

RECOMMENDATIONS FOR TRACE MINERALS FOR DAIRY COWS

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SUMMARY

- The NRC (2001) requirements for most trace minerals and vitamins appear adequate but modest safety factors (~1.2 to 1.5 X NRC) should be used to reduce risk
- The trace minerals contained in basal ingredients, including forages, have some degree of availability and concentrations should not be set to 0
- NRC (2001) requirements for Co and Mn are too low and total dietary concentrations need to be increased substantially
- Be wary of long term overfeeding of Cu. Health issues may be develop at dietary concentrations as low as 20 ppm when fed over long periods

INTRODUCTION

Providing adequate trace minerals to dairy cows is essential for high production and good health. However feeding excess trace nutrients inflates feed costs and could be detrimental to production and cow health. Unfortunately quantifying the supply of available trace nutrients and their requirements is extremely difficult which leads to a high degree of uncertainty relative to diet supplementation. This paper provides suggested strategies for formulating diets to provide adequate but not excessive amounts of trace minerals under a variety of conditions. When this paper was written (January, 2017), the NRC was in the process of updating the Nutrient requirements of Dairy Cows publication. This paper will concentrate on those trace nutrients in which newer (published since 2000) information is available. These include Co, Cr, Cu, and Mn, vitamins D and E and a few water soluble vitamins. The upcoming NRC may or may not reflect the opinions in this paper.

REQUIREMENTS: GENERAL

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) are summed to generate the requirement for absorbed mineral in either gram or milligrams/day. Because requirements are calculated on an absorbed mineral basis, absorption 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.

For minerals, the maintenance requirement is defined as 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 (Fe) to more than 70% of the total requirement. Measuring the inevitable losses of minerals is very difficult which leads to errors in estimating the maintenance requirement. Mineral status of the animal affects the inevitable loss of minerals. For example, 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 state (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 decades ago) used non-lactating cows. Intake is much higher for a 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). However, maintenance requirements are based on body weight, not DMI.

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 many minerals is extremely difficult
- Actual absorption data are limited; therefore most AC 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.

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. 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 sulfur and chloride but often these are separate tests. Most labs do not routinely measure Cr, Co and Se 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). Although we can get accurate total mineral concentrations 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 2.5 grams of Cu (to put this in perspective a penny weighs about 2.5 g).

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 averages 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.

In a normal distribution (the classic bell shaped curve) 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. 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 soil contamination. 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.

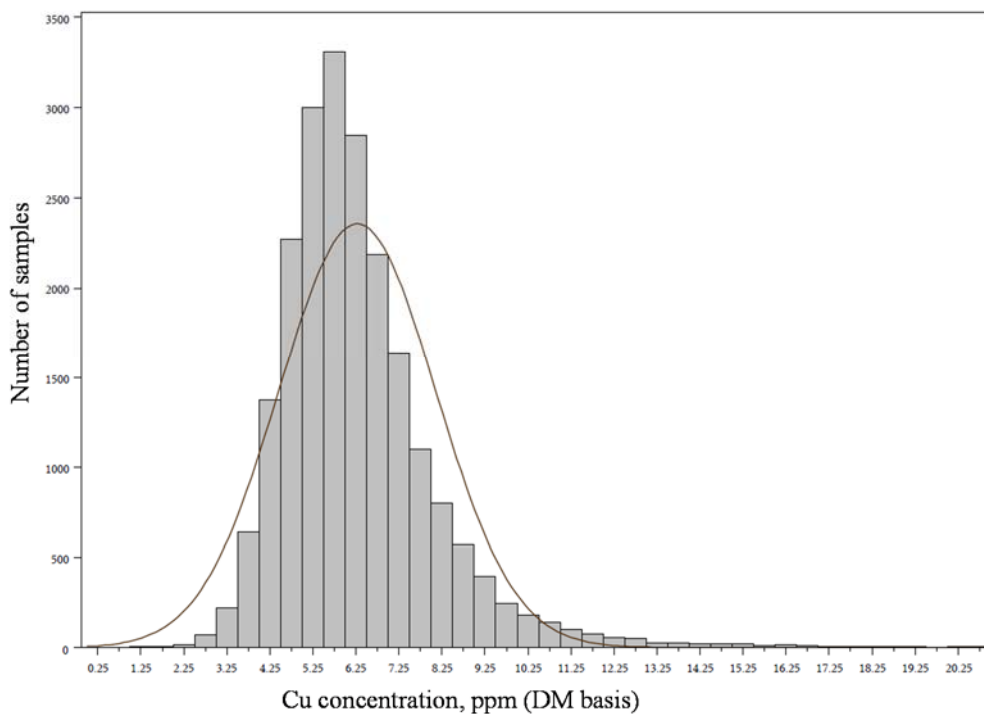


Figure 1. Distribution of Cu concentrations in corn silage grown throughout the U.S. The smooth line indicates a normal distribution would while the bars indicate the actual distribution. (Knapp et al., 2015).

