Trace Mineral Recommendations for Dairy Cows: 2015 Version

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Summary

Providing adequate trace minerals to dairy cows is essential for high production and good health; conversely, providing excess trace minerals inflates feed costs and could be detrimental to production and cow health. Basal ingredients such as corn silage and hay provide absorbable trace minerals to cows and their contribution should be included in ration formulation. The 2001 NRC recommendations for most trace minerals appear adequate and should be the starting point for ration formulation. Because of uncertainty regarding absorption and requirements, a modest safety factor of 1.2 to 1.5 X NRC requirements is appropriate for most trace minerals under normal conditions. The NRC does not consider antagonism which is common for Cu. In those cases, Cu supplementation may have to be increased substantially; however, feeding excess Cu over the long term results in high concentrations of Cu in the liver which may be detrimental to cows. Based on newer data, the 2001 NRC recommendations for Mn and Co may be too low. The NRC did not establish a requirement for Cr, but the majority of production studies with transition cows have shown increased milk yield.

Mineral Supply

A major change that occurred in NRC (2001) was that requirements were calculated for absorbed mineral rather than total mineral. This was a major advance because we know mineral from some sources are more absorbable than minerals from other sources. However the use of absorbable mineral has limitations:

- Measuring absorption of most minerals is extremely difficult; few measured absorption coefficients exist
- Absorption is affected by physiological state of the animal and by numerous dietary factors (many of which have not been quantified).
- For many trace minerals, the AC is extremely small and because it is in the denominator (i.e., Dietary mineral required = absorbed requirement/AC) a small numerical change in the AC can have a huge effect on dietary requirement.

Concentrations of Minerals in Basal Ingredients

For most minerals good analytical methods that can be conducted on a commercial scale at reasonable costs are available. Assuming the feed sample is representative, a standard feed analysis (using wet chemistry methods for minerals) should provide accurate concentration data for most trace minerals. Although chromium, cobalt, and selenium are of nutritional importance, most labs do not routinely measure these because the concentrations commonly found in feeds are lower than what commercial labs can reliably measure or because of contamination caused by routine sample processing such as using a steel feed grinder (a major concern for Cr).

Concentrations of trace minerals in feeds are low. For example 1 ton of average corn silage (35% dry matter) only contains about 2.5 grams of Cu (a penny weighs about 2.5 g). Sampling error is a problem for most nutrients and when concentrations are low, sampling error is usually high. From a survey we conducted on forages, sampling variation for trace minerals was greater than true variation. This means that mineral concentration data from a single sample should not be used. The mineral concentration of soils is a major factor affecting the concentrations of minerals in forages. Means of samples taken from a farm over time (up to a few years) or from a group of farms within a small geographic area (e.g., a few counties) should be a truer estimate of the actual mineral concentration of a forage than a single sample.

Besides sampling issues, the concentrations of many minerals in feeds are not normally distributed (a normal distribution is the classic bell shaped curve). In a normal distribution about half the samples have less than the mean concentration, about half the samples have more than the average, and about 95% of the samples are within $\pm$ 2 standard deviation (SD) unit of average. However when distributions are skewed, the average and the SD may not be good descriptors of the population (Figure 1). Often the distributions have long tails often because some samples are contaminated with soil. The more skewed that data, the less valuable the average and SD become in describing the feed. The median is the concentration where half of the samples have a lower mineral concentration and half of the samples have more mineral. For concentrations of trace minerals, the median is usually less than the average. In most situations, the average overestimates the trace mineral concentration in the majority of samples. Averages for trace mineral concentrations in forages (and perhaps other feeds) found in tables should be used with caution, but because of substantial sampling variation, data from a single sample should also not be used. The best advice is to generate median values for trace minerals for forages grown within a limited geographical area.

Do the trace minerals in basal feeds have nutritional value?

Essentially every feedstuff used in dairy diets contains some minerals. The question is, are those minerals biologically available to cows? Based on personal observations it is not uncommon for nutritionists to set trace mineral concentrations for forages at 0. This approach would be valid if the trace minerals in feedstuffs were not biologically available to cows. Although substantial uncertainty exists regarding the absorption coefficients for most minerals in most feeds, a portion of the trace minerals found in all feedstuffs is clearly available to cows. On average, unsupplemented diets for lactating cows in Ohio based mostly on corn silage, alfalfa, corn grain and soybean meal contain 7 to 9 ppm Cu and 30 to 40 ppm Zn. For an average Holstein cow (75 lbs of milk/day and 53 lbs of dry matter intake) basal ingredients supply about 80% and 75% of NRC requirements for Cu and Zn. Ignoring minerals supplied by basal ingredients can result in substantial over formulation for trace minerals.

