Practical Recommendations for Trace Minerals for Lactating Dairy Cows

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Summary

Providing adequate trace minerals to dairy cows is essential for high production and good health. Providing excess trace minerals inflates feed costs and could be detrimental to production and cow health. This paper provides suggested strategies for formulating diets to meet the trace mineral requirements of cows. Basal ingredients, such as corn silage and hay, provide absorbable trace minerals to cows. Concentrations of trace minerals in basal ingredients should not be set to 0. However, single samples of feeds probably will not provide an accurate estimate of the true concentrations of trace minerals in feeds. The NRC (2001) recommendations for most trace minerals (Mn is an exception) 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, and for Cu, antagonism can be quite common (high intake of S from diet or feed, grazing, and dietary Mo). In those cases, absorption coefficients should be reduced (perhaps more than 50%) so that cows are fed diets with adequate absorbable Cu. However, feeding excess Cu over the long term (months or years) can result in high concentrations of Cu in the liver, which may be detrimental to cows. The NRC (2001) recommendation for Mn is too low. Some data suggest that Mn requirements for lactating cows should be increased by a factor of 1.8. The NRC recommendation for Co may be too low. Total diet Co may have to be 1 to 1.3 ppm (current NRC requirement is about 0.1 ppm), but in many cases, the basal diet may be adequate. The NRC did not establish a requirement for Cr, but the majority of production studies with transition cows have shown increased milk yield. The decision to supplement Cr is largely an economic decision based on cost of feed, cost of supplemental Cr (Cr propionate is the only approved source of Cr in the U.S.), and price of milk.

Introduction

When this paper was written (March, 2015), the National Research Council was in the process of updating the Nutrient requirements of Dairy Cows publication. The previous version was published in 2001 (NRC, 2001) and provided an up-to-date review of the scientific literature on mineral nutrition of dairy cattle and the requirements were based on the knowledge available at that time. Several nutrition models are used in the U.S. (e.g., NRC, CNCPS, Amino Cow, etc.) to formulate diets for dairy cows and they often differ substantially in their recommendations regarding energy and protein. However, mineral requirements from essentially every nutrition model currently used in the US

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are derived directly or almost directly from the NRC (2001) recommendations. Because of space limitations, this paper will concentrate on six trace minerals (Cr, Co, Cu, Mn, Se, and Zn). The upcoming NRC may or may not reflect the opinions in this paper.

Currently Used Requirement System (e.g., NRC, 2001)

The requirements for most minerals (S, Se, I, and Co are exceptions) are calculated using the factorial approach. Mineral needed for maintenance plus mineral deposited in the growing fetus (gestation requirement) and body (growth requirement) plus mineral secreted in milk (lactation requirement) were summed to generate the requirement for absorbed mineral in either gram or milligrams/day. Because requirements were calculated on an absorbed mineral basis, absorbtion coefficients **(AC)** for all the minerals had to be generated and multiplied by mineral concentrations to calculate the concentration of absorbed mineral in the diet.

The factorial system has been used for decades to determine requirements for energy and protein and more recently for minerals. Requirements are based on research that measures responses. In other words, the lactation requirement for protein was determined by feeding different amounts of protein and measuring the marginal response in milk production. That marginal response (X grams of protein consumed per pound increase in milk) equaled the lactation requirement. However, conceptually, separating requirements into maintenance, gestation, growth, and lactation components is flawed, and because of their biological functions, the factorial approach may be extremely flawed for many minerals. A major problem is defining maintenance. For example, if extra Cu is needed by the immune system to prevent mastitis, is that a maintenance function or a lactation function? If extra Se is needed to prevent retained placenta, is that a maintenance function or a reproduction function? The problem with partitioning mineral requirements into various functions is not simply an academic exercise, it can result in erroneous estimates of mineral requirements.

'Maintenance' Requirement

For minerals, the maintenance requirement is equal to the amount of mineral that would be excreted in feces and urine (and maybe skin sloughing) if the animal was fed a diet void of the mineral (i.e., inevitable losses). Depending on the mineral, the current (NRC, 2001) maintenance requirement ranges from 0 (e.g., Fe) to more than 70% of the total requirement (for most minerals maintenance is 30 to 40% of total requirement). Experimentally, measuring the inevitable losses of minerals is very difficult, which can lead to errors in estimating the maintenance requirement. More importantly, mineral status of the animal can affect the inevitable loss of minerals. Gut cells and other cells that contribute to the inevitable loss probably contain less Zn if a cow was fed a diet barely adequate in Zn compared with a cow in good Zn status. Another question is whether cows in different physiological states (for example, lactating vs. dry) have the same inevitable losses of mineral. Much of the research conducted to determine maintenance requirements (most of which was conducted years or decades ago) used non-lactating cows. Intake is much higher for a lactating cow than for a non-lactating cow and inevitable loss of mineral is probably positively correlated with DMI (more digesta is flowing through the system, causing increased secretion and cell losses in the digestive tract).

