Update on Trace Minerals and Vitamins for Dairy Cows

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Introduction

Providing adequate trace minerals and vitamins 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 vitamins and trace minerals under a variety of conditions. When this paper was written (December, 2019), the NRC was in the process of updating the Nutrient requirements of Dairy Cows publication. The upcoming NRC may or may not reflect the opinions in this paper.

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 numero0us 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

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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).

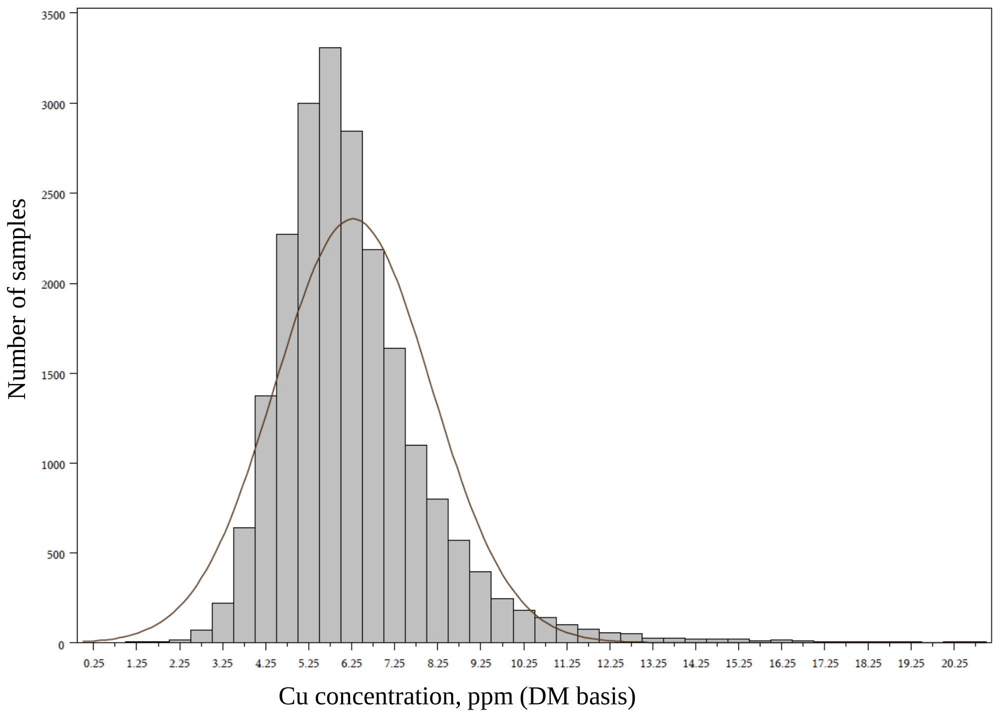

Figure 1. Distribution of Cu concentrations in corn silage grown throughout the U.S. The smooth line indicates a normal distribution would while the bars indicate the actual distribution. (Knapp et al., 2015).

Sampling error is a problem for most nutrients and when concentrations are low, sampling error is usually larger. From a survey we conducted, 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. 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 $\pm$ 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 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.

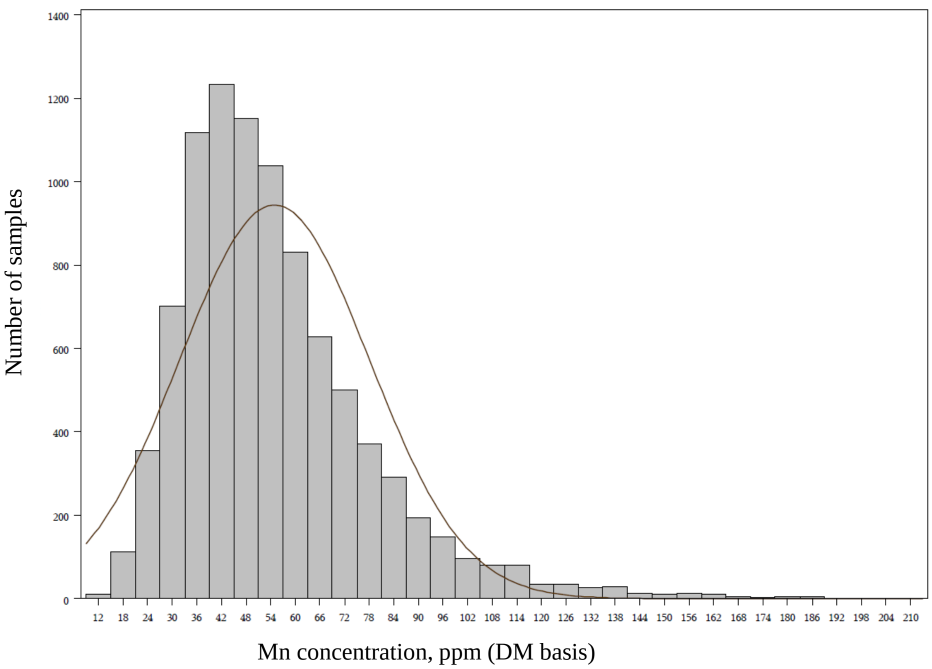

Figure 2. Distribution of Mn concentrations in mixed, mostly legume silage grown throughout the U.S. The smooth line indicates a normal distribution would while the bars indicate the actual distribution (Knapp et al., 2015).

