Update on Vitamin Nutrition of Dairy Cows[1]

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Vitamins are organic compounds needed in minute amounts that are essential for life and must be absorbed from the gastro-intestinal tract. Either the vitamin must be in the diet (dietary essential) or be synthesized by microorganisms in the digestive system and absorbed by the host animal. Currently there are 14 recognized vitamins but not all animals require all 14 vitamins (Table 1). When an animal absorbs an inadequate quantity of a particular vitamin, various responses are observed depending on the vitamin and the degree and duration of deficiency. The most severe situation (seldom observed in the U.S. dairy herd) is a clinical deficiency. For example, rickets and scurvy result from a clinical deficiency of vitamin D and vitamin C, respectively. Marginal deficiencies of vitamins usually have more subtle and less defined signs. Unthriftiness, reduced growth rate, milk production, or fertility, and increased prevalence of infectious diseases can be observed when animals absorb inadequate amounts of vitamins.

Of the 14 known vitamins, only two (vitamins A and E) have absolute dietary requirements for dairy cows. Those two vitamins (or their precursors) must be in the diet or cows will become clinically deficient. Adequate vitamin D can be synthesized by skin cells when they are exposed to enough sunlight. The liver and kidney of the cow can synthesize vitamin C. Ruminal and intestinal bacteria synthesize most, if not all, of the B-vitamins and vitamin K, and under most situations cows probably do not need to consume those vitamins to prevent clinical deficiency.

The purpose of this paper is to discuss recent (last 10 years) research on vitamin nutrition of dairy cows. If recent data with ruminants are lacking, the vitamin is not discussed.

Background and What's New in Vitamins

Vitamin A and B-carotene

The current NRC (2001) requirement for **supplemental** vitamin A is 50 IU/lb of body weight (BW) or about 70,000 to 77,000 IU/day for an adult cow. B-carotene can be converted into vitamin A but also has biological effects independent of vitamin A. A separate requirement for B-carotene has not been established. Limited data show that vitamin A or B-carotene supplementation of dairy cows may improve mammary gland host defense (i.e., immune function) and may have some positive effects on mammary gland health (Michal et al., 1994). Some epidemiological data also suggest a link between vitamin A and mastitis (LeBlanc et al., 2004). However (and this is important), there are no data showing that supplementation of vitamin A at rates above the current NRC requirement has any positive effect on mammary gland

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health or reproductive efficiency; a possible exception is increased ovulation rate when cows are superovulated (Shaw et al., 1995).

Table 1. Compounds currently recognized as vitamins.

	General function
Fat-soluble vitamins	
Vitamin A	Gene regulation, immunity, vision
Vitamin D	Ca and P metabolism, gene regulation
Vitamin E	Antioxidant
Vitamin K	Blood clotting
Water-soluble vitamins	
Biotin	Carbohydrate, fat, and protein metabolism
Choline	Fat metabolism and transport
Folacin (folic acid)	Nucleic and amino acid metabolism
Niacin	Energy metabolism
Pantothenic acid	Carbohydrate and fat metabolism
Riboflavin	Energy metabolism
Thiamin	Carbohydrate and protein metabolism
Pyridoxine (vitamin B6)	Amino acid metabolism
Vitamin B12	Nucleic and amino acid metabolism
Vitamin C	Antioxidant, amino acid metabolism

Vitamin E

The current requirement for supplemental vitamin E is about 0.3 IU/lb of BW for a lactating cow and 0.7 IU/lb BW for a dry cow. This is equivalent to approximately 500 and 1000 IU/day for lactating and dry cows. Fresh pasture usually contains very high concentrations of vitamin E, and little or no supplemental vitamin E is needed by grazing dairy cows. Although the 2001 requirement was increased substantially compared with the 1989 NRC, newer data suggest that higher supplementation rates may be warranted in some situations. Cows fed 4000 IU of supplemental vitamin E per day during the last 2 weeks before calving and 2000 IU/day during the first week of lactation had significantly reduced mammary gland infections and clinical mastitis compared with feeding 1000 and 500 IU/day during the dry and early lactation period (Weiss et al., 1997; Figure 1). In that study cows were fed diets with only 0.1 ppm of supplemental selenium and that might have affected the response (i.e., a smaller response to vitamin E may have been observed if 0.3 ppm of Se was fed). A study from Italy (Baldi et al., 2000) found that cows fed 2000 IU/d of supplemental vitamin E from 2 weeks before until 1 week after calving had significantly lower SCC at 7 and 14 days in milk compared with cows fed 1000 IU/d of vitamin E. They also reported fewer services per conception for cows fed the higher amount of vitamin E but the number of cows in that study was low and treatment effects on reproductive measures may not be accurate. In two large field studies (Erskine et al., 1997; LeBlanc et al., 2002), injected vitamin E (3000 IU at either 14 or 7 d prepartum) reduced prevalence of retained fetal membranes. Responses were generally more positive for heifers than for cows possibly because heifers were in lower initial vitamin E status than cows.