‘Productive’ (gestation, growth, and lactation) Requirements

By definition, mineral requirement for gestation, growth, and lactation is the amount of mineral that is deposited into the conceptus, body tissue, and milk, respectively. This approach mirrors the net energy approach. For example, the net energy requirement for lactation equals the amount of energy secreted in milk. However for net energy, an efficiency value is used. For example, it requires 1 Mcal of absorbed energy (called metabolizable energy) to secrete 0.64 Mcal into milk. For minerals, the efficiency of putting a mineral into fetal tissue, body tissue, or milk is 100%. This means that there is no mineral cost (or requirement) to make milk or synthesize body tissue. Oxidative metabolism increases in direct portion to energy use (a high producing cow uses a lot more oxygen than a low producing cow). Many trace minerals are components of antioxidant enzymes and the more oxygen a cell uses, the more free radicals produced which should increase the need for antioxidant enzymes. If this increases the need for Cu to make the enzyme superoxide dismutase, this increased requirement is not considered in the current system.

At least conceptually, the current system could underestimate the requirements for many minerals under standard conditions. In addition, certain disease states ,such as a severe infection, increase loss of certain minerals via feces and urine. This may mean that an immune or health requirement needs to be considered, and if necessary, included in the factorial system.

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 minerals from some sources are more absorbable than minerals from other sources. However, the use of absorbable mineral has limitations:

- Measuring absorption of some minerals is extremely difficult.
- Actual absorption data and AC are limited. Many values are estimates.
- Absorption is affected by physiological state of the animal and by numerous dietary factors (many of which have not been quantified).
- For many of the 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 (see text box).

Concentrations of Minerals in Basal Ingredients

For most minerals of nutritional interest, good analytical methods that can be conducted on a commercial scale at reasonable costs are available for feeds. Assuming the feed sample is representative, a standard feed analysis (using wet chemistry methods for minerals) should provide accurate concentration data for Ca, P, Mg, K, Na, Cu, Fe, Mn, and Zn. Labs can also routinely measure S and Cl, but often these are separate tests. Although Cr, Co, and Se 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 (i.e., inadequate analytical sensitivity) or because of contamination caused by routine sample processing, such as using a steel feed grinder (a major concern for Cr). Although we can get accurate total mineral concentration data for basal ingredients, you must be careful when evaluating and using the data. Concentrations of minerals in feeds, even most macrominerals, are low. For example, 1 ton of average corn silage

(35% dry matter) only contains about 1.7 lb of Ca and 2.5 g of Cu (to put this in perspective a penny weighs about 2.5 g).

Example of the impact of a change in absorption coefficient (AC) on Cu supplementation.

Assumptions:

1. Dry matter intake = 50 lb/day
2. Cow requires 12 mg/day of absorbed Cu/day
3. Basal ingredients provide 220 mg/day of total Cu
4. AC for Cu from copper sulfate (25% Cu) = 5% (NRC, 2001)

If AC for basal diets was 0.03, the diet would provide 220 * 0.03 = 6.6 mg of absorbed Cu, then the cow would need to be supplemented with 12 – 6.6 = 5.4 mg of absorbable Cu **=108 mg of Cu from Cu sulfate (5.4/0.05)**

If AC for basal ingredients was 0.05, the diet would provide 220 * 0.05 = 11 mg of absorbed Cu, then the cow would need to be supplemented with 12 – 11 = 1 mg of absorbable Cu **= 20 mg of Cu from Cu sulfate (1/0.05)**

A change in AC of basal diets from 0.03 to 0.05 (the AC from NRC = 0.04) would increase the amount of supplemental Cu needed by almost 5 X

