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Recent Advances in Minerals and Vitamins on Nutrition of Lactating Cows

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Abstract: Highly productive lactating cows have much greater needs for minerals and vitamins than low-producing animals. The antioxidant vitamins, vitamin E and $-carotene are beneficial in reducing mastitis. Vitamins (D, E, C and $-carotene) and minerals (Cu, Zn, and Se) are needed for an optimum immune response. Vitamin E is effective in counteracting gossypol toxicity. New research suggests the need for supplemental biotin for dairy cattle. Milk fever is best prevented with anionic diets. There is environmental concern from use of excess P. Grazing lactating cows should have access to high quality free-choice mineral mixtures.

Key words: Lactating cows, vitamins, minerals, nutritient values

Introduction

A great deal of information has recently become available for better nutrition strategies for feeding minerals and vitamins to livestock, including lactating cows. Textbooks and new publications are available for minerals (McDowell, 1992; 1999; McDowell and Valle, 2000). In 1999, a publication titled "Minerais para Ruminantes sob Pastejo em Regiões Tropicais, Enfatizando o Brasil" (McDowell, 1999) was available. This publication and a recent journal article (Tokarnia *et al*., 2000) review both older literature and the newest findings of mineral research in Brazil and specifies regions of Brazil with reported deficiencies. Due to the enormity of this subject, this report will emphasize newer information most applicable to lactating dairy cows. The report will attempt to discuss problems for high density dairy operations feeding considerable concentrates to smaller operations that are dependent on grazing cows that receive minimal or no concentrations.

Mineral and vitamin requirements for cattle: Mineral requirements and toxic levels and vitamin requirements suggested by the National Research Council (NRC) for lactating dairy cows are presented in Table 1. Mineral and vitamin requirements are highly dependent on the level of productivity. Increased growth rates and milk production will greatly increase mineral requirements. Improved management practices that lead to improved milk production and growth rates for cattle will necessitate more attention to mineral and vitamin nutrition. Marginal mineral and vitamin deficiencies, under low levels of production, become more severe with increased levels of production, and previously unsuspected nutritional deficiency signs usually occur as production levels increase.

Immunity and antioxidant roles of trace minerals and vitamins: Both trace minerals and vitamins play important roles in the health of cattle. For lactating dairy cows, nutrient supplementation for trace minerals and vitamins go beyond correcting for deficiencies but are aimed rather at minimizing stress and optimizing production efficiency.

Free radicals can be extremely damaging to biological systems (Padh, 1991). Also, phagocytic granulocytes undergo respiratory burst to produce oxygen radicals to destroy intracellular pathogens. However, these oxidative products can, in turn, damage healthy cells if they are not eliminated. Antioxidants serve to stabilize these highly reactive free radicals, thereby maintaining the structural and functional integrity of cells (Chew, 1995). Therefore, antioxidants are very important to immune defense and health of humans and animals.

Tissue defense mechanisms against free-radical damage generally include vitamin C, vitamin E, and $-carotene as the major vitamin antioxidant sources. In addition, several metalloenzymes which include glutathione peroxidase (Se), catalase (Fe), and superoxide dismutase (Cu, Zn, and Mn) are also critical in protecting the internal cellular constituents from oxidative damage. The dietary and tissue balance of all these nutrients are important in protecting tissues against free-radical damage. Both *in vitro* and *in vivo* studies show that these nutrients generally enhance different aspects of cellular and non-cellular immunity. The antioxidant function could, at least in part, enhance immunity by maintaining the functional and structural integrity of important immune cells. A compromised immune system will result in reduced animal production efficiency through increased susceptibility to diseases, thereby leading to increased animal morbidity and mortality.

Trace minerals: There are numerous potential sites for trace elements to affect immune function. Virtually every aspect of immunity involves Zn. A nutritional deficiency of Zn is consistently associated with increased morbidity and mortality (Kincaid, 1999). The immune response to many pathogens cause a rapid decline in blood Zn, perhaps a 50% drop within a few hours. Zinc deficiency is associated with reduced phagocytosis and killing by macrophages. Zinc deficiency results in a decrease in blood lymphocyte population (Fraker and King, 1998) and atrophy of the spleen and thymus. The responsiveness of T-lymphocytes to mitogens (Droke *et al*., 1993) and the cytokines (Tanaka *et al*., 1990) is inhibited in zinc-deficient animals. Zinc also is important in B-cell activation. Calves fed zinc methionine had greater antibody response against bovine herpesvirus (Spears *et al*., 1991). Zinc as Zn methionine has reduced somatic cell counts (SCC) about 22% in some trials (Kincaid *et al*., 1999).

Copper deficiency reduces the number of circulating T cells, B cells, and neutrophils. Impairment of bactericidal activity can occur early in the development of Cu deficiency in cattle and sheep. Copper-deficient sheep had increased mortality from bacterial infection (Chew, 2000). Antibody titers to *Brucella abortus* and proliferation responses to concanavalin A and soluble antigen-stimulated mononuclear cells were lower in

Table 1: Suggested mineral and vitamin requirements and trace element toxicities for lactating dairy cows (dry basis)

Required elements	Lactating dairy cows[a] Suggested value
Macroelements (%)	0.43 - 0.77
Calcium	0.25 - 0.49
Phosphorus (P)	0.20 - 0.25
Magnesium (Mg)	0.90 - 1.00
Potassium (K)	0.18
Sodium (Na)	0.20 - 0.25
Sulfur (S)	
Microelements (mg/kg)	
Cobalt (Co)	0.1
Copper (Cu)	10.0
Iodine (I)	0.6
Iron (Fe)	50.0
Manganese (Mn)	40.0
Molybdenum (Mo)	---
Selenium (Se)	0.3
Zinc (Zn)	40.0
Vitamins (IU/kg)	
Vitamin A	3200
Vitamin D	1000
Vitamin E	15
Toxic Elements[b] (mg/kg)	
Copper (Cu)	80
Fluorine (F)	30
Molybdenum (Mo)	6
Selenium (Se)[c]	5
Zinc (Zn)	500

[a]National Research Council (1989)
[b]National Research Council (1980)
[c]McDowell (1992)

Cu-deficient heifers (Cerone *et al*., 1995). Ceruloplasmin, an acute-phase protein, did not have the normal post-inoculant (bovine herpesvirus-1) increase in Cu-deficient calves (Arthington *et al*., 1996).