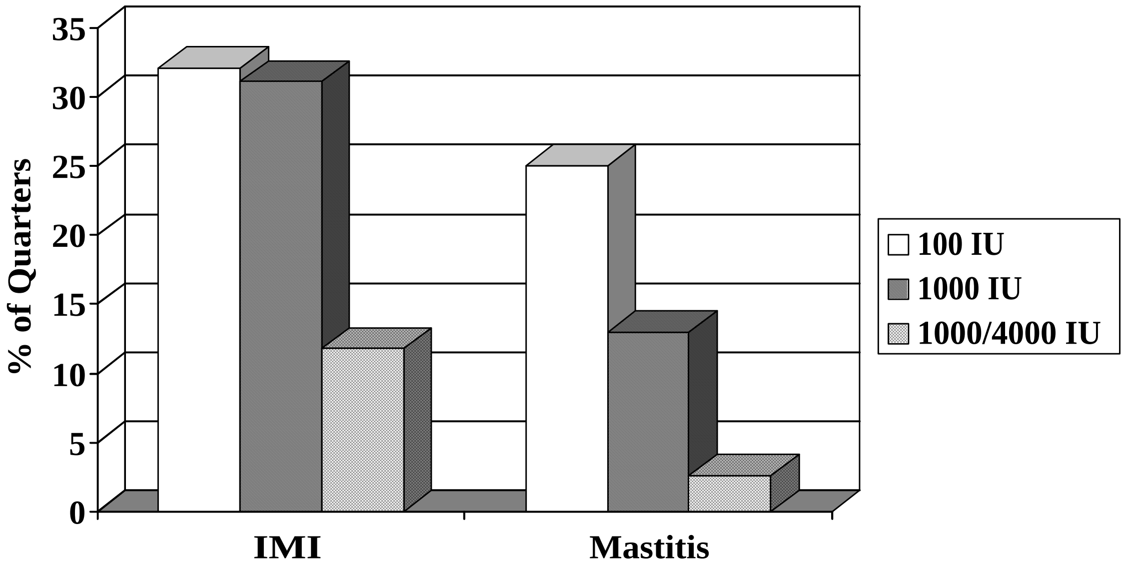

Figure 1. Effect of feeding different amounts of supplemental vitamin E during the dry period (100 or 1000 IU/day for 60 days or 1000 IU/d for 46 days and 4000 IU/day for the last 14 days of the dry period) on intramammary infections (IMI) and clinical mastitis (Weiss et al., 1997).

Biotin

A dietary biotin requirement has not been established for dairy cows (or any other ruminant). Most concentrate feeds contain <0.1 mg of biotin/lb of DM. Less is known about biotin concentrations in forages. Data from a very limited number of studies suggest that typical diets fed to lactating dairy cows contain between 0.1 and 0.2 mg of biotin/lb of DM (based on typical dry matter intakes this equals 4 to 10 mg of biotin/day). Limited in vivo data generally shows a small net increase (~1 mg) in flow of biotin out of the rumen compared with biotin intake.

Numerous clinical trials have been conducted to examine the effect of supplemental biotin on hoof horn lesions and lameness in dairy cows (Table 2). Although the response variable varied among experiments, all studies reported reduced prevalence of specific lesions or clinical lameness when biotin was supplemented. The supplementation rate was 20 mg/d in most studies but one study with beef cows fed only 10 mg/d and reported a positive response. All studies involved long term (months) supplementation. Potzsch et al. (2003) reported that 6 months was required for biotin to reduce the risk of lameness caused by white line disease in lactating cows. Midla et al. (1998), however, reported a significant reduction in white line separation after approximately 3 months of supplementation. Potzsch et al. measured lameness but Midla et al. measured lesions which could be the reason for the difference in the length of time required to see a response.