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.

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 (low availability). Feeds with substantially greater 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.

Form of supplemental trace mineral (newer information)

In the U.S. the primary form of most supplemental trace minerals is the sulfate salts but some chloride salts are also used. These forms of trace minerals are a good compromise between price and availability. Other commercially available forms of trace minerals include organic and hydroxyl metals (identified as specialty minerals). Several different commercial forms of organic minerals (mostly Cu, Cr, Co, Mn, and Zn) are available and in those products the metal is usually chelated or complexed to a specific amino acid, a blend of amino acids, a sugar or an organic acid. Hydroxy trace minerals are inorganic but their chemical structure differs from sulfates. The metals in sulfates and chloride salts are linked with ionic bonds that readily dissociate in the rumen and hydroxyl and some organic minerals are linked with covalent bonds which are less likely to be broken in the rumen. Potential differences between specialty minerals and sulfate minerals include increased absorption by the cow, different metabolism within cells, and effects on microbes within the rumen and hind gut (i.e., digestive tract microbiome).

Measuring absorption of trace minerals is extremely difficult and we have almost no data on actual absorption of specialty minerals but we do have relative absorption information, especially for Cu (change in liver Cu is an indicator of absorption). In general, organic Cu is more available than copper sulfate and differences often are greater in the presence of antagonists. Because we do not have a good index of relative absorption for Zn or Mn data are lacking on whether specially Zn or Mn is more bioavailable than the sulfates. Some cell culture data suggests that amino acid complexed Zn may be taken up at greater rates than Zn chloride (Sauer et al., 2017).

Clinical and production responses to organic trace minerals compared with sulfates or chlorides generally is positive (Siciliano-Jones et al., 2008; Rabiee et al., 2010). Because multiple trace minerals are usually supplemented we do not know whether the form of one or several minerals is eliciting the responses. Mode of action is not known. It could be increased bioavailability but if that was the primary mechanism, we would expect to see some responses to increased supplementation rates of conventional minerals (i.e., above NRC) but we seldom observe positive effects. Specialty minerals could be metabolized differently within the body but data is lacking showing this. Form of mineral does, however, affect the microbiome and this is a rapidly developing area of research. In vivo digestibility of NDF by dairy cows was less when sulfate trace minerals were fed compared to when hydroxyl minerals were fed (Faulkner and Weiss, 2017). We hypothesized that the sulfate minerals dissociated within the rumen and were toxic to rumen bacterial and reduced fiber digestibility. We also found that feeding Zn glycinate rather than Zn sulfate reduced the fecal abundance of a microbe that is associated with digital dermatitis. We hypothesized that reduced hoof exposure to the pathogen when cows walk in manure could be a mode of action for improved hoof health with organic Zn.

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) much of the data on Cr concentrations in feed are not valid. However, a limited data base based on proper analytical techniques is available (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 (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

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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 multiparious cows, but no effect in first lactation animals when supplemental Co increased from 0 to about 1 ppm. Older cows tend to have lower concentrations of B-12 in their livers which could explain the parity effect. 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 low concentrations in milk, as milk yield increases, the NRC requirement for Cu increases slightly. However, DMI (and Cu intake) usually increase as milk yield increases to a greater extent than secretion of Cu in milk. Therefore the dietary concentration of Cu needed to meet the requirement may actually decrease as milk yields increase. Dry cows require less milligrams of Cu per day than a lactating cow, but because of dry matter intake differences, the concentration of Cu in dry cows diets may need to be greater than those for lactating cows.

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)making it a good marker of mineral status.

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 a general guide, 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*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), however 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 defiency (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.

VITAMINS

Because of very limited data, the term requirement should not be used for vitamins. Rather we should use the term 'Adequate Intake' or AI. This is the quantity of vitamin that has been shown to prevent health problems or result in statistically reduced prevalence or severity of disease. Some vitamins increase milk yields, but because effects on milk yields must be put into economic context (i.e., price of milk, price of feed and cost of the vitamin) milk yield response should not be a major factor when setting AI. However this does not mean that supplementation rates that increase milk yield but do not affect health should not be used in situations where they are profitable. Data on concentrations of vitamins in basal ingredients is extremely limited or lacking entirely which adds to uncertainty. Concentrations of certain vitamins in feeds can be extremely variable (e.g., concentrations of tocopherol in hay crop forages can range from almost 0 to more than 150 ppm). Because supply of vitamins from basal ingredients will almost never be known, AI are usually based on supplemental vitamins. Adequate data are available to determine AI for biotin, niacin, and vitamins A, D, and E.

