

MINERALS AND VITAMINS FOR DAIRY COWS: MAGIC BULLETS OR JUST BULLETS?

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INTRODUCTION

A more accurate title for this paper would be “Under or Over supplementation of Minerals and Vitamins Can be Bad for Cows and Dairy Farm Profitability” but that is a bit verbose. Although, it is becoming dated, the Dairy NRC (2001) is still the best source for estimates of requirements of minerals and vitamins. For good health and high milk yields, cows need to be fed the proper amounts of available minerals and vitamins, however numerous factors (many of which are unknown) influence the requirements of minerals and vitamins and their availability. Concentrations of minerals and vitamins in feeds can be extremely variable and often they are not assayed. Newer data plus the substantial uncertainty regarding the quantity of minerals and vitamins consumed, the quantity absorbed (or available), and the quantity needed by cows under different situations mandates appropriate adjustments to NRC requirements. .

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 Ca and Ca supplements are inexpensive, Ca deficiency is not a real world problem in the U.S. 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). Because Ca is inorganic and contains no energy, high Ca diets tend to be lower in energy.

Bottom line: 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%).

Bottom line: 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. When byproducts providing extra P, diets with 0.5 to 0.55% P are safe 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 possibly 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) and in Weiss (2004) dietary K ranged from 1 to 2.65% (most from alfalfa). A diet with approximately 0.16% Mg usually meets NRC requirement. If the diet contained 1.7% K, dietary Mg should be 0.22% (equation 1) or 0.17% Mg (equation 2). Because Mg deficiency is more costly than excess Mg, I would err on the side of potentially overfeeding and use Equation 1.

Bottom line: In most situations, K deficiency will not occur but supplemental K may be beneficial for high corn silage diets. High K for dry cows (>0.7 to 1%) increases risk of milk fever and high K (>1%) in lactating diets reduces Mg absorption. Extra Mg is needed when high K diets are fed.

Magnesium

Most typical diets without supplemental Mg will contain 0.15 to 0.2% Mg which is approximately the NRC requirement, however typical diets tend to be high in Mg absorption antagonists (e.g., K and soluble N). Inadequate Mg is a clear risk factor for milk fever. 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 60 lbs) 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.

Bottom line: 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.

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 = 70 lbs, 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.

Bottom line: 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 reduces 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

Bottom line: 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%.

Cobalt

Cobalt is required by ruminal bacteria and the current NRC requirement is 0.11 mg/kg of diet DM. Data published since NRC suggest that increased concentrations of Co may be beneficial (Stangl et al., 2000; Kincaid et al., 2003). Depending on the response criteria, cows, including dry cows, should be fed diets with between 0.2 and 0.9 mg/kg Co. Older cows may benefit more from extra Co than younger cows. The Co effect is likely via vitamin B-12 and factors affecting responses to B-12 are numerous including supply of methionine, choline, and folic acid). Because of the uncertainty of response, supplementation rates of Co between 0.2 to 0.5 mg/kg is a good compromise. Cattle can tolerate high concentrations of Co (at least 20 mg/kg diet).

Copper

The current NRC requirement for Cu is about 14 mg/kg. Diets that are marginally low in Cu are a risk factor for increased infectious disease and feeding diets that are excess in Cu increases the risk for sudden death. Most typical diets contain about 10 mg/kg Cu from basal ingredients which means about 4 or 5 mg/kg supplemental Cu will be required. Numerous real-world antagonists to Cu absorption can be present including S (>0.25% of diet), reduced (as opposed to oxidized) Fe, Mo, excess Zn, and pasture consumption (most likely caused by soil ingestion). Because of potential antagonists and because of high variability in Cu concentration in feeds a safety factor of about 20% can be easily justified (i.e., feed diets with about 17 mg/kg Cu). With high S water and substantial inclusion of distillers grains you should increase another 20 to 40% (20 to 25 mg/kg) and consider using organic source of Cu. If water is also high in Fe (>3 mg/L) additional Cu may be needed. Diets with more than 25 mg/kg total Cu are rarely justified and long term feeding of excess Cu will cause it to accumulate in the liver. Long term feeding (many months) of diets with 37 mg/kg total Cu resulted in clinical Cu toxicity in Holstein cows (Bradley, 1993). Jersey cows appear to accumulate Cu more efficiently than Holstein which puts them at increased risk of Cu toxicity.