Sampling error is a problem for most nutrients, and when concentrations are low, sampling error is usually larger. 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 be viewed very suspiciously. The mineral concentration of soils is a major factor affecting the concentrations of most minerals in forages. Therefore, 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 or average concentration, about half the samples have more than the average, and about 95% of the samples are within ± 2 standard deviation **(SD)** unit of average. This means that if you know the average concentration and the SD, you have a good description of the population. This information helps with risk assessment. If a feed has an average concentration of Mg of 0.4% and an SD of 0.01% and the distribution is normal, about 95% of the samples of that feed should have between 0.38 and 0.42% Mg. With that information, you should probably conclude it is not worth analyzing that feed for Mg, because even if your sample is 2 or 3 SD units from the mean, it will have no effect on the diet or the animal. However, when distributions are skewed, the average and the SD may not be good descriptors of the population, and for many minerals, concentrations within feeds are not normally distributed (Figures 1 and 2). Often the distributions have long tails because concentrations cannot be less than 0 but can be extremely high for various reasons. Some samples have high concentrations of certain minerals because of contamination with soil or other substances. such as mineral supplements. The more skewed the 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, and in a normal distribution, the mean and the median are essentially equal. For concentrations of trace minerals and some macro minerals, the median is usually less than the average because their distributions are skewed. What this means is that for most situations, using the average trace mineral concentration (e.g., feed table data), overestimates the trace mineral concentration in the majority of samples. For skewed populations, the median is a better descriptor of the population than the mean; however, simply replacing average concentration with median concentration does not fix all the problems associated with a skewed distribution.

As a distribution becomes more skewed, the risk that a specific feed will contain excess mineral increases. The Mn data shown in Figure 2 is a good example. The data have an average of 55 ppm and an SD of 23. Assuming a normal distribution, one would expect about 2.5% of the samples to have more than about 100 ppm (55 + 2 SD unit) and about 2.5% of the samples to have less than about 9 ppm. However, no samples had less than 9 ppm and 5.2 % had more than 100 ppm. If your particular sample of mixed mostly legume silage was in the 5 out of every 100 samples with a very high Mn concentration, your diet would contain substantially more Mn than expected. Excess dietary Mn is rarely a problem for cows, but excess dietary Cu can be (discussed below). Corn silage in Figure 1 had a mean Cu concentration of 6 ppm with a SD of 1.8. With a normal distribution, about 2.5% of the samples should have more than about 10 ppm Cu. However, about 5% of samples have more than 10 ppm Cu (i.e., twice the risk). If you formulate a diet assuming the corn silage is 6 ppm Cu, but it really has 12 ppm and corn silage comprises a significant portion of the diet, over the long term (many months), excess dietary Cu could become a problem.

The bottom line is that averages for trace mineral concentrations in forages (and perhaps other feeds) found in tables should be used with caution. Because of substantial sampling variation, data from a single sample should not be used. The best advice is to generate mean 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? Although survey data of nutritionists are lacking, but based on personal experience, it is not uncommon for field nutritionists to set trace mineral concentrations in basal ingredients or at least 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 AC for most minerals in most feeds (this includes mineral supplements), a portion of the trace minerals found in most (all?) feedstuffs is clearly available to cows. Tissues from wild ruminants ,such as deer (Wolfe et al., 2010) and grazing beef cattle (Sprinkle et al., 2006) that have not received supplemental minerals contain trace minerals, indicating that some absorption of basal minerals occur.

The NRC (2001) estimates that Cu, Mn, and Zn from basal ingredients are 4, 0.75, and 15% absorbable, respectively. 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 data 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. However, those feeds would still contain some available mineral.

As discussed above, determining the AC for trace minerals is extremely difficult. At least into the foreseeable future, lab tests will not be available to estimate AC for trace minerals from feedstuffs; therefore, we are limited to using the constants provided by sources such as the NRC (2001). On average (and remember the issues with using averages), unsupplemented diets for lactating cows in Ohio based mostly on corn silage, alfalfa, corn grainn and soybean meal contain 7 to 9 ppm Cu, 25 to 35 ppm Mn, and 30 to 40 ppm Zn (specific farms may differ greatly from these ranges). For an average Holstein cow (75 lb/day of milk and 53 lb of DMI) using NRC requirements, basal ingredients supply about 80, 235, and 75% of requirements for Cu, Mn, and Zn, respectively. Ignoring minerals supplied by basal ingredients can result in substantial over formulation for trace minerals.

Evaluating Trace Mineral Status

The primary indicators of trace mineral status (either inadequate or excess) are often sick or poor producing animals. For both research purposes and practical diet formulation, more sensitive indicators or markers of mineral status are clearly needed. These would improve our ability to evaluate requirements, mineral sources, and diet adequacy. No biological measures are known which accurately reflect Zn, Mn, and Cr status in cattle. Plasma (or serum) Zn may be able to discern severe or clinical Zn deficiency, but too many other factors influence serum concentrations to make it sensitive marker of Zn status. Stress and infections reduced plasma Zn in beef cattle (Nockels et al., 1993) and parturition and clinical milk fever has reduced plasma Zn in dairy cows (Goff and Stabel, 1990). Mastitis may also reduce plasma Zn concentrations.

