ABSTRACT

Requirements and factors that affect dietary requirements for several trace minerals and vitamins in ruminants are poorly defined. Most B vitamins and vitamin K are believed to be synthesized by bacteria in the rumen in adequate amounts to meet the requirement of the animal. Nonetheless, several studies indicate that supplementing high-producing dairy cows with approximately 20 mg/d of biotin can decrease hoof lesions and lameness and in many instances increase milk yield. In vivo synthesis of choline is also likely limiting milk production in early lactation. The vitamin E requirement for optimal immunity and health in receiving cattle and transition dairy cows continues to be an area of interest, with responses to supplementation varying. Requirements for vitamin D are being reevaluated in light of its potential effects on immunity. Studies clearly indicate that P requirements of cattle are less than those recommended 20 yr ago. Because of increased use of ethanol by-product feeds that are high in S, considerable research has been conducted to determine the effects of high dietary S (in feedstuffs and water) on performance and incidence of polioencephalomalacia. Requirements for certain microminerals are affected by antagonists. Sulfur and Mo are important Cu antagonists that can greatly affect dietary Cu bioavailability. High dietary Fe, when present in a bioavailable form, is a potent Cu and Mn antagonist. Recent research suggests that NRC recommendations for Co and Mn might underestimate requirements. An estimated requirement for Cr should be considered in the future based on responses to Cr supplementation in cattle.

Key words: beef cattle, dairy cattle, mineral, trace mineral, vitamin

INTRODUCTION

Minerals and vitamins are required for the normal functioning of essentially all metabolic processes in ruminants. Dietary deficiencies or excesses of certain minerals and vitamins can result in substantial economic losses in animal productivity. Vitamin and mineral requirements for beef and dairy cattle were last published by the NRC (2000, 2001). Since that time, considerable research has been published dealing with minerals and vitamins in cattle nutrition. This paper will not attempt to cover all minerals and vitamins but will focus on minerals and vitamins for which new information is available that could affect future published requirements or recommendations.

UPDATE ON MINERALS FOR RUMINANTS

Phosphorus has received the most attention of the macrominerals in regard to defining requirements. Limited research evaluating the requirements of other macrominerals has been published in the past 15 yr. The concentration of S in many cattle diets has increased in recent years as a result of increased use of by-product feeds that are high in S. High dietary S can decrease DMI and ADG and lead to polioencephalomalacia (PEM; NRC, 2005). Considerable research has been conducted to define upper levels of dietary S that can be tolerated by cattle without adversely affecting performance or health (Loneragan et al., 2001; Spears et al., 2011; Sarturi et al., 2013).

It is important to note that trace mineral requirements listed in the beef and dairy NRC publications are for total dietary concentrations (diet plus supplemental), not supplemental concentrations; however, requirements of some trace minerals can be affected by dietary antagonists, which could affect requirements. Recent literature with cattle related to responses to supplementation of control diets with chromium, cobalt, copper, manganese, and zinc will be covered in this paper.

Phosphorus

Based on new research findings, P requirements for lactating cows were
decreased considerably, whereas P requirements for dry cows and growing heifers were decreased slightly in the last dairy NRC (2001) compared with previous NRC editions. Phosphorus requirements (percentage of dietary DM) were approximately 0.36% during early lactation, 0.22% for dry cows, and 0.28% (6 mo old) to 0.18% (18 mo old) for growing heifers (NRC, 2001). Research findings published since 2001 suggest that P requirements listed in the dairy NRC are adequate to support normal growth, milk production, reproduction, and health.

Milk yield, measures of ovarian activity, and reproductive performance did not differ among Holstein cows fed 0.35 or 0.47% P from calving through 44 wk of lactation (Tallam et al., 2005). In a study conducted in the United Kingdom over 4 successive lactations, lactating dairy cows fed 0.36% total dietary P had similar feed intake, milk yield, milk composition, fertility, SCC, bone ash, and incidence of lameness and mastitis as cows receiving 0.42 (summer period) to 0.49% P (winter period; Ferris et al., 2010a,b). Plasma P concentrations were less and bone P concentrations were slightly less in cows fed 0.36% P. In a relatively short-term study, varying P from 0.34 to 0.43 or 0.52% P did not affect immune response of lactating dairy cows (Mullarky et al., 2009). Bone development in growing Holstein and Holstein × Jersey crossbred heifers did not differ among heifers fed 0.29 versus 0.39% P from 4 to 21 mo of age (Esser et al., 2009).

Studies with finishing cattle suggest that P requirements are less than those recommended in the beef NRC (2000). Erickson et al. (1999, 2002) reported no improvements in performance, carcass characteristics, or bone ash from P supplementation of finishing cattle fed diets containing 0.14 to 0.16% P. Experimental diets used in these studies were higher in fiber than diets typically used for finishing cattle in the United States. Phosphorus is known to function in acid–base balance, and studies are needed to determine the role of dietary P in controlling acidosis in cattle fed high-concentrate diets. The major route of P excretion changes from feces in ruminants fed high-fiber diets to the urine when high-concentrate diets are fed (Scott and Buchan, 1985). Reed et al. (1965) found a positive relationship between the P content and titratable acidity of urine in steers fed high-concentrate diets.

