Update on Trace Mineral Requirements for Dairy Cattle[1]

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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.

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)

This paper will discuss current information regarding requirements for those minerals except for Fe, Mo, and I. No recent data are available on Fe requirements of cattle. In addition essentially all basal diets will contain adequate Fe and it is unlikely that an Fe deficiency will be observed in cattle. Although several enzymes require Mo as a co-factor (meaning that Mo is a required nutrient for cattle), deficiencies have not been reported and supplementation is not suggested. Iodine is required for the synthesis of thyroid hormones, but little research has been conducted on I for cattle during the last 30 years. A dietary concentration of 0.3 to 0.45 mg of I/kg of diet DM (i.e., ppm) is recommended.

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

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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**).

The NRC model aggregates requirements into the broad categories of maintenance, lactation, reproduction, and growth. Based on the definitions used by the NRC subcommittees on nutrient requirements, the lactation requirement is the amount of a nutrient secreted in milk, the reproduction requirement is the amount of a nutrient retained in the growing fetus and associated maternal tissues (i.e., conceptus), and the growth requirement is the amount of nutrient retained in growing tissues. Although some are difficult and expensive to measure, all those requirements can be quantified. Milk yield can be measured and sampled to determine the lactation requirement. Serial slaughter experiments can be used to measure the retention of nutrients in the conceptus and in growing animals. The maintenance requirement is defined as the amount of absorbed nutrient needed by a cow to maintain a healthy life when she is not pregnant, growing, or lactating. Quantifying this requirement is extremely difficult. The NRC (2001) defined maintenance requirement for most trace minerals as the "endogenous fecal losses and insensible urinary losses." Measuring these losses accurately is extremely difficult. In addition, the maintenance requirement as defined by NRC may not adequately describe requirements for some trace minerals. Many trace minerals are cofactors for enzymes. The enzyme activity needed to maintain health may require increased intakes of trace minerals and therefore, endogenous fecal losses and insensible urinary losses may be increased.

For Co and Se, the NRC requirements were calculated using a response system rather than a nutrient requirement model. In this system, data from experiments in which graded amounts of a nutrient are fed and different responses are measured are used. The amount or concentration that yields the 'optimal' response was set as the requirement. The major problems with this approach are: 1) identifying the correct response variable or variables can be difficult; 2) defining the 'optimal' response is difficult; and 3) variation in bioavailability of the trace mineral among feedstuffs is not usually considered.

Quantifying the requirements of dairy cattle for trace minerals accurately is an extremely difficult task. Trace minerals are needed in minute amounts, but variation in feed composition and dry matter intake can be high making precise and accurate measurements of intake of trace minerals difficult. Many trace minerals can be stored in various body tissues (especially the liver) which means that experimental diets may have to be fed for several months before body stores equilibrate with dietary intake. Probably the largest impediment to accurate determination of trace minerals requirements is measuring endogenous fecal losses. One method of estimating endogenous fecal loss is to feed diets that are devoid of the mineral of interest and measure fecal output of the mineral. In this case all of the fecal output would have to be endogenous. This approach is not practical because all common feedstuffs contain trace minerals. Radioactive or stable isotopes can be fed or injected to label the body pools and then withdrawn and fecal excretion of isotope is measured. This approach is expensive and for some trace minerals endogenous fecal excretion is not in equilibrium with body pools. Less direct approaches can also be used (statistical techniques with nutrient balance data) but these are imprecise and are based on several, somewhat tenuous, assumptions. The bottom line is that estimates of trace mineral requirements are usually much less accurate than estimates of requirements for macronutrients including macrominerals.