Cleft palate and other calf deformations at birth (Hansen et al., 2006) are specific indicators of clinical Mn deficiency, but markers of marginal deficiencies have not been identified. New, enhanced analytical methods (mass spectroscopy) has greatly increased our ability to accurately measure plasma Mn, and with additional research, plasma and liver Mn concentrations may have value as a status indicator. The glucose tolerance test has been able to differentiate between different dietary supplies of Cr; however, this test is not practical under field conditions.

Copper is stored in the liver and liver Cu concentrations are currently considered the gold standard for evaluating Cu status. Adult cattle liver Cu concentrations are deemed "adequate" between 120 to 400 mg/kg on a DM basis or approximately 30 to 110 mg/kg on a wet weight basis (McDowell, 1992). Over supplementation of Cu can result in Cu toxicity. Therefore, the range of adequate Cu status reflects both the minimum (110 or 30 mg/kg) and maximum (400 or 120 mg/kg) recommended concentrations of liver Cu on a DM or wet wt. basis, respectively. The recommended range for liver Cu is the same for both Jersey and Holstein; however, livers from Jersey cows will usually have a greater concentration of Cu than those from Holsteins when fed similar diets. Liver Cu concentrations decrease when cattle are fed diets deficient in Cu and increase in a systematic manner as dietary Cu supply increases (Yost et al., 2002), which fits important criteria of a good marker of mineral status. However, liver biopsies are costly and invasive, and generally not practical on a large scale basis. Other Cu measures (e.g., enzyme activity, ceruloplasmin, and Cu concentration in blood fractions) have been suggested as indicators of Cu status. However, liver Cu is mobilized during depletion to support cellular function and changes in enzyme activity or ceruloplasmin and Cu blood concentrations do not reflect status until the liver is depleted of the majority of its Cu stores.

Cobalt has no known nutritional function other than as a component of vitamin B_{12}, so when we refer to Co status, we really mean vitamin B_{12} status. Liver B_{12} concentrations reflect Co intake. Assumed adequate hepatic B_{12} concentrations are between 200 to 400 nmol/kg on a wet weight basis (Stangl et al., 2000). Similar to Cu, liver biopsies to determine B_{12} concentrations and subsequent Co status are invasive and not practical on a large scale (vitamin B_{12} is also difficult to measure). Dramatic increases in plasma concentrations of methylmalonic acid and homocysteine are able to indicate Co deficiency in cattle, but these metabolites are not sensitive enough to detect optimal Co status of cattle. (Stangl et al., 2000).

Selenium status of cattle can be evaluated by assaying Se concentrations in blood fractions. Based on the effects of Se supplementation on immune function, reproduction, and mastitis, adequate serum (Weiss and Hogan, 2005) and whole blood (Kommisrud et al., 2005) Se concentrations are around 0.06 and 0.15 µg/mL, respectively. Approximately 60% of the Se in whole blood is in the erythrocytes, which have a half-life of almost 100 days in cattle. Therefore, whole blood Se is a more accurate long-term indicator of Se status compared to plasma or serum, which reflects short-term changes in Se intake more accurately. Whole blood glutathione peroxidase activity is often assayed to determine relative bioavailability of Se sources. However, glutathione peroxidase activity is somewhat dependent on the lab, so adequacy must be evaluated compared with lab reference values. Selenium supplementation has been shown to increase Se concentrations in milk, but the relationship is highly dependent on Se source (Weiss, 2005). Concentrations also are usually lower than those found in plasma and can be difficult to measure accurately.

Concentrations of Fe in serum and liver can be used to confirm Fe deficiency in cattle. Adequate Fe serum and liver concentrations are 1.3 µg/mL and 65 mg/kg of wet weight, respectively (Kincaid, 2000). Other assays which can assist in evaluating Fe status include serum iron binding capacity or saturation (Weiss et al., 2010), red blood cell count, packed cell volume, serum hemoglobin concentration, and ferritin concentration (Smith, 1989). Assayed serum Fe concentration can provide false results if hemolysis occurs in the serum or plasma due to Fe content of erythrocytes. To avoid erythrocyte Fe contamination, an assay specific for non-heme iron is conducted. Minimum adequate reference values for many of the Fe status markers are unknown due to the almost non-existent occurrence of Fe deficiency in cattle in the US. Many studies (e.g. Weiss et al., 2010) have reported values that, represent animals in adequate Fe status, and those values can be evaluated as a reference if needed.