Phosphorus requirements of growing beef cattle and beef cows grazing pasture are not well defined, and responses to P supplementation have been variable (Karn, 2001). Ternouth et al. (1996) estimated P requirements of growing cattle in Australia grazing tropical pasture or being fed barley straw–based diets. In cattle gaining 1.0 kg/d, estimated P requirements decreased from 0.34% at 100 kg of BW to 0.18% at 400 kg BW. A series of long-term P supplementation studies under range conditions have been conducted at the USDA Northern Great Plains Research Laboratory in Mandan, North Dakota (Karn, 1995, 1997). In these studies, the P content of harvested roughages fed during the winter and pastures grazed during the growing season ranged from 0.10 to 0.24% P on a DM basis. In a 5-yr study, providing beef cows supplemental P (4 to 6 g/d) twice a week in a grain carrier increased calf weaning weights in 3 of the 5 yr (Karn, 1997). Phosphorus supplementation did not affect percentage of cows calving or average calving date. Weight gain of growing Hereford and Hereford × Angus replacement heifers was not affected by supplementing 4 to 6 g of P/d during a 462-d study (Karn, 1995). In a subsequent study with Herford × Simmental replacement heifers, P supplementation increased gain by approximately 0.04 kg/d (Karn, 1995).

Chromium

Chromium functions by potentiating the action of insulin in insulin-sensitive tissues. Studies showing improvements in immunity, glucose clearance, and milk production as a result of Cr supplementation of cattle diets were discussed in the last beef NRC (2000) and dairy NRC (2001); however, both publications indicated that information was not sufficient to estimate Cr requirements of cattle. Considerable research has been published with Cr in the past 12 yr that may allow NRC committees to estimate Cr requirements of beef and dairy cattle. The FDA issued a regulatory discretion letter in 2006, which permitted the use of Cr propionate as a source of supplemental Cr in cattle diets, at levels up to 0.5 mg of Cr/kg of DM.

Studies have indicated that Cr supplementation to diets of growing cattle (Sumner et al., 2007; Spears et al., 2012), dairy cows (Hayirli et al., 2001), and beef cows (Stahlhut et al., 2006a) can increase insulin sensitivity following i.v. glucose administration. A recent dose-titration study examined glucose and insulin metabolism in growing heifers supplemented with 0, 3, 6, or 9 mg of Cr/animal daily (Spears et al., 2012). These daily doses corresponded to 0 (control diet analyzed 0.20 mg of Cr/kg of DM), 0.47, 0.94, and 1.42 mg of supplemental Cr/kg of DM. All levels of supplemental Cr increased insulin sensitivity based on lower insulin concentrations and lower molar ratios of insulin to glucose following i.v. glucose administration. Results of this study indicated that Cr requirements of growing heifers, based on insulin sensitivity, can be met by supplementing 0.47 mg of Cr/kg of DM (Spears et al., 2012).

Responses to supplemental Cr might be greatest under conditions that decrease insulin sensitivity. It is well documented that insulin resistance occurs in late gestation and continues during early lactation in both dairy and beef cows (Sano et al., 1993). Several studies (Hayirli et al., 2001; McNamara and Valdez, 2005; Smith et al., 2005) have reported that Cr supplementation of dairy cow diets during late gestation and early lactation increased DMI and milk production during early lactation. Chromium supplementation has improved reproductive performance and decreased postpartum BW loss in young beef cows (Aragon et al., 2001; Stahlhut et
al., 2006b). Pregnancy rate in dairy cows has tended to be improved by Cr supplementation in some studies (Bryan et al., 2004; Soltan, 2010).

Hormones produced during stress can decrease insulin sensitivity and also increase urinary excretion of Cr in humans and rats (Spear and Trivedi, 2013). In dairy cows exposed to heat stress, Cr supplementation increased DMI and milk production (Al-Saiady et al., 2004; An Qiang et al., 2009; Soltan, 2010). Increased release of cortisol during stress is known to suppress a variety of immune responses, and Cr supplementation to diets of stressed cattle has decreased blood cortisol concentrations (Spear and Trivedi, 2013). Calves supplemented with 0, 0.1, 0.2, or 0.3 mg of Cr/kg of DM exhibited a linear improvement in ADG and G:F during a 56-d receiving period (Bernhard et al., 2012). Morbidity also tended to be decreased by Cr supplementation in this study. In addition, supplementing 0.2 mg of Cr/kg of DM decreased BW loss in steers following an i.v. lipopolysaccharide challenge (Bernhard et al., 2012).

