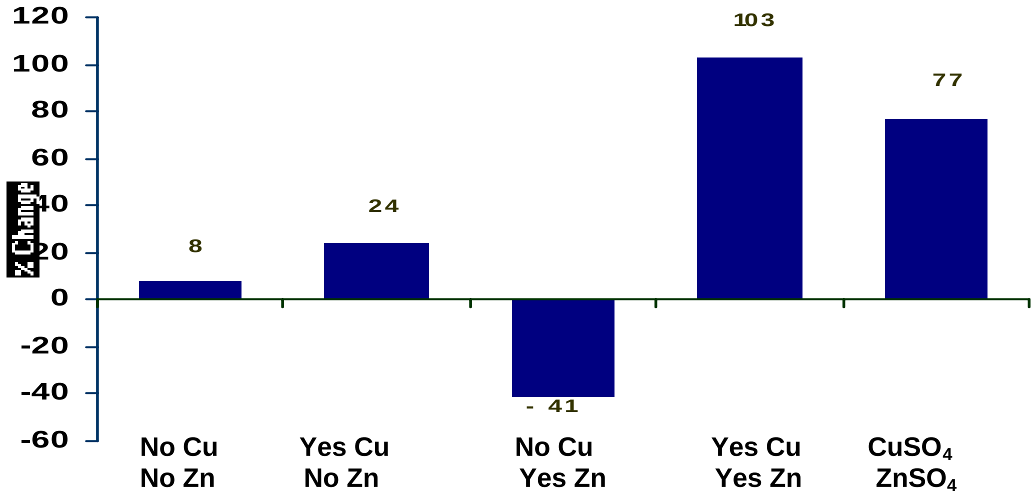
If you assume that the bioavailability of the trace minerals is equal to 100, then the bioavailability of copper oxide would be 0 (no availability), copper chloride 105% (five percentage units better than copper sulfate) and organic copper 130% (30 percentage units better than copper sulfate). Similarly, zinc carbonate and zinc chloride would have a lower bioavailability than an organic form of zinc.

Q: Why do I need to feed a "balanced" mineral supplement rather than just provide single mineral supplementation?

Workers at the University of Kentucky found that if they supplemented too much zinc in a diet, they decreased the utilization of copper. Montana State University workers also found this to be the case when they compared liver retention of copper after 90 days in heifers fed high levels of zinc (Figure 3).

These results suggest that copper supplementation alone increased liver copper concentrations 24%. However, if heifer were supplemented only with zinc, this actually reduced liver copper concentrations by 41%. By supplementing both copper and zinc, liver copper levels increased 100% over the 90-day experiment. These results indicate a need for balanced mineral supplements rather than single element supplementation. We believe the zinc to copper ratio needs to be between 3:1 and 5:1.

Figure 2. Effect Of Copper and/or Zinc Supplementation On Liver Copper Storage In Heifers
Wellington et at., 1998



Q: What are the effects of trace mineral supplementation on reproduction?

Manspeaker (1987) compared no supplementation to supplementation with Cu, Zn, Mn, Fe and Mg (chelated forms) for dairy heifers. Results of this experiment are presented below (Table 8).

Table 8. Effect of Trace Mineral Supplementation on Reproductive Measures (Manspeaker)

Measurement	No mineral supplement	Cu, Zn, Mn, Fe and Mg Supplementation
Infections (bacteria isolated from cervix & uterus), %	25	5
Ovarian activity (mature follicles 30-80 days after calving)	20	35
Embryonic mortality (palpated embryonic depression 35-55 d post-insemination, %)	20	0
Incidence of endometrial scarring, %	58	10

Supplementation reduced the percentage of uterine infections, embryonic mortality and endometrial scarring, and improved the post-partum involution and tone of the pregnant horn. Connie Swenson, as part of her PhD project at MSU, supplemented Cu, Zn, Co and Mn in either the inorganic-sulfate form or in an amino acid-complexed form to first calf heifers. Her findings are listed below (Table 9):

Table 9. Effect of Trace Mineral Supplementation on Reproductive Traits (Swenson, PhD dissertation , Montana State University)

Reproduction parameters	Control supplement	Inorganic trace minerals (sulfate forms of Cu, Zn, Mn and Co)	Complexed trace minerals (Cu, Zn, Mn, Co)
Significant structures by day 45, %	87a	89a	50b
Cows exhibiting estrus by day 45, %	47ab	67a	28b
Cows bred by AI, %	47cd	33c	61d

a,b Significantly different (P<.05)
c,d Significantly different (P=.09)

Results from her research showed that even though the significant structures and the percentage of cows exhibiting estrus by day 45 were lower when complexed minerals were supplemented, the percentage of cows bred by AI was numerically improved.

The results of a second study by Swenson showed that the time from calving to conception was reduced by 10 days in first calf heifers supplemented with amino acid complex forms of Cu, Zn, Mn and Co compared to sulfate forms and controls with no additional trace minerals.

An interesting study by Tim Stanton from Colorado State University showed that supplementing a high level of inorganic trace minerals actually decreased weaning weights of calves. A lower level of inorganic or a high level of organic minerals resulted in heavier calf weaning weights and more cows becoming pregnant after artificial insemination (Table 10).

Table 10. Effects of source and level of trace mineral supplementation on cow-calf performance (Stanton et al., 1999)

Item	Inorganic Low Level [a]	Inorganic High Level [b]	Organic High Level [c]
No. of head	99	100	100
Initial wt., lb	1287	1289	1278
Final wt., lb	1309	1274	1289
Wt. change, lb	22[d]	15e	11[d]
Calf weaning wt, lb	460[d]	447e	471[d]
Pregnant to artificial insemination	61[d]	56[d]	75e
Pregnancy rate overall, %	88	81	88

[a] Trace mineral mix contained on a ppm basis; 501 Cu, 2160 Zn, 1225 Mn and 11 Co from inorganic sources
[b] Trace mineral mix contained on a ppm basis; 1086 Cu, 3113 Zn, 1764 Mn and 110 Co from inorganic sources
[c] Trace mineral mix contained on a ppm basis; 1086 Cu, 3113 Zn,1767 Mn and 110 Co from an amino acid complex (AvailaÂ®-4, Zinpro, Eden Prairie, Minnesota, USA).
[d,e] Within a row, means which have unlike superscripts differ ($P<0.05$).

Summary

The interactions between trace minerals, animal production, and disease resistance are extremely complex. Many factors can affect an animal's response to trace mineral supplementation such as the duration and concentration of trace mineral supplementation, physiological status of an animal (pregnant vs. open), the absence or presence of dietary antagonists, environmental factors, and the influence of stress on trace mineral metabolism. Breed differences in trace mineral metabolism have also been documented (Wiener et al., 1978; Gooneratne, et al., 1994; Ward et al., 1995: Du et al., 1996; Mullis et al., 1997). Furthermore, research has indicated that different breeds of cattle respond differently to the same immune challenge (Schultz et al., 1971; Blecha et al., 1984; Engle et al., 1999). This may, in part, be related to differences in trace mineral metabolism between different breeds of cattle. Moreover, future research is needed to further investigate the mechanisms by which trace minerals are absorbed and metabolized. A better understanding of trace mineral absorption and metabolism will allow for a better prediction of how trace minerals may interact at the gut and metabolic levels. Recent experimental results indicate that providing supplemental trace minerals can positively influence reproductive efficiency by improving uterine involution and reduces the days to breeding (postpartum interval). Over-supplementation with inorganic trace minerals may be detrimental to calf weaning weights.

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