Selenium deficient animals have impaired bactericidal activity. Selenium, as part of the enzyme glutathione peroxidase, protects the cytosol against peroxides produced during respiratory burst. There may be an increase in reactive oxygen species in Se deficiency and this could affect immune responses (Kincaid, 1999). Accordingly, cows supplemented with Se have neutrophils in milk with increased intracellular kill of bacteria, and reduced extracellular hydrogen peroxide concentrations. Mean plasma selenium concentration was inversely correlated with bulk tank (SCC in dairy herds (Weiss *et al*., 1990).

Vitamins: In addition to the relationship of Se to Vitamin E, Vitamin E, Vitamin C and $-carotene as antioxidant vitamins together have important tissue defense mechanisms against free-radical damage. Even Vitamin D [1,25 $(OH)_2$ D_3] has been shown to booster humoral responses to vaccines (Reinhardt *et al*., 1999). Vitamin A, not so much as an antioxidant, has important immune functions.

Vitamin A deficiency affects immune function, particularly the antibody response to T-cell-dependent antigens (Ross, 1992). The RAR-"mRNA expression and antigen-specific proliferative responses to T lymphocytes are influenced by vitamin A status *in vivo* and are directly modulated by retinoic acid (Halevy *et al*., 1994). Vitamin A deficiency affects a number of cells of the immune system, and that repletion with retinoic acid effectively reestablishes the number of circulating lymphocytes (Zhao and Ross, 1995).

A diminished primary antibody response could also increase the severity and/or duration of an episode of infection, whereas a diminished secondary response could increase the risk of developing a second episode of infection. Vitamin A deficiency causes decreased phagocytic activity in macrophages and neutrophils. The secretory immunoglobulin (Ig) A system is an important first line of defense against infections of mucosal surfaces (McGhee *et al*., 1992). Several studies in animal models have shown that the intestinal IgA response is impaired by vitamin A deficiency (Wiedermann *et al*., 1993; Stephensen *et al*., 1996).

Vitamin A-deficient cattle have depressed activity of natural killer cells, decreased antibody production, decreased responsiveness of lymphocytes to mitogenic stimulation, and increased susceptibility to infection (Ross, 1992; Nonnecke *et al*., 1993; Michal *et al*., 1994; Rajaraman *et al*., 1998).

Carotenoids have been shown to have biological actions independent of vitamin A (Chew, 1995; Burton, 1989; Aréchiga *et al*., 1998). University of Florida research indicated significantly increased milk production in dairy cows receiving supplemental $-carotene (Aréchiga *et al*., 1998). In this large, three-part study using intensive management, the supplemented cows (400 mg/day) produced from 6.2 to 11.3 percent more milk than the unsupplemented controls. Also, for cows fed supplemental $-carotene for **$**90d, pregnancy rate at 120 d postpartum was increased in Experiment 1 (35.4% vs. 21.1%).

Recent animal studies indicate that certain carotenoids with antioxidant capacities, but without vitamin A activity, can enhance many aspects of immune functions, can act directly as antimutagens and anticarcinogens, can protect against radiation damage, and can block the damaging effects of photosensitizers. $-carotene can function as a chain-breaking antioxidant, it deactivates reactive chemical species such as single oxygen, triplet photochemical sensitizers and free radicals which would otherwise induce potentially harmful processes (e.g., lipid peroxidation).

Vitamin A and $-carotene have important roles in protecting animals against numerous infections including mastitis. Potential pathogens are regularly present in the teat orifice, and under suitable circumstances can invade and initiate clinical mastitis. Any unhealthy state of the epithelium would increase susceptibility of a mammary gland to invasion by pathogens. There are reports of improved mammary health in dairy cows supplemented by $-carotene and vitamin A during the dry (Dahlquist and Chew, 1985) and lactating (Chew and Johnston, 1985) periods.

Polymorphonuclear neutrophils (PMN) are the major line of defense against bacteria in the mammary gland. $-carotene supplementation seems to exert a stabilizing effect on PMN and lymphocyte function to the period around dry off (Tjoelker *et al*., 1990). Daniel *et al*. (1991a, b) reported that $-carotene enhanced the bactericidal activity of blood and milk PMN, against *S. auereus* but did not affect phagocytosis. Vitamin A either had no effect or suppressed bactericidal activity and phagocytosis. Control of free radicals is important for bacterial activity but not for phagocytosis. The antioxidant activity of vitamin A is not important; it does not quench or remove free radicals. $-carotene, on the other hand, does have significant antioxidant properties and effectively quenches singlet oxygen free radicals (Mascio *et al*., 1991; Zamora *et al*., 1991).

One of the protective effects of vitamin C may partly be mediated through its ability to reduce circulating glucocorticoids (Degkwitz, 1987). The suppressive effect of corticoids on neutrophil function in cattle was alleviated with vitamin C supplementation (Roth and Kaeberle, 1985). In addition, ascorbate can regenerate the reduced form of "-tocopherol, perhaps accounting for observed sparing effect of these vitamins (Jacob, 1995). In the process of sparing fatty acid oxidation, tocopherol is oxidized to the tocopheryl free radical. Ascorbic acid can donate an electron to the tocopheryl free radical, regenerating the reduced antioxidant form of tocopherol.

Vitamin C is the most important antioxidant in extracellular fluids and can protect biomembranes against lipid peroxidation damage by eliminating peroxyl radicals in the aqueous phase before the latter can initiate peroxidation (Frei *et al*., 1989). Vitamin C and E supplementation resulted in a 78% decrease in the susceptibility of lipoproteins to mononuclear cell-mediated oxidation (Rifici and Khachadurian, 1993). Ascorbic acid is very high in phagocytic cells with these cells using free radicals and other highly reactive oxygen containing molecules to help kill pathogens that invade the body. In the process, however, cells and tissues may be damaged by these reactive species. Ascorbic acid helps to protect these cells from oxidative damage.

Considerable attention is presently being directed to the role vitamin E and Se play in protecting leukocytes and macrophages during phagocytosis, the mechanism whereby animals immunologically kill invading bacteria. Both vitamin E and Se may help these cells to survive the toxic products that are produced in order to effectively kill ingested bacteria (Badwey and Karnovsky, 1980). Macrophages and neutrophils from vitamin E-deficient animals have decreased phagocytic activity.

Since vitamin E acts as a tissue antioxidant and aids in quenching free-radicals produced in the body, any infection or other stress factors may exacerbate depletion of the limited vitamin E stores from various tissues. The protective effects of vitamin E on animal health may be involved with its role in reduction of glucocorticoids, which are known to be immunosuppressive. Vitamin E also most likely has an immune enhancing effect by virtue of altering arachidonic acid metabolism and subsequent synthesis of prostaglandin, thromboxanes and leukotrienes. Under stress conditions, increased levels of these compounds by endogenous synthesis or exogenous entry may adversely affect immune cell function (Hadden, 1987).

