

RECOMMENDATIONS FOR MINERALS FOR DAIRY COWS

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INTRODUCTION

Providing adequate minerals to dairy cows is essential for high production and good health. However feeding excess minerals inflates feed costs and could be detrimental to production and cow health. Unfortunately quantifying the absorbable supply of minerals 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 minerals under a variety of conditions. When this paper was written (Summer, 2017), the NRC was in the process of updating the Nutrient requirements of Dairy Cows publication and requirements may change.

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

Although we can get accurate analysis of many minerals, you must be careful when evaluating and using the data. From a survey we conducted on forages, sampling variation for 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 or from a group of farms within a small geographic area should be a truer estimate of the 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 and about half the samples have more than the average. For many minerals, especially trace minerals, concentrations within feeds are not normally distributed (Figure 1). 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. What this means is that for most situations, using the average trace mineral concentration (e.g., feed table data), overestimates the mineral concentration in the majority of samples. For skewed populations, the median is a better descriptor of the population than the mean. As a distribution becomes more skewed, the risk that a specific feed will contain excess mineral increases. Corn silage in Figure 1 had a mean Cu concentration of 6 ppm with a SD of 1.8. 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 mineral concentrations in forages 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.

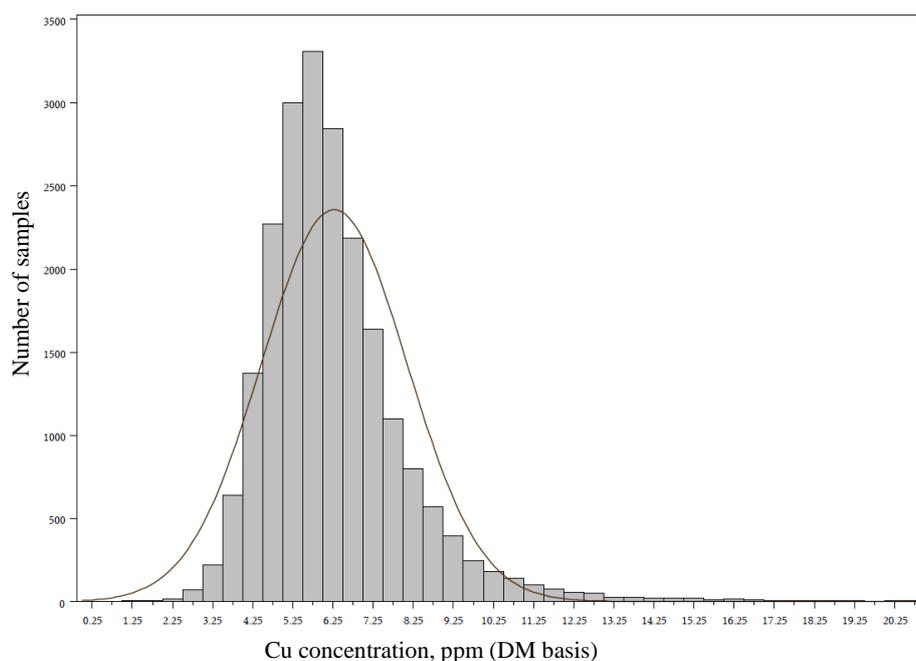


Figure 1 - Distribution of Cu in corn silage grown throughout the U.S. The smooth line indicates a normal distribution while the bars indicate the actual distribution. (Knapp et al., 2015).



Do Minerals in Basal Feeds have Nutritional Value?

Essentially every feedstuff used in dairy diets contains some minerals and most nutritionists enter assayed values for concentrations for macrominerals (e.g., Ca, Mg, K). Although survey data of nutritionists is 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. For an average Holstein cow using average feed composition and NRC (2001) requirements, basal ingredients supply about 80% and 75% of requirements for Cu and Zn. Ignoring minerals supplied by basal ingredients can result in substantial over formulation for trace minerals.