Table 2. Summary of controlled, published research on effect of biotin supplementation on hoof lesions and lameness in dairy cows.

Treatment	Design	Results	Ref.
0 or 20 mg biotin/d from calving until 300 DIM	Field trial, 1 pen of 1st lactation Holstein cows per treatment	Treatment reduced prevalence of while line separation at 100 DIM	1
0 or 10 mg biotin/d for 18 months	Field trial, 1 group of 1 and 2 yr old beef heifers per treatment	Treatment reduced prevlence of vertical fissures on claw wall	2
0 or 20 mg biotin/d for 13 months	Field trial, 10 farms per treatment (lactating Holstein cows)	Treatment improved locomotion score and reduced prevalence of clinical lameness	3
0 or 20 mg/d for 18 months	Field trial, 1 group of lactating Holstein cows per treatment on 5 farms	Treatment reduced prevalence of white line separation	4
0 or 40 mg/d for 50 d	Controlled study, 12 nonlactating dairy cows per treatment	Treatment improved healing of sole ulcers	5
0 or 20 mg/d for 14 months	Field trial, supplement fed via computer, lactating Holstein cows	Treatment reduced prevalence of sole hemorrhages	6

[1] Citations are: 1) Midla et al., 1998; 2) Campbell et al., 2000; 3) Fitzgerald et al., 2000; 4) Hedges et al., 2001; 5) Lischer et al., 2002; 6) Bersten et al., 2003.

Six studies have been conducted that measured milk production responses to biotin supplementation (Table 3). The most common treatments were control (no supplementation) and 20 mg of supplemental biotin per day. In studies with higher producing cows (>75 lbs/day) supplementation increased milk production 2 to 7 lbs/day in four studies (average response = 3.4 lbs/day), but no response was observed in one study. In a study with lower producing cows (<45 lbs/d) biotin supplementation had no effect. Available data suggest that an additional response with supplementation rates greater than about 20 mg/d is unlikely. Milk production response appears to occur shortly after supplementation begins.

Table 3. Summary of experiments on effects of biotin supplementation on milk yield.

Treatment	Design	Results	Ref.
0 or 20 mg biotin/d from calving until 300 DIM	Field trial, 1 pen of 1st lactation Holstein cows per treatment	Treatment increased 305 d ME by 682 lbs ($P < 0.05$). Control ME = 25,900 lbs.	1
0 or 20 mg biotin/d for 13 months	Field trial, 10 farms per treatment (lactating Holstein cows)	No effect on milk yield. Yields were 42 lbs/d for control and 40 lbs/d for treatment.	2
0 or 20 mg/d for 14 months	Field trial, supplement fed via computer, lactating Holstein cows	Treatment increased 305 d milk by 1058 lbs. ($P < 0.05$). Control milk = 22,200 lbs	3
0, 10, or 20 mg/d from 14 d before through 100 days after calving	Controlled study, 15 Holstein cows/ trt, first 100 d of lactation	Linear ($P<0.05$) effect. 81, 83, and 87 lbs/d for 0, 10, and 20 mg	4
0 or 20 mg/d for 28 d periods	Latin square, 24 observations per treatment, early lactation Holstein cows	Treatment increased milk 2.2 lbs/d ($P < 0.05$). Control milk = 82 lbs/day.	5
20 or 40 mg/d for 28 d periods	Latin square, 24 obs. per treatment, early lactation Holstein cows	No difference in milk production between treatments. Average production = 90 lbs/d	5
0 or 30 mg/d from calving until 70 days in milk	Controlled study, 18 and 20 cows/trt	No difference in 4% fat-corrected milk (77 vs. 76 lbs)	6

[1] Citations are: 1) Midla et al., 1998; 2) Fitzgerald et al., 2000; 3) Bersten et al., 2003; 4) Zimmerly and Weiss, 2001; 5) Majee et al., 2003; 6) Rosendo et al., 2004.