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. Cr is needed to transport glucose into cells that are sensitive to insulin. Because of analytical difficulties (e.g., normal grinding of 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 (Hayirli et al., 2001; Sumner et al., 2007; Spears et al., 2012). 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 often observed when Cr is supplemented. Most of the production studies evaluating Cr supplementation (studies used Cr propionate, Cr-methionine, Cr-picolinate, and Cr yeast) started supplementation a few weeks before calving and most ended by about 42 DIM (but a few went later into lactation). Supplementation rates varied but most were 6 to 10 mg/day (approximately 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 lb/day (the SD among responses was 3.5 lb/day). About 75% of the treatment comparison yielded an increase in milk of more than 2 lb/day. Although a comprehensive meta-analysis is needed, based on this preliminary analysis of studies, increased milk yield of at least 2 lb/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. When Cr is supplemented, intake usually increases as expected based on increased milk yield (approximately 0.65 to 0.75 lb increased DMI/lb of increased milk). The potential return on investment from milk can be calculated by using the value of milk and cost of feed plus the cost of the supplement and assuming a median response of about 4 lb of milk, with an expected increase in DMI of about 2.8 lb. At this time, a milk response should only be assumed to occur up to about 42 DIM.

In addition to increased milk yield, supplemental Cr may enhance certain aspects of the immune system and may help reduce morbidity in stressed cattle. Positive effects of Cr on morbidity have mainly been observed in beef cattle (Mowat et al., 1993). Supplemental Cr has usually enhanced cytotoxic T-lymphocyte function in cattle (perhaps via reduced cortisol) but has had variable or no effects on other types of immune function (Weiss and Spears, 2005).

Cobalt

The current NRC requirement for Co is expressed on a dietary concentration basis (i.e., 0.11 ppm in diet DM) rather than on a mg/day of absorbable Co basis. 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 Co concentration data for feeds is very limited, the NRC requirement is for total Co, and in many cases, basal ingredients would provide adequate Co. However, because Co concentrations in feeds are often quite low, feed Co data may be questionable. In studies conducted in WA, basal diets typically contained 0.2 to 0.4 ppm Co (Kincaid et al., 2003; Kincaid and Socha, 2007). In a study conducted in WI, the control diets (no added Co) contained between 1 and 2 ppm Co (Akins et al., 2013). Based on older research (<1970), diets with 0.11 ppm Co maintained adequate concentrations of vitamin B-12 in the liver of cows. Bacteria in a ruminal in vitro system increased B-12 production as supplemental Co was increased up to 1 ppm in the incubation media (Tiffany et al., 2006). However, the response was not linear. The greatest response was found when Co was increased from 0 to 0.1 ppm (B-12 concentration increased about 60%). The increase in B-12 when Co was increased ten-fold (0.1 to 1.0 ppm) was 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 (approximately twice as high as current recommendation). 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 have 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 (from Co glucoheptonate). Older cows tend to have lower concentrations of B-12 in their livers, which could explain the parity effect. Based on current data, the NRC (2001) requirement does not result in maximal liver B-12 concentrations in dairy cows. Liver B-12 concentrations generally increase with increasing dietary Co, whereas milk yield responses have been much more variable. Across studies, when total dietary Co (basal plus supplemental) was about 1 to 1.3 ppm, maximum milk responses were observed. In some locations, basal ingredients may provide that much Co.

Copper

The NRC (2001) requirement for Cu is expressed on a mg/day of absorbable Cu basis and over a wide range of milk yields (40 to 150 lb), with requirements ranging from about 7 to 15 mg/day of absorbed Cu under normal conditions. Because Cu is secreted in milk, as milk yield increases, the NRC requirement for Cu increases. However, because basal ingredients contain Cu and because DMI usually increases as milk yield increases, the dietary concentration of Cu needed to meet the requirement may not change as milk yield increases (Table 1). 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 cows, 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 among nutritionally important trace minerals in that it is toxic at relatively low intakes (~3 to 4 times requirement), which should dictate caution regarding over supplementation. On the other hand, Cu has numerous real world antagonists which mandate the need to over supplement in several situations. The NRC requirement assumes no antagonism (i.e, dietary S at 0.2% of DM); however, several situations commonly exist which result in reduced Cu absorption including:

- 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), and
- Feeding clay-based 'binders'.