Chromium

The NRC (2001) has not established a requirement for Cr but it is clearly an essential trace nutrient (NRC, 1997). The best understood metabolic function of Cr is as a component of the glucose tolerance factor (GTF) which enhances the action of insulin. Most of the studies examining effects of Cr supplementation of ruminant have concentrated on immune function and health and this was reviewed recently (Weiss and Spears, 2005). In the reviewed studies, supplementation rates ranged from about 0.15 to 1.0 ppm of diet dry matter. The source of supplemental Cr varied and included Cr-enriched yeast, Cr nicotinate, Cr picolinate, Cr-amino acid chelates, and $CrCl_3$. Overall, responses to supplemental Cr have been inconsistent. Of the 11 studies with cattle (9 with growing cattle and 2 with early lactation dairy cows), 6 reported that Cr supplementation reduced serum cortisol concentrations, 4 reported no effect, and 1 reported increased cortisol. Glucocorticoids such as cortisol can be immunosuppressive. Some of the changes in immune function observed when Cr is supplemented could be mediated by changes in cortisol concentrations. Chromium supplementation has not been shown to influence bovine neutrophil function , but has usually improved in vitro measures of cytotoxic T-lymphocyte function (Weiss and Spears, 2005). Other components of the cellular and humoral immune system generally have not been influenced by Cr supplementation.

The ultimate measure of enhanced immune function is increased resistence to disease. Chromium supplementation reduced morbidity in beef calves following transportation and/or a short term fast in four studies, but a similar number of studies reported no effect of Cr on morbidity (reviewed by Weiss and Spears, 2005). Chromium supplementation of dairy cows had no effect on incidence of clinical mastitis or intramammary infections (Chang et al., 1996). When cattle were challenged experimentally with different pathogens (*Pasteurella haemolytica* and IBR), Cr supplementation generally had few beneficial effects (Kegley et al., 1996, Arthington et al., 1997, Kegley et al., 1997).

Essentially no data are available from which to determine a Cr requirement using the nutrient requirement model, and immune function and health data are too inconsistent to estimate a requirement using a response system. At this time, I cannot recommend routine supplementation of Cr.

Cobalt

The NRC (2001) requirement for Co is set at 0.11 ppm of dietary DM (approximately 1.2 mg/day for a dry cow and 2.4 mg/day for a lactating cow). Cobalt is not actually a required nutrient for cattle, but rather it is used by ruminal microorganism to make vitamin B-12 which is required by cattle. The Co requirement is based on the amount of dietary Co required to maintain concentrations of vitamin B-12 above an established threshold value (experiment used sheep). Since the NRC publication, additional research has been published on Co. Using various measures of vitamin B-12 status, Stangl et al. (2000) determined that the Co requirement for growing beef cattle was between 0.15 and 0.2 ppm. Tiffany et al. (2003) came to essentially the same conclusion. In a series of studies with dairy cattle the addition of supplemental dietary Co (supplemental Co ranged from approximately 0.3 to 1ppm of the diet) did not affect Co concentrations in liver or serum or serum concentrations of vitamin B-12 (Kincaid et al., 2003). However in those experiments, the control diets contained 0.4 to 0.5 ppm of Co (substantially higher than estimates of Co requirements). Concentrations of Co in the liver of older cows (average age 6.5 years) was about 50% of the concentration in younger cows (average age 2.5 years) suggesting that Co stores are depleted as cows get older. The concentration of serum vitamin B-12 was also significantly higher in primiparous cows compared with multiparous cows and concentrations decreased from 30 days prepartum through 120 days in milk. No interaction between Co supplementation and stage of lactation was observed suggesting that supplemental Co did not effect the decline in serum B-12 as lactation progressed.

Using a response-based system, the current NRC requirement for Co (0.11 ppm) may be too low, although definitive data with lactating dairy cows are lacking. Based on data from feedlot cattle, diets should contain 0.15 to 0.2 ppm of Co. Based on rumen microbial activity, concentrations up to 0.5 ppm may be optimal (from studies cited by Stangl, et al. (2000)). Diets that provided more than about 0.4 ppm Co did not influence vitamin B-12 or Co status in dairy cows. Typical diets without supplemental Co will contain about 0.1 ppm of Co, therefore the addition of 0.1 to 0.2 ppm of supplemental Co should be adequate.