**Cobalt**

Cobalt functions as a component of vitamin $B_{12}$. Ruminal microorganisms are capable of synthesizing vitamin $B_{12}$ from dietary Co. When dietary Co is adequate in the diet, ruminal synthesis of vitamin $B_{12}$ is generally sufficient to meet the requirement of the host animal. In the beef (NRC, 2000) and dairy NRC (2001) Co requirements were estimated at 0.10 and 0.11 mg/kg of DM, respectively. Considerable research has now been published indicating that previous recommendations for Co are probably too low. In Germany, long-term studies (Schwarz et al., 2000; Stangl et al., 2000) were conducted with Simmental males to define dietary Co requirements based on animal performance and vitamin $B_{12}$ concentrations in plasma and liver. In these studies, cattle were fed corn silage ad libitum and 2.5 kg/d of an energy-protein supplement for 280 d. Graded levels of Co were supplemented to the diet to provide total dietary Co concentrations ranging from 0.07 to 0.69 mg/kg of DM. Cattle fed the control diet (0.07 mg of Co/kg) had lower ADG, ADFI, and carcass weights at slaughter than animals supplemented with Co (Schwarz et al., 2000). Cobalt requirements, based on maximal plasma and liver vitamin $B_{12}$ concentrations, were estimated to be 0.26 and 0.24 mg/kg of DM, respectively (Stangl et al., 2000). Based on regression analysis, Co requirements were determined to be 0.12 mg/kg of DM for maximal BW gain and 0.16 to 0.18 mg/kg for maximal feed intake (Schwarz et al., 2000).

Two studies (Tiffany, 2003; Tiffany et al., 2003) have examined Co requirements of growing and finishing Angus and Angus-crossbred steers. Control diets in these studies analyzed 0.04 to 0.05 mg of Co/kg of DM, and Co was supplemented at concentrations of 0, 0.05, 0.10, and 1.0 mg/kg of DM. Performance was not affected by dietary Co during the growing phase in either study; however, plasma $B_{12}$ concentrations were greater in Co-supplemented cattle by d 56 of the growing phase. Cobalt supplementation to the control diet during the finishing phase increased ADG and ADFI in both studies. Feed intake was further increased when supplemental Co was increased from 0.10 to 1.0 mg/kg of DM in one study (Tiffany et al., 2003), but increasing supplemental Co above 0.05 (total diet Co of 0.10 mg/kg) did not significantly increase ADG in either study.

Plasma $B_{12}$ concentrations in plasma, liver, and ruminal fluid were greatly increased by supplemental Co in finishing cattle (Tiffany, 2003; Tiffany et al., 2003). Increasing supplemental Co from 0.10 to 1.0 mg/kg of DM also greatly increased plasma and ruminal fluid $B_{12}$ concentrations and moderately increased liver vitamin $B_{12}$. These results clearly indicate that increasing supplemental Co above 0.10 mg/kg (0.15 mg/kg of total Co) increases vitamin $B_{12}$ status in finishing cattle; however, the concentration of vitamin $B_{12}$ in plasma and liver required for normal metabolic processes has not been determined. Methylmalonyl CoA mutase is an important vitamin $B_{12}$ enzyme in ruminants that is involved in the metabolism of propionate to succinate, as it catalyzes the conversion of l-methylmalonyl CoA to succinyl CoA. If vitamin $B_{12}$ is deficient, methylmalonic acid (MMA) increases in plasma because of methylmalonyl CoA not being efficiently converted to succinyl CoA. Plasma MMA concentrations were elevated in steers fed the control diet containing 0.05 mg of Co/kg of DM (Tiffany, 2003). Cobalt supplementation decreased plasma MMA concentrations, and plasma MMA concentrations were decreased when supplemental Co was increased from 0.05 to 0.10 mg/kg of DM; however, increasing supplemental Co from 0.10 to 1.0 mg/kg did not further decrease plasma MMA concentrations. Collectively, these results suggest that the dietary Co (diet plus supplemental) requirement of finishing cattle fed corn-based diets is approximately 0.15 mg/kg of DM. Limited research indicates that finishing cattle fed barley-based diets might have a greater Co requirement than those fed corn-based diets (Tiffany and Spears, 2005).

Increasing dietary Co in lactating dairy cows fed control diets containing 0.19 (Kincaid and Socha, 2007), 0.37 (Kincaid et al., 2003), or 1.0 mg of Co/kg of DM (Akins et al., 2013) has not affected DMI, milk yield, milk composition, or plasma or serum vitamin $B_{12}$ concentrations. Cobalt supplementation has increased (Akins et al., 2013) or tended to increase colostrum and milk vitamin $B_{12}$ concentrations.