Iron

The NRC iron requirement is approximately 20 to 25 mg/kg and most unsupplemented diets are well in excess of that concentration. However, much of the iron in feeds, especially forages is poorly absorbed because the Fe is actually from soil contamination. When evaluating dietary Fe, the concentration of Fe in forages should be set at 0. If the remaining basal ingredients provide about 25 mg/kg Fe, the diet is probably adequate. If supplemental Fe is needed, use reduced source of Fe (e.g., iron sulfate). Because of antagonism of Fe to Cu and Zn and because high Fe increases the requirements for Se and vitamin E, supplemental Fe should be limited to 50 mg/kg. A study with early lactation cows reported no milk yield response when 30 mg/kg supplemental Fe was fed (Weiss et al., 2010). Iron in water at levels as low as 0.3 mg/L can reduce water consumption but is not adequate to cause other problems.

Manganese

The NRC requirement for Mn is approximately 18 mg/kg and data published after NRC clearly show that the NRC requirement is much too low. In beef heifers, feeding diets with 18 mg/kg Mn resulted in **clinical** Mn deficiency (Hansen et al., 2006). Using digestibility trials to estimate Mn maintenance requirements we estimated total Mn requirements were between 30 and 50 mg/kg (Weiss and Socha, 2005). Because cows can be fed diets with 1000 mg/kg of Mn with no effect, feeding diets with 40 or 50 mg/kg of Mn poses no risk and will essentially eliminate any potential of deficiency.

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.

Bottom Line (Trace minerals): NRC requirements for Co and Mn are too low based on recent studies. Co should be 0.2 to 0.9 mg/kg (0.4 mg/kg seems a good compromise). Dietary Mn should be between 30 and 50 mg/kg. The Zn and Fe requirements appear adequate. For Zn a small safety factor of 20% is justified based on variation in Zn of basal ingredients. The Fe contribution from forages should be ignored when computing supply of Fe but otherwise the NRC Fe requirement is adequate. Because high Fe can be a problem, a safety factor is not recommended. The maximum legal amount of Se should be supplemented. Initially this should be from inorganic or a blend of inorganic and Se-yeast (this is based solely on economics). If Se status is still not adequate increase the amount of Se-yeast and reduce or eliminate the inorganic Se. The NRC requirement for Cu is adequate for many situations but because of uncertainty a safety factor of 20% is justified. With high S diets (e.g., distillers grains) or water, Cu should be increased another 20 or 40%. Diets with more than 25 ppm total Cu are rarely justified and long term feeding (months) may cause problems.

VITAMINS

Vitamins were discussed in detail at the 2005 meetings. Requirements for vitamins are difficult to establish because measuring vitamins in feeds is sometimes very difficult, vitamins can be destroyed or synthesized in the rumen, and responses to changes in vitamin supply is often very subtle and may take months to observe.

Vitamin A

The NRC (2001) requirement for vitamin A is about 82,000 IU/day for a dry cow and 72,000 IU/day for a lactating cow. Cows fed adequate vitamin A have reduced mastitis, metritis, retained fetal membranes, and abortions than cows fed no supplemental vitamin A, but there are no data suggesting any health benefit to feeding more than the current NRC recommendation. However, cows fed 170,000 IU/day (about 2X NRC) during the dry period and first 6 wk of lactation produced more milk (88 vs. 77 lbs/day) than cows fed 50,000 IU/day (0.7x NRC) during that period (Oldham et al., 1991). Conversely, feeding very high vitamin A during the dry period (550,000 vs. 80,000 IU/day) reduced total yield of energy-corrected milk during the first 100 days of lactation (Puvogel et al., 2005). Vitamin A is among the least stable vitamins and loss of activity can be ~10%/month depending on storage conditions (Shurson et al., 2011).

Vitamin D

Because of the interest in vitamin D for human health, vitamin D for dairy cows is also being re-evaluated. Although adequate data are not available to quantitatively adjust the current NRC vitamin D requirement (approximately 20,000 IU/day), data are available suggesting potential benefits from increasing vitamin D supplementation. Studies with humans and limited research with bovine cells have shown that vitamin D has important roles in immune function and that blood concentrations of 25-OH vitamin D required for maximal immune response was greater than concentrations required for optimal Ca metabolism in humans (Lippolis, 2011). Whether this is true for dairy cows will require new studies. Dairy cows housed inside without exposure to sun and fed vitamin D at NRC rates had significantly lower (about 30%) plasma concentrations of 25-OH vitamin D than cows fed no supplemental vitamin D but housed outside in the summer with extensive sun exposure (Hymøller et al., 2009). The optimal concentration of plasma 25-OH vitamin D is not known but current supplementation rates do not provide for maximal concentrations. Some older studies (see page 165 in NRC) found improved reproduction measures and increased milk yield when vitamin D was supplemented at about 40,000 IU/day (i.e., 2X NRC). Excess (~2000 IU/day for months) dietary vitamin D can cause calcification of soft tissues.