Copper

The nutrient requirement model was used to establish Cu requirements in the 2001 NRC. The maintenance requirement for absorbed Cu was set at 0.007 mg/kg of body weight (approximately 4.3 mg/day for an average cow), the growth requirement was set at 1.15 mg/kg of growth (0.5 mg/lb), the lactation requirement is 0.15 mg/kg of milk (0.07 mg/lb), and the pregnancy requirement was set at between 0.5 mg/day (less than 100 days in gestation) to 2 mg/day (greater than 225 days in gestation). Therefore, an average Holstein cow producing 70 lbs of milk/day and is less than 100 days pregnant will require approximately 10 mg of absorbed Cu per day. For an average dry Holstein cow, the requirement is about 7 mg/day. The AC for Cu in the NRC range from 0.01 (copper oxide) to 0.05. Most diets that do not include copper oxide will have an AC for Cu of 0.04 to 0.045. Therefore to meet NRC (2001) Cu requirements, diets for dry and lactating cows need to contain about 13 to 15 ppm of Cu.

Copper has numerous functions in the body, but recent attention has concentrated on its effects on immune function and disease resistance. Optimizing immune function and disease resistance may require more Cu than that needed to meet the basic requirements as calculated by the NRC. The preponderance of data (8 of 13 studies) show that neutrophils from cattle in reduced Cu status have reduced killing ability as compared with cattle in adequate Cu status. This is likely a reflection of reduced superoxide dismutase activity and ceruloplasmin (two components of cellular antioxidant systems) from cattle in low Cu status. Most of the studies examining effect of Cu status on immune function fed diets that were adequate in Cu (control) and diets that contained high concentrations of Cu antagonists such as Mo, Fe, and S. Therefore, determining whether the effects were caused solely by low Cu status or by some toxic effects of the antagonists is not possible.

A recent study (Scaletti et al., 2003) in which the control diet contained 6 to 7 ppm of Cu was compared with the same diet plus 20 ppm of supplemental Cu (from copper sulfate) provides direct evidence that diets with inadequate Cu affects disease resistance in dairy cows. In that study heifers were fed a diet with about 7 ppm of Cu from 5 months of age until about 60 d prepartum. Half the animals were then given supplemental Cu and half remained on the basal diet. At the start of the study (60 day prepartum), all animals were moderately to severely deficient in Cu based on liver Cu concentrations. The approximate concentration of dietary Cu to meet NRC requirements for growing heifers is 10 ppm. In that study, liver Cu remained low in animals fed the low Cu diets throughout the experiment (ended at 42 days in milk). Within about 5 weeks of receiving supplemental Cu, Cu status of treatment animals would be considered adequate based on liver Cu. At approximately 34 days in milk, all animals were given an intramammary gland challenge with *E. coli*. Cows fed supplemental Cu had less severe clinical signs of mastitis, lower *E. coli* numbers in the challenged quarter, and reduced SCC as compared with cows fed no supplemental Cu. This study shows clearly that feeding cows less Cu than NRC (2001) results in reduced disease resistance and that feeding more Cu that NRC (2001) improves disease resistance. This study does not show that NRC (2001) Cu requirements are inadequate. In a study we conducted (explained in more detail in Mn section), dry cows fed diets that contained 11 ppm Cu were in negative Cu balance (Figure 1) suggesting that diets for dry cows need to contain more than 11 ppm.