The effects of vitamin E and Se supplementation on protection against infection by several types of pathogenic organisms, as well as antibody titers and phagocytosis of the pathogens have been reported for calves (Reddy *et al*., 1987a). As an example, calves receiving 125 IU of vitamin E daily were able to maximize their immune responses compared to calves receiving low dietary vitamin E (Ready *et al*., 1987b). Antioxidants, including vitamin E, play a role in resistance to viral infection. Vitamin E deficiency allows a normally benign virus to cause disease (Beck *et al*., 1994). A Se or vitamin E deficiency leads to a change in viral phenotype, such that an avirulent strain of a virus becomes virulent and a virulent strain becomes more virulent (Beck, 1997).

Supplemental levels of vitamin E higher than recommended by the dairy cattle NRC (1989) have been beneficial in the control of mastitis. Smith and Conrad (1987) reported that intramammary infection was reduced 42.2% in vitamin E-selenium supplemented versus unsupplemented controls. The duration of all intramammary infections in lactation was reduced 40 to 50% in supplemented heifers. Weiss *et al*. (1990) reported that clinical mastitis was negatively related to plasma Se concentration and concentration of vitamin E in the diet.

Many new intramammary infections (IMI) occur in the 2 weeks before and after calving. Deficiencies of either vitamin E or Se have been associated with increased incidence and severity of IMI, increased clinical mastitis cases, and higher somatic cell counts (SCC) in individual cows and bulk tank milk. Somatic cell counts are a primary indicator of mastitis and milk quality in dairy herds. The polymorphonuclear neutrophil (PMN) is a major defensive mechanism against infection in the bovine mammary gland. A known consequence of vitamin E and Se deficiency is impaired PMN activity and postpartum vitamin E deficiencies are frequently observed in dairy cows. Dietary supplementation of cows with Se and vitamin E results in a more rapid PMN influx into milk following intramammary bacterial challenge and increased intracellular kill of ingested bacteria by PMN. Subcutaneous injections of vitamin E approximately 10 and 5 d before calving successfully elevated PMN "-tocopherol concentrations during the periparturient period and negated the suppressed intracellular kill of bacteria by PMN that commonly is observed around calving (Smith *et al*., 1997).

Diets of multiparous dairy cows were supplemented with either 0 or 1,000 IU vitamin E (as *dl-* "-tocopheryl acetate) during the dry period (Smith *et al*., 1984). Cows were additionally administered Se at the rate of 0 or 0.1 mg per kg body weight via i.m. injection 21 days prepartum. No vitamin E or Se were supplemented during lactation. Incidence of new clinical cases of mastitis was reduced by 37% in both groups receiving vitamin E compared to controls. The reduction in clinical mastitis was only 12% when cows were injected with Se but not supplemented with dietary vitamin E. These authors also reported that clinical cases in the vitamin E supplemented-selenium injected cows were consistently of shorter duration than those occurring in all other groups. Erskine *et al*. (1989) investigated specific effects of Se status of dairy cattle on the induction of mastitis by *E. coli*. Bacterial concentrations were significantly higher in Se-deficient than in Se-adequate cows and Se supplementation reduced both severity and duration of clinical mastitis.

Plasma concentrations of "-tocopherol decreased at calving for cows fed dietary treatments with low or intermediate concentrations of vitamin E, but not for cows fed the high vitamin E treatment (Weiss *et al*., 1997). High dietary vitamin E increased concentration of "-tocopherol in blood neutrophils at parturition. The high vitamin E treatment was 1,000 IU/d of vitamin E during the first 46 d of the dry period, 4,000 IU/d during the last 14 d of the dry period, and 2,000 IU/d during lactation.

The percentage of quarters with new infections at calving was not different (32.0%) between cows receiving treatments that contained low and intermediate concentrations of vitamin E but was reduced (11.8%) in cows receiving the high vitamin E treatment. Clinical mastitis affected 25.0, 16.7 and 2.6% of quarters during the first 7 d of lactation for cows receiving the low, intermediate, and high vitamin E treatments, respectively. Cows with plasma concentrations of "-tocopherol > 3.0 µg/ml at calving were 9.4 times more likely to have clinical mastitis during the first 7 d of lactation than were cows with plasma concentrations of "-tocopherol < 3.0 µg/ml (Weiss *et al*., 1997).

Additional benefits of vitamin E supplementation: There have been more recent reports on benefits of vitamin E supplementation for livestock than any other vitamin (McDowell *et al*., 1996). Vitamin E was originally supplemented to poultry and livestock for prevention of exudative diathesis, encephalomalacia, white muscle disease,

Table 2: Relationship of gossypol and vitamin E on semen characteristics of dairy bulls[a]

	Treatment		
Item	TRT[b]	TRT2[c]	TRT3[c]
Normal, %	64.7 ± 6.4^{h}	31.4 ± 7.4^{i}	54.6 ± 6.4^{h}
Abnormal[e], %	4.4 ± 1.3^{h}	13.4 ± 1.5^{i}	4.8 ± 1.2^{h}
DSPG[f] ($x10^{6}$/g)	14.6 ± 1.0^{h}	10.2 ± 1.0^{i}	17.6 ± 1.0^{h}
DSP[g] ($x10^{9}$)	3.2 ± 3.0^{h}	2.2 ± 3.0^{i}	4.1 ± 3.0^{h}

[a] Least square means ± SEM. [b] Diet based on SBM, corn and 30 IU vitamin E/kg of supplement. [c] Diet containing 14 mg free gossypol/kg BW/d and 30 IU vitamin E/kg of supplement. [d] Diet containing 14 mg free gossypol/kg BW/d and 4,000 IU vitamin E/bull/d. [e] Midpiece abnormalities evaluated in isotonic formal saline. [f] Daily sperm production per gram of parenchyma. [g] Daily sperm production total.
[h,i] Means in a row with different superscript differ $p < 0.05$.

liver degeneration and other degenerative diseases. Recent research has revealed the benefits of improving disease resistance (see previous section) as well as improving product quality. Supplementing vitamin E in well balanced diets has been shown to increase humoral immunity for ruminants (Hoffmann-La Roche, 1994). These results suggest that the criteria for establishing requirements based on overt deficiencies or growth do not consider optimal health.

Recent research has shown a beneficial response for vitamin E supplementation on male reproduction for Holstein bulls fed high concentrations of gossypol. Velasquez-Pereira *et al*. (1998) reported that bulls which received 14 mg free gossypol/kg body weight had a lower ($p < 0.05$) percentage of normal sperm than those which also received supplemental vitamin E, 31 vs 55%, respectively (Table 2). Likewise, sperm production per gram of parenchyma and total daily sperm production were higher ($p < 0.05$) when gossypol treated animals also received vitamin E. Bulls receiving gossypol exhibited more sexual inactivity ($p > 0.05$) than bulls in other treatments. Vitamin E supplementation to bulls receiving gossypol improved number of mounts in the first test and time of first service in the second test. The final conclusion of the Florida data is that vitamin E is effective in reducing or eliminating important gossypol toxicity effects for male cattle.