Vitamin E

The NRC requirement for vitamin E is about 500 IU/day for lactating cows and 1000 IU/day for dry cows. Essentially no new research has been conducted evaluating vitamin E requirements for lactating cows but several experiments have been conducted with dry cows. Increasing vitamin E supplementation during the transition period (2 or 3 wk prepartum until 1 or 2 wk post partum) has improved measures of immune function or improved mammary gland health in several, but not all studies. Supplementation rates during the transition period ranged from 2000 to 4000 IU/day. No study has shown any negative effects of high supplementation rates in the prefresh period. Therefore the only known cost is the cost of the additional vitamin E but because the supplementation

period is short (a few weeks) and the potential payoff is high (reduced mastitis and retained placenta) increasing vitamin E supplementation during the prefresh period is justified. Increasing vitamin E supplementation during the entire dry period, however, is not justified. A recent study (Bouwstra et al., 2010) evaluated the effects of feeding 3000 IU of vitamin E/day (controls were fed approximately 130 IU/day) during the dry period. On 3 of 5 farms, more cases of mastitis occurred when cows were fed high vitamin E and on 2 farms little difference in mastitis was observed between treatments. Overall, they reported that feeding high vitamin E increased the risk of mastitis by 1.7X compared with the control. Although I have some technical concerns regarding the paper (e.g., methods used to diagnose mastitis), the paper clearly shows no benefit of increasing amounts of vitamin E and potentially it might have negative effects. Vitamin E supplementation during the dry period should be limited to 1000 IU/day.

Bottom line (Fat soluble vitamins): Poor stability of vitamin A and potential increased milk yield with extra vitamin A justifies supplementing vitamin A at 1.1 to 2 X NRC (e.g., 80,000 to 150,000 IU/day). Supplementation in excess of 150,000 IU/day cannot be justified based on available data. The current vitamin E levels are adequate except during the prefresh period when 2000 to 4000 IU/day can be justified. Much more research is needed with vitamin D but circumstantial evidence suggests benefits from increasing supplementation up to 2X NRC or ~40,000 IU/day). Because of potential effects on milk fever and complete lack of data, dry cows should be fed at approximately NRC levels for vitamin D.

Water soluble vitamins

Biotin, choline, and niacin are the only water soluble vitamins commonly supplemented to dairy cows. The data supporting routine biotin supplementation (approximately 20 mg/day) is strong. A meta-analysis (Lean and Rabiee, 2011) determined that a 2.9 lb/day increase in milk yield is expected with biotin supplementation and most studies evaluating hoof health have reported benefits with supplemental biotin. Based on current prices, these responses would be profitable. Data supporting the response to supplemental rumen-protected choline (RP-Choline) is also good. A meta analysis found an expected increase in milk yield of about 4.4 lbs, however based on their statistical model, a supplementation rate of about 20 g of RP-choline (actual choline, not product) was required to obtain this response (Sales et al., 2010). Feed intake is often not statistically altered but there is no reason to think choline improves efficiency so an increase in DM intake of 2 to 2.5 lbs/day should be considered in any economic analysis. The milk yield response to RP-choline is substantial but RP-choline is expensive so that its use may not always be profitable (especially at the 50g/day rate). Most experiments with RP-choline use early lactation cows because they are most likely to be limited in choline. We do not know whether these responses will occur in later lactation. If pens contain cows at several stages of lactation, rather than just early lactation, overall response may be less and this should be considered when deciding on potential profitability. Supplemental RP-choline (only studied at the 50 g/day rate) during the prefresh and fresh period may have some value in reducing fatty liver and type 2 ketosis (Cooke et al., 2007). Ketosis/fatty liver is a very

expensive disease and if RP-choline reduces its incidence it would almost definitely be profitable. Longer term approaches to reducing incidence of these diseases are available (e.g., proper management of body condition and DM intake during the dry period) and should be pursued but if ketosis/fatty liver is a problem supplementation of RP choline at 50g/day during the prefresh period should be considered. A meta-analysis (Schwab et al., 2005) found little benefit of supplemental niacin at 6 g/day but at 12 g/day milk protein yields were increased and depending on milk price, it may be profitable at times. Rumen protected niacin is now available and some data show that it may help cows under heat stress conditions but it is expensive and responses in milk yield have generally been quite small.

Bottom line (water soluble vitamins): Cows should be supplemented with biotin (20 mg/day), RP-choline increases production but because of cost, the decision to supplement depends on milk price, and current data do not justify routine supplementation of niacin.

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