The Cu concentration of most typical diets without supplemental Cu range from about 5 to 15 ppm (substantial variation exists). Therefore, Cu deficiencies caused by inadequate consumption of Cu can be observed under field conditions. A more common cause of Cu deficiency, however, is the presence of Cu antagonists in the diet. Diets (including water) that contain excessive amounts of S, especially in the presence of higher than normal Mo (>1 to 1.5 ppm) can greatly reduce absorption of Cu. Although equations have been derived to quantify the effects of Mo and S on Cu absorption (e.g., page 134; NRC, 2001), field application of equations have not been highly successful. On average, increasing dietary S from 0.2% (requirement) to 0.4% results in a 30 to 50% reduction in Cu absorption when diets contain <2 ppm Mo. This means that if a diet contains the equivalent of about 0.4% S (including S from water) dietary concentration of Cu should be increased 1.3 to 1.5X (equal to about 17 to 20 ppm total diet Cu). High intakes of Fe also reduce Cu absorption and if the Fe is in a reduced form (e.g., iron sulfate) may also increase the Cu requirement. Most studies that examine Fe effects on Cu feed at least 500 to 1000 ppm of supplemental Fe (usually from iron sulfate). That Fe concentration is much higher than should be observed under field conditions with the exception of animals consuming water that is significantly contaminated with Fe. In most situations, adjustments to Cu supplementation for dietary Fe is probably not necessary, but if water is a substantial source of Fe, additional Cu may be needed. Soil ingestion (can occur during grazing or by eating silage and hay contaminated with soil) significantly reduces Cu absorption in sheep. Ingestion of soil is probably much higher for grazing cattle (especially when pasture supply is limited) and additional Cu supplementation is probably warranted with grazing cattle.

No data are available showing that the current NRC requirement for Cu (approximately 15 ppm of Cu) is inadequate when normal amounts of antagonists are present. However, numerous real-world situations exist when diets contain greater than normal concentrations of antagonists suggesting that Cu supply should be increased above NRC to ensure adequacy. On the other hand, Cu is probably the most toxic mineral supplemented to cattle. Diets that contain 40 to 50 ppm of Cu (only three times greater than requirement) have produced toxicity in some studies (Auza et al., 1999). Because of variation in feed composition and the imprecision associated with the maintenance requirement and AC, including a small safety factor (probably 10 to 20%) for Cu is advisable. Diets that contain concentrations of S greater than about 0.25% and concentrations of Mo greater than about 1.5 ppm (water composition should be considered for both minerals) should contain more Cu than NRC recommendations. The exact increase needed cannot be calculated at this time but most data support an increase of approximately 50% (total diet Cu around 23 ppm). Dietary Cu should also be increased if animals are consuming a substantial amount of pasture. If pasture comprises the entire diet, twice as much Cu as NRC may be needed. If pasture makes up 60% of the diet, an adjustment of 1.6 times may be needed.

Manganese

The requirements for Mn are arguably the least well-defined of all trace minerals. Concentrations in body tissues and fluids, and absorption from the gut are extremely low making accurate measurements difficult. The NRC (2001) established requirements for Mn using the requirement model. The maintenance requirement for absorbed Mn was set at 0.002 mg/kg of body weight (1.2 mg/day for an average Holstein cow), the growth requirement was set at 0.7 mg/kg of growth (0.3 mg/lb), pregnancy requirement was set at 0.3 mg/d and the lactation requirement was set at 0.03 mg/kg of milk (0.014 mg/lb). For a typical Holstein cow producing 70 lbs of milk, the total requirement for absorbed Mn is about 2.2 mg/day and for a dry cow it is about 1.7 mg/day. Assuming typical dry matter intakes and AC, diets with about 17 to 18 ppm of Mn will meet the NRC (2001) requirement. That represents a decrease of about 50% compared with the recommendation (not requirement) made by the previous NRC (1989).