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. That data has 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 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 (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 median values for trace minerals for forages grown within a limited geographical area.

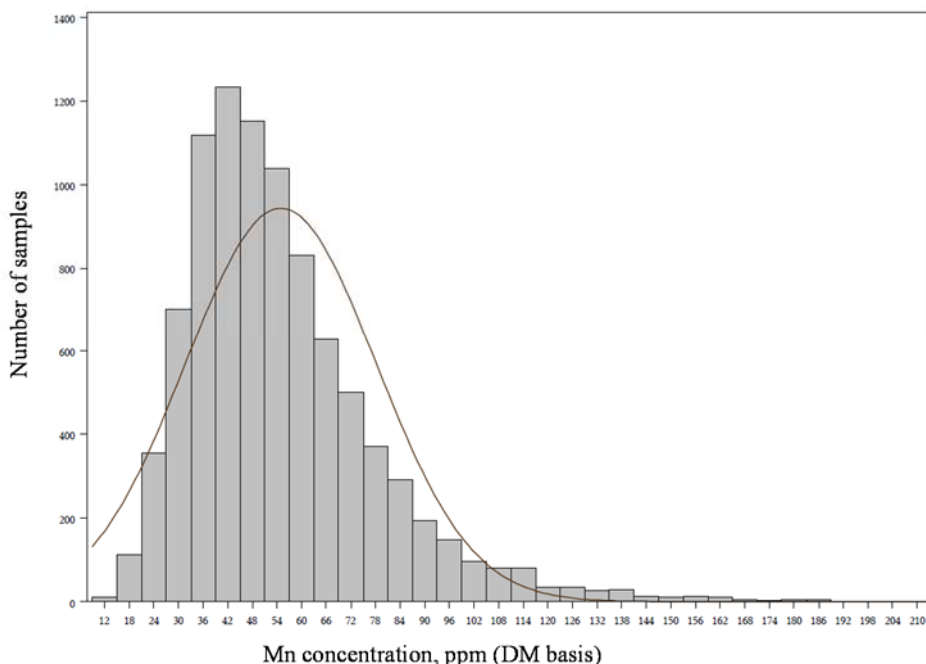


Figure 2. Distribution of Mn concentrations in mixed, mostly legume silage grown throughout the U.S. The smooth line indicates a normal distribution would while the bars indicate the actual distribution (Knapp et al., 2015).

Do Trace Minerals in 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, based on personal experience it is not uncommon for 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 absorption coefficients for most minerals in feeds, 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) contain trace minerals indicating that absorption of basal minerals occur.

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 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 trace minerals in basal feeds, especially forages, are in 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 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.

On average (and remember the issues with using averages), unsupplemented diets for lactating cows in the US based mostly on corn silage, alfalfa, corn grain 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 lbs of milk/day and 53 lbs of dry matter intake) using NRC requirements, basal ingredients supply about 80%, 235% (do not believe this), and 75% of requirements for Cu, Mn, and Zn. 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 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 a 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). Cleft palate and other birth defects in calves (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.

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 – 400 mg/kg on a DM basis or approximately 30 – 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 30mg/kg) and maximum (400 or 120mg/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 Jerseys and Holsteins; 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. 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 B₁₂ so when we refer to Co status we really mean vitamin B₁₂ status. Liver B₁₂ concentrations reflect Co intake. Assumed adequate hepatic B₁₂ concentrations are between 200-400 nmol/kg on a wet weight basis (Stangl et al. 2000). Similar to Cu, liver biopsies to determine B₁₂ concentrations and subsequent Co status are invasive and not practical on a large scale (vitamin B₁₂ 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. Based on the effects of Se supplementation on various biological responses, adequate serum (Weiss, 2005) and whole blood (Kommisrud et al., 2005) Se concentrations are around 0.06 µg/mL and 0.15 µg/mL, respectively. About 60% of the Se in whole blood is in the erythrocytes which have a half-life of almost 100 d 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. 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.