The NRC (2001) estimates that Cu, Mn, and Zn from basal ingredients are 4, 0.75 and 15% absorbable. The AC assigned to basal ingredients are usually lower than AC for the sulfate form of trace minerals even though most of the trace minerals contained within plant cells would be in an organic form. The lower AC for trace minerals in basal ingredients may reflect an adjustment for soil contamination. Some of the trace minerals in basal feeds, especially forages, are in the soil that is attached to the feed and those minerals are often in the oxide form (i.e., low availability). This suggests that feeds with substantially higher ash and trace mineral concentration than typical (i.e., the tails discussed above) likely have AC that are lower than the NRC values for trace minerals. Concentrations of trace minerals substantially greater than median value should be discounted but an exact discount cannot be calculated at this time, but those feeds would still contain some available mineral.

Recommendations

The primary trace minerals of interest in dairy nutrition are chromium (Cr), cobalt (Co), copper (Cu), iodine (I), iron (Fe), manganese (Mn), selenium (Se) and zinc (Zn). The NRC (2001) did not establish a requirement for Cr, but for the other trace minerals, the NRC should be the starting point. Iron will not be discussed because basal diets almost always contain adequate Fe. Iodine also will not be discussed because of limited new information.

Chromium

Feeding diets with more than 0.5 ppm of supplemental Cr or from sources other than Cr propionate is not legal in the U.S. Chromium is a required nutrient, however, the NRC (2001) did not provide a quantitative recommendation. Because of analytical difficulties (e.g., grinding feeds prior to chemical analysis can contaminate them with Cr) we do not have good data on Cr concentrations in feedstuffs. Some studies with cattle have shown that supplemental Cr (usually fed at 0.4 to 0.5 ppm of diet DM) reduced the insulin response to a glucose tolerance test. Elevated insulin reduces glucose production by the liver and enhances glucose uptake by skeletal muscle and adipose tissue. These actions reduce the amount of glucose available to the mammary gland for lactose synthesis and this may be one mode of action for the increased milk yield when Cr is supplemented. Most of the production studies evaluating Cr supplementation started supplementation a few weeks before calving and most ended by about 42 DIM. Supplementation rates varied but most were 0.3 to 0.5 mg Cr/kg of diet DM. The median milk response from 30 treatments from 14 experiments (treatments that fed supplemental Cr well in excess of the permitted 0.5 ppm were excluded) was +4.1 lbs/day. Although a comprehensive meta-analysis is needed, based on this preliminary analysis of studies, increased milk yield of at least 2 lbs/day is highly probable when approximately 0.5 ppm Cr is supplemented to early lactation cows. Whether this response would be observed throughout lactation is not known. The potential return on investment from milk can be calculated by using the value of milk and cost of increased feed intake plus the cost of the supplement and assuming a median response of about 4 lbs of milk, an expected increase in DMI of about 2.8 lbs. At this time, a milk response should only be assumed to occur up to about 42 DIM.

Cobalt

The current NRC requirement for Co is expressed on a dietary concentration basis (i.e., 0.11 ppm in diet DM). This was done because Co is mostly (perhaps only) required by ruminal bacteria and the amount they need is a function of how much energy (i.e., feed) is available to them. Although data is limited, studies have reported Co concentrations of 0.3 to 2 ppm in the basal diets which is often adequate to meet the Co requirement. Based on older research, diets with 0.11 ppm Co maintained adequate concentrations of vitamin B-12 in the liver of cows, but

B-12 production in an in vitro ruminal system increased as Co increased up to 1 ppm in the incubation media (Tiffany et al., 2006). The greatest response was when Co was increased from 0 to 0.1 ppm (B-12 concentration increased about 60%). When Co was increased ten-fold (0.1 to 1.0 ppm), B-12 increased only an additional 40%. Data using growing beef animals (Stangl et al., 2000) found that liver B-12 was maximal when diets contain 0.22 ppm Co. With dairy cows, liver B-12 concentrations continued to increase as supplemental Co (from Co glucoheptonate) increased up to 3.6 ppm ((Akins et al., 2013). In that study elevated liver B-12 did not translate into any health or production benefits. Indicating that maximal liver B-12 may not be necessary. Milk production responses to increased Co supplementation has been variable. One study (Kincaid et al., 2003) reported a linear increase in milk yield in multiparious cows, but no effect in first lactation animals when supplemental Co increased from 0 to about 1 ppm. Older cows tend to have lower concentrations of B-12 in their livers which could explain the parity effect.