Vitamin A

NRC (2001) recommendations for vitamin A appear adequate for average cows (i.e., 110 IU of supplemental vitamin A/kg of BW). For a typical Holstein cow that equals about 70,000 IU per day. Milk contains about 0.3 mg of retinol/kg (about 1000 IU/kg or 450 IU/lb); therefore, high producing cows can secrete substantial amounts of A into milk. However this is not obligatory (i.e., feeding less retinol reduces the concentration of retinol in milk). The average cow in the NRC (2001) database produced about 35 kg of milk/d (77 lbs). For cows producing >77lbs of milk, feeding an additional 450 IU of vitamin A/d per lb. of milk >77 lbs will replace what is normally secreted in milk. For example for a Holstein cow producing 70 lbs of milk/d, the adequate intake of vitamin A is 70,000 IU but for a cow producing 100 lbs of milk, the adequate intake would be 70,000 + [(100-77)*450] = 80,350 IU/day. No data are available showing NRC (2001) vitamin A recommendations for dry and prefresh cows are not adequate. However because of reduced dry matter intake by prefresh cows, concentrations of vitamin A should be increased to maintain the AI of vitamin A (approximately 83,000 IU/d for a dry Holstein cow).

Vitamin D

Calcium homeostasis was long considered the primary function of vitamin D, but its effects on cells and animals go far beyond Ca including effects on immune function and health. The 2001 NRC requirement (14 IU of supplemental vitamin D/lb. BW or about 20,000 IU/d for a Holstein cow) is adequate with respect to Ca; however it may not be adequate for optimal immune function. Using a plasma concentration of 30 ng of 25-hydroxyvitamin D/ml to indicate sufficiency, 45 or 50 IU/kg BW (about 30,000

IU/d) may be needed for lactating cows (Nelson et al., 2016). Cows that spend a few hours outside during summer months probably synthesize adequate vitamin D but sun exposure in spring, fall, and winter (in the US) probably lacks intensity for adequate synthesis rates.

Vitamin E

The 2001 NRC recommendations of 500 and 1000 IU/d of supplemental vitamin E for lactating and dry cows are adequate; however, sufficient data exists to justify increasing supplementation during the last 14 to 21 d of gestation. Studies that evaluated the effect of additional vitamin E during the prefresh period used supplementation rates of 2000 to 5000 IU/d and in most studies some improvement in health was noted. Because of cost, the lowest supplementation rate that showed benefits (2000 IU/d) is the recommended AI for prefresh cows. This rate of supplementation has reduced early lactation mastitis and metritis.

Other vitamins

Adequate consistent data exist to set the AI for supplemental biotin at about 20 mg/day. This inclusion rate often improves hoof health and milk production (Lean and Rabiee, 2011). Niacin has been extensively researched but data are equivocal; about half the studies report a benefit and half report no effect. Supplementation at 12 g/d is more likely to elicit a production response (increased milk yield and milk component yields) in early lactation cows than the commonly used rate of 6 g/d. The majority of data do not support the use of niacin to reduce ketosis. Therefore, in most situations, the AI of supplemental niacin is likely 0. Supplemental rumen-protected choline (approximately 13 g/d of actual choline) increases milk yield in early lactation by 4 to 5 lbs/day (Sales et al., 2010; Arshad et al., 2019) and may help reduce fatty liver. In most studies, DM intake also increased with choline. A meta-analysis indicated that the milk yield response to supplemental choline was less as supply of metabolizable methionine increased (Arshad et al., 2019). Most production studies evaluated effects of choline the first 30 to 60 days of lactation and it is likely that response to supplementation would decrease as lactation progressed and DM intake increased. However, supplementing choline only the first 3 weeks of lactation resulted in increased energy-corrected milk yields (about 4 lbs.) for at least the next 9 wk after stopping supplementation (Zenobi et al., 2018). The common supplementation rate is 12-15 g of actual choline/d but the choline must be rumen protected. Because the data on health is equivocal at this time, choline does not have an AI, but it often is profitable because of its effect on milk yield.

Conclusions

Adequate supply of trace minerals and vitamins 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, Se and vitamin A 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. Cows benefit from greater amounts of supplemental vitamin E during the prefresh period and lactating cows without great sun exposure may benefit from additional vitamin D supplementation.

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 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

Supplying vitamin E in excess of NRC (2001) requirement to peripartum cows provides health benefits

Supplying vitamin D in excess of NRC (2001) to cows with limited sun exposure may be needed to maintain adequate D status relative to general health

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