ROLE OF TRACE MINERALS IN ANIMAL PRODUCTION

What Do I Need to Know About Trace Minerals for Beef and Dairy Cattle, Horses, Sheep and Goats?

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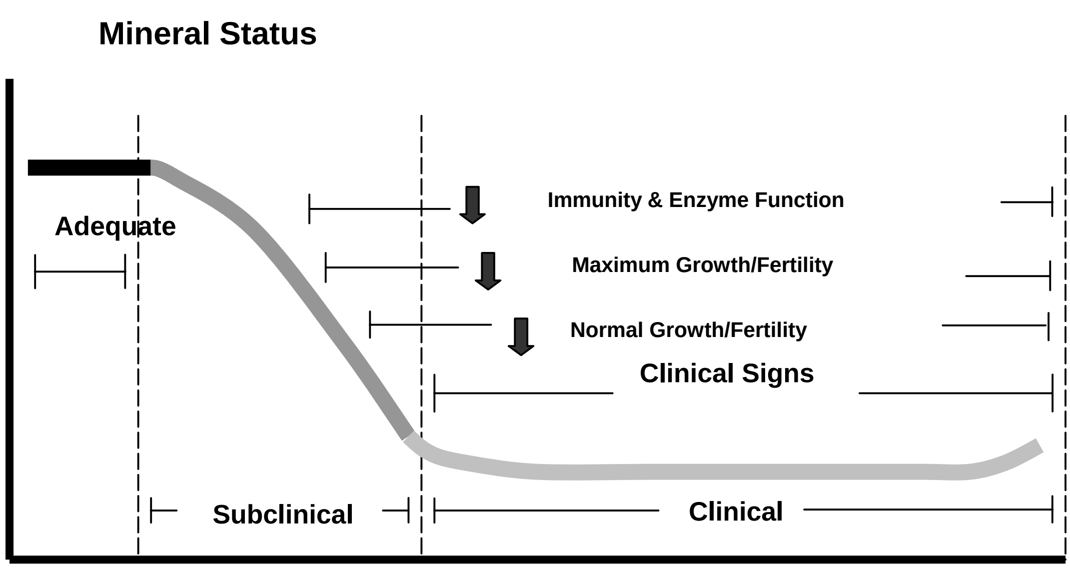
Introduction

The role of trace minerals in animal production is an area of strong interest for producers, feed manufactures, veterinarians and scientists. Adequate trace mineral intake and absorption is required for a variety of metabolic functions including immune response to pathogenic challenge, reproduction and growth. Mineral supplementation strategies quickly become complex because differences in trace mineral status of all livestock and avian species is critical in order to obtain optimum production in modern animal production systems. Subclinical or marginal deficiencies may be a larger problem than acute mineral deficiency because specific clinical symptoms are not evident to allow the producer to recognize the deficiency; however, animals continue to grow and reproduce but at a reduced rate. As animal trace mineral status declines immunity and enzyme functions are compromised first, followed by a reduction in maximum growth and fertility, and finally normal growth and fertility decrease prior to evidence of clinical deficiency (Figure 1; Fraker, 1983; Wikse 1992). In order to maintain animals in adequate trace mineral status, balanced intake and absorption are necessary.