Copper

The NRC (2001) requirement for Cu and over a wide range of milk yields (40 to 150 lbs), range from about 7 to 15 mg of absorbed Cu /day under normal conditions. Because Cu is secreted in milk, as milk yield increases, the NRC requirement for Cu increases. However, the usual increase in intake with increasing milk yield is greater than the increase in secretion of Cu which means the dietary concentration of Cu needed to meet the requirement may decrease as milk yield increases. Contrary to popular practice, diets for pens of high producing cows often do not need to contain higher concentrations of many trace minerals than diets for lower producing cows. Whereas fresh cow pens, because of low DMI often need to be fed diets with increased concentrations of trace minerals.

All trace minerals have antagonists that reduce absorption but often these do not occur in real situations. All trace minerals are toxic but for most of the minerals the intakes needed to produce toxicity are usually quite high. Copper, however, is unique in that it is toxic at relatively low intakes (~3 to 4 times requirement) which dictates caution regarding over supplementation. On the other hand, Cu has numerous real world antagonists which mandate the need to over supplement in several situations. Antagonists include:

- Excess intake of sulfur (provided by the diet and water)
- Excess intake of molybdenum (effect is much worse if excess S is also present)
- Excess intake of reduced iron (may reduce absorption and increase Cu requirement)
- Pasture consumption (probably related with intake of clay in soil)

Most of these antagonisms have not been quantitatively modeled, and specific recommendations cannot be provided. In most situations dietary S will be <0.25% of the DM, but when dietary S equivalent (this includes S provided by the diet and the drinking water) is >0.25%, additional absorbable Cu should be fed. Diets with high inclusion rates of distillers grains and diets that contain forages that have been fertilized heavily with ammonium sulfate can be high in S. Water S concentration is dependent on source. Water should be sampled and assayed on a regular basis (at least annually) to determine whether water is adding to the S load in the diet. As an approximation, for an average Holstein cow, for every 100 mg/L (ppm) of S in water add 0.05 percentage units to the S concentration in the diet to estimate dietary equivalent S. For example, if your diet has 0.26% S and your water has 400 mg/L of S, dietary equivalent S = 0.26 + 4*0.05 = 0.46%. Some labs report concentrations of sulfate, not S. If your lab reports sulfate, multiply that value by 0.333 to obtain concentration of S.

Although the presence of antagonist justifies feeding additional Cu or using Cu sources that are more resistant to antagonism, no data are available indicating that the current NRC requirement is not adequate under normal conditions. Because of uncertainties associated with AC and the actual requirement, a **modest** safety factor of 1.2 to 1.5 X NRC can be justified for risk management and it also should prevent excessive accumulation of Cu in tissues over the life of the cow. For an average lactating cow, NRC requirement for absorbed Cu is about 10 mg/day. Applying the 1.2 to 1.5 X safety factor, the diet should be formulated to provide between 12 and 15 mg of absorbed Cu/day. For an average Holstein cow fed a diet without any antagonists and using Cu sulfate as the source of supplemental Cu, the diet should contain 12 to 15 ppm of **total** Cu (i.e., basal + supplemental). If using a Cu source that has higher availability than Cu sulfate, the safety factor would be the same but because of a greater AC, the concentration of total Cu in the diet would be less because less supplemental Cu would be needed.

If antagonists are present, the NRC model will overestimate absorbed Cu supply and the safety factor will need to be increased, but specific recommendations cannot be made. However, for an average Holstein cow fed a diet with substantial antagonists, total dietary Cu may need to be 20 to 30 ppm to provide 12 to 15 mg/d of absorbed Cu. Some specialty Cu supplements have been shown to be much less affected by antagonism (Spears, 2003) and if those products are used total Cu concentration should reflect the higher bioavailability of those products.