The lactation, growth, and pregnancy requirement was derived from direct measurements and should be considered reliable. The maintenance requirement (which makes up more than 50% of the total requirement) was not derived from direct measurements but was estimated from the dietary concentration of Mn (16 to 17 ppm) that produced deficiency signs in beef cows (Dyer and Rojas, 1965). This approach was used because no quantitative data were available on the maintenance requirement. Three studies conducted after the NRC publication (two with beef cattle and one with dairy cows) suggest the NRC (2001) requirement may be too low. In growing beef heifers (about 550 lbs) rate of growth and feed efficiency were not affected when a basal diet (20 ppm Mn) was supplemented with 10 to 50 ppm of Mn suggesting diets with 20 ppm Mn were adequate for these animals (Hansen et al., 2004). However, various measures of reproductive performance were improved with supplemental Mn. In another study with growing steers, supplemental Mn did not improve growth performance compared with the control diet that contained 30 ppm of Mn (Legleiter et al., 2004). We recently conducted a series of experiments (Weiss and Socha, 2005) to determine the amount of dietary Mn needed by dry and lactating dairy cows to maintain stores of body Mn. In the first experiment, dry cows were fed a basal diet (43 ppm Mn) or the basal diet plus 200 mg/day of supplemental Mn from Mn-methionine (Mn-met) or Mn sulfate (equal to about 60 ppm Mn in total diet). Intake and fecal and urinary excretion of Mn was measured. Apparent absorption was increased with supplemental Mn (Figure 2) because the Mn provided by the supplements were more digestible than the Mn in the basal diet and/or because of dilution of endogenous fecal excretion. Because these cows were in late gestation, Mn should have been retained in the body because of fetal growth. For the control cows, Mn retention was not statistically different from 0, but cows fed supplemental Mn had statistically positive Mn retention (Figure 2). This data would suggest that a dry cow needs a diet with about 40 ppm Mn to maintain body stores and provide adequate Mn for the growing fetus. In the second experiment, we combined Mn digestibility data from a number of experiments with lactating cows with the data we obtained from the dry cows. The regression of intake of Mn on intake of digestible Mn (Figure 3) was used to estimate the maintenance requirement for Mn:

Intake of digestible Mn (mg/d) = -151 + 0.26 x Intake of Mn (mg/d)

Dividing the intercept of that equation (151) by the slope (0.26) yields an estimate of the intake of Mn needed to meet the maintenance requirement. Using that approach, the maintenance requirement is approximately 580 mg/day of dietary Mn. To meet the lactation and pregnancy requirement of these cows were require an addition 1 to 3 mg/d of dietary Mn for a total dietary requirement of Mn of about 582 mg/day. Based on average dry matter intakes in these studies (46 lbs./day for lactating cows and 26 lbs./day for dry cows), diets for lactating and dry cows needed to contain approximately 28 and 49 ppm Mn to meet their Mn requirements. These concentrations are 1.6 and 2.8 times higher than NRC recommendations.

Recent data suggest that the NRC Mn requirement may be too low. Based on reproduction measures and balance data, diets for lactating and dry cows should contain about 30 and 50 ppm of Mn, respectively.

Selenium

The NRC (2001) Se requirement was established using the response system approach. Immune function and incidence of clinical disease were used as the response variables. Based on available data, the subcommittee concluded that optimal immune response and disease resistance occurred when cows were fed diets that contained about 0.3 ppm of supplemental Se. Since the concentration of supplemental Se that can be added to diets is regulated and currently set at 0.3 ppm, dietary concentrations higher than this have not been evaluated extensively. Diets containing more than 0.3 ppm of supplemental Se are not legal to feed, but 0.3 ppm Se appears to be adequate in most situations.

Zinc

The NRC used the nutrient requirement model to determine Zn requirements. The maintenance requirement for absorbed Zn was set at 0.045 mg/kg of body weight (approximately 27 mg/day for a Holstein cow), the pregnancy requirement (during the last 90 days of gestation) was set at 12 mg/day, the growth requirement was set at 24 mg/kg of growth (11 mg/lb) and the lactation requirement was set at 4 mg/kg of milk (1.8 mg/lb). For an average Holstein cow producing 70 lbs of milk and assuming a typical dietary AC, diets with 40 to 45 ppm will meet the requirement. For a dry cow, diets with about 23 ppm will meet the requirement. Since publication of the NRC report very little new information on Zn requirements has been published.

