NASEM 2021: What's New for Minerals and Vitamins for Dairy Cows

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Summary

The NASEM (2021) dairy committee conducted a thorough review of mineral and vitamin nutrition of dairy cattle. Requirements and recommendations for most minerals and vitamins were changed, although for several of the nutrients, the changes were quite modest when applied to average cows fed typical diets. However, many of the equations are more biologically correct which means that they should be more accurate over a wider range of cows and when fed in a wider diversity of diets. For most minerals, requirements for absorbed mineral are estimated and then divided by an absorption coefficient to obtain dietary requirements. Magnesium and manganese dietary requirements changed the most, and on average, they are about twice as high as those estimated by NRC (2001). Copper requirements were substantially increased for dry cows but decreased substantially for high producing cows. Vitamin A recommendations increased for high producing cows and vitamin D recommendations increased for lactating cows. Although no recommendations were established for water-soluble vitamins, the vitamin chapter contains a thorough review of expected responses when they are supplemented. The mineral chapter contains up-to-date information on factors that can affect absorbed requirements and absorption of minerals. Many of these factors are not included in equations; therefore, the book will be helpful to nutritionists to fine tune diets.

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Introduction

The NASEM (2021) committee evaluated the previous (NRC, 2001) requirements for all essential minerals and vitamins and reviewed scientific papers published since about 2000 to determine whether updates were needed. Based on that review, requirements were revised for almost every essential mineral and vitamin. Although for many minerals and vitamins, previous recommendations were accurate for average lactating cows fed typical midwestern diets, they were less accurate for higher producing cows and dry cows and when cows were fed less typical diets. For several minerals, dietary requirements changed only slightly compared with NRC (2001), even though many of the equations changed markedly. A major aim of the committee was to make equations more biologically correct so that they would work better for cows that were not average and not fed typical diets. No changes were made to iron and selenium recommendations, and phosphorus and iodine recommendations changed very little from NRC (2001) and these will not be discussed. Mineral and vitamin recommendations for pre-weaned calves underwent substantial updates, but those also will not be discussed. Lastly, very little research is conducted on the vitamin and mineral needs of growing heifers and either recommendations from the beef NRC (2016) or extrapolation from dairy cow experiments are used. Growing heifers will only be discussed briefly.

Requirement vs. Adequate Intake vs. Response

The NASEM (2021) uses two terms to describe the quantitative needs for minerals and vitamins: requirements and adequate intake **(AI)**. Requirements are established when the committee had enough data to be highly confident in the equations. A requirement will meet the needs of the average cow in a defined population (e.g., 1500 lb Holstein cow producing 80 lb/day of milk). Requirements were established for calcium **(Ca)**, phosphorus **(P)**, magnesium **(Mg)**, sodium **(Na)**, chloride **(Cl)**, sulfur **(S)**, copper **(Cu)**, and zinc **(Zn)**.

The term AI means that in the committee's expert opinion, cows fed this much mineral or vitamin will not be deficient and that the AI elicited a positive response above that when a lesser amount was fed. Adequate intake is similar to a requirement except that it means the committee did not have the same degree of confidence because of limited data. An AI was used when titration data were lacking (i.e., most studies only used two treatments, a control with no supplemental mineral or vitamin and one treatment with some level of the nutrient of interest), when data on basal intakes were limited or lacking, or when very few experiments were conducted on the mineral or vitamin. For diet formulation, a requirement and an AI can usually be considered the same thing. An AI was established for cobalt **(Co)**, iodine **(I)**, iron **(Fe)**, manganese **(Mn)** and selenium **(Se)**.

Some minerals and vitamins can increase milk production when supplemented; however, this does not necessarily mean that the supplementation rate is the requirement or AI. Primary examples are chromium **(Cr)**, biotin, rumen-protected choline and dietary cation anion difference **(DCAD)**. Cows require Cr and milk production often increases when diets are supplemented with about 0.5 mg/kg of Cr (Lashkari et al., 2018). However, a clinical deficiency of Cr has not been described, perhaps because basal concentrations of Cr are usually adequate to prevent them, and although supplemental Cr can increase milk production, it is not a requisite to high production. Diets contain biotin and rumen bacteria can synthesize it so clinical deficiencies do not occur. However, supplementing biotin at rates between 10 and 20 mg/day can increase production and improve hoof health (Lean and Rabiee, 2011). Supplemental protected choline at rates of 10 to 15 g of actual choline can increase milk production and reduce fatty liver (Sales et al., 2010). There is a minimum requirement for DCAD based on requirements for K, Na, Cl, and S, but exceeding that requirement (approximately 175 mEq/kg) often increases milk, milk fat, and DMI (Iwaniuk and Erdman, 2015). Conversely feeding reduced DCAD to dry cows reduces hypocalcemia. The responses to these nutrients are discussed in the text, but AI or requirements were not derived by the committee.