Figure 1. Effect of declining trace mineral status on animal performance

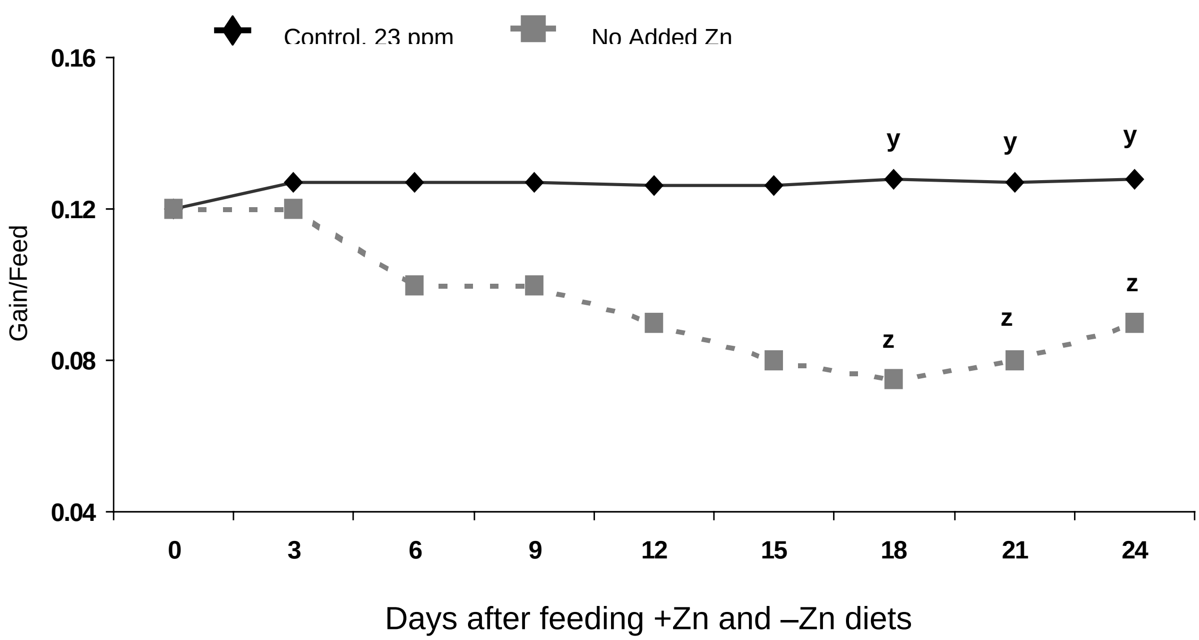


Trace Mineral Function

To better understand the role of trace minerals in animal production it is important to recognize that trace elements are functional components of numerous metabolic events. Trace mineral functions can be described by four broad categories (Underwood and Suttle, 1999): structural, physiological, catalytic and regulatory. Structural function refers to minerals forming structural components of body organs and tissue. An example is the contribution of zinc to molecular and membrane stability. Physiological function occurs when minerals in body fluids and tissues act as electrolytes to maintain osmotic pressure, acid base balance, and membrane permeability. Catalytic function is probably the largest category for trace minerals as it refers to catalytic role of metalloenzymes in enzyme and hormone systems. Trace elements serve as structural components of metalloenzymes. Upon removal of the trace element or lack of adequate trace mineral levels the enzyme activity is lost. There are numerous metalloenzymes that are required for a wide range of metabolic activities such as energy production, protein digestion, cell replication, antioxidant activity and wound healing. Regulatory function is exemplified by the role of zinc to influence transcription and iodine serving as a constituent of thyroxine, a hormone associated with thyroid function and energy metabolism.

The importance of enzyme function as it relates to animal performance was illustrated by zinc depletion-repletion trials reported by Engle et al. (1998). Zinc was shown to have a critical role in proteolytic enzyme systems associated with muscle protein turnover. Muscle protein accretion was shown to decrease when supplemental zinc was removed from the basal forage diet for 21 days; however,

Figure 2. Effect of zinc depletion on feed efficiency in beef calves



yz Means at single time points lacking a common superscript letter differ (P<.05) when zinc was added back to the diet for 14 days, muscle protein accretion returned to normal levels. The role of zinc in protein enzyme systems was further illustrated in a companion study. Average daily gain, feed conversion (Figure 2) and cell-mediated immune response all decreased within 21 days of removing supplemental zinc during a depletion period. Decline in animal performance was evident without a change in zinc plasma or liver concentration, suggesting performance was more sensitive to the marginal deficiency status of the animal. Repletion with a zinc amino acid complex improved gain and feed conversion within 3 days and increased immune response within 14 days. These results suggest that marginal deficiencies can occur in a short period of time as indicated by the measurable loss of animal performance.