Niacin

No requirement for dairy cows has been established for niacin, but niacin is involved in most energy-yielding pathways and for amino acid and fatty acid synthesis and therefore is important for milk production. Niacin has also been evaluated for possible prophylactic and therapeutic effects on ketosis and fatty liver syndrome. Although a few studies reported that niacin supplementation during the periparturient period (usually 6 to 12 g/day) reduced blood ketones and plasma nonesterified fatty acids (NEFA), the vast majority of studies show no effect (see page 171 of NRC, 2001 for listing of the studies).

The NRC (2001) also summarized experiments that measured milk yield responses to supplemental niacin (supplementation rates were usually 6 to 12 g/day). Of the 30 studies examined only one reported a statistically significant ($P < 0.05$) increase in milk production and

29 reported no statistical effect. Since the NRC was published two additional studies were published and one (Drackley et al., 1998) reported an increase in milk yield and one (Minor et al., 1998) reported no effect. Although most studies report no statistical effect on milk production with niacin supplementation the average numerical increase in milk yield is about 1 lb/day when niacin is supplemented. In another review of niacin (Girard, 1998) experiments were classified on stage of lactation (Table 4). In about 60% of the studies with early lactation cows, niacin increased or tended to increase milk yield (average response was 6% or 3 to 5 lbs/day). In mid and lactation cows, niacin supplementation usually did not affect production. Based on this, niacin supplementation would likely be profitable if limited to early lactation cows, but return on investment would decrease markedly if niacin was supplemented to the entire herd.

Table 4. Summary of studies evaluating milk yield responses to supplemental niacin. Niacin was usually fed at about 6 g/day (Girard, 1998).

	No. of studies	Mean increase	Range in responses
Early lactation cows			
Significant increase	3	6.7%	4 to 10%
Increase trend	5	6.3%	3 to 9%
No effect	5	0%	. . .
All studies	13	4%	. . .
Midlactation cows			
Significant increase	3	3.9%	2 to 7%
No effect	7	0	. . .
All studies	10	1.2%	. . .
Late lactation cows			
No effect	2	0	. . .

Other B-vitamins

Research is extremely limited on the effects of supplementing B-vitamins other than biotin and niacin to dairy cows. Milk production was increased when cows were fed a mixture of B-vitamins (biotin, folic acid, niacin, pantothenic acid, B-6, riboflavin, thiamin, and B-12) compared with cows not fed supplemental B-vitamins but was not different from a treatment in which only biotin was supplemented (Majee et al., 2003). When the amount of supplemental B-vitamins was doubled, intake and milk production was similar to control cows (i.e., lower than the 1-X supplementation treatment). In three experiments, Shaver et al. (2000) examined the effects of supplemental thiamin on milk production. In one experiment, yield of milk, milk fat, and milk protein increased when cows were fed 150 mg of thiamin per day. In two other experiments, cows fed thiamin at 300 mg/day had similar milk yields as control cows. Milk yield by multiparous cows increased linearly as supplemental folic acid was increased from 0 to 1.2 or 2.4 g/day, but no response was observed with first lactation animals (Girard and Matte, 1998). Responses to folic acid may be caused by increased methionine status. Injections of riboflavin (2.5 mg/kg of BW) improved neutrophil function and reduced SCC in cows with intramammary infections of *Staphylococcus aureus* but did not affect cure rates (Sato et al., 1999). At this time data do not support routine supplementation of ‘other’ B-vitamins. However, as productivity of cows continues to increase and as new experiments are conducted, this conclusion may change.

Choline

Choline does not fit the definition of a vitamin. It is required in gram quantities (not milligram or microgram quantities) and it is synthesized by the cow. Very little, if any, dietary choline (with the exception of rumen-protected supplements) is absorbed from the gut because it is degraded in the rumen. Milk yield responses to supplemental choline (either fed in a rumen-protected form or infused post-ruminally) are inconsistent with about 50% of the studies reporting a positive response and 50% reporting no effect (Donkin, 2002). Supplemental choline during the transition period may reduce liver fat but results have not been consistent. Rumen-protected choline may have a greater effect on liver fat in over-conditioned cows (BCS > 3.75). Because choline can be synthesized from methionine, diets that provide marginal amounts of metabolizable methionine may be more likely to respond to choline supplementation.