Many attempts have been made to control lipid oxidation in meats through the use of antioxidants. Dietary supplementation of vitamin E, and intravenous infusion of vitamin C immediately before harvest, are efficacious techniques for increasing the concentration of these vitamins in beef skeletal muscle (Schaefer *et al*., 1995). Meat with elevated levels of either and probably both of these antioxidant vitamins possesses greater stability of oxymyoglobin and lipid, which results in less discoloration and rancidity. Vitamin E would seem to be the most practical since it is administered dietetically.

Dramatic effects of vitamin E supplementation (500 IU per head daily) to finishing steers on the stability of beef color have been observed (Faustman *et al*., 1989). Loin steaks of control steers discolored two to three days sooner than those supplemented with vitamin E. Supplemental dietary vitamin E extended the color shelf life of loin steaks from 3.7 to 6.3 days. This was most likely due to the increased "-tocopherol content of the loin tissue of the supplemented animals, which was approximately 4-fold greater than controls (Faustman *et al*., 1989). Color is an extremely critical component of fresh red meat appearance and greatly influences the consumer perception of meat quality.

Feeding supplemental vitamin E at levels of 1,000 to 2,000 mg of naturally-occurring mixed tocopherols per cow per day increased the vitamin E content of milk and its stability against oxidized flavor (Neilsen *et al*., 1953). The vitamin E content of milk from cows fed stored feeds was lower than that of milk from cows on pasture and their milk was more susceptible to development of oxidized flavor. Feeding supplemental vitamin E as *dl*- "-tocopheryl acetate, providing an equivalent of 500 mg of *dl*- "-tocopheryl per cow per day, increased the vitamin E content and oxidative stability of milk (Dunkley *et al*., 1967). Nicholson *et al*. (1991) suggest that adequate selenium improves the transfer of dietary tocopherol to milk.

The ability of vitamin E to affect growth, health and reproduction of animals is documented. A vitamin E supplementation program utilizing both parenteral and oral administration is often suggested, particularly when fresh green pasture is lacking.

The need for supplementation of vitamin E is dependent on conditions of production, and in relation to available vitamin E in food or feed sources. The primary factors that influence the need for supplementation include (1) vitamin E- and or Se-deficient concentrates and roughages; (2) excessively dry ranges or pastures for grazing livestock; (3) confinement feeding where vitamin E-rich forages are not included or only forages of poor quality are provided; (4) diets that contain predominantly non-"-tocopherol and thereby are less biologically active; (5) diets that include ingredients that increase vitamin E requirements (e.g., unsaturated fats, waters high in nitrates); (6) harvesting, drying, or storage conditions of feeds that result in destruction of vitamin E and/or selenium; (7) accelerated rates of gain, production and feed efficiency that increase metabolic demands for vitamin E; and (8) intensified production that also indirectly increases vitamin E needs of animals by elevating stress, which often increases susceptibility to various diseases (McDowell, 1992; 2000). After stress, livestock may have reductions in "-tocopherol concentrations in certain tissues. Supplemental vitamin E may be required after stress to restore "-tocopherol in tissues (Nockels *et al*., 1996).

Biotin, niacin and thiamin: Due to ruminal and intestinal synthesis of biotin, a need for supplemental sources was at one time not expected for ruminants. Nevertheless, promising preliminary results in preventing lameness in dairy cattle with biotin supplementation were reported (Frigg *et al*., 1993). Hoof disease is considered by many experts in dairy cattle health to be the most costly health problem in the dairy industry. Hoof disorders occur in both confinement and pasture-based dairy production systems, and result in considerable economic loss to the dairy industry. In the U.S., it is estimated that hoof disorders cost an average of $345 per case in treatment and lost milk production. Successful biotin treatment of dairy cows with claw problems has been reported (Midla *et al*., 1998; Fitzgerald *et al*., 2000). From Australia (Fitzgerald *et al*., 2000), biotin-supplemented herds exhibited better locomotion scores than the unsupplemented herds. In the wet summer period, the number of lame cows, as observed by the farmer, were significantly fewer during the rainy period for the biotin-supplemented herds and required fewer antibiotic treatments than unsupplemented herds.

In biotin-deficient dairy cows, the hoof horn is of poor quality, soft, and crumbling, with no distinct separation of keratinizing and cornified cells. This results in the omission of the granular layer at the epidermis of the bulb of the heel. Decreased stabilizing filaments in the upper spiny layer of the hoof corium in biotin-deficient cows reveals the depressed hormone-like activity of biotin in the synthesis of protein.

Increased plasma biotin levels have been associated with hardness and conformational changes in the bovine hoof (Higuchi and Nagahata, 2000). Dairy cows supplemented with

20 mg of biotin per cow over an 11-month period expressed a steepened angle of the dorsal border and height of the heel; length of the diagonal and size of the ground surface increased (Distl and Schmid, 1994). The hardness of the hoof was also significantly greater in the biotin-treated group. Feeding dairy and beef cows 20 mg/day of supplemental biotin not only resulted in reduced incidence of hoof lesions but also increased milk production (Zimmerly, 2000). Zimmerly (2000) indicated that biotin supplementation increased milk and milk protein yield.

"Fatty Liver" syndrome is a metabolic disorder that occurs primarily around the days surrounding parturition when energy intake is low. Low energy intake causes the cow to mobilize fat from its adipose tissue and deposit it in the liver. The consequences of a fatty liver can be significant. A fatty liver is less able to perform its necessary functions such as to synthesize glucose, detoxify ammonia to urea, and oxidize fat to obtain energy. Cows with fatty liver are more likely to develop ketosis and suffer milk production losses.

During development of fatty liver, the rate of gluconeogenesis and key rate-limiting enzyme activities may be suboptimal (Rukkwamsuk *et al*., 1999). If hepatic lipidosis occurs, a number of multi-factorial associated diseases such as ketosis, retained placenta, metritis, milk fever, mastitis and even laminitis may appear at parturition (Bruss, 1993; Breukink and Wensing, 1998). On the basis of a positive effect of biotin on reducing fatty liver conditions in other species, current University of Florida research is studying the effect of supplemental biotin on reducing fatty liver syndrome in lactating Holsteins. We hypothesized that short-term supplemental biotin to dry and periparturient cows might alter the occurrence of metabolic disorders such as fatty liver and ketosis through regulatory effects of the products from hepatic biotin-dependent carboxylases.