Calculation of Requirements or AI

Requirements or AI for most minerals were calculated using the factorial approach. The exceptions are Co, Se, and S. Cobalt and S are bacterial requirements, not cow requirements, and are therefore expressed as a dietary concentration (0.2 mg/kg and 0.2%, respectively). The concentration of supplemental Se in diets is regulated by FDA; therefore, its AI is expressed on dietary concentration basis (0.3 mg/kg diet). The factorial approach estimates the amount of absorbed (not dietary) mineral needed for maintenance plus the amount of mineral secreted in milk (lactation requirement) and accreted in tissue (growth requirement) or conceptus (gestation requirement). Maintenance requirement is estimated as the sum of endogenous fecal and urinary losses; however, except for electrolytes, endogenous urinary losses are either set to 0 or are very small. The total absorbed requirement is divided by an absorption coefficient **(AC)** to obtain the dietary requirement. For most minerals (Ca and P are exceptions), the same AC is used for all basal ingredients, but the AC for the mineral supplements can vary. All mineral requirements or AI are for total, not supplemental minerals. Users should include the minerals provided by basal ingredients in all supply calculations. Lastly requirements or AI are for the average cow in a defined population, which means that the requirement may underfeed about 50% of the cows. Appropriate safety factors should be applied when formulating diets. In my opinion (this is not NASEM, 2021), increasing supply of minerals by 1.2 times NASEM average requirement or AI is a reasonable safety factor. However, a safety factor is not needed for P, S, and Se. Because moderately excess sulfur can cause several problems (discussed below), it should be fed at about the NASEM requirement (i.e., 0.2% of diet DM). The requirements for P are very well defined and because of recycling within the cow, P deficiencies are extremely unlikely when the average cow in the pen is fed to meet NASEM (2021) average requirements. A safety factor is not needed. A safety factor often cannot be applied to Se because supplementation may be limited by regulation. In most areas of the world, nutritionists should formulate dairy diets to the maximum legally allowable Se concentration.

Requirements or AI for most minerals and vitamins are on a milligram, gram, or IU/day basis, not on a dietary concentration basis. However, expressing requirements on a concentration basis can be useful when evaluating diets if estimated dry matter intake is reasonable. Table 1 contains dietary concentrations of minerals that will meet the requirement or AI for an average Holstein cow producing about 80 lb/day of milk assuming the cow is eating about 54 lb of dry matter.

Calcium

Two major changes were made to Ca and they are related. In NRC (2001), endogenous fecal Ca (i.e., maintenance requirement) was a function of body weight; however, it should be a function of dry matter intake **(DMI)**. The more a cow eats, the greater the loss of endogenous fecal Ca should be, and the new maintenance requirement is estimated based on DMI. This will result in an increased maintenance requirement for high producing, high DMI cows. The second change was to the AC. The AC for Ca from all Ca supplements were reduced from a range of about 70 to 95% to 45 to 60%. The AC for Ca from basal feeds either were not changed or increased slightly. The net result is the dietary Ca concentrations to meet the requirements will need to be slightly higher than previously, and the less basal Ca in the diet, the greater the increase will need to be.

Electrolytes (Na, K, Cl)

A large database was assembled to estimate AC and endogenous fecal excretion for K, Na, and Cl. The AC for K and Na was set at 100% and 92% for Cl compared with 90% used for all three in NRC (2001). The maintenance requirements for electrolytes can include endogenous fecal and urinary excretion. Total maintenance requirements did not change greatly for K and are slightly greater for Na and Cl compared with NRC (2001). The greatest change was in the route of excretion (urinary or fecal), and the new equations better reflect measured excretion data. For example, very little Na is excreted in urine when cows are fed at requirements, whereas urinary K is quite high and the 2021 equations reflect those differences.