Vitamin C

Vitamin C also is not considered a vitamin for dairy cows because the cow can synthesize ascorbic acid. Vitamin C is probably the most important water soluble antioxidant in mammals. Most forms of vitamin C are extensively degraded in the rumen, therefore the cow must rely on tissue synthesis. The concentration of ascorbic acid is high in neutrophils and increases as much as 30-fold when the neutrophil is stimulated. Santos et al. (2001) reported that plasma ascorbic acid concentrations in dairy cows were not correlated with SCC, however, the range in SCC was limited (67,000 to 158,000/ml) and cows were only sampled once. Injecting cows that received an intramammary challenge of endotoxin with vitamin C (25 g IV at 3 and 5 hours post challenge) had limited positive effects on clinical signs (Chaiyotwittayakun et al., 2002). We recently conducted an experiment to examine changes in ascorbic acid status following an intramammary challenge with *E. coli* (Weiss et al., 2004). Large decreases in vitamin C status were statistically related to longer duration of clinical mastitis and larger decreases in milk production following challenge were associated with larger decreases in vitamin C status (Figure 2). Data from this experiment does not mean that increasing vitamin C status of cows will reduce the prevalence or severity of mastitis. We do not know whether lower vitamin C status allowed severity of mastitis to increase or whether increased severity depleted body vitamin C. More data are needed before the use of vitamin C to prevent or help cure mastitis can be recommended.

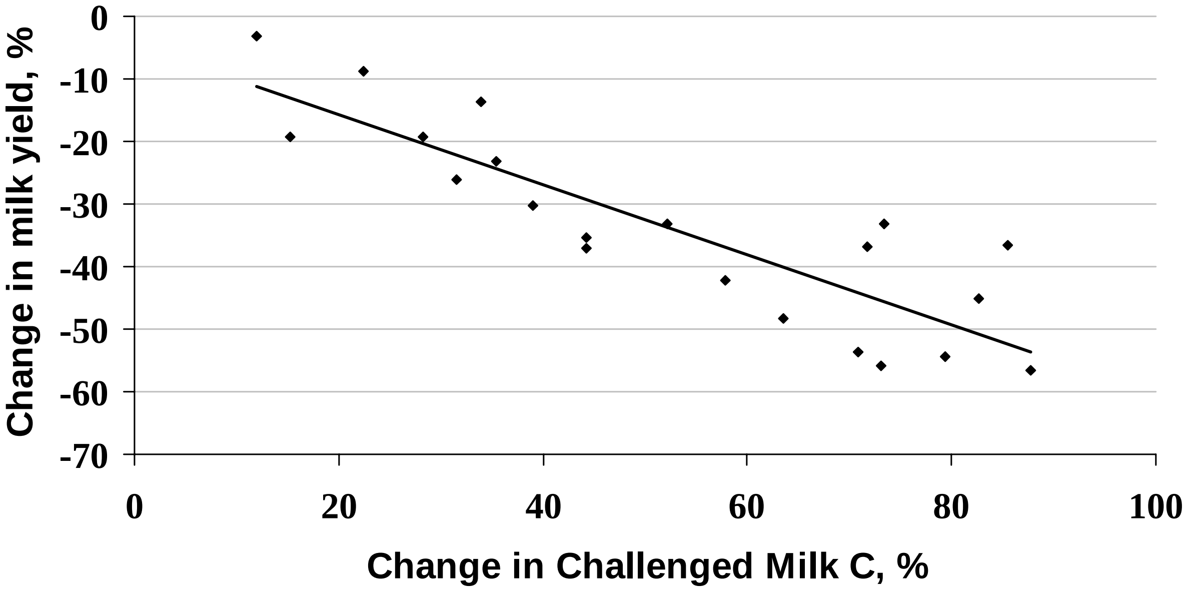

Figure 2. Relationship between the decrease in milk vitamin C (concentration at 24 h post challenge compared with concentration prechallenge) and decrease in milk production caused by an intramammary challenge with E. coli (Weiss et al., 2004).

Recommendations

Although the word, 'requirement', was used liberally in the above discussion, that word implies a much greater knowledge base regarding vitamin nutrition than is actually available. We know very little regarding vitamin flow out of the rumen and even less regarding efficiency of absorption of vitamins from the gastro-intestinal tract of cows. Indeed, most studies with ruminants designed to evaluate responses to vitamins do not even report vitamin concentrations in the basal diet. Undoubtedly, vitamin supply (dietary and ruminal synthesis) is affected by basal diet, dry matter intake, and numerous other factors and the supply of vitamins from the basal diet will effect the response to vitamin supplementation. Without reliable data regarding vitamin supply from basal diets (i.e., control diets) actual requirements cannot be determined.