Balance among the nutrients, protein, energy, minerals and vitamins, is a key component in striving towards optimum animal production. Balance among the trace minerals themselves is also important consideration and often poses a large challenge due to antagonist interactions that can occur between minerals. The primary interactions that are recognized include the negative impact of high molybdenum and sulfur levels on copper absorption (Suttle et al., 1984; McDowell, 1985; Suttle, 1991), interference caused by high iron levels for absorption of zinc, copper and manganese (Bremner et al., 1987; Gengelbach et al., 1994), and decreased zinc absorption in the presence of high dietary calcium. One trace mineral interaction that is often over-looked is that of zinc and copper. In order to maintain optimal status of both elements, dietary levels should be within a 1:3 up to 1:5 ratio of copper:zinc. Data reported by Wellington (1998) illustrated the negative effect zinc has on copper status. Liver copper decreased 41% in 90 days when zinc was added to the diet to provide 90 ppm in the daily dry matter intake and no additional copper was added. The study also showed a synergistic effect of zinc and copper supplementation. Liver copper increased 103% with addition of copper and zinc together compared to a 26% increase with copper alone. To support this research from an animal performance perspective, Lee (1993) reported improvement in gain for calves grazing wheat pastures with the addition of zinc and copper that surpassed gains of cattle receiving either zinc only or copper only.

Many of today's animal production systems and expectations for performance induce periods of stress to the animal. In the presence of stress, trace mineral status of the animal is critical in minimizing negative effects on production. Nockels et al. (1993) illustrated the effect of stress on copper retention. A sequence of events was carried out to simulate stress encountered by transported calves. Baseline copper retention value was 8.1% for copper sulfate which is in agreement with 7.8% retention value in another metabolism trial. Following the induced stress, copper retention decreased to 3.3%. The decrease in retention was attributed to an increase in biliary copper excretion. These results suggest that stress can potentially reduce status due to a decline in the animal's ability to retain specific trace minerals. Campbell et al. (1999) reported the impact of retained placentas, considered stress, on reproduction parameters in dairy cows. Control cows received a standard inorganic trace mineral supplement and a second treatment group received the standard supplement with the addition of complexed forms of zinc, copper, manganese and cobalt. Control cows with retained placentas had increased days to first estrus, first luteal activity and first corpus luteum, while those with adequate trace mineral status prior to the stress had no effect on reproduction parameters when placentas were retained. These studies imply that it is important to have animals in adequate status prior to and over-lapping periods of greatest risk.

Animal Health

Health concerns are universal in production across all livestock and avian species. Medication costs, lost performance in sick animals and death loss can rapidly reduce profitability in an operation. The immune system is a highly developed mechanism that utilizes a diverse cell population to protect its host against invasion of bacteria, fungi, parasite and viruses. Trace minerals that have been identified as important for normal immune function and disease resistance include zinc, iron, copper, manganese and selenium (Fletcher *et al.*, 1988). A deficiency in one or more of these elements can compromise immunocompetence of an animal (Beisel, 1982; Suttle and Jones, 1989). The first level of defense in the immune system is the skin. Zinc and manganese are key elements for maintaining epithelial tissue integrity. In broiler studies, the addition zinc and manganese amino acid complexes to the diet resulted in fewer skin tears and increased percentage of acceptable paws. Both of these factors contribute to increased carcass value of the broilers. As we consider epithelial tissue, we must also recognize that the lining of the respiratory tract, lungs, gastro intestinal tract and reproduction tract are also epithelial tissue. Maintaining the integrity and health of the tissue in these areas can result in a reduction of infiltration by pathogens.

In order to respond immunologically, whether it be to a foreign antigen that has been given as in a vaccine or one from the production environment, an animal needs to have an immune system that is responsive and capable of meeting any challenge. This defense system must attempt to eliminate these harmful challenges or antigens. Specific cells and proteins are produced to neutralize or destroy these specific antigens. This is the “acquired immune response” in action. The immune system can be divided into two categories: 1) specific immunity referred to as cell-mediated and humoral, or 2) nonspecific immunity action of phagocytes, macrophages and polymorphonuclear neutrophils.