Niacin is the most common water-soluble vitamin added to dairy cow diets. One report indicated that about 50% of dairy cows in high-production herds go through borderline ketosis during early lactation. The concentration of $-hydroxybutyrate was reduced from 1.24 to 0.74 mmol/L after 5 days, when 10 g of niacin was given to cows with ketosis (Flachowsky *et al*., 1988). Fronk and Schultz (1979) indicated that treating ketotic dairy cows with 12 g of nicotinic acid daily had a beneficial effect on the reversal of both subclinical and clinical ketosis. Other studies indicate that 6 g of niacin may be sufficient (Hoffmann-La Roche, 1994). Klippel *et al*. (1993) reported that supplemental niacin decreased milk short- and medium-chain fatty acids and increased monounsaturated fatty acids. Feeding cows niacin has been shown to correct fat-induced milk protein depression (Driver *et al*., 1990; Cervantes *et al*., 1996).

Thiamin deficiency is common in feedlot cattle fed high concentrate diets, with the condition (nervous disorder) referred to as polioencephalomalacia (PEM). The condition affects mainly calves and young cattle between 4 months and 2 years old. The incidence of PEM is reported to be between 1 and 20%, and mortality may reach 100%. Clinical signs in mild cases include dullness, blindness, muscle tremors (especially of the head) and opisthotonos. High-sulfur diets and antithiamin compounds (e.g., thiaminases) are associated with thiamin deficiency and PEM (Gould, 1998; McDowell, 2000). Lactating dairy cows seem less affected by PEM.

Milk fever (parturient paresis) relationship to CA, P and vitamin D: Milk fever (parturient paresis) in dairy cows is caused by a temporary imbalance between Ca availability and high Ca demand following the onset of lactation (Oetzel, 1996). Calcium leaves the extracellular fluid to enter the mammary gland faster than it can be replaced by intestinal Ca absorption or bone Ca resorption (Goff and Horst, 1993). Despite much research, milk fever incidence has remained steady in the United States at 8 to 9%. Milk fever is an economically important disease and can reduce the productive life of a dairy cow by 3.4 years. Each case of milk fever leads to a loss of $334 to the producer by way of treatment charges and milk loss (Horst *et al*., 1997). If left untreated, about 60 to 70% of cows die.

Aged cows are at the greatest risk of developing milk fever. Heifers almost never develop milk fever. Older animals have a decreased response to dietary Ca stress due to both decreased production of 1,25-(OH)$_2$D$_2$ and decreased response to the 1,25-(OH)$_2$D. Target tissues of cows with milk fever may have defective hormone receptors, and the number of receptors declines with age. In older animals, fewer osteoclasts exist to respond to hormone stimulation, which delays the ability of bone to contribute Ca to the plasma Ca pool. The aging process is also associated with reduced renal 1"-hydroxylase response to Ca stress, therefore reducing the amount of 1,25-(OH)$_2$D produced from 25-OHD (Goff *et al*., 1991).

Special Ca and P supplementation is required for high-producing dairy cows to prevent parturient paresis. Parturient paresis can be prevented effectively by feeding a prepartum diet low in Ca and adequate in P. Prepartal low-Ca diets are associated with increased plasma parathyroid hormone (PTH) and 1,25-(OH)$_2$D$_2$ and 1,25-(OH)$_2$D$_3$ concentrations during the prepartal period. These increased PTH and 1,25-(OH)$_2$D concentrations resulted in "prepared" and effective intestinal and bone Ca homeostatic mechanisms at parturition that prevented parturient paresis.

Supplemental vitamin D has been used to prevent parturient paresis in dairy cows for a number of years. Treatment with high levels of vitamin D has been successful, but toxicity problems have sometimes resulted, and for some animals, the disease has been induced by treatment. Hodnett *et al*. (1992) used a combination of 25-OHD$_3$ plus 1"-hydroxycholecalciferol to reduce parturient paresis in dairy cows fed high dietary Ca. The incidence of the disease was reduced from 33 to 8%.

Anion-cation balance of prepartum diets (sometimes referred to as acidity or alkalinity of a diet) can also influence the incidence of milk fever (Gaynor *et al*., 1989; Horst *et al*., 1997; Pehrson *et al*., 1999; Vagnon and Oetzel, 1998). Diets high in cations, especially Na and K, tend to induce milk fever, but those high in anions, primarily C1 and S, can prevent milk fever. The incidence of milk fever depended on the abundance of the cations Na^+ and K^+ relative to the anions C1G and SO_4^{2G}. This concept is now generally referred to as the cation-anion difference (CAD). Because most legumes and grasses are high in K, many of the commonly used prepartum diets are alkaline. There are large variations in the mineral content of roughages fed on different farms, and that the mineral content of grass, and consequently, the CAD of a diet can be significantly altered by different types of fertilization (Pehrson *et al*., 1999). Addition of anions to a prepartal diet is thought to induce in the cow a metabolic acidosis, which facilitates bone Ca resorption and intestinal Ca absorption (Horst *et al*., 1997). Diets higher in anions increase osteoclastic bone resorption and synthesis of 1,25-(OH)$_2$D$_3$ in cows (Goff *et al*., 1991). Both of these physiologic processes are controlled by PTH. Workers at the Rowett Research Institute (Abu Damir *et al*., 1994) have also recently reported that 1,25-(OH)$_2$D $_3$ production is enhanced in cows fed acidifying diets.

Collectively, these data suggest that a major underlying cause of milk fever is metabolic alkalosis, which causes an inability of cow tissues to respond adequately to PTH (Horst *et al*., 1997). This lack of response in turn reduces the ability of the cow to draw on bone Ca stores, and production of the second Ca-regulating hormone, 1,25-$(OH)_2D$, which is needed for active transport of Ca within the intestine. The presumption is that metabolic alkalosis somehow disrupts the integrity of PTH receptors on target tissues. Low CAD diets prevent metabolic alkalosis, increasing target tissue responsiveness to PTH, which controls renal 1"-hydroxylase and resorption of bone calcium.

