Are Your Cows Getting the Vitamins They Need?

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■ Take Home Message

‣ Proper supplementation of vitamins can improve the health and increase milk production by dairy cows

‣ Vitamins A, D, and E should almost always be supplemented

‣ As milk production increases, positive responses to supplemental B-vitamins (especially biotin, folic acid, and perhaps niacin) are more likely

■ Introduction

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 North American dairy cows) is a clinical deficiency. For example, rickets result from a clinical deficiency of vitamin D. 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.

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
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
Choline	Fat metabolism and transport
Vitamin C	Antioxidant, amino acid metabolism

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 research on vitamin nutrition of dairy cows. If a particular vitamin is not discussed, it is because no recent information is available. Detailed reviews

regarding B-vitamin nutrition (Schwab and Shaver, 2005) and fat-soluble vitamin nutrition (Weiss, 1998) of dairy cattle are available.

■ B-Vitamins

For many years, there has been little interest in B-vitamins (biotin, folic acid, niacin, pantothenic acid, riboflavin, thiamin, B-6, and B-12) for dairy cows. The typical feeds used in dairy diets are good sources of many B-vitamins and rumen bacteria appear to synthesize most, if not all, of the B-vitamins. Clinical deficiencies of B-vitamins almost never occur in adult ruminants. However, the numbers of scientific publications on B-vitamins and dairy cattle have increased markedly and supplementation of some B vitamins is becoming common. Why has the interest in B-vitamins increased? The easy answer to that question is because cows have changed.

As with all nutrients, a response to supplementation of B-vitamins will only be observed if: 1) supplementation actually increases the supply of vitamin to the tissues that require it, and 2) the nutrient is first limiting. The primary function of B-vitamins is to act as co-factors for enzymes. Many of these enzymes are involved with energy and protein metabolism and their activities need to increase in direct proportion to increased milk production. This means that the requirements for B-vitamins will be a function of milk production. The supply of B-vitamins is a function of dry matter intake (DMI), concentration of the vitamins in the basal diet, ruminal degradation and synthesis, and absorption from the intestines. It is unlikely the concentration of B vitamins in basal diets has changed markedly over the last several decades. Dry matter intake increases as milk production increases but not on a one to one basis. On average, the ratio of milk yield to DMI is about 1.5:1 (or about 0.7 kg of DM per kg of milk). Assuming no major change in vitamin concentrations in the diet, this would mean that milk production has increased more than intake of B-vitamins. Not much is known regarding factors that affect synthesis of B vitamins in the rumen or absorption of the vitamins from the intestine. In vitro research suggests that net synthesis rate of some B-vitamins by rumen microbes may decrease as the amount of concentrate in diets increases (as has happened during the last several decades). In addition, as DMI increases, rumen retention time decreases, which could also adversely affect ruminal synthesis of B-vitamins. Overall, there are good reasons to suspect that supply of B-vitamins (without supplementation) has not increased as much as the requirement. This means that responses to B-vitamin supplementation may be more likely with today's higher producing cows.

Biotin

Several published, clinical trials have shown that supplementing approximately 20 mg of biotin/d to dairy cows reduces the prevalence of hoof lesions and lameness (Table 2). The exact mode of action is not known but it may involve the effect of biotin on differentiation of hoof cells and on the production of keratin by those cells. Biotin supplementation has been shown to reduce the moisture concentration, increase the lipid concentration, and increase hardness of hoof soles of dairy cows. These changes are likely one reason for the clinical observations. Overall, the published data very clearly show a beneficial effect of biotin supplementation of hoof health. The typical supplementation rate is 20 mg/d. All studies involved long term (months) supplementation. At least 3 to 6 months of supplementation appear to be needed before significant improvements in hoof health are observed.

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

Treatment	Results	Ref.[1]
0 or 20 mg biotin/d from calving until 300 DIM	Treatment reduced prevalence of white line separation at 100 DIM	1
0 or 10 mg of biotin/d for 18 months	Treatment reduced prevalence of vertical fissures on claw wall	2
0 or 20 mg biotin/d for 13 months	Treatment improved locomotion scores and reduced prevalence of clinical lameness	3
0 or 20 mg biotin/d for 18 months	Treatment reduced prevalence of white line disease	4
0 or 40 mg biotin/d for 50 days	Treatment improved healing of sole ulcers	5
0 or 20 mg biotin/d for 14 months	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) Bergsten et al., 2003.

Data are also accumulating showing that supplemental biotin can often increase milk production (Table 3), and this effect can be independent of any beneficial effect biotin has on hoof health. The most common treatments were control (no supplementation) and 20 mg of supplemental biotin per day. In studies with higher producing cows (>34 kg/day) supplementation increased milk production 1 to 3 kg/d in five studies (average response = 1.6 kg/day), but no response was observed in one study. In a study with lower producing cows (<20 kg/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 occurs shortly after supplementation begins.