Copper functions in the immune system through the following: energy production, neutrophil production and activity, antioxidant enzyme production, development of antibodies and lymphocyte replication (Niederman et al., 1994; Nockels, 1994). The importance of copper for maintaining the functions of the immune system has been demonstrated in several studies. Viral and bacterial challenges have been shown to increase serum ceruloplasmin and plasma copper in copper-repleted cattle indicating a major protective role for copper in infectious diseases (Stable et al., 1993). Low copper status has resulted in decreased humoral and cell-mediated immunity (Jones and Suttle, 1981a and 1981b; Xin et al., 1991 Gengelback et al, 1997), as well as decreased neutrophil bactericidal capability in steers. In vitro activities of T lymphocytes and neutrophils isolated from adult male rats chronically fed a diet marginally low in copper were significantly suppressed without marked alterations in traditional indicators of copper status (Hopkins and Failla, 1995). Lower than normal tissue reserves in the fetal calf as a result of deficiency in the dam can impair development and growth (Abdelrahman and Kincaid, 1993). Increased incidence of scours, occurrence of abomasal ulcers shortly after birth and respiratory problems have both been attributed to inadequate copper levels in newborn calves (Naylor et al., 1989; Smart et al., 1986).

Zinc functions in the immune system through energy production, protein synthesis, stabilization of membranes against bacterial endotoxins, antioxidant enzyme production, and maintenance of lymphocyte replication and antibody production (Nockels, 1994; Kidd, 1996). Zinc deficiency has been shown to have an important impact on immunity (Gershwin et al., 1985; Droke and Spears, 1993). Decreased cellular immunity, lowered antibody response and disrupted growth of T-dependent tissue have resulted from inadequate intake of zinc (Fletcher et al., 1988). Zinc supplementation for stressed cattle enhanced recovery rate in infectious bovine rhinotracheitis virus-stressed cattle (Chirase et al., 1991). Zinc methionine has also been shown to increase antibody titer against bovine herpesvirsu-1 (Spears et al., 1991). Supplementing zinc to dairy cows during lactation resulted in fewer infections of mammary gland (Spain et al., 1993). North Carolina Researchers (Ferket and Qureshi, 1992) showed the one major cause in reducing early mortality of turkey poults was increasing the zinc and manganese levels and varying these sources in their diet. Adding complexed trace minerals to the lower level of inorganic supplementation improved responses compared to higher levels of inorganic trace minerals. Adding additional complexed trace minerals significantly increased both antibody titer levels and macrophage killing ability over the highest level of inorganic trace mineral supplementation.

Reproduction

Reproductive performance of cattle may be compromised if zinc, copper, or manganese status is in the marginal to deficient range. Common copper deficiency symptoms in cattle include delayed or suppressed estrus, decreased conception, infertility and embryo death (Phillippo et al., 1987; Corah and Ives, 1991). Inadequate zinc levels have been associated with decreased fertility, abnormal estrus, abortion, and altered myometrial contractibility with prolonged labor (Maas, 1987; Duffy et al., 1977). Manganese deficiency in cows results in suppression of conception rates, delayed estrus in post-partum females and young prepuberal heifers, infertility, abortion, immature ovaries and dystocia (Brown and Casillas, 1986; Maas, 1987; Corah and Ives, 1991).

Feeding complexed trace minerals to beef and dairy cows enhances reproductive performance early in the breeding season. Research results in beef cattle indicate that first-calf heifers have confirmed pregnancies 10 d earlier (Swenson et al., 1998), a 17 to 35% improvement in AI conception rates (Spears and Kegley, 1991; Stanton et al., 1999) and an increase in number of ova ovulated per heifer (6.3 versus 2.8; Ansotegui et al., 1999) when females fed complexed trace minerals were compared to those fed iso-sulfate forms. Strategic complex trace mineral supplementation in beef cattle targets 60 d pre-calving through 80 d post-calving.