Several options exist regarding methods for the control of milk fever (Horst *et al*., 1997). The current understanding of the CAD concept suggests that milk fever could be managed more effectively if dietary K as reduced (Goff and Horst, 1997). Calcium chloride has been used to reduce blood pH (Dhiman and Sasidharan, 1999; Schonewille *et al*., 1999b). This reduction is beneficial but excessive oral calcium chloride can induce metabolic acidosis (Goff and Horst, 1994), which can cause inappetence at a time when feed intake is already compromised. Dietary acidity can be monitored via the pH of urine, which should be below 7.5. Calcium propionate treatment has been beneficial in reducing subclinical hypocalcemia in all trials and reduced the incidence of milk fever in a herd having a problem with milk fever (Goff *et al*., 1996; Pehrson *et al*., 1998). Commercial preparations of HC1 mixed into common feed ingredients as a premix could offer an inexpensive and palatable alternative to anionic salts as a means of controlling the incidence of milk fever in dairy cows (Goff and Horst, 1998).

Treatment of milk fever returns serum Ca concentration to the normal range and must be carried out at the earliest possible opportunity to avoid muscular and nervous damage of downer cows. This is facilitated by maintaining close surveillance over cows that have calved in the preceding 72 hr. Calcium borogluconate is most commonly used, with Mg added to the injectable Ca preparation when hypomagnesemia is in evidence. The produce is preferably administered intravenously for rapid response, but subcutaneous administration permits slow absorption of the Ca ion and may lessen the danger of cardiac arrest.

Dietary mineral buffers: Mineral buffers are included in cow diets to improve lacational performance, milk composition and a favorable acid-base balance. Buffers are used in the diets of dairy cows to combat milk fat depression. Downer and Cummings (1987) estimated that more than 50% of all dairy farms in the US may be using dietary buffers, such as $NaHCO_3$G, for this purpose. Researchers have concluded that responses to dietary buffers occur via reduced ruminal acidity and subsequent improvements in systemic acid-base status, particularly during sudden ration changes.

Schneider *et al*. (1986) hypothesized that responses of lactating cows to dietary buffers are the result of both the HCO_3 (buffering effect) and Na moiety (solute effect). Russell and Chow (1993) suggested that bicarbonates function not by increasing ruminal buffering capacity, but by increasing water intake, ruminal fluid dilution, and flow of undegraded starch and by reducing ruminal propionate production (Staples and Lough, 1989).

Metabolic acidosis is a complicating factor in a number of diseases that affect cattle, including ketoacidosis, lactic acidosis (grain overload), enterotoxigenic diarrhea of calves, and some enteric diseases of adult cattle. Treatment with $NaHCO_3$, i.v. or orally, is an effective method to restore blood pH to normal (Kasari, 1990; Roussel, 1990).

Orally administered $NaHCO_3$ and Na propionate were equally effective in correcting the acid-base balance of blood (Bigner *et al*., 1997). Sodium propionate may be considered a more effective treatment of metabolic acidosis in diseases such as ketosis because the added propionate can serve as a source of glucose for the cow.

Phosphorus and environmental concerns: Increasing environmental concerns and proposed regulations have also stimulated renewed interest in the role of P in dairy cattle and feedlot rations (Spears, 1996; Erickson *et al*., 1999; Satter and Wu, 1999; Valk and Sebek, 1999). Environmental regulation, which limits the quantity of P applied to land, are either in place or are being considered in a number of countries.

Society wishes to maintain a reasonable level of productivity in lakes and rivers, but this requires the presence of very low levels of mineral nutrients. Several bodies of water have progressed from oligotrophic conditions (low mineral and high dissolved oxygen) to mesotrophic conditions and finally to eutrophic conditions (high mineral and low dissolved oxygen). Eutrification is the over enrichment of surface water with mineral nutrients. This results in the excessive production of algae and cyanobacteria. High levels of algae and cyanobacteria, with their high respiration rates, lead to low levels of dissolved oxygen, which in turn leads to a loss of aquatic animals (Correll, 1999). Phosphorus is the limiting element for freshwater algae and aquatic plants; therefore, P is the limiting nutrient for the eutrification process. Most discussions of pollution focus on reduction techniques in excreta. Phosphorus-reducing techniques center on better knowledge of the requirements and using more available sources of P. Excessive field trials in the UK and The Netherlands have shown that P surplus can be reduced by up to 90% by dietary manipulations without apparent detrimental effect on milk production (Valk *et al*., 2000). Recently published data showed dietary P level of 80% of current feeding practices had no effect on milk production or reproductive performance (Wu and Satter, 2000).

An additional environmental concern relates to fertilization with biosolids (municipal sewage sludge). The use of biosolids as pasture fertilizer is of interest to animal scientists because some contain high Mo, as well as other metals, which could be absorbed by plants and ingested by grazing species and thereby induce toxicity. Use of biosolids as fertilizer could prove beneficial, if they increase the often-deficient mineral status of tropical forages without creating an environment in which plants could accumulate excessive levels of undesirable metals.

Tiffany *et al*. (2000) reported mineral status of cattle that grazed forage fertilized with two high Mo (12 or 33 ppm) containing biosolids for 176 days. Forage Mo uptake was low due to good drainage and acid soils. However, resulting forages contained high S (>0.4%) which significantly reduced animal Cu status (liver and plasma). High dietary S reduces Cu absorption, possibly due to unabsorbable Cu sulfide formation, independent from its part in thiomolybdate complexes (Underwood and Suttle, 1999). If cattle are to graze pastures treated with high levels of biosolids where forages with low Cu status are grown, Cu supplementation is essential.

Providing free-choice minerals to grazing lactating cows: The most efficient methods of providing supplemental minerals in through use of mineral supplements combined with concentrates. This assures an adequate intake of mineral elements by each animal as it consumes other nutrients. This procedure represents an ideal system for providing supplemental minerals to lactating cows under more intensive production system but it cannot be used with grazing cattle which receive little concentrates and depend on forages.

Cattle not consuming concentrates are less likely to receive an adequate mineral supply; free-choice minerals are much less palatable than concentrates and are often consumed irregularly. Intakes of free-choice mineral mixtures by grazing cattle are highly variable and not related to mineral requirements (McDowell, 1985, 1999). Factors that affect the consumption of mineral mixtures have been listed by Cunha *et al*. (1964) and McDowell (1992, 1999) as follows: (1) soil fertility and forage type consumed, (2) season of year, (3) available energy-protein supplements, (4) individual requirements, (5) salt content of drinking water, (6) palatability of mineral mixture, (7) availability of fresh mineral supplies, and (8) physical form of minerals.

Biological availability of mineral sources: There is considerable difference in the availability of a mineral element provided from different sources. The bioavailability and percentage of mineral elements in inorganic sources commonly used in mineral supplements have been reported (McDowell, 1999). These variations in bioavailability of sources must be taken into consideration when evaluating or formulating a mineral supplement.