EVALUATING MINERAL STATUS

The primary indicators of 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. Concentrations of Ca and Mg in blood have diagnostic value but often cows will be showing clinical signs and blood data are just used to confirm the diagnosis. Measuring urinary Mg excretion reflects intake of absorbable Mg, but published ranges of adequate excretion do not exist and probably depend on the physiological state of the cow. 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. 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 concentration) 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 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

Calcium. The cow can remove Ca from bone so that a short term deficiency of Ca has little effect on lactating cows. A long term deficiency can result in weak bones and other skeletal problems. However, because most common feedstuffs contain some available Ca and Ca supplements are inexpensive, Ca deficiency is not often a real world problem. A Ca deficiency during the dry period and early lactation period can cause clinical (i.e., milk fever) and subclinical hypocalcemia; however, Ca deficiency is rarely the cause of hypocalcemia. Excess Ca is much more common than Ca deficiency and just modest over feeding of Ca (e.g., 115% of requirement) to dry cows increases the risk of hypocalcemia. With lactating cows, substantial overfeeding (>150% of requirement is needed before problems might be seen. Diets with >1% Ca substantially reduced selenium absorption by dry cows. This has not been shown in lactating cows but because Se status is often sub-optimal, feeding lactating cows diets with more than 1% Ca should be avoided. Diets with >1.5% Ca may reduce feed intake and milk yield (this is more than twice the requirement). For lactating cows, no data suggest that modest overfeeding (i.e., 120% of requirement) causes any problem and will ensure diets are not deficient. Dietary Ca for dry cows should be fed precisely to requirements.

Phosphorus. For a lactating cow, a diet with approximately 0.35 to 0.4% P is usually adequate and diets based on typical ingredients without any supplemental usually will contain between 0.3 and 0.4% P. Diets that provide inadequate P to dry cows (an extremely rare event) can increase the risk of hypocalcemia. Milk yields were reduced when cows were fed diets that provided



approximately 85% of P requirement (Wu et al., 2000; Wu, 2005) but no study has reported any benefits (production, reproduction, or health) when diets provided more P than NRC requirements. Modest overfeeding P (~120% of requirement) to dry cows significantly increases the risk of hypocalcemia. Diets with up to ~0.7% P generally have not adversely affected lactating dairy cows but reductions in availability of Ca and Mg are possible. There is no reason to feed diets with 0.7% P but because many byproducts (e.g., distillers grains, corn gluten feed, wheat midds) are rich in P and are often economical, diets for lactating cows with 0.5 to 0.55% P are not uncommon. This concentration of P should not have adverse effects on cows but you should consider increasing dietary Ca and Mg slightly. Manure excretion of P can be an environmental issue and it will be substantially greater when cows are fed diets with 0.5% P compared with diets at requirement (~0.38%). For lactating cows, low P diets have reduced milk yields indicating that modest overfeeding should be practiced. Because of environmental concerns, a safety factor of 105 to 110% of requirement is probably adequate when inorganic P is needed. Diets with high inclusion rates of common byproducts often are excessive in P (perhaps 0.5 to 0.55%). These are safe for cows but be aware of environmental implications. For dry cows, P should be fed precisely to requirements.

Potassium. Diets for lactating or dry cows rarely require K supplementation to meet requirements (~0.55% for dry cows and 1.1% for lactating cows) because haycrop forages are extremely rich in K. Diets based heavily on corn silage, especially corn silage with a high starch concentration, may be marginal in K. Erdman et al. (2011) reported increased milk yield and improved feed efficiency when a corn silage-based diet was supplemented with K (increased diet K from about 1.1% to 1.4%). The K requirement increases under heat stress but if diets have some haycrop forage, supplemental K probably will not be needed. Dry cow diets will almost never need supplemental K; however, excess



K is a substantial problem in practical diets. For dry cows, increasing K linearly increases the risk of milk fever (Lean et al., 2006). For lactating cows, diets with up to 3% K probably will not affect intake or milk but will increase urine output (more manure) and reduce Mg absorption substantially. Dietary Mg should be increased whenever dietary K is greater than about 1%:

[1] Increase dietary Mg by 0.08 percentage units above NRC (2001) for every 1 percentage unit dietary K exceeds 1% (Weiss, 2004)

[2] Increase dietary Mg by 0.02 percentage units above NRC (2001) for every 1 percentage unit dietary K exceeds 1% (Schonewille et al., 2008)

Those two equations are markedly different because the data bases used were very different. In Schonewille et al. (2007) dietary K ranged from 0.7 to 7.5% (most from grasses), diets averaged 0.45% Mg and most of the data is for dry cows. In Weiss (2004) dietary K ranged from 1 to 2.65% (most from alfalfa), diet Mg averaged 0.27% and data were from lactating cows. The large difference between the two studies is probably because the high Mg concentration in Schonewille et al (2008) overcame the antagonism. Because Mg deficiency is more costly than excess Mg, I would err on the side of potentially overfeeding and use Equation 1. In most situations, K deficiency will not occur but supplemental K may be beneficial for high corn silage diets. Increasing the dietary cation-anion difference by supplementing certain forms of K (e.g., potassium carbonate) has increased milk fat and gross feed efficiency. To obtain these benefits, dietary K has to be substantially higher than NRC requirements (1.5 to 1.8 x NRC). If extra K is supplemented, additional Mg must also be supplemented. High K for dry cows (>0.7 to 1%) increases risk of milk fever and high K (>1%) in lactating diets reduces Mg absorption.