Summarized dairy data illustrates a 15 d reduction in open days and an 8 d reduction in days to first service. Dairy producers can benefit from year round complexed trace mineral supplementation due to additional effects such as improved claw integrity, enhanced milk production and reduced somatic cell counts. Improving reproductive performance of beef and dairy cows by achieving confirmed conception rates early in the breeding period can have economic returns to the producer.

Growth

Enhanced profitability of many animal production units is dependent upon optimum gain and efficient feed conversion of livestock or poultry. As illustrated by Engle et al. (1998), one of the first indicators of a marginal zinc deficiency is a depression in gain and conversion that are often present prior to any change in blood or liver levels. Providing adequate levels of bioavailable trace minerals can affect growth performance. In view of the role of trace minerals in growth, zinc, copper and manganese all serve as components in numerous enzyme systems associated with carbohydrate and protein metabolism. Manganese is also instrumental in skeletal development and growth. Copper is required for synthesis of collagen and elastin fibers that provide structure and elasticity to connective tissue and blood vessels. Zinc is essential for epithelial tissue integrity, cell division and repair, and uptake transport mechanism and utilization of Vitamins A and E.

In a summary of fourteen broiler studies, the addition of zinc methionine and manganese methionine to diets containing inorganic sources improved body weight 1.61 % and feed/gain 2.52%. Similar gain benefits can be observed in nursery pigs. Data summarized from seventeen nursery trials evaluating copper sources illustrated that copper lysine was an effective growth promoting source of copper. Benefits to feeding a more bioavailable copper source included faster growth, increased feed intake, and fewer days to market that translates into more profits per pig. When zinc methionine was added to swine finishing diets, average daily gain increased from 0.82 to 0.90 kg and conversion improved from 3.17 to 3.07.

Trace mineral supplementation to cow/calf pairs has been shown to increase adjusted weaning weights in calves (Spears and Kegley, 1991; Stanton et al., 1999). Summarized results of twenty-two feedlot trials showed a significant 3.26% increase in daily gain and a 4.05% improvement in feed conversion when zinc methioinine was added to the control diet. The trials were conducted at numerous locations under different environmental conditions and utilizing variable sources of cattle. In consideration of the variation in trials, it is important to recognize the consistency in performance response that were present in order to identify significant improvements.

Environmental Issues and Formulation Strategy

Today's producers are faced with many challenging issues in reference to sustainable agriculture. Of those, environmental issues have begun to make an impact on production practices. In the near future, regulations may possibly limit the level of trace minerals fed in order to reduce the amount found in animal wastes. When producers are confronted with these types of restriction, form of trace minerals fed may become more critical in relation to bioavailability to the animal. The question then becomes, can lower levels of more bioavailable organic minerals give the same response as higher levels of inorganic minerals? In the swine industry it is a common practice to include copper sulfate at elevated levels

(200-250 ppm) to enhance growth in the nursery. In a trial evaluating levels of copper sulfate and copper lysine, pigs fed 100 ppm copper lysine gained more weight and consumed more feed than those fed 250 ppm copper sulfate (Coffey et al, 1994). Feeding lower levels will also reduce the total amount of mineral excreted in the feces. In a study evaluating copper metabolism in growing calves, retention was improved when copper complex was the sole source of supplemental copper or blended with sulfate source and compared to copper sulfate alone.

In the poultry industry, the actual value of increasing zinc level to impact production performance has been fairly well identified as illustrated in Figure 3. It is evident that once supplemental zinc levels exceed 100 ppm there is a plateau in performance. However, research has shown than when a complexed zinc form is added above that 100 ppm zinc sulfate, an increase in performance is measured (Figure 4). This formulation strategy supports the practice of blending organic complexed trace minerals with sulfate form to strive for optimum production in all livestock and avian species. As environmental issues impose restrictions it may become necessary to lower supplemental trace mineral levels and adjust proportions of inorganic to organic in order to maintain optimum performance and profitability.