Excellent reviews on the significance of chelates and complexes of minerals for the feed industry have been prepared (Nelson, 1988; Kincaid, 1989; Patton, 1990; Spears *et al*., 1991). In a review, Spears (1991) concluded that the use of certain organic trace mineral complexes or chelates in ruminant diets has increased performance (growth and milk production), carcass quality and immune responses and decreased somatic cell counts in milk compared with animals fed inorganic forms of the mineral. Trace minerals sequestered as amino acid or polysaccharide complexes have the highest biological availability and also have a higher stability and solubility. These mineral forms also have a lack of interaction with vitamins and other ions and are effective at low levels. In cases where there is high dietary Mo, Cu in chelated form would have an advantage over an inorganic form as it may escape the complexing that occurs in the digestive system among Mo, Cu and S (Nelson, 1988).

Some studies have shown no benefit from chelated and complex minerals, but most have shown positive responses when compared to inorganic sources. Zinc and Cu complexed with proteins or amino acids, such a methionine or lysine, tended to have an advantage over inorganic forms of trace elements when given to stressed cattle.

Weaning weights were higher for zinc methionine and manganese methionine supplemented calves compared to control or oxide supplemented calves (Spears and Kegley, 1991). Herrick (1989) reviewed zinc-methionine feeding in four dairy trials and concluded that the Zn complex treated animals had lower somatic cell counts and higher milk yields than control cows.

Kincaid *et al*. (1986) compared copper proteinate and copper sulfate in terms of their ability to increase copper status in calves fed a diet naturally high in Mo (3.1 ppm) and low in Cu (2.8 ppm). Calves fed Cu proteinate had higher plasma (0.87 vs. 0.75 mg/1) and liver (325 vs. 220 ppm) Cu concentrations than calves supplemented with a similar level of Cu from the sulfate form after 84 days. Zinc in the form of zinc lysine resulted in the highest levels of metallothionein in liver, pancreas and kidney compared to other Zn sources, thus indicating a more bioavailable source of Zn (Rojas, 1994). Copper lysine at 16 ppm Cu was more beneficial for cattle that were borderline to deficient in Cu status versus copper sulfate (Rabiansky *et al*., 1999).

Much more needs to be learned about the selectivity of chelating agents toward minerals, the kind and quantity most effective, their mode of action, and their behavior with different species of animals and with varying diets. Dietary requirements for minerals may be greatly reduced by the addition of chelating agents to animal diets, but cost-to-benefit relationships need to be established.

The supplemental form of Se most widely used is the inorganic form of sodium selenite. An alternative organic Se source derived from yeast has been developed whereby Se is incorporated into the protein structure of growing yeast cells (Mahan, 1996). Dairy cattle have exhibited a higher glutathione peroxidase activity when the organic form of selenium is fed compared to when selenite was provided (Pehrson *et al*., 1998, cited by McDowell, 1999). In the future, organic Se will likely be an extremely important source of supplementation of this element.

Typical free-choice mixtures: Even though grazing cattle have been found not to balance their mineral needs perfectly when consuming a free-choice mixture, there is usually no other practical way of supplying mineral needs under grazing conditions. As a low-cost insurance to provide adequate mineral nutrition, modified complete mineral supplements should be available free-choice to grazing cattle (Cunha *et al*., 1964). A modified complete mineral mixture usually includes salts, a low fluoride-phosphorus source, Ca, Co, Cu, Mn, I, Fe and Zn. Except where selenosis is a problem, most free-choice supplements should contain Se. Magnesium, K, S, or additional elements can also be incorporated into a mineral supplement or can be included at a later date as new information suggests a need.

Calcium, Cu, or Se, when in excess, can be more detrimental to ruminant production than any benefit derived by providing a mineral supplement. In regions where high forage Mo predominates, three to five times the Cu content in mineral mixtures is needed to counteract Mo toxicity (Cunha *et al*., 1964). As little as 3 ppm Mo has been shown to decrease Cu availability by 50%. Sulfur at 0.4% can have the same effect. Thus, the exact level of Cu to use in counteracting Mo or S antagonism is a complex problem and should be worked out for each area. Table 3 lists the characteristics of a modified complete mineral supplement (McDowell, 1992).

Special free-choice mixtures: A oral Mg supplement is of value only during seasonal occurrences of grass tetany (Allcroft, 1961). Unfortunately, many commercial Mg-containing, free-choice mineral supplements are often of little value because (1) they contain inadequate amounts of Mg to protect against tetany during susceptible periods, and (2) provision of such supplements to normal animals during non-susceptible periods is useless as a prophylactic measure, since additional Mg will not provide a depot of readily available Mg for emergency use. Some producers feed Mg supplements about a month before the Mg tetany season, to decrease the amount of Mg needed daily during the susceptible period.

The provision of special high-Mg mineral blocks or mineral salt mixtures on pasture was more effective in raising blood Mg levels quickly after the initial drop than was the Mg fertilization (Reid *et al*., 1976). Various combinations of magnesium oxide with salt, protein supplements, molasses, other concentrate ingredients and other feeds have been used to obtain optimal Mg intakes. From West Virginia, average consumption of Mg by beef cows given a free-choice mixture of 40% salt, 40%

Table 3: Characteristics of a recommended complete free-choice cattle mineral supplement

An acceptable complete cattle mineral supplement should be as follows.

1. Contains a minimum of 6-8% total P. In areas where forages are consistently lower than 0.20% P, mineral supplements in the 8-10% P are preferred.
2. Has a Ca:P ratio not substantially over 2:1.
3. Provides a significant proportion (e.g. about 50%) of the trace mineral requirements for Co, Cu, I, Mn, and Zn.[a] In known trace mineral deficient regions, 100% of specific trace minerals should be provided.
4. Includes high-quality mineral salts that provide the best biologically available forms of each mineral element, and avoidance of minimal inclusion of mineral salts containing toxic elements. As an example, phosphates containing high F should be either avoided or formulated so that breeding cattle would receive no more than 30-50 mg/kg F in the total diet. Fertilizer or untreated phosphates could be used to a limited extent for feedlot cattle.
5. Is sufficiently palatable to allow adequate consumption in relation to requirements.
6. Is backed by a reputable manufacturer with quality-control guarantees as to accuracy of mineral-supplement label.
7. Has an acceptable particle size that will allow adequate mixing without smaller size particles settling out.
8. Is formulated for the area involved, the level of animal productivity, the environment (temperature, humidity, etc.) in which it will be fed., and is as economical as possible in providing the mineral elements used.

[3] For most regions it would be appropriate to include Se, unless toxicity problems have been observed. Iron should be included in temperate region mixtures but often both Fe and Mn can be eliminated for acid soil regions. In certain areas where parasitism is a problem, Fe supplementation may be beneficial.

dicalcium phosphate and 20% magnesium oxide ranged from 1.3 to 4.2 g per head per day (Reid *et al*., 1976). This compared to an intake level of 5-10 g Mg from a similar mixture containing 20% dried molasses, or 4.1-8.8 g Mg from commercial molasses-magnesium oxide blocks (15% mg).

