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Trace Mineral Requirements for Dairy Cattle

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Abstract

A host of nutrients are needed by cattle to support functions associated with life, and to grow, reproduce, and nourish their offspring (i.e., produce milk). A vast amount of resources have been expended to quantify the amounts of specific nutrients needed to perform these function so that economically efficient diets can be formulated. Feeding diets that provide adequate, but not excessive, amounts of nutrients helps improve profitability of dairy operations while reducing the environmental impact of dairy farms. The trace minerals zinc, copper, manganese, and selenium are components of a wide variety of enzymes and proteins that support metabolism, growth, production, and reproduction. Trace mineral supplements are added to dairy cattle rations to prevent mineral deficiencies, and supplementation has traditionally been provided in the form of inorganic salts.

Key word: Trace mineral, Dairy cattle, Nutrition

Introduction

Minerals required by dairy cattle in minute quantities (usually microgram or milligram amounts/day) are called trace minerals. Nine trace minerals are considered essential for dairy cows but additional minerals are probably required. The nine trace minerals that are known to be essential are:

- Chromium (Cr)
- Cobalt (Co)
- Copper (Cu)
- Iodine (I)
- Iron (Fe)
- Manganese (Mn)
- Molybdenum (Mo)
- Selenium (Se)
- Zinc (Zn)

The importance of trace mineral nutrition relative to the maintenance of productivity and prevention of deficiency symptoms has been recognized for quite some time (Miller, 1981; NRC, 2001). However, scientists in industry and academia have shown a more recent interest in understanding factors influencing trace mineral requirements and digestibility. Specifically, goals of more recent work include: 1) determining the effect of trace mineral chemistry on mineral retention, and 2) measuring potential benefits of trace mineral supplementation above predicted requirements upon dairy cattle health and productivity (Nocek et al., 2006; Siciliano-Jones et al., 2008; Spears and Weiss, 2008).

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NRC Nutrient Requirements: General Information

Two systems are used to determine nutrient requirements or recommendations: nutrient requirement models and nutrient response models (St-Pierre and Thraen, 1999). For most trace minerals, the 2001 Dairy NRC is a nutrient requirement model. In a nutrient requirement model, various animal factors and perhaps environmental factors are used to calculate the amount of a nutrient needed to perform various functions. A diet formulation program can then be used to determine which combination of ingredients will supply the nutrients needed to meet those requirements. The NRC model calculates requirements at the tissue level, therefore when evaluating or formulating a diet, the supply of trace minerals must also be calculated on a tissue or absorbed basis (i.e., dietary supply times and absorption coefficient, AC).

Roles of Zinc, Copper, Manganese, and Selenium

Zinc is widely distributed throughout the body as a component of metalloenzymes and metalloproteins (Vallee and Falchuk, 1993). Zinc finger proteins play an integral role in regulating gene expression, consequently impacting a wide variety of body functions including cell division, growth, hormone production, metabolism, appetite control, and immune function (Predieri et al., 2003; Vallee and Falchuk, 1993). Zinc has a catalytic, coactive, or structural role in a wide variety of enzymes that regulate many physiological processes including metabolism, growth, and immune function (Vallee and Falchuk, 1993). The coactive role of Zn in one such enzyme, superoxide dismutase (SOD), will be further discussed below. Because Zn is required for production of protective keratins in the hoof and teat, one area of recent attention has been evaluating the role Zn plays in maintaining structural integrity and health of the hoof and udder (Tomlinson et al., 2004, 2008).importance of Zn mechanism showed in Figure1.