RECOMMENDATIONS

Chromium

Chromium is a required nutrient, however, the NRC (2001) did not provide a quantitative recommendation. Furthermore, feeding diets with more than 0.5 ppm of supplemental Cr or from sources other than Cr propionate is not currently legal in the U.S. 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 (fed at 0.4 to 0.5 ppm of diet DM) reduced the insulin response to a glucose tolerance test (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 6 wk. 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 was +4.1 lbs/day (the SD among responses was 3.5 lbs/day). About 75% of the treatment comparison yielded an increase in milk of more than 2 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 probably 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 feed plus the cost of the supplement and assuming a median response of about 4 lbs of milk and 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 concentration basis (i.e., 0.11 ppm in diet DM) rather than mg of absorbable Co/day 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. In studies conducted in WA, basal diets contained 0.2 to 0.4 ppm Co (Kincaid et al., 2003; Kincaid and Socha, 2007) but basal diets from WI contained 1 and 2 ppm Co (Akins et al., 2013). 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 reported a linear increase in milk yield in multiparous 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. Based on current data, the NRC (2001) requirement does not result in maximal liver B-12 concentrations in dairy cows. 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 of absorbable Cu/day basis and over a wide range of milk yields (40 to 150 lbs), requirements 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 slightly. However, because DMI (and Cu intake) usually increases as milk yield, the dietary concentration of Cu needed to meet the requirement may not change 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 and dry 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 minerals in that it is toxic at relatively low intakes 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 (e.g., 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)
- Feeding clay-based 'binders'

Most of these antagonisms have not been quantitatively modeled, and specific recommendations cannot be provided. 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. As an approximation, for an average lactating Holstein cow, for every 100 mg/L (ppm) of S in water add 0.04 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 500 mg/L of S, dietary equivalent S = $0.26 + 5 \times 0.04 = 0.46\%$. 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 high 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 antagonist 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, 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 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 (2001) overestimates absorbed Cu supply and Cu supply will need to exceed NRC requirements. For an average Holstein cow fed a diet with substantial antagonists, total dietary Cu may need to be 20 ppm, or perhaps more, to provide 12 to 15 mg/d of absorbed Cu. Some specialty Cu supplements are less affected by antagonism (Spears, 2003) and under antagonistic conditions, those sources of Cu should be used. 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., a few weeks) the change in liver Cu may be insignificant but when Cu is overfed for many months, liver Cu concentrations can become dangerously elevated. Jerseys are at 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 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 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, 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 copper poisoning is subclinical and can cause liver degeneration, which is evident based on elevated liver enzyme (AST and GGT) activities in plasma (Bidewell et al., 2012). Accumulating evidence suggests problems may start occurring at much lower concentrations of liver Cu (500 or 600 mg/kg DM). Activity of AST, and GGT 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 was considered acceptable overfeeding of Cu (e.g., ~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/d of absorbable Mn and based on typical DMI translates to 14 to 16 ppm of total Mn in the diet. However, the 2001 NRC probably greatly overestimated the AC for Mn. Seventy percent of the calves borne from beef heifers fed a diet with about 16 ppm Mn for the last 6 month of gestation displayed signs of classic Mn deficiency (Hansen et al., 2006). Using Mn balance studies in lactating cows (Weiss and Socha, 2005; Faulkner, 2016), we estimated that lactating cows (average milk yield in the experiment = 84 lbs/day) needed to consume about 580 mg of Mn to be in Mn balance. Based on the DMI in those experiments, that translated into a dietary concentration of ~30 ppm for total dietary 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 30 ppm and after the safety factor is applied, diets for lactating cows should have 36 to 45 ppm **total** Mn.

CONCLUSIONS

Adequate supply of trace minerals improves the health and productivity of dairy cows; excess or inadequate trace nutrients can 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 Cu, numerous antagonists exist and in those cases, diets need to provide substantially more Cu than recommended by NRC or a high quality organic Cu should be fed. Although many situations dictate higher concentrations of dietary Cu, be aware of excessive Cu supplementation. Modest overfeeding Cu for months or years can result in high liver Cu concentrations that may be negatively affecting cow health. Manganese requirement is likely much higher than 2001 NRC and Co requirement also likely needs to be increased.

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