Most of these antagonisms have not been quantitatively modeled, and specific recommendations cannot be provided. Cows that consume substantial pasture (~50% of the diet) may need to be fed about 2X the NRC requirement when Cu sulfate is used. When dietary sulfur equivalent (this includes S provided by the diet and the drinking water) is >0.25 to 0.3%, additional absorbable Cu should be fed. At higher concentrations of dietary equivalent S (0.4 to 0.5%), cows may need to be fed 2 to 3 X NRC requirement when Cu sulfate is used. We have developed a simple spreadsheet that will calculate dietary sulfur equivalent concentration. Inputs include milk yield, DM intake, dietary S concentration, water S concentration, minimum daily temperature, and dietary Na concentration (http://dairy.osu.edu/resource/OSUdairypubs.html#computer; click on "Water Minteral Intake with DCAD"). 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%. Note that some labs report concentrations of sulfate, not S. If your lab reports sulfate, multiply that value by 0.333 to obtain concentration of S.

In most situations, dietary S will be <0.25% of the DM. Diets with high inclusion rates of distillers grains and diets that contain forages that have been fertilized heavily with ammonium sulfate can have substantially higher concentrations of 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.

Although the presence of antagonists justifies feeding additional absorbable 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 should be used when formulating diets. Under normal situations, feeding 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, the 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/day of absorbed Cu. For an average Holstein cow fed a diet without any antagonists and using Cu sulfate as the source of supplemental Cu, the diet should be formulated to 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 adjustments should be made to the AC. 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/day of absorbed Cu (when Cu sulfate is fed). 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 (see example below).

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 Jersey cows are at a higher risk of Cu toxicity because they accumulate greater amounts of Cu in the liver than Holstein cows when fed the same diet (Du et al., 1996), toxicity can occur in Holstein cows.

Example of Cu fortification needed when antagonists are present.

Assumptions

1. Absorbed Cu requirement is 10 mg/day, but a safety factor of 1.5 is used; desired absorbed Cu requirement = 15 mg/day
2. Basal diet (DMI = 52 lb = 23.6 kg) is 8 ppm Cu with a normal AC = 0.04; however, with antagonists, the AC = 0.02.
3. Cu sulfate has an AC = 0.05 but with antagonist, AC = 0.025
4. A specialty Cu product has been shown to have a relative AC of 2X Cu sulfate when antagonists are present; therefore, its AC = 0.025 X 2 = 0.05

Calculations

Basal diet provides 3.8 mg of absorbed Cu/day (23.6 kg/day x 8 x 0.02).
Absorbed Cu needed from specialty source = 15 mg/day desired – 3.8 basal = 11.2 mg/day.
Supplemental Cu needed = 11.2 mg/day/ 0.05 = 224 mg/day.
Total dietary Cu concentration = 8 ppm basal + (224/23.6) = 17 to 18 ppm.
If Cu sulfate was used rather than the specialty mineral, twice as much supplemental Cu would be needed so that total dietary Cu = 27 ppm.

In non-lactating cows that were in good (or excess) Cu status based on liver Cu concentrations and fed diets with approximately 20 ppm total Cu, liver Cu accumulated at an average rate of 0.8 mg/kg DM per day (Balemi et al., 2010). Although milk contains Cu, because of differences in DMI (and subsequent Cu intake), this accumulation of liver Cu is likely similar for 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. However, beef cattle usually have short lifespans and may not be good models for dairy cows. Chronic Cu poisoning is subclinical and can cause liver degeneration, which is evident based on liver enzyme aspartate transaminase **(AST)** and gamma-glutamyl transpeptidase **(GGT)** activities in plasma (Bidewell et al., 2012). Accumulating evidence suggests problems may start occurring at much lower concentrations (500 or 600 mg/kg DM). Elevated activity of AST and GGT can indicate liver dysfunction, and activity of those enzymes were significantly 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.

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/day of absorbable Mn, which based on typical DMI, translates to 14 to 16 ppm of total Mn in the diet. Recent research with pregnant beef heifers strongly suggests that the current NRC recommendation is not adequate (Hansen et al., 2006). In that study, beef heifers were fed a diet with about 16 ppm Mn for the last 6 month of gestation and 70% of the calves borne from those heifers had clinical defects directly related to Mn deficiency. Because of intake, a lactating cow will consume substantially more Mn per day than a gestating heifer and milk is not a major draw on Mn; therefore, the dietary concentration that elicited clinical deficiency in heifers may not cause clinical deficiency in lactating cows. Using Mn balance studies in lactating cows (Weiss and Socha, 2005), we estimated that lactating cows (average milk yield in the experiment = 84 lb/day) needed to consume 580 mg of Mn to be in Mn balance. Based on the DMI in that experiment, that translated into a dietary concentration of 28 ppm for total dietary Mn. We think that is a more accurate estimate of Mn requirement than the NRC (2001) requirement. One reason for the discrepancy is that lactating dairy cows have high requirements for Ca and P, and those minerals, especially P, 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 from 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 is a good idea. Using Se-yeast in situations with excess S should also be considered.