In addition to mammalian metabolism, Co also affects metabolism of certain ruminal microorganisms. In some bacteria, the pathway involved in the conversion of succinate to l-methylmalonyl CoA and then to propionate is the reverse of that found in the liver of ruminants and involves vitamin $B_{12}$-dependent methylmalonyl CoA mutase (Tiffany and Spears, 2005). Kennedy et al. (1991) showed that ruminal and plasma succinate
concentrations were greatly increased in lambs fed Co-deficient barley diets. Cobalt supplementation to corn- or barley-based diets that were low in Co increased molar proportion of propionate in ruminal fluid and decreased the acetate:propionate ratio in finishing steers (Tiffany et al., 2003; Tiffany and Spears, 2005).

**Copper**

It is well documented that Cu requirements of ruminants are greatly affected by dietary concentrations of Mo, S, and Fe. The beef NRC (2000) indicated that 10 mg of Cu/kg of DM should be adequate for beef cattle if their diets do not exceed 0.25% S and 2 mg of Mo/kg. In the dairy NRC (2001) Cu requirements were calculated assuming diets contained 0.25% S and 1 mg of Mo/kg. Estimated Cu requirements for dairy cattle were approximately 11, 12 to 18, and 10 mg/kg of DM for lactating cows, late gestation cows, and growing heifers, respectively.

Breed might also affect Cu requirements, as well as susceptibility to Cu toxicosis in cattle. Simmental and Charolais cattle seem to have a higher minimal Cu requirement than Angus cattle (Ward et al., 1995; Mullis et al., 2003). Recently, mRNA expression of transporters involved in Cu absorption in the duodenum were found to be lower in pregnant Simmental cows than in Angus cows (Fry et al., 2013). Jersey cows tended to have greater liver Cu concentrations than Holstein cows when Cu was supplemented to diets at high (80 mg/kg; Du et al., 1996) or moderately high concentrations (20 mg/kg; Sol Morales et al., 2000).

Milk yield, DMI, SCC, and plasma Cu concentrations were similar in lactating Holstein cows supplemented with 0 (control diet analyzed 8 mg of Cu/kg), 15, or 30 mg of Cu/kg during an 83-d study (Chase et al., 2000). Within each Cu treatment, cows in this study received 0 or 500 mg of supplemental Fe/kg of DM. High dietary Fe decreased liver Cu in control cows but had little effect on liver Cu concentrations in Cu-supplemented cows. Supplementing 10 or 40 mg of Cu/kg of DM to a control diet, containing 0.24% S, 8.9 mg of Cu, 1.1 mg of Mo, and 239 mg of Fe/kg of DM, also did not affect milk yield, DMI, SCC, or plasma Cu concentrations in lactating Holstein cows (Engle et al., 2001). Liver Cu concentrations did not change during the 61-d study in cows fed the control diet (374 on d 0 vs. 372 mg of Cu/kg of DM on d 61), suggesting that 8.9 mg of Cu/kg of DM was adequate to meet requirements.

Studies examining the effect of dietary Cu on immune responses in cattle have been reviewed (Weiss and Spears, 2006). Scalletti et al. (2003) evaluated the effect of dietary Cu on responses of Holstein heifers to an intramammary *Escherichia coli* challenge at 34 d of lactation. Heifers were fed a control diet (6.5 mg of Cu/kg) or the control diet supplemented with 20 mg of Cu/kg from 60 d prepartum through 42 d of lactation. Heifers supplemented with Cu had lower *E. coli* numbers and SCC in milk, lower clinical scores, and lower peak rectal temperatures than controls. Although the severity of *E. coli* infection was decreased by supplemental Cu, the duration of infection was not affected by Cu (Scalletti et al., 2003).

Mullis et al. (2003) estimated the Cu requirements of Angus and Simmental females fed corn silage–based diets. Based on a decline in liver Cu over time, a diet containing 0.26% S, 6.4 mg of Cu, and 1.2 mg of Mo/kg of DM did not meet the Cu requirements of growing Angus or Simmental heifers during a 160-d study. A diet containing 0.26% S, 4.4 mg of Cu, and 1.2 mg of Mo/kg of DM did not meet the Cu requirements of growing Angus or Simmental heifers during a 160-d study. A diet containing 0.26% S, 4.4 mg of Cu, and 1.2 mg of Mo/kg of DM did not meet the Cu requirements of growing and first-calf heifers of both breeds and resulted in increases in liver Cu. Based on plasma Cu concentrations (Mullis et al., 2003), Simmental females had a greater minimal Cu requirement than Angus females. Plasma Cu concentrations decreased in Simmental heifers fed the control diets over time to levels indicative of at least marginal Cu deficiency. In Angus heifers fed the control diets, plasma Cu concentrations remained within the normal range throughout the study. Copper supplementation to corn silage–based diets containing 5.2 (Ward and Spears, 1997) to 10.2 mg of Cu/kg of DM (Engle and Spears, 2000a, 2001; Engle et al., 2000b) did not affect performance of growing steers. Furthermore, liver Cu concentrations did not decrease from initial levels in growing steers fed control diets containing 5 to 8 mg of Cu/kg and 1.7 to 1.8 mg of Mo/kg also did not affect performance of growing and finishing male cattle intensively reared in Spain (Garcia-Vaquero et al., 2011).