Adequate absorbable Cu must be fed to maintain good health in dairy cows, however excess Cu is detrimental to cows. Acute Cu toxicity can occur but of a greater concern are the effects of long term overfeeding of Cu. When cows are overfed Cu, liver Cu concentrations increase. If Cu is overfed for a short period of time (i.e., weeks to a few months) the change in liver Cu may be insignificant but when Cu is overfed for the lifetime of the animal, liver Cu concentrations can become dangerously elevated. Although Jerseys are at a higher risk of Cu toxicity because they accumulate greater amounts of Cu in the liver than Holsteins (Du et al., 1996), toxicity can occur in Holsteins. In non-lactating cows that were in good (or excess) Cu status and fed diets with approximately 20 ppm total Cu, liver Cu increased at about 0.8 mg/kg DM per day (Balemi et al., 2010). This accumulation of liver Cu is likely similar to a lactating cow fed a diet with 20 ppm Cu. Over a 305 day lactation, a cow fed a diet with ~20 ppm Cu (without antagonists) could accumulate ~250 mg/kg DM in the liver. Over 2 or 3 lactations, liver Cu concentrations would become extremely high. Classic toxicity is thought to occur when liver Cu concentrations are >2000 mg/kg DM. Beef cattle are tolerant to extremely high liver Cu concentrations (Felix et al., 2012), and many of the studies used to establish the upper limit for liver Cu used beef cattle. Beef cattle usually have short lifespans and may not be good models for dairy cows. Chronic copper poisoning is subclinical and can cause liver degeneration. Elevated activity of AST and GGT can indicate liver dysfunction, and activity of those enzymes were greater in heifers and bulls that had average liver Cu concentrations of 640 mg/kg DM compared with animals with average liver Cu of 175 mg/kg DM (Gummow, 1996). What may be considered acceptable overfeeding of Cu (e.g., ~15 or 20 ppm supplemental Cu) may result in problems because of the duration of the overfeeding.

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Manganese

The 2001 NRC greatly reduced the requirement for Mn compared with the earlier NRC. Based on NRC (2001) most lactating cows need between 2 and 3 mg/d of absorbable Mn which based on typical DMI translates to 14 to 16 ppm of total Mn in the diet. About 70% of the calves borne from beef heifers fed a diet with about 16 ppm Mn the last 6 month of gestation expressed clinical defects directly related to Mn deficiency (Hansen et al., 2006). Using Mn balance studies in lactating cows (Weiss and Socha, 2005), lactating cows needed to consume 580 mg of Mn to be in Mn balance (approximately 28 ppm for total dietary Mn). Lactating cows may need additional Mn is because they have high requirements for Ca and P and those minerals can reduce absorption of Mn. As discussed above uncertainty exists and reasonable safety factors (i.e., 1.2 to 1.5 X) should be applied. For Mn, the starting point is 28 ppm and after the safety factor is applied, diets for lactating cows should have 33 to 42 ppm **total** Mn.

Selenium

Per US FDA regulations, the amount of supplemental Se in dairy cow diets cannot exceed 0.3 ppm. Fortunately, in the vast majority of situations, diets with 0.3 to 0.4 ppm total Se (basal at 0.1 + 0.3 supplemental) is adequate. Excess S (from water and diet) reduces the absorption of Se substantially (Ivancic and Weiss, 2001), however the only legal option to overcome that problem is to use a high quality Se-yeast product rather than selenite or selenate. Under normal conditions, inorganic Se provides adequate available Se to the cow. However, Se yeast results in substantially greater concentrations of Se in milk and colostrum and in the newborn calf if the dam was fed Se yeast during the dry period (Weiss, 2005). Clinical measures such as mastitis prevalence or immune function have not shown any consistent differences when inorganic Se or Se yeast was fed. Because of increased transfer of Se to the fetus and into colostrum, feeding a portion of Se as Se-yeast to dry cows is a good idea. Using Se-yeast in situations with excess S should also be considered.

Zinc

The Zn requirement in NRC (2001) for lactating cows ranges from about 110 to 260 mg of absorbed Zn/day (dependent on milk yield). Assuming typical AC and DMI, diets with 40 to 50 ppm **total** Zn should be adequate. No new data are available contradicting the current NRC recommendation. Real world antagonists for Zn are not a major concern; therefore the current requirement plus a modest safety factor (1.2 to 1.5 X NRC) for risk management is adequate. As with Cu, if you are using forms of Zn with greater bioavailability, dietary concentrations should be less than if diets are based on Zn sulfate. Suppliers of those minerals should have data on relative (usually relative to Zn sulfate) bioavailability of their products.