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

Treatment	Results	Ref[1]
0 or 20 mg biotin/d until 300 DIM	Treatment increased 305 d ME by 310 kg (P < 0.05). Control ME = 11,770 kg	1
0 or 20 mg biotin/d for 13 months	No effect on milk yields (18 vs. 19 kg/d)	2
0 or 20 mg biotin/d until 120 DIM	Treatment increased milk from 37 to 39 kg/d	3
O or 20 mg biotin/d for 14 months	Treatment increased 305 d milk by 480 kg (P < 0.05). Control milk = 10,090 kg	4
0, 10, or 20 mg biotin/d until 100 DIM	Linear (P < 0.05) increase in milk yield (37, 37.7, and 39.5 kg/d)	5
0 or 20 mg biotin/d for 28 d periods	Treatment increased milk 1 kg/d (P < 0.05). Control milk = 37.3 kg	6
20 or 40 mg biotin/d for 28 d periods	No effect on milk yield. Average yield = 40.9 kg/d	6
0 or 30 mg biotin/d until 70 DIM	No difference in fat-corrected milk (35 vs 34.5 kg/d)	7

[1] Citations are: 1) Midla et al., 1998; 2) Fitzgerald et al., 2000 ; 3) Margerison et al., 2002 ; 4) Bergsten et al., 2003 ; 5) Zimmerly and Weiss, 2001 ; 6) Majee et al., 2003 ; 7) 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 is important for milk production. Niacin has also been evaluated for possible beneficial 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.

Numerous summaries of niacin experiments examining milk responses have been conducted. The most recent summary by Schwab et al (see Schwab and Shaver, 2005 for details) was conducted using a new statistical method and is probably the best current summary. They concluded that supplementing 6 g/d of niacin (commonly used supplementation rate) had no effect on milk production or milk composition. At 12 g/d of supplemental niacin, 3.5% fat-corrected milk was increased 0.5 kg/d, fat yield was increased 26 g/d and milk protein yield was increased 17 g/d. Positive responses appear more likely in early lactation, high producing cows. One reason for the very small response to niacin supplementation may be that

niacin is extensively degraded in the rumen (>90%). Rumen-protected niacin may be worth developing and evaluating but data currently are not available on such a product.

Folic Acid and Vitamin B-12

A substantial amount of research has been conducted by Christine Girard's group at Agriculture & Agri-Food Canada, Lennoxville, Quebec (Girard et al., 2005; Girard and Matte, 2005) on folic acid and B-12 nutrition of dairy cows. Vitamin B-12 is essential for folic acid to work properly and therefore, these two vitamins must be considered together. Both vitamins are involved in methionine metabolism, among other functions. Vitamin B-12 can be synthesized by rumen bacteria if adequate cobalt is in the diet (NRC cobalt requirement is 0.11 mg/kg of diet DM but newer research suggests that 0.2 to 0.3 mg/kg may be better). The effect of folic acid supplementation (typical rates are between about 2 and 3 g/day) on milk production has been variable. In one study, milk production of multiparous cows was increased by 2 to 3 kg/d when folic acid was supplemented, but no effect was observed with first lactation cows. In other experiments folic acid has not affected milk production. One reason for the variable responses maybe that vitamin B-12 status was limiting. If cows are limited in B-12, they are unlikely to respond to folic acid supplementation. Interactions between methionine supply, folic acid, and B-12 are also likely. In a study from Girard's group, cows fed supplemental folic acid had increased milk production when injected with vitamin B-12. Both vitamin B-12 and folic acid are expensive and we still do not understand all the factors that influence responses to supplementation. Additional research is needed before routine supplementation of these vitamins is recommended.

Other B-vitamins

Research is extremely limited on the effects of supplementing B-vitamins other than biotin and niacin to dairy cows. Randy Shaver and his group at the University of Wisconsin found that 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. When the amount of supplemental B-vitamins was doubled, feed intake and milk production was similar to control cows (i.e., lower than the 1-X supplementation treatment). Another study from that same group 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.   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.

■ Other Water Soluble Vitamins

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. Choline must be rumen-protected to be effective and the products are expensive.

Vitamin C

Vitamin C also is not considered an essential 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. One study reported no correlation between milk SCC and plasma concentrations of vitamin C but the range in SCC was quite small (67,000 to 158,000/ml). Another study found that plasma vitamin C concentrations were much higher in cows that had uninfected mammary glands than in those that had glands infected with either environmental or contagious pathogens. We conducted an experiment to examine changes in vitamin C status following an intramammary challenge with *E. coli*. Large decreases in vitamin C status were statistically related to longer duration of clinical mastitis and larger decreases in milk production. 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.

■ **Fat-soluble Vitamins**

Vitamin A and B-carotene

The current NRC (2001) requirement for **supplemental** vitamin A is 110 IU/kg 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. Some epidemiological data also suggest a link between vitamin A and mastitis. 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 health or reproductive efficiency; a possible exception is increased ovulation rate when cows are superovulated.

Vitamin E

The current NRC requirement for supplemental vitamin E is about 0.7 IU/kg of BW for a lactating cow and 1.5 IU/kg 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 additional vitamin E is needed by grazing dairy cows. Newer data suggest that higher supplementation rates may be warranted in some situations. In a study we conducted, 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. 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 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. In two large field studies from Ontario and Michigan State University 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.

■ Recommendations

Although the word, 'requirement', is often used for vitamins with dairy cows, that word implies a much greater knowledge base regarding vitamin nutrition than is actually available. 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.   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).   Benefits of supplementing vitamins in excess of NRC recommendations may include improved health, increased production, and improved reproduction.

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. Milk yield is likely to increase in high producing herds.

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 unlikely when cows are supplemented with 6 g of niacin/day. A response is more likely at 12 g/day, but the response may not be profitable. Little benefit would be expected when mid and late lactation cows are fed supplemental niacin. 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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