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Overview of Mineral Nutrition in Cattle: The Dairy and Beef NRC

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Introduction

Minerals are required for normal functioning of basically all biochemical processes in the body. A number of macro and microminerals have been shown to be essential for animals. Providing adequate amounts of essential minerals to meet animal requirements is critical to maximizing productivity and health of cattle.

Dietary requirements are a function of the metabolic requirement and endogenous or inevitable losses of a particular mineral and efficiency in which a mineral is absorbed from the diet. Requirements for most minerals are not constant, but are affected by a number of dietary and physiological factors that affect either absorption or metabolic demand. Physiological factors, that affect requirements of certain minerals, include genetics, age, sex, type of production (maintenance, growth, reproduction, and lactation), and level of production. Dietary factors usually affect mineral requirements by altering absorption of mineral from the gut. Mineral requirements in NRC and other publications are actually estimates of requirements. Precise requirements for a particular mineral under a given set of conditions may be lower or higher than values shown in NRC publications.

In the recent dairy cattle NRC (2001) requirements for most minerals were estimated using a factorial modeling approach. In contrast previous dairy (NRC, 1989) and beef NRC (1996) reports have estimated requirements for most minerals based on results from experiments where different mineral concentrations were fed to animals. This paper will discuss mineral requirements in the latest beef and dairy NRC publications and compare the different methods used to arrive at requirements. Recent research examining copper and cobalt requirements will also be reviewed.

Mineral Requirements in the Dairy NRC

The new dairy cattle NRC (2001) estimates the requirements for absorbed mineral based on needs for maintenance and production (growth, lactation, pregnancy). Dietary requirements were estimated by dividing the absorbed or net mineral requirements for a given mineral by an absorption coefficient. Maintenance requirements in the model were comprised of endogenous fecal and insensible urinary and sweat losses. The lactation requirement was determined from the concentration of mineral in milk multiplied by 4% fat-corrected milk yield. The requirement for growth was derived from the amount of mineral retained per kg body weight gain. The pregnancy requirement was defined as the amount of mineral retained within the reproductive tract (fetus, uterine contents, and uterus) at each day of gestation. Mineral requirements of females pregnant less than 190 days was considered small and not considered in modeling requirements.

The major advantage of the factorial approach is that requirements can be estimated for a wide range of production levels and stages. For example, in the dairy NRC (2001) estimated requirements of most minerals, when expressed as percent or mg/kg diet, vary with stage of pregnancy and level of milk production (Table 1).

Accuracy of mineral requirements derived from the factorial approach is dependent on the data used in the model. It is possible to determine the amount of a mineral present in milk and body gain with a high degree of accuracy. Maintenance requirements and absorption coefficients used in the model, potentially, are major sources of error. Both of these are difficult to accurately measure and as a result, studies estimating maintenance requirements and absorption coefficients are scarce for most minerals. Endogenous fecal losses comprise the major component of the maintenance requirement for most minerals. The endogenous fecal component consist of minerals secreted into the gut that are not reabsorbed. Mineral secretions into the gut include those in saliva, bile, digestive juices, and sloughed off intestinal cells. Measurement of endogenous fecal mineral generally requires the use of radioisotopes and values obtained can be affected by dietary level and body stores of mineral (Thompson, 1965).

Quantitative measurements of true absorption coefficients, especially for trace minerals, is difficult and research data are limited for many minerals. Absorption coefficients are also affected by dietary (antagonist, level of mineral, etc.) as well as animal related factors such as age and physiological state (non-lactating vs lactating). Absorption coefficients for minerals such as zinc, iron and calcium are most meaningful when they are measured at levels at or below the animal's requirement. When dietary levels of these minerals exceed requirements, homeostatic control mechanisms, within the animal, reduce percent absorption to maintain tissue mineral concentrations within a narrow range (Miller, 1975).

Mineral requirements for lactating cows, dry pregnant cows and growing heifers in the 2001 and 1989 dairy cattle NRC are compared in Table 2. Primarily because of the different approach used to arrive at requirements, estimated requirements in the 2001 NRC are slightly and in some instances substantially different from those published in the 1989 NRC. The most striking changes occurred for magnesium, iron, and manganese. Requirements for these minerals are considerably lower in the new dairy NRC. Calcium and phosphorus requirements were estimated using the factorial method in both the 1989 and 2001 NRC. Differences in estimated requirements for calcium and phosphorus between the two relate largely to different absorption coefficients and maintenance values being used in the models.