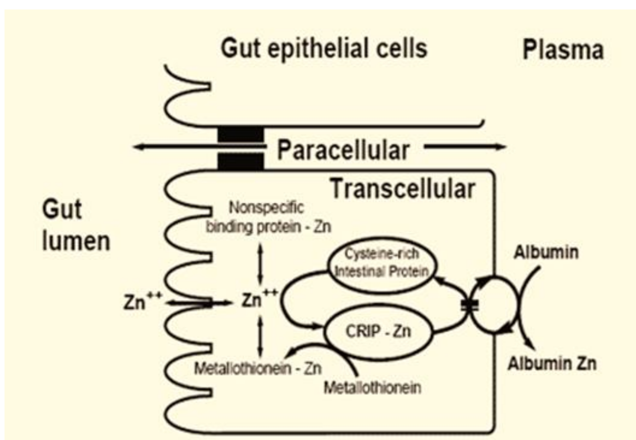

Fig 1. importance of Zn mechanism

Copper and Mn function as components of metalloenzymes that take part in reduction reactions. These metalloenzymes are involved in multiple physiological processes including respiration, carbohydrate and lipid metabolism, antioxidant activities, and collagen formation (Andrieu, 2008; NRC, 2001; Tomlinson et al., 2004). One of the Cu-containing enzymes, ceruloplasmin, binds up to 95% of circulating Cu, regulates iron availability, takes part in oxidation-reduction reactions, and may regulate immune function (Healy and Tipton, 2007). Like Zn, both Cu and Mn are important for keratin formation and are components of SOD (Tomlinson et al., 2004). Selenium functions as a component of at least 25 different selenoproteins (Andrieu, 2008). In these proteins, sulfur (S) is replaced with Se, which allows the proteins to donate hydrogen and take part in reduction reactions. Selenoproteins include the enzyme iodothyronine deiodinase which is important in regulating metabolism and glutathione peroxidase and thioredoxin reductase which are important components of antioxidant and immune systems (Andrieu, 2008; NRC, 2001). Due to the diversity of proteins and enzymes containing Zn, Cu, Mn, and Se, these trace minerals are essential for a wide variety of physiological processes regulating growth, production, reproduction, and health. Deficiencies in these nutrients consequently lead to reduced performance, and dairy cattle diets are formulated with trace mineral supplements to prevent deficiencies (Miller, 1981; NRC, 2001). However, chemical composition of trace mineral supplements varies, and research is showing that some supplements are better available to support animal productivity and health than others.

Chemical Structure of Trace Mineral Supplements

Traditionally, Zn, Cu, and Mn supplements have been fed as inorganic salts, for example zinc sulfate, cupric sulfate, or magnesium sulfate. In these salts, the trace mineral is associated with sulfate in a dry form but dissociates from the sulfate when hydrated in the rumen. Trace minerals are absorbed only minimally across the rumen epithelium and they cannot be absorbed by the animal until they reach the small intestine (Wright et al., 2008). Dissociated trace minerals in the reticulo-rumen, omasum, and abomasum can form insoluble or indigestible compounds that pass into the manure. For example, minerals can bind with plant polyphenols and sugars to form indigestible complexes (McDonald et al., 1996) and minerals can form insoluble complexes with other minerals that precipitate out of digesta (Spears, 2003). Formation of such compounds in the reticulo-rumen, omasum, and abomasum reduces mineral absorption in the small intestine.

What is Bioavailability?

The proposed benefit to feeding organic trace minerals is that they should undergo less dissociation in the reticulo-rumen, omasum, and abomasum than their inorganic counterparts. Organic trace minerals that remain intact in the upper gastro-intestinal tract are less likely to form insoluble and indigestible compounds than inorganic trace minerals, and availability of organic trace minerals for absorption by intestinal tissues should be enhanced. An ideal organic trace mineral supplement must be resilient enough to remain intact as the pH changes throughout the digestive tract but must still be available for absorption and metabolism by animal tissues (Andrieu, 2008). In reality, this ideal organic trace mineral does not exist. In vitro studies have shown that organic trace minerals are more effectively absorbed by gut tissues than inorganic trace minerals (Predieri et al., 2005; Wright et al., 2008). However, some extent of dissociation and loss of organic trace minerals in the upper gastro-intestinal tract is unavoidable (Cao et al., 2000). Despite these inevitable losses, organic trace mineral supplementation can be of benefit to ruminant nutrition if they are absorbed to a greater extent than inorganic trace minerals and/or are better available to support production. The meaning of the term bioavailability is fairly ambiguous, but it generally describes mineral absorption by and/or retention within the animal. Theoretically, a mineral supplement that is more bioavailable than another will provide a greater proportion of absorbed minerals to support animal production and health. An additional benefit of a more bioavailable mineral is that less can be fed to the animal, potentially reducing feed mineral use and mineral losses to the environment. The most accurate way to measure bioavailability is by conducting animal feeding trials in which animals are fed different trace mineral sources and indices of mineral availability are measured. Indices of mineral availability include blood or liver mineral concentrations, blood or liver concentration of mineral-containing proteins, activity of mineral-containing enzymes, or mineral retention calculated as the difference between consumed and excreted minerals. Results of individual feeding trials are dependent upon test conditions (for example, feed ingredients, stage of lactation, environmental conditions) and the particular indices of bioavailability chosen. Due to these variables, conclusions from any one trial cannot be used to assign a bioavailability value to a given mineral supplement (Cao et al., 2000).