Conversely, using NRC (2001) equations, urinary Na was high, but K was low. Lactation requirements for Na and Cl were reduced substantially, reflecting the lower concentrations of those two minerals in milk produced today compared with milk produced 50 years ago (the source of data used in NRC, 2001). This is likely because mastitis is much less today than 50 years ago and cows with mastitis secrete milk with elevated Na and Cl concentrations. Overall, the change in maintenance and lactation requirements mostly cancel out and total requirements for Na, Cl, and K are about the same as in NRC (2001).

Sulfur

The S requirement did not change (0.2% of diet DM), but the discussion regarding S was substantially updated and expanded. Most of the discussion regards all the potential negative effects that are associated with feeding excess S. These include reduced absorption of Cu, Se, Mn, and maybe Zn. High S usually is associated with lower DCAD which can reduce DMI, milk, and milk fat. High S can reduce fiber digestibility and although unlikely with dairy cows, high S increases the risk for polioencephalomalacia. If the S concentration in water is high (generally greater than about 300 mg/L of sulfate-S), that should be included when determining whether S intake is great enough to cause problems.

Magnesium

The requirement for Mg changed the most of any micromineral. The amount of data available to estimate AC and requirements increased markedly after the NRC (2001) was published which allowed the committee to make several changes. First, maintenance (endogenous fecal Mg) is estimated from DMI, not body weight. This resulted in about a doubling of the absorbed maintenance requirement. The other big change was to the AC. In NRC (2001), the calculated AC for basal ingredients was about 30% but because of the high variability of that estimate, the committee reduced the AC by 1 standard deviation to 16%. Presumably the AC for Mg supplements were calculated using a basal AC of 16% rather than 30% and this resulted in overestimating the AC for the supplements. Using a larger database, the same AC was obtained for basal ingredients (30%) but rather than reducing that by 1 standard deviation, the committee incorporated an equation that reduced AC as dietary K increases. Dietary K is a major antagonist to Mg absorption and a major source of variation in the AC of Mg. Using 30% AC for basal ingredients (standardized to 1.2% K), magnesium oxide and magnesium sulfate have AC of 23 and 27% compared with 70 and 90% used by NRC (2001). The change in maintenance along with change in AC means that the dietary requirement for Mg is about 1.5 to 2 times greater than NRC (2001). The potential benefit of excess Mg during the prefresh period is not included in the requirement calculations (it is considered a response).

Cobalt

Different biomarkers can be used to assess adequacy of Co, including liver vitamin B-12 concentrations and serum concentrations of homocysteine. Experiments published since 2000 indicated that the NRC (2001) requirement of about 0.11 mg/kg of diet was not optimal for beef cattle based on common biomarkers. Based on that experiment, the AI for Co was about doubled to 0.2 mg/kg of diet DM. Measuring Co in feeds is difficult, but it is likely that many diets contain enough Co in basal ingredients to meet the AI.

Copper

Because of increasing concerns about Cu toxicity, Cu requirements underwent an especially rigorous review. Two major changes were made to requirement calculations. Inadequate data were available to calculate endogenous fecal excretion of Cu as a function of DMI and it remained a function of body weight. A study using isotopic Cu was used to develop a new equation to estimate absorbed maintenance requirement and it about doubled from NRC (2001). However, the value used to estimate endogenous fecal Cu affects calculation of the AC and the AC for Cu increased by 25%. The net effect was about a 60% increase in dietary maintenance requirement.This means that for growing heifers and dry cows, total dietary Cu requirement has increased about 50% compared with NRC (2001). The other substantial change was in the lactation requirement. The Cu concentration of milk used in NRC (2001) was 0.15 mg/kg, but a review of data published during the last 20 years found that milk averages only about 0.04 mg Cu/kg. The lactation requirement decreased by about 70%. For a Holstein cow producing about 80 lb/day of milk, the total requirement for dietary Cu is about the same as NRC (2001), but as production increases, the total requirement for dietary Cu calculated using NASEM (2021) will become less than that calculated by NRC (2001).

Manganese

A study with pregnant beef heifers (Hansen et al., 2006) demonstrated that the NRC (2001) Mn requirement was too low. Very little research is conducted on Mn with dairy cattle, so the committee set an AI rather than a requirement. Based on a single study published after NRC (2001), the NASEM (2021) increased the absorbed maintenance requirement by about 30%.

A study was also found that measured absorption of Mn by dairy cattle, resulting in a substantial lowering of its AC. The net result of these two changes was that dietary requirements for Mn are slightly more than twice as great as they were in NRC (2001).