Conclusions

Adequate supply of trace minerals improves the health and productivity of dairy cows; excess or inadequate trace minerals have the opposite effect. The 2001 NRC requirements for Cu, Zn, and Se are adequate in most situations and only a modest safety factor should be applied for risk management. Because of regulations, no safety factor can be applied to Se. For most minerals, diets should be formulated for total absorbable minerals and the minerals provided by

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basal ingredients must be included. This also means that diets that include sources of supplemental mineral that have higher bioavailability should have lower total concentrations of trace minerals than diets based on trace mineral sulfates. For Cu, numerous antagonists exist and in those cases, diets need to provide substantially more Cu than recommended by NRC. Although many situations dictate higher concentrations of dietary Cu, be aware of excessive Cu supplementation. Overfeeding Cu for months or years can increase high liver Cu concentrations and that may be negatively affecting cow health. The bottom line is to feed slightly more than adequate, but not excessive, amounts of trace minerals.

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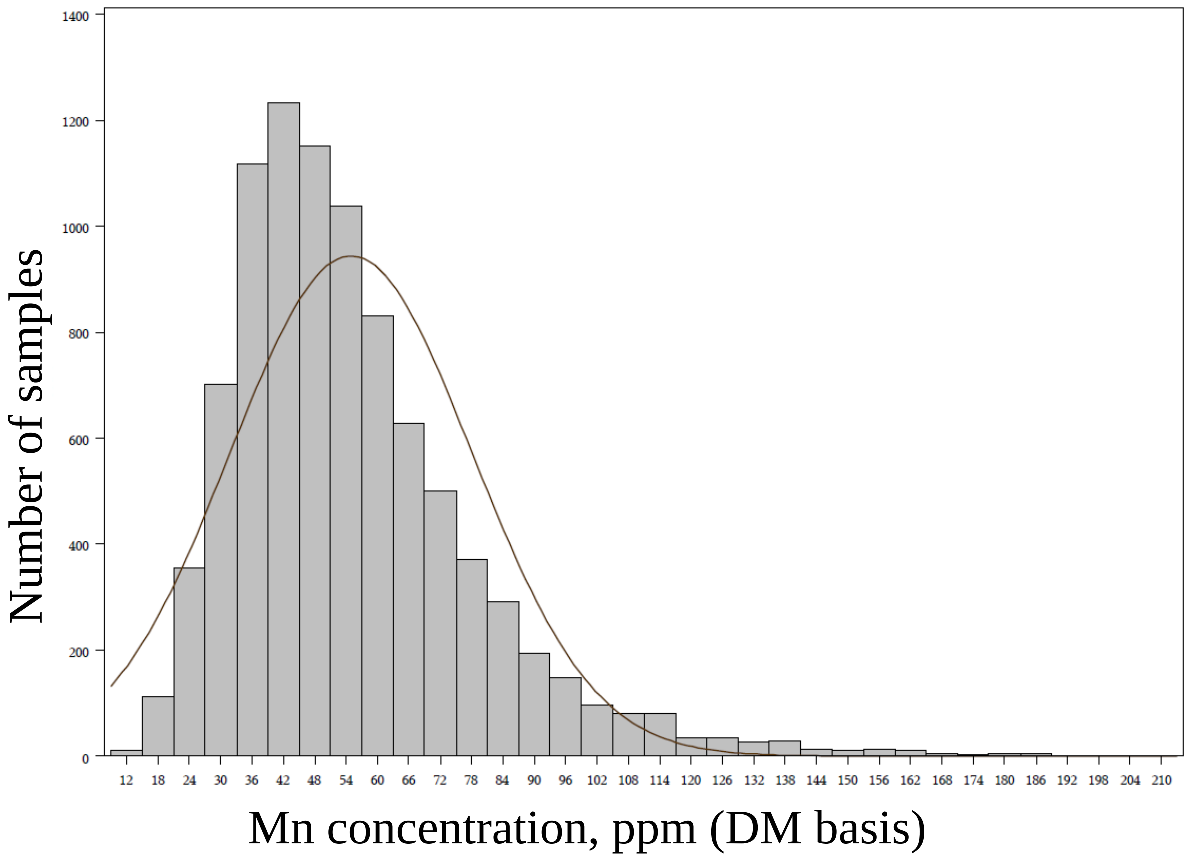

Figure 2. Distribution of Cu concentrations in mixed, mostly legume silage grown throughout the U.S. (Knapp et al., 2015). The smooth line indicates a normal distribution would while the bars indicate the actual distribution. Note the long tail.