Several relatively successful free-choice consumption formulas of both liquid and dry supplements are as follows: (1) magnesium oxide plus molasses at a ratio of 1:1; (2) 97% molasses plus 3% magnesium chloride (often with urea and a source of P); (3) equal parts of magnesium oxide, salt, bonemeal and grain; (4) a 1:1 ratio of salt and magnesium oxide. In the southeastern US, a complete mineral mixture with 25% magnesium oxide (14% Mg) has been effective in preventing a grass tetany in beef cattle (Cunha, 1973). Licking wheels or licking belts are sometimes used to slowly dispense Mg oxide or magnesium sulfate in molasses.

Other methods of tetany control, including administration of Mg through fertilizer, foliar application, enemas, water and injections, have been reviewed (McDowell, 1992; McDowell, 1999). Berger (1992) calculated that, in a 100-cow herd, preventing the loss of a single cow every 3 years from grass tetany would more than pay the cost of Mg supplementation.

Often young forages contain high concentrations of K, with K level an important risk factor in the development of tetany. Potassium decreases Mg absorption (Schonewille *et al*., 1999). However, there are some conditions where cattle need supplemental K. Generally, forages contain considerably more K than required by cattle. However, mature pastures that have weathered or hay that has been exposed to rain and sun or was overly mature when harvested can have K levels less than adequate for good nutrition (Karn and Clanton, 1977; McDowell, 1985). Potassium is a very soluble element, and dead material that is allowed to leach will have a reduced K content.

Even though mature forages are low in K, deficiency does not occur if ruminants are provided in the winter or dry season with a molasses-urea supplement. Molasses counteracts low forage K, as it has a high K level (about 4.0%). When molasses is too expensive for ruminant livestock supplementation, the chances of K deficiency are greatly increased.

Most often S is not included in free-choice supplements. Sulfur supplementation will most likely be needed to meet the requirements of ruminants when poor quality roughages grown on S-deficient soils or feed combined with urea are fed. There is no S in urea, therefore the element may need to be added when high levels of urea are fed. Pasture fertilization programs have changed in recent years from using a source of S in single-superphosphate (approx. 12% S) to triple-superphosphate and other high-analysis fertilizers that contain little or no S. In a review (Miles and McDowell, 1983) which summarized four cattle supplementation trials, control diets contained between 0.04 and 0.10% S. Intake by S-supplemented cattle increased from 7 to 260% and production of milk and meat increased by 6 to more than 400%.

Some reports from tropical regions indicate that S fertilization may increase forage intake by improving palatability of less palatable species. Low levels of S have been found in young regrowths of *Digitaria decumbens* and feeding a S supplement has increased voluntary feed intake by 28% (Rees *et al*., 1974). Holstein cows fed S-fertilized Bermudagrass hay had improved apparent digestibility of nitrogen and tended to consume more hay dry matter (Mathews *et al*., 1994).

Free-choice mineral supplement evaluation: Problems concerned with mineral supplementation programs in diverse world regions have been summarized (McDowell, 1999) and include: (1) insufficient chemical analyses and biological data to determine which minerals are required and in what quantities; (2) lack of mineral consumption data needed for formulating supplements; (3) inaccurate and/or unreliable information on mineral ingredient labels; (4) supplements that contain inadequate amounts or imbalances; (5) standardized mineral mixtures that are inflexible for diverse ecological regions (e.g. supplements containing Se distributed in a Se-toxic region); (6) farmers not supplying mixtures as recommended by the manufacturer (e.g. mineral mixtures diluted 10:1 and 100:1 with additional salt); (7) farmers not keeping minerals in front of animals continually; (8) difficulties involved with transportation, storage and cost of mineral supplements. Many of these problems are more related to tropical versus temperate regions, as in temperate regions (more developed countries) there is better quality control of products produced. However, some of the problems with temperate mineral mixes are related to inadequate quantities of Cu and Zn in mixtures, with some products low in P while others still not providing Se.

Responsible firms that manufacture and sell high-quality mineral supplements provide a great service to individual farmers. However, there are companies that are responsible for exaggerated claims of advertising, and some that produce

Table 4: An inferior mineral mixture available in Latin America[a,b,c]

	Mineral dietary allowance	Amount in mixture (%)	Allowance provided from mineral mix	% Allowance from mineral mixture (%)
Sodium Chloride	0.50%	20.00	0.10%	20.0
Calcium	0.30%	29.44	0.147%	49.1
Phosphorus	0.25%	1.80	0.009%	3.6
Magnesium	2000.0 mg/kg	3.2	0.016%	8.0
Iron	100.0 mg/kg	0.88	44.0 mg/kg	44.0
Zinc	50.0 mg/kg	0.02	1.0 mg/kg	2.0
Cobalt	0.1 mg/kg	0.002	0.1 mg/kg	100.0
Iodine	0.80 mg/kg	0.001	0.05 mg/kg	6.25
Copper	10.0 mg/kg	0.015	0.75 mg/kg	7.5
Manganese	25.0 mg/kg	0.075	3.75 mg/kg	15.0
Selenium	0.10 mg/kg	0.0005	0.025 mg/kg	25.0

[a]From McDowell *et al*., 1999). [b]Mineral mixture is recommended by the manufacturers for cattle, sheep, pigs and chickens. It is assumed that mineral consumption will average approximately 0.5% of the total dietary intake. This is based on an estimated intake of 50 g of mineral mixture for cattle and 10 kg of total dry feed per head daily. [c]Criticisms of mineral mixture are as follows: (1) the mixture is extremely low in P and exceptionally high in Ca. The Ca:P ratio is 16.4:1; (2) the supplement does not provide a significant proportion (i.e. 50%) of the trace mineral requirements of Cu, I, Mn and Zn; (3) the majority of the Fe is from ferric oxide, an unavailable form of this element; (4) since this contains 29.4% Ca and only 20% salt (NaC1), it is likely to be of low palatability.

inferior products that are of little value, or worse, those likely to be of detriment to animal production. Table 4 provides an example of an inferior mineral mixture available in Latin America. This particular mineral supplement is recommended for cattle, sheep, pigs and chickens. It is impossible to adequately meet requirements of both ruminants and monogastric animals with the same mixture. This unbalanced mineral mixture, which is extremely high in Ca (29.4%) and low in P (1.8%), would likely be more detrimental to grazing cattle than having no access to supplemental minerals, and may actually contribute to a P deficiency.

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