Magnesium. Typical diets without supplemental Mg contain 0.15 to 0.2% Mg which is approximately the NRC requirement, however most diets tend to have antagonists to Mg absorption (e.g., K, Ca, P, RDP, fat and potentially undigested fiber). These real world antagonists, the site of absorption (i.e., reticulo-rumen), variation in solubility of Mg from different sources, and the lack of homeostatic regulation cause a wide range in Mg absorption among diets (-4 – 30% of intake; Weiss, 2004). Small labile stores of Mg exist in the cow (3 to 4 g) making inconsistent intakes of inadequate absorbable Mg a risk factor for hypomagnesemia and hypocalcemia. A meta-analysis found that increasing Mg up to 0.4% (NRC requirement is approximately 0.13%) linearly (and substantially) reduced the risk of milk fever indicating that dry cows diets should contain up to 3X NRC recommended concentrations of Mg. Feeding diets with 0.4% Mg should not cause any problem but will increase supplementation costs. Benefits of high dietary Mg for lactating cows are much less clear. Some (but not all) older studies (milk yields averaging about 27 kg) reported increased milk yields and/or milk fat when diets contained 0.3% Mg compared with control diets (approximately 0.2%). Although diets with up to 0.4% Mg will not cause problems to lactating cows, current data do not justify that rate of supplementation. Because of potential milk yield response and potential antagonism from high K, diets with 0.25 to 0.3% Mg can be justified. Dry cows must be fed diets with 0.3 to 0.4% Mg to reduce the risk of milk fever. Benefits of feeding high concentrations of Mg to lactating cows is less clear but balancing the cost of overfeeding (only higher supplementation costs) to potential increases in milk and milk fat, a safety factor of 1.4 to 1.6 times NRC is justified.

The source of Mg in the diet can have substantial effects on Mg absorption and production. New data suggests that Mg absorption for typical basal diets average about 30% (SD = 16) compared to 16% used in NRC (2001). The high variation associated with basal absorption should be considered and



justifies overfeeding Mg. Conversely, new data suggests that the absorption coefficients for Mg supplements such as MgO in NRC (2001) were about twice as high as actual values. Overall, basal ingredients are likely better sources of Mg than previously thought, but Mg supplements are not as good as previously thought. Absorption of Mg from inorganic sources also depends on the inclusion of monensin. For diets with MgO, monensin increased absorption about 25 to 30% whereas monensin decreased the absorption about 20 to 25% in diets with MgSO₄ (Tebbe et al., submitted). Feeding MgO was also better for milk production than MgSO₄. However, for dry cows, MgSO₄ is likely a better source than MgO because it helps maintain blood Ca after calving (Roche et al., 2002). The availability of Mg also varies within source. Jesse et al., (1981) found Mg availability was negatively related to particle size, and simply grinding the MgO to a fine dust could increase available Mg over 700%. The temperature at which MgO was calcined from organic source also effects availability with 1500°C being the most optimal. For all types of diets, modest overfeeding Mg does not appear to be a risk factor. Because of substantial variation in absorbability of Mg among sources, especially MgO, nutritionists should purchase MgO from reputable sources.

Sodium and Chloride. All diets will need supplemental Na (i.e., salt) but because salt is inexpensive NaCl deficiencies are extremely rare. Over feeding Na via excess salt or in combination with Na bicarbonate is common. Feeding Na at approximately 2X NRC requirements from a variety of sources (salt + sodium sulfate + sodium sesquicarbonate) over an entire 308 d lactation had no effect on milk yield (lactation average milk yield = 32 kg, 3.5% fat), composition, or intake (Clark et al., 2009). Sometimes feeding excess Na (from buffers) can increase milk fat but this is dependent on starch, fiber, forage, etc. Cows can tolerate high Na diets (up to about 1% of diet) as long as non-saline water is readily available. Diets with high Na will increase urine excretion and



manure output. Diets with excess Na (approximately 0.5 to 0.6% which is about 2X NRC) from buffers will not cause any problem for cows if clean water is readily available but milk yield responses are not consistent.