Performance responses to Cu supplementation of corn-based finishing diets have been inconsistent. Copper supplementation (5 mg/kg of DM) increased ADG and G:F in steers fed a control diet containing 0.25% S, 2.9 mg of Cu, and 0.9 mg of Mo/kg of DM (Ward and Spears, 1997). Gain and DMI were also increased by Cu supplementation (20 mg/kg of DM) in finishing steers fed a control diet containing 0.28% S, 4.9 mg of Cu, and 0.6 mg of Mo/kg of DM (Engle et al., 2000b). In other studies, Cu supplementation to finishing diets containing 4.9 to 5.2 mg of Cu/kg has not affected performance (Engle and Spears, 2000b, 2001; Engle et al., 2000a) or decreased cattle performance (Engle and Spears, 2000a). Copper addition to finishing diets containing 2.9 to 5.2 mg of Cu/kg has decreased backfat without affecting marbling and increased PUFA concentrations in muscle in several studies with Angus and Angus-crossbred cattle (Engle, 2011). Dietary Cu did not affect backfat or PUFA in muscle of finishing Simmental steers (Engle and Spears, 2001).
Manganese

Results of studies published in the past 10 yr suggest that the current beef NRC (2000) Mn recommendation of 20 mg/kg of DM for growing and finishing cattle is adequate. Performance of growing and finishing male calves fed a corn silage-based diet, containing 20.9 mg of Mn/kg of DM, was not affected by Mn supplementation (Kirchgessner et al., 1997). Manganese supplementation to a control diet at 10, 20, 30, 120, or 240 mg/kg of DM resulted in a linear increase in liver and LM Mn concentrations but did not affect performance or carcass characteristics in growing and finishing cattle (Legleiter et al., 2005). The control diet used in this study contained 29 mg of Mn/kg of DM during the 84-d growing phase and 8 mg of Mn/kg of DM during the finishing phase, which averaged 112 d. Manganese addition to a control diet containing 16 mg of Mn/kg of DM did not affect gain or feed efficiency in growing beef heifers during a 196-d study (Hansen et al., 2006a).

Manganese requirements for reproduction seem to be higher than for growth. The beef NRC (2000) recommends 40 mg of Mn/kg for breeding cattle, whereas the dairy NRC (2001) recommends 16 to 18 mg of Mn/kg during gestation and 12 to 14 mg of Mn/kg of DM for lactating cows. Recent research indicates that the current dairy NRC (2001) underestimates Mn requirements for cows. Based on regression of digestible Mn on Mn intake, Weiss and Socha (2005) estimated maintenance requirements for Mn to be 49 and 28 mg/kg of DM, respectively, for dry and lactating dairy cows. The addition of 10 to 50 mg of Mn/kg to a control diet containing 16 mg of Mn/kg of DM did not affect age at conception or services to cows. The addition of 10 to 50 mg of Mn/kg to a control diet containing 16 mg of Mn/kg of DM was inadequate for proper fetal development. Calves born to control heifers were lighter at birth and had lower whole-blood Mn concentrations than calves from Mn-supplemented heifers. Approximately 50% of calves born to heifers fed the control diet (16 mg of Mn/kg of DM) exhibited clinical signs of Mn deficiency, including superior brachygnathism, unsteadiness, swollen joints, and disproportionate dwarfism (Hansen et al., 2006b).

High dietary Fe might increase Mn requirements. Manganese seems to use the same transporter (divalent metal transporter1) from the small intestine as Fe, and high dietary Fe (810 mg/kg of DM) decreased Mn concentrations in duodenal mucosal scrapings of calves (Hansen et al., 2010). Limited evidence also suggests that high dietary Ca and P might decrease Mn bioavailability (Spears, 2003).

Zinc

Based on the variable responses to Zn supplementation that have been observed, Zn requirements of cattle seem to be affected by dietary factors, but factors that affect Zn bioavailability are not well defined (Spears, 2003). Limited research suggests that growing heifers have a greater Zn requirement for growth than bulls and steers (Price and Humphries, 1980). The requirement for Zn was estimated at 30 mg/kg of DM in the last beef NRC (2000). Estimated Zn requirements for dairy cattle were approximately 52, 21, and 32 mg/kg of DM for lactating cows, late gestation cows, and growing heifers, respectively (NRC, 2001). Performance and morbidity of receiving cattle were not affected by Zn supplementation (360 mg of Zn/d) to a control diet containing approximately 25 mg of Zn/kg (Kegley et al., 2001). In a 35-d receiving study with heifers, supplementing 75 mg of Zn/kg to a control diet that analyzed 52.5 mg of Zn/kg of DM did not affect morbidity but tended (P = 0.11) to decrease ADG and decreased G:F (Nunnery et al., 2007).