Zinc

The Zn requirement in NRC (2001) is on a mg/day of absorbed Zn basis, and for lactating cows, it ranges from about 110 to 260 mg/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 for risk management is adequate. For an average Holstein cow (75 lb of milk), the absorbed Zn requirement is 165 mg/day and with a safety factor of 1.2 to 1.5 X, that cow should be fed a diet that provides 200 to 250 mg/day of absorbed Zn. As with Cu, if you are using a form 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 (or the FDA regulation) 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 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 result in high liver Cu concentrations 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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Table 1. Effect of intake and milk production on requirements (NRC, 2001) of certain trace minerals.[1]

	Early lactation cow 75 lb milk; 35 lb DMI		High producing cow 120 lb milk; 67 lb DMI		Average cow 75 lb milk; 53 lb DMI	
	Absorbed requirement (mg/day)	Dietary requirement (mg/kg of diet DM)	Absorbed requirement (mg/day)	Dietary requirement (mg/kg of diet DM)	Absorbed requirement (mg/day)	Dietary requirement (mg/kg of diet DM)
Cu	9.7	14	12.8	10	9.7	10
Fe	34.0	22	54.4	18	34.0	14
Mn	2.3	19	2.9	13	2.3	13
Zn	165	61	247	49	165	43

[1] Basal diets were assumed to contain 8, 225, 30, and 35 ppm of Cu, Fe, Mn, and Zn, respectively. Basal absorption coefficients were 0.04, 0.10, 0.0075, and 0.15 for Cu, Fe, Mn, and Zn, respectively. If supplemental minerals were needed, absorption coefficients for sulfate forms were used.