Sulfur. Sulfur is essentially a nutrient for rumen bacteria, not the cow. Diets with inadequate S can reduce fiber digestibility, microbial protein synthesis and feed intake. Diets with approximately 0.2% S are usually adequate to prevent these problems and in most situations, dairy cow diets are about 0.2% S without any supplemental S. Because most S in diets is found in amino acids, diets with lower protein also tend to have lower S concentrations and may need some supplemental S. Diets with supplemental S from inorganic sources during the prefresh period reduce the risk of hypocalcemia. The amount needed depends on concentrations of Na, K, and Cl. Diets with more than 0.25 to 0.3% S can cause problems when fed for long periods of time (months, not weeks) and diets with more than about 0.5% S can cause problems even when fed for short periods of time. With the exception of prefresh diets (i.e., low DCAD), there is no reason to increase dietary S above 0.25% with supplemental S; however, because of the increased use of distillers grain and because some water can be very high in sulfate, cows often consume diets (or diets equivalent) with more than 0.25% S (water with 350 mg/L sulfate-S is equivalent to increasing dietary S by 0.2 percentage units). A diet with 35% distillers may have more than 0.4% S. Diets with >0.25% S reduce Cu and Se absorption and supplementation rates for those two minerals should be increased or more bioavailable forms should be fed. Although very rare for dairy cattle, diets with 0.35 to 0.4% S have caused increased mortality in feedlot cattle (mostly via polioencephalomalacia). High starch diets increase the risk of S toxicity; dairy cattle fed moderate starch diets (relative to feedlot diets) probably can handle diets with 0.5% S. S supplementation for lactating cows is usually not required with the possible exception of lower protein



diets. Feeding diets with S concentrations of 0.3 to 0.4% during prefresh period can reduce hypocalcemia. Excess S is a much greater risk than S deficiency. Attempt to keep diets (including water) to 0.25% S or less. Increase Cu and Se by at least 1.2X NRC if dietary S is >0.25%.

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 very much good data on Cr concentrations in feedstuffs (Spears et al., 2017). 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 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. The median milk response from 30 treatments from 14 experiments was 1.9 kg/day (the SD among responses was 1.6 kg/day). About 75% of the treatment comparison yielded an increase in milk of more than 0.9 kg/day. Although a comprehensive meta-analysis is needed, based on this preliminary analysis of studies, increased milk yield of at least 0.9 kg/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.



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, 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 exists 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, under normal conditions, feeding about 1.2 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 X safety factor, the diet should be formulated to provide about 12 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 about 12 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). In non-lactating cows that were in good 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). 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), we estimated that lactating cows 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 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.

Selenium. The benefits of feeding diets adequate in Se to the health of dairy cows are unequivocal. All diets fed to dairy animals (calves, heifers, dry cows, lactating cows) in the Eastern U.S. should contain 0.3 mg/kg of **supplemental** Se (this is the maximum allowed by FDA regulations). Basal ingredients typically contain about 0.1 mg/kg Se so that total diet is about 0.4 mg/kg.

Cows have been fed diets with as much as 12 mg/kg of Se (from selenite) for 4 months without any negative effects. Because of legal constraints, a safety factor for Se cannot be recommended. If feeding 0.3 mg/kg of supplemental Se from selenite is not adequate, replacing some or all of the supplemental Se with Se-yeast may help. On average true absorption of Se from inorganic source is about 50% and about 60% for Se from



Se-yeast (calculated from Walker et al. (2010)). Based on blood, enzyme, and true absorption, Se from Se-yeast is about 20% more available than Se from selenite when antagonists are not present. The difference may be greater for diets with high S.

Zinc. The NRC requirement for Zn is between about 40 and 55 mg/kg (depending on milk yield) and there is no data showing substantial benefits from feeding more than this. Cattle can be fed very high concentrations of Zn (>500 mg/kg) without negative effects. High Zn (approximately 100 mg/kg), however can reduce Cu absorption and therefore should be avoided. Diets with a reasonable safety factor (1.2X NRC) to account for uncertainty in Zn concentrations of basal ingredients are justifiable and pose no risk.

CONCLUSIONS

- The current NRC requirements appear adequate for most macrominerals but modest safety factors (1.2X NRC) should be applied. Additional K when it increases DCAD may improve feed efficiency and milk fat yield but will reduce Mg absorption and additional Mg may be needed
- The NRC (2001) requirements for most trace minerals (Cu, Fe, Se, Zn) 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 concentrations need to be increased substantially
- Be wary of long term overfeeding of Cu. Health issues may be develop at dietary concentrations <20 ppm when fed over long periods



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