Consistent with earlier studies (NRC, 2000), responses to Zn supplementation of growing and finishing cattle diets have also been variable in recent studies. The addition of 25 mg of Zn/kg to a corn silage-based diet containing 33 mg of Zn/kg of DM increased ADG of growing steers by 0.10 kg/d during an 84-d study (Spears and Kegley, 2002). In other studies with growing diets, Zn supplementation has not affected performance of cattle fed control diets containing 38 mg of Zn/kg of DM (Kessler et al., 2003), or 28 mg of Zn/kg of DM (Wright and Spears, 2004).

Performance did not differ among finishing steers supplemented with 20 (total dietary Zn of 90 mg/kg), 100, or 200 mg of Zn/kg of DM; however, fat thickness and yield grade increased quadratically with increased dietary Zn (Malcolm-Callis et al., 2000). Zinc supplementation (25 mg of Zn/kg) to a control diet containing 26 mg of Zn/kg of DM did not affect performance of finishing steers but increased quality grades slightly (Spears and Kegley, 2002). In contrast, carcass characteristics were not affected by dietary Zn in finishing heifers, but heifers fed the control diet (50.5 mg of Zn/kg) tended to gain less (P = 0.11) and have a lower (P = 0.06) G:F than those supplemented with 75 mg of Zn/kg of DM (Nunnery et al., 2007).

Increasing total dietary Zn from 41 to 63 mg/kg of DM did not affect milk yield, milk composition, milk Zn concentrations, or hoof hardness and locomotion scores of lactating dairy cows (Cope et al., 2009). Milk from cows fed the higher level of Zn had lower SCC and lower concentrations of amyloid A, an acute-phase protein, than cows fed 41 mg of Zn/kg of DM.
The lower SCC and milk amyloid A concentrations suggest improved under health in cows receiving 63 mg of Zn/kg of DM.

**UPDATE ON VITAMINS FOR RUMINANTS**

Responses to supplemental vitamins by ruminants include improved immune function, fewer clinical health problems, increased productivity, and changes in meat characteristics. Responses vary depending on the vitamin, dose, and species or type of animal supplemented. Not all the 14 recognized vitamins (for this review, choline is considered a vitamin) have been shown to elicit whole-animal responses (e.g., health or production measures) when supplemented to ruminants. Therefore, discussion will be limited to vitamins A, D, E, and B<sub>12</sub>, biotin, choline, niacin, and thiamine because sufficient newer (1998 to 2013) whole-animal data are available to reach conclusions regarding field application.

**Vitamin A**

The beef NRC (2000) recommendations (IU/kg of DMI) for vitamin A are 2,200, 2,800, and 3,900 IU/kg of DMI for growing or finishing animals, gestating animals, and lactating cows or breeding bulls, respectively. Based on a survey of nutritionists, finishing beef cattle are commonly supplemented with vitamin A at almost twice NRC recommendations (Vasconcelos and Galyean, 2007). Feeding supplemental vitamin A to finishing steers at up to 4 times NRC recommendations did not enhance production or carcass measurements (Bryant et al., 2010). Indeed, some negative effects were observed when diets contained 2 to 4 times the recommended amount of vitamin A. In addition, the concentration of α-tocopherol in liver was inversely related with rate of vitamin A supplementation, indicating the possibility of a secondary vitamin E deficiency when excess vitamin A was fed. Some (Gorocica-Buenfil et al., 2007; Pickworth et al., 2012; Ward et al., 2012), but not all (Gorocica-Buenfil et al., 2008; Bryant et al., 2010), studies have reported improved marbling and quality grade when feedlot cattle were fed no supplemental vitamin A during the finishing phase compared with cattle fed at approximately NRC recommended levels. No negative effects on growth or efficiency were associated with feeding diets devoid of supplemental vitamin A in any of the studies cited above. Current data indicate no advantage to feeding greater than NRC recommendations for vitamin A to finishing cattle. Indeed current data suggests that vitamin A supplementation rates for feedlot cattle could be decreased.

The current vitamin A requirement for lactating cows is 110 IU/kg of BW (NRC, 2001). That recommendation is based mostly on animal health and immune function data. Newer data (LeBlanc et al., 2004; Bertoni et al., 2008) supported the link between fewer health problems and enhanced vitamin A status but did not show that higher rates of supplementation were necessary to achieve good vitamin A status. The commonly observed decrease in plasma retinol concentrations that occurs around calving was eliminated by supplementing dry cows with 880 IU/kg of BW of vitamin A (Puvogel et al., 2005) or by feeding 300 mg/d of β-carotene (Chawla and Kaur, 2004); however, the effect of those treatments on cow health was not determined because of insufficient animal numbers. Nonetheless, the very high supplementation rate of vitamin A (Puvogel et al., 2005) decreased milk yield during the first 100 DIM. The current NRC (2001) recommendation seems adequate for health and milk production, although because of potential losses of potency during storage (Shurson et al., 2011), including a modest safety factor is recommended.