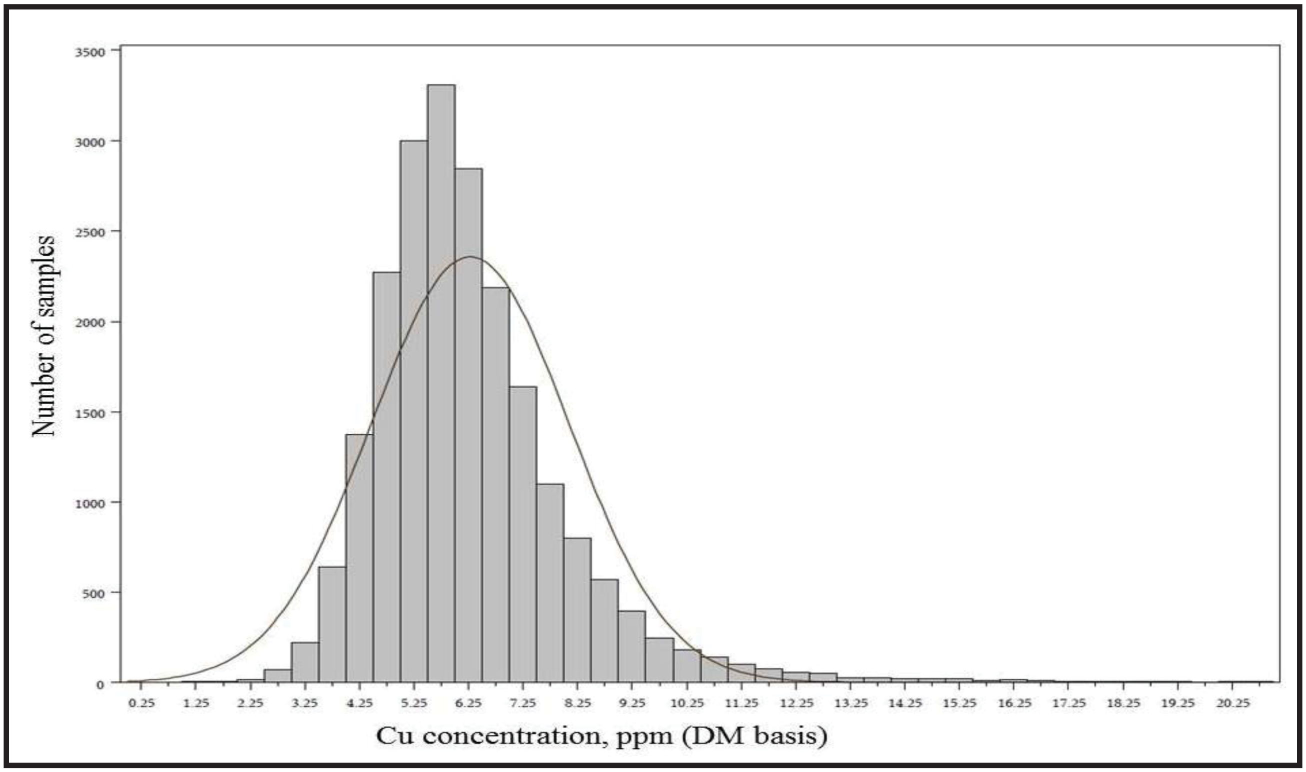

Figure 1. Distribution of Cu concentrations in corn silage grown throughout the U.S. The smooth line indicates a normal distribution, while the bars indicate the actual distribution. Figure courtesy of J. Knapp (Knapp et al., 2015).

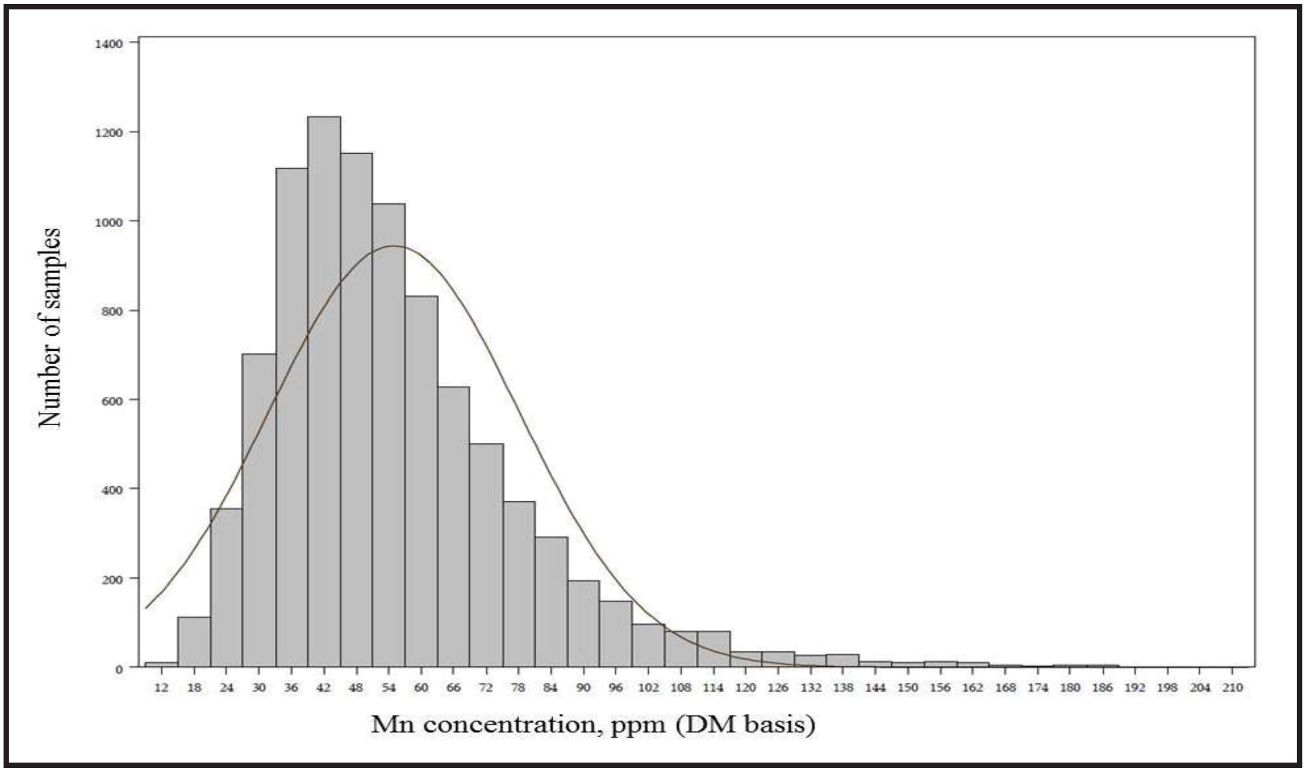

Figure 2. Distribution of Mn concentrations in mixed, mostly legume silage grown throughout the U.S. The smooth line indicates a normal distribution, while the bars indicate the actual distribution. Figure courtesy of J. Knapp (Knapp et al., 2015).