Animal Responses to Organic Zinc, Copper, and Manganese

Bioavailability of organic Zn, Cu, and Mn relative to inorganic salts has been evaluated in many studies and has been the subject of several reviews (Andrieu, 2008; Spears, 1996, 2003). Results of studies have been variable. For example, Zn-met was found to increase serum and liver Zn concentrations compared to zinc oxide in feedlot steers in one study (Chirase et al., 1991). In another study comparing zinc sulfate, Zn-met, or a Zn-glycine complex, there were no treatment differences in plasma Zn concentration, although liver Zn concentrations were increased by Zn-glycine but not by Zn-met (Spears et al., 2004). Similarly, organic Cu sources have been shown to be more bioavailable than inorganic Cu sources in some studies but not others (Spears, 2003). Although few studies have examined supplemental Mn sources, bioavailability of Mn-methionine was found to be greater than manganese sulfate or manganese oxide in lambs (Henry et al., 1992). Despite the variable effects of trace mineral source upon bioavailability measures, studies generally point to improved animal production and health responses for organic versus inorganic trace mineral supplements. Benefits of organic trace minerals include improvements in growth, milk production, reproduction, and somatic cell score (Andrieu, 2008; Spears, 1996, 2003; Spears and Weiss, 2008). Improvements in animal production despite measured differences in bioavailability suggest that current measures of bioavailability are either not sensitive enough to detect differences or do not reflect actual pools of minerals available to support animal physiology.

Potential Benefits of Trace Mineral Supplementation above Predicted Requirements

There is some indication that supplementation of trace minerals above predicted requirements may improve dairy cattle health, particularly during the transition period or during other times of stress. One reason for this indication is the role that these trace minerals play in the antioxidant system as has been described in several reviews (Andrieu, 2008; Miller et al., 1993; Tomlinson et al., 2008). Oxidation is a normal process that produces free radicals, and the antioxidant system functions to neutralize these free radicals before they cause cellular damage. Zinc, Cu, and Mn are integral components in this system due to their presence in SOD which reduces the free radical superoxide to hydrogen peroxide. Selenium is a component of glutathione peroxidase which then converts hydrogen peroxide into water.

Conclusions

Quantifying the requirements for trace minerals of dairy cows is extremely difficult and the methods and models currently used may not be appropriate because of the different metabolic functions of trace minerals. The requirements for trace minerals determined using the factorial approach must be compared with data from experiments in which various responses are measured. For trace minerals, health and disease resistance are important responses, however those experiments are extremely expensive and data are very limited. Available data support NRC (2001) recommendations for Cu, Se, and Zn (approximately 15, 0.3, and 42 ppm, respectively). Data published after 2000 suggest that the NRC recommendation for Co may be too low and diets should contain 0.15 to 0.2 ppm Co (NRC recommendation is 0.11 ppm). Both the NRC recommendation and newer data on Mn are equivocal. The NRC recommendation(approximately 18 ppm) is very close to dietary concentrations that have produced clinical Mn deficiencies in beef cows. A method based on Mn balance estimated that diets should contain 30(lactating) and 50 (dry cows) ppm of Mn.

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