**Vitamin D**

The NRC beef requirement for vitamin D is about 300 IU/kg of DMI, but beef animals are usually housed outside, with sun exposure making the need for supplementation rare. The only recent research on vitamin D for beef is the use of very high supplementation rates (≥1 million IU/d) for approximately the last week of the finishing period to improve the tenderness of the beef. This protocol usually decreases short-term growth rates, feed intake, or feed efficiency (Karges et al., 2001; Reiling and Johnson, 2003; Montgomery et al., 2004a). That vitamin D protocol has improved tenderness of beef cuts in some studies (Karges et al., 2001; Montgomery et al., 2004b) but not in others (Scanga et al., 2001; Reiling and Johnson, 2003). The inconsistency of improved tenderness linked with the consistent negative production effects will likely limit application of this protocol.

For dry and lactating dairy cows, the vitamin D requirement is 30 IU/kg of BW, which was based almost entirely on the amount needed to maintain calcium status. New data mostly from nonruminant studies have shown that vitamin D has a plethora of effects other than calcium homeostasis, including profound effects on immune cell function. Studies that evaluate the effects of supplementing dairy cows with vitamin D on health problems (other than hypocalcemia) are lacking, but linkages between vitamin D and bovine immunity have been shown (Nelson et al., 2010). In addition, infusing 25-OH vitamin D into mammary gland quarters that were infected with Streptococcus uberis significantly decreased the severity of mastitis (Lippolis et al., 2011). In humans, low concentrations of plasma 25-OH vitamin D is a risk factor for several health problems (Christakos and DeLuca, 2011), and similar data are being generated with cattle. Dairy cows that were seropositive for Mycobacteria antibodies had reduced concentrations of plasma 25-OH vitamin D than cows that were seronegative (Sorge et al., 2013). Plasma concentrations of 25-OH vitamin D in dairy cows supplemented with NRC levels of vitamin D and housed with limited access to sunlight were significantly lower than concentrations found in
cows with full exposure to sunlight (Hymøller et al., 2009). This finding might mean that the current recommendation does not result in maximal vitamin D status, but the ideal or optimal concentration of 25-OH in bovine plasma has not been determined. A few older studies (conducted in the 1970s and early 1980s; see NRC, 2001, for references) reported that feeding vitamin D at approximately 2 times the current recommendation increased milk yields. Thus, the vitamin D requirements need to be reevaluated in light of its effects on milk yields, immune function, and mastitis.

**Vitamin E**

The beef NRC (2000) suggested that most beef cattle require little or no supplemental vitamin E to maintain good health and productivity. Production and reproductive studies published since the last beef NRC (2000) have generally found no benefit of increased vitamin E supplementation (Cusack et al., 2005; Horn et al., 2010a,b; Burken et al., 2012). Immune function of feedlot cattle has been enhanced with supplemental vitamin E, but effects on morbidity and clinical health measurements have been small to nonexistent (Rivera et al., 2002; Cusack et al., 2005, 2009). In those studies, the supplementation rate usually ranged from about 300 to 1,000 IU/animal daily. Supplementing approximately 500 IU of vitamin E during the last several weeks of the finishing phase can increase color stability in beef cuts, which might become more important when animals are fed diets with high concentrations of PUFA, such as those with high inclusion rates of distillers grains (Burken et al., 2012).

The dairy NRC (2001) requirement for supplemental vitamin E is approximately 500 IU/d for lactating cows and 1,000 IU/d for dry cows. These recommendations were based on health and immune function. Results of newer studies support the concept that enhanced vitamin-E status decreases retained fetal membranes and improves mammary gland health in both dairy cows and dairy ewes (Morgante et al., 1999; LeBlanc et al., 2004; Rezamand et al., 2007; Politis et al., 2012). In addition, low concentrations of plasma tocopherol have been found to be a risk factor for displaced abomasum (Qu et al., 2013); however, these studies do not provide support for increasing the vitamin E requirement for most types of dairy cows. On the other hand, results of several studies have indicated that supplementing 2,000 to 4,000 IU/d of vitamin E during the peripartum period (2 to 3 wk before calving) improves health compared with the current NRC recommendation of 1,000 IU/d (Weiss et al., 1997; Baldi et al., 2000; Politis et al., 2004). Longer-term (60 d) supplementation of vitamin E of 3,000 IU/d to dry cows (3 times the current recommendation) was found to increase clinical mastitis on commercial farms, and the authors suggested that high plasma concentrations of tocopherol might be a risk factor (Bouwstra et al., 2010a,b). Newer research findings contradict the link between high plasma tocopherol and increased mastitis (Politis et al., 2012), but these data show no benefit and perhaps a negative effect of feeding more than NRC requirement for most of the dry period.