Zinc balance was measured in the dry cow experiment discussed in the Mn section. The diets contained 49 ppm Zn and Zn balance was positive suggesting that diets with 49 ppm are more than adequate for dry cows (Figure 1). Based on the regression of Zn intake on Zn retention (Figure 4), a diet with 36 ppm Zn was required to maintain a zero Zn balance in dry cows, but that value is based on a very limited data set. Feedlot steers fed a diet with 90 mg/kg of Zn (supplemental Zn from Zn-methionine) maintained lower rectal temperatures following an experimental challenge with IBR than did steers fed a diet with approximately 35 ppm of Zn; however no difference in rectal temperature following challenge was observed between steers fed approximately 100 and 160 ppm of Zn (Chirase et al., 1991). Whether the effect of treatment on rectal temperatures was a response unique to Zn-methionine or a response to Zn in general could not be determined in this experiment. These data do suggest, however, that diets with 35 ppm of Zn may not be adequate for optimal immune response.

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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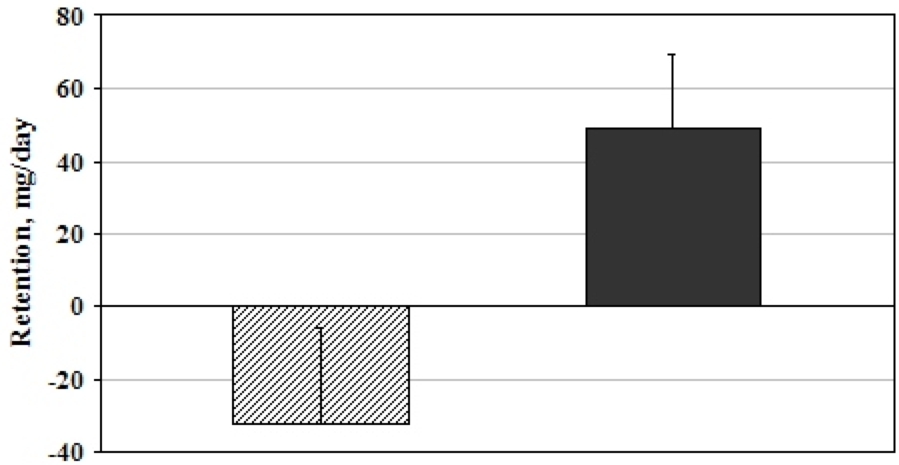

Figure 1. Apparent retention of copper (hashed bar) and zinc (solid bar) in dry cows approximately 30 d before calving. Diets contained 11 ppm Cu and 49 ppm Zn. The diets contained adequate Zn to maintain a positive balance but dietary Cu was inadequate to maintain body Cu stores (Weiss, unpublished).

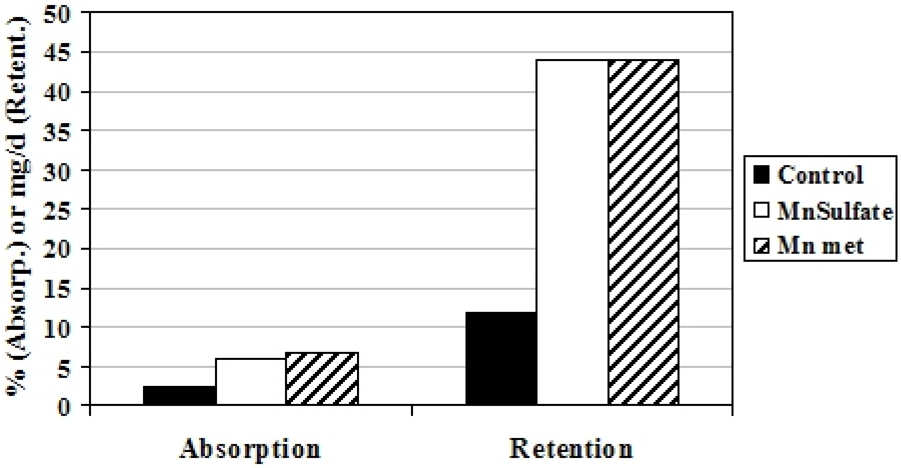

Figure 2. Apparent absorption and retention of manganese in dry cows (approximately 30 d before calving) when fed a diet with no supplemental Mn (control) or diets that provided 200 mg/day of Mn from Mn sulfate or Mn-methionine. Cows fed supplemental Mn had significantly higher absorption and retention than cows fed no supplemental Mn (Weiss and Socha, 2005).