Zinc

An equation was developed to estimate the maintenance requirement for absorbed Zn from DMI and the resulting values are greater than those calculated by NRC (2001). Other requirements (growth, lactation, and gestation) did not change. The AC for Zn were also modified using the new estimate for endogenous fecal losses. Overall, total dietary requirements for Zn will be 10 to 15% greater for heifers, dry cows, and lactating cows than NRC (2001) estimates.

Vitamin A

Inadequate data were available to estimate requirements; therefore, the committee established an AI for supplemental vitamin A. No new data were available to bring into question the requirement (i.e., 50 IU/lb of body weight) set in NRC (2001). However, the experiments used to generate that requirement were conducted long ago and maximum milk production was only about 75 lb/day. Milk contains about 450 IU of vitamin A (as retinol)/lb. The AI for vitamin A of 50 IU/lb of body weight was used for dry cows and cows producing less than 75 lb/day of milk and to cover the loss of vitamin A in milk, the AI is increased by 450 IU/day for every pound of milk produced that is greater than 75 lb. For example, a 1500 lb cow producing 70 lb/day of milk would have an AI of 1500 x 50 = 75,000 IU/day, but the same cow that produced 85 lb/day of milk would have an AI of 75,000 + ((85-75) x 450) = 79,500 IU/day.

Vitamin D

Because of limited data, supplemental vitamin D has an AI. Previously, the requirement for vitamin A was based almost exclusively on Ca metabolism; however, we now know that vitamin D is involved in a multitude of functions well beyond Ca metabolism. The AI for vitamin D for dry cows and heifers was not changed from NRC (2001) and remains at about 14 IU/lb of body weight. For lactating cows, the AI was based on how much vitamin D is needed to maintain the concentration of 25-OH vitamin D in the blood at 30 ng/ml or greater (Nelson et al., 2016). Based on that criteria, the AI for lactating cows was set at 18 IU/lb of body weight.

Vitamin E

The AI for supplemental vitamin E did not change for dry (0.7 IU/lb of body weight) or lactating cows (0.36 IU/lb of body weight). Based on experiments showing less mastitis and metritis with prefresh cows (approximatley the last 3 weeks of gestation) when additional vitamin E is fed, the AI for prefresh cows was set at 1.4 IU/lb of body weight (about 2000 IU/day). Because pasture is usually an excellent source of tocopherol, the AI for vitamin E is reduced when cows are grazing based on how much pasture is being consumed. If more than about 50% of the diet dry matter is from fresh green pasture, the AI for supplemental vitamin becomes essentially zero.

Conclusions

- Almost all calculations used to estimate dietary mineral and vitamin requirements and AI have been revised; however, total requirements for many of those nutrients did not change greatly.
- Requirements or AI for Mg, Mn, Cu, and Co changed the most from NRC (2001).
- The requirements (or AI) calculated by NASEM are for the average cow in a defined population. Safety factors are not included but often will need to be incorporated into diet formulation.
- Several factors affect requirements and absorption of minerals. Many of these are not included in the equations. Users are encouraged to read the text to determine how specific situations affect diet formulation for minerals.

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Table 1. Dietary concentrations (dry matter basis) of minerals and vitamin that should meet average requirements of a Holstein cow producing 80 lb/day of milk. Assumed dry matter intake is 54 lb/day.

Mineral	Concentrations to meet NASEM (2021)
Ca, %	0.57
P, %	0.32
Mg (1.2% K), %	0.16
Mg (2% K), %	0.20[1]
K, %	1.00
Na, %	0.20
Cl, %	0.28
S, %	0.20
Co, mg/kg	0.20
Cu (2 g/kg S and 1 mg/kg Mo), mg/kg	10
Cu (4 g/kg S and 5 mg/kg Mo), mg/kg	10[2]
Fe, mg/kg	16
I, mg/kg	0.4
Mn, mg/kg	27
Se, mg/kg	0.3
Zn, mg/kg	55
Vitamin A, IU/lb	1430
Vitamin D, IU/lb	500
Vitamin E, IU/lb	10

[1]The NASEM model reduces the absorption coefficient of Mg as dietary K increases.

[2]Although increased dietary (including water) S and Mo significantly reduces Cu absorption, inadequate data were available to include this effect in the NASEM equations. Users should read the text and make appropriate dietary adjustments for antagonism.