Figure 3. Influence of increasing zinc levels on broiler performance

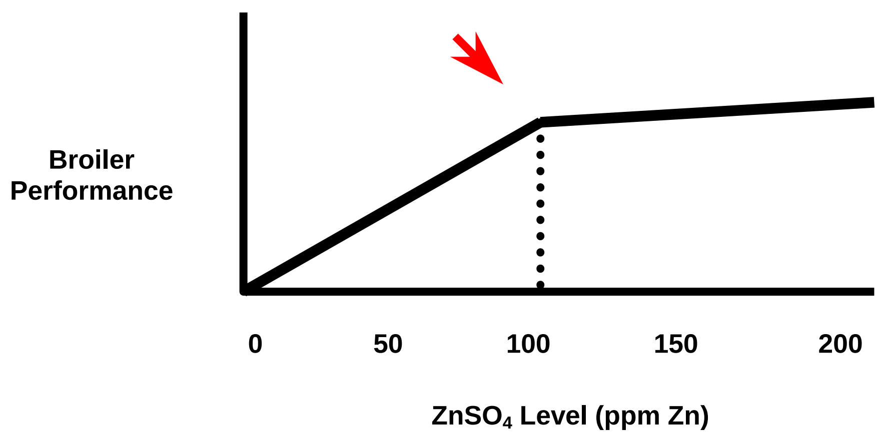
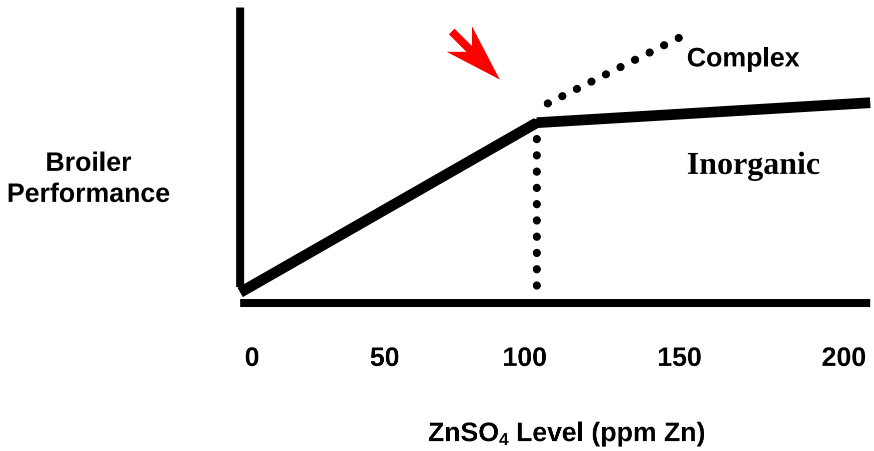


Figure 4. Influence of additional complexed zinc on broiler performance



Another consideration for formulations is differences among the species for trace mineral upper safe limits. Differences are great for copper than the other trace elements. It is widely recognized that copper becomes toxic to sheep at a lower level than for cattle. Goats have a more similar copper tolerance to cattle than sheep. Horses have an even greater tolerance to high copper levels than cattle. However, in livestock that are more tolerant, more copper does not always equate to improved performance. Feeding high copper levels over time increases the amount of copper stored in the liver. The risk of high liver copper levels is that in the event of stress or a bacterial infection, copper is quickly mobilized out of the liver into the blood. High copper levels in the blood result in a hemolytic crisis that can be fatal to the animal.

Summary

Trace elements are required for numerous metabolic functions in livestock, and optimal production and performance require adequate intake of balanced trace minerals. As trace mineral status of the animal declines from adequate to marginal, immunity and enzyme function are compromised followed by the loss of performance and reproduction. Animals in a subclinical or marginal deficiency status are often difficult to identify; however, changes in a trace mineral program can result in improved production. Immunity, growth and reproduction are influenced by trace minerals. Formulation strategies should account for mineral forms, levels and for possible synergistic combinations such as zinc to copper ratios. Trace mineral nutrition continues to be an area of interest for research and production applications.

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