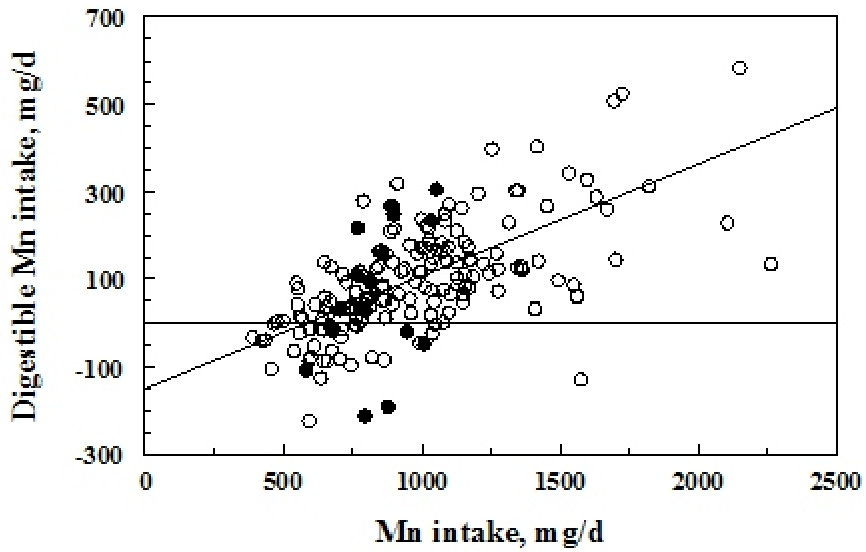

Figure 3. Relationship between intake of Mn and intake of digestibility Mn in dry (solid circles) and lactating (open circles) cows. The X-intercept (-151) is an estimate of metabolic fecal Mn excretion and the intercept divided by the slope (0.26) is an estimate of the amount of Mn needed to be consumed to meet that requirement (580 mg/day) (Weiss and Socha, 2005).

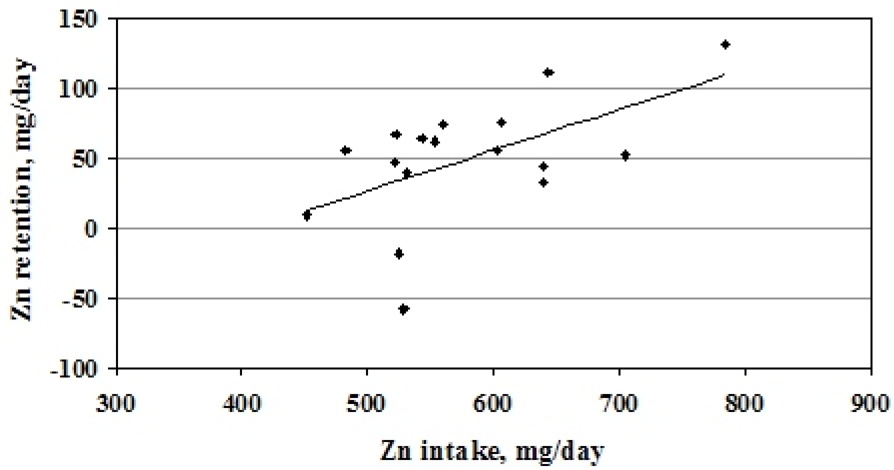

Figure 4. Relationship between zinc intake and Zn retention in dry Holstein cows (approximately 30 days before calving). An intake of approximately 400 mg of Zn/day was needed to obtain a Zn retention of 0 (Weiss, unpublished).