For ration formulation purposes, knowing the true requirement for vitamins is not essential. The question that needs to be asked is, what vitamins should be supplemented and at what rates? Good animal husbandry requires that diets be formulated to provide enough vitamins to prevent clinical deficiencies. Following NRC (2001) guidelines (i.e., supplementing diets with vitamins A, D, and E and providing no supplemental water soluble vitamins) will prevent essentially all clinical signs of vitamin deficiencies. Some unique situations may require special supplementation to prevent clinical signs (for example supplemental vitamin K should be provided when cows are fed moldy sweet clover hay). The NRC guidelines should be the starting point when developing a vitamin nutrition program.

Determining whether vitamins should be supplemented at rates exceeding NRC should be based on expected benefits compared with the expected costs. The effect of increased vitamin supplementation on feed costs can be determined easily. Few studies show marked effects on feed intake when vitamins are supplemented, therefore, the increased feed costs associated with vitamin supplementation is dependent on the price of the vitamins. Increased supplementation of vitamins will cost from < 1 cent/day per cow (vitamin A and D) to 30 or 40 cents/day (rumen protected choline). At typical supplementation rates, vitamin E and most common B-vitamins will cost between 5 and 10 cents/day per cow. Excessive supplementation also may incur a cost by having negative effects on health and productivity (true toxicity can also occur but generally vitamin intakes have to be extremely high). For example, Majee et al. (2003) observed a quadratic effect of B-vitamin supplementation on feed intake and milk production by dairy cows. Benefits of supplementing vitamins in excess of NRC recommendations may include improved health, increased production, and improved reproduction. The economic return of these benefits usually is much greater than the impact of vitamin supplementation on feed costs.

Vitamins A and D: Very little data are available showing any positive effects at rates higher than NRC (approximately 70,000 IU/day for A and 20,000 IU/day for D), but because vitamin A and D are inexpensive and because of some possible (but not highly likely) benefits over supplementation is advisable. A safety factor of 20 to 40% should be adequate. Therefore diets that provide an average of 84,000 to 100,000 IU of vitamin A/day should be adequate for dry, prefresh, and lactating cows. Cows that are grazing probably can be fed substantially less supplemental vitamin A. Diets that provide an average of 24,000 to 28,000 IU/day of vitamin D should be adequate.

Vitamin E: Data showing positive effects when vitamin E is supplemented to lactating dairy cows at rates exceeding NRC are not available. Limited data are available showing positive responses when peripartum cows are fed vitamin E at rates above NRC. Diets for lactating cows >15 to 30 days in milk should provide an average of about 500 IU/day and diets for dry cows <265 days of gestation should provide approximately 1000 IU/day. Cows during the last 14 days of gestation and the first 2 to 4 weeks of lactation may benefit from consuming 2000 to 4000 IU of vitamin E/day. Cows consuming a substantial amount of fresh forage probably need little supplemental vitamin E.

Biotin: Substantial data are available showing improved hoof health when cows are fed 20 mg of biotin/day and more limited data show increased milk production. Herds with hoof problems will likely benefit from biotin and should be fed diets (all stages of lactation and gestation) that provide 20 mg/day of supplemental biotin. High producing herds are likely to see an increase in milk production.

Choline: Rumen-protected choline fed at 50 to 60 g/day (actual product, not choline) has resulted in increased milk production and reduced liver fat in some studies, but the cost of supplementation is substantial. A response in milk production is most likely in early lactation (up to about 60 days in milk) and to maximize the likelihood of a profitable return on investment, supplementation should be limited to early lactation cows. Choline supplementation may reduce the risk of ketosis and fatty liver in over-conditioned dry cows and the use of choline is probably warranted in that situation.

Niacin: A positive return on investment is likely when early lactation cows are fed approximately 6 g/d of supplemental niacin. Little benefit would be expected when mid and late lactation cows are fed supplemental biotin. The use of supplemental niacin in herds that feed a single diet to all cows is unlikely to have a positive return on investment.

Other vitamins: At this time, insufficient data are available to recommend supplementation of other B-vitamins and vitamin C to dairy cows.

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