**Biotin**

Neither the beef (NRC, 2000) nor dairy NRC (2001) established a requirement for biotin; however, the vast majority of data support supplementing cattle with biotin. Clinical studies with beef (cows and growing) cattle, sheep, and dairy cattle report improved hoof health when animals were fed 10 to 20 mg of biotin/d (3 to 5 mg/d for sheep) for several weeks or months (Mida et al., 1998; Campbell et al., 2000; Fitzgerald et al., 2000; Hedges et al., 2001; Bergsten et al., 2003; Pöttsch et al., 2003; Higuchi et al., 2004; Bampidis et al., 2007; da Silva et al., 2010). Milk yield also usually increases with biotin supplementation (Lean and Rabiee, 2011), which is likely a metabolic response and not caused by improved hoof health.

**Choline**

The NRC requirements have not been established for choline, but more recent studies have reported increased ADG and improved feed efficiency with beef cattle and sheep (Bryant et al., 1999; Bindel et al., 2000) and increased milk yield in early lactation dairy cows (Sales et al., 2010) when rumen-protected choline was fed. Because of almost complete ruminal degradation, choline must be rumen protected to elicit responses. Supplementation rates were approximately 5 and 15 g/d of actual choline for beef and dairy cattle, respectively. In addition to production responses, supplemental rumen-protected choline (approximately 15 g/d of actual choline) during the peripartum period might help prevent or decrease the severity of fatty liver and fatty liver–associated ketosis (Cooke et al., 2007; Zom et al., 2011). The use of choline to elicit production responses should be based on potential rate of return, and often, at least for dairy cows, the response is profitable. The cost of ketosis is difficult to quantify because it is related to so many other health problems (e.g., mastitis and displaced abomasum), but decreasing its prevalence could be quite profitable.

**Other B Vitamins**

Although some positive milk production responses have been reported when vitamin B<sub>12</sub> is supplemented or injected (Girard and Matte, 2005), most studies report no or very limited increases (Preynat et al., 2009, 2010; Akins et al., 2013). No new data on vitamin B<sub>12</sub> for beef cattle were found. Based on the inconsistency of response, routine supplementation of vitamin B<sub>12</sub> is not warranted, but adequate cobalt must be fed. Niacin supplementation is not normally practiced in the beef industry but is common for dairy cows. Milk and milk-component yields have been increased markedly by niacin supplementation.
in some individual studies (e.g., +2.1 kg/d of FCM; Drackley et al., 1998), but just as commonly, niacin has no effect on production (Minor et al., 1998). A meta-analysis determined that on average, supplementing 12 g of niacin daily increases milk protein yield (Schwab et al., 2005). Early lactation cows are more likely to respond (Girard, 1998), but specific dietary conditions that increase the likelihood of a positive response have not been identified. Rumen degradation of supplemental niacin seems to be >90% (Santschi et al., 2005), which has led to the development and commercialization of rumen-protected niacin. Milk production responses to rumen-protected niacin have been small (Yuan et al., 2011, 2012; Zimbelman et al., 2013), but it might help decrease heat stress (Zimbelman et al., 2013).

Thiamine supplementation is not common for dairy cows and has not been studied extensively; however, with the increased use of distillers grains in beef feedlot diets, supplementation is becoming more common for those animals. High concentrations of dietary S are a risk factor for PEM, and some distillers grains have very high concentrations of S. Injecting a large amount of thiamine is standard therapy for animals suffering from PEM. Feeding supplemental thiamine at approximately 120 mg/kg of DMI to cattle consuming water with 1,000 mg/L of sulfate-S (Ward and Patterson, 2004) or feeding 240 mg of thiamine/kg of diet DM to sheep fed a diet with about 0.6% S (Olkowski et al., 1992) significantly decreased the incidence of PEM. In the cattle study (Ward and Patterson, 2004), consumption of the high-sulfate water was approximately equivalent to feeding a diet with 0.5% added S. In a recent study (Neville et al., 2010) with sheep fed diets with 60% distillers grains and 0.7% S in the total diet DM, supplemental thiamine (up to 150 mg/d) had minimal effects on growth and feed efficiency. The prophylactic effects of thiamine (if any) could not be evaluated because no cases of PEM were observed with any of the diets.

**IMPLICATIONS**

Meeting mineral and vitamin requirements is critical for optimizing production and health in beef and dairy cattle. Recommended requirements for minerals and vitamins were last set by the NRC for beef cattle and dairy cattle in 2000 and 2001, respectively. Mineral and vitamin recommendations may change as new research enhances our understanding of mineral and vitamin needs. Supplemental biotin has consistently improved hoof health in cattle, and providing rumen-protected choline has increased milk production in dairy cows. Chromium supplementation has enhanced insulin sensitivity in cattle and resulted in improved production and health in some studies. Estimating requirements for biotin, choline, and Cr should be considered by future NRC committees. Vitamin D requirements should be reevaluated based on its potential effects on immunity. Current recommendations appear to overestimate P requirements of beef finishing cattle. Recent research suggests that NRC recommendations for Co and Mn may underestimate requirements.

**LITERATURE CITED**