Mineral Requirements in the Beef NRC

With the exception of calcium and phosphorus, mineral requirements in the beef NRC (1996) were estimated using results from supplementation trials. The basic approach has been to supplement a diet deficient or suspected of being deficient in a mineral with one or more levels of the mineral. Responses in one or more criteria (growth, reproduction, bone strength, plasma or tissue mineral concentrations, etc.) are then measured as an indicator of the animal's requirement for a particular mineral. When sufficient studies have been conducted, it is possible to define mineral concentrations that are deficient and those that are clearly adequate. An advantage of supplementation trials is that one can arrive at an estimate of the requirement in the whole animal. However, supplementation trials rarely give precise estimates of requirements (because of the range in mineral levels evaluated) and it is difficult and costly to estimate requirements using experimental trials for cattle of different ages and at varying physiological states (growth, maintenance, reproduction, lactation, etc.).

Mineral requirements for different classes of beef cattle are shown in Table 3. Calcium and phosphorus requirements are not shown because requirements were estimated using the factorial method and vary greatly depending on factors including age, rate of growth, and milk production. For most trace minerals, research data from supplementation trials is not sufficient to estimate different requirements for growing cattle vs gestating or lactating cows.

Cobalt Requirements

Cobalt functions as a component of vitamin B_{12}. Ruminants are not dependent on a dietary source of vitamin B_{12} because rumen microorganisms are capable of synthesizing vitamin B_{12} from dietary cobalt. Depressed intake and growth are early signs of cobalt deficiency. As the deficiency becomes more severe, ruminants exhibit: 1) severe unthriftiness, 2) rapid weight loss, 3) pale skin and mucous membranes due to pernicious anemia, and 4) fatty degeneration of the liver (Smith, 1987).

Estimates of cobalt requirements in cattle have ranged from 0.07 to 0.11 mg/kg diet, based largely on observations in grazing animals (Mills, 1981). Recently, controlled studies (Schwarz et al., 2000; Stangl et al., 2000; Tiffany et al., 2001) have evaluated the cobalt requirements of growing cattle. In Germany, low term studies have been conducted with German Simmental bulls to define dietary cobalt requirements based on animal performance and vitamin B_{12} concentrations in plasma and liver. Bulls, with an average initial weight of 236 kg were fed corn silage ad libitum and 2.5 kg/d of an energy-protein supplement for 280 days. Graded levels of cobalt, as cobalt sulfate, were supplemented to the diet to provide total diet cobalt concentrations ranging from 0.07 to 0.69 mg Co/kg. Blood and liver samples for vitamin B_{12} determination were obtained at the end of the 280-day study (Stangl et al., 2000). Vitamin B_{12} concentrations in plasma and liver were much lower in bulls fed diets containing 0.07 or 0.09 mg Co/kg (Figure 1). Cobalt requirements were estimated to be 0.26 and 0.24 mg/kg diet based on plasma and liver B_{12} concentrations, respectively (Stangl et al., 2000).

Bulls fed the control diet containing 0.07 mg Co/kg had lower gains, feed intake and carcass weights at slaughter than animals supplemented with cobalt (Table 4; Schwarz et al., 2000). Based on regression analysis, cobalt requirements were determined to be 0.12 mg/kg for maximum growth and 0.16 to 0.18 mg/kg for maximum feed intake. Results of these studies suggest that cobalt requirements for maximum cattle performance are lower than those needed for maximum vitamin B_{12} concentrations in plasma and liver. The German studies also suggest that current cobalt requirement estimates of 0.10 (NRC, 1996) and 0.11 mg/kg (NRC, 2001) may be too low.

Research at North Carolina State University has examined cobalt requirements of growing and finishing Angus steers (Tiffany et al., 2001). Steers were fed a growing diet for 56 days followed by a high corn finishing diet for 112 days. The control diet analyzed approximately 0.04 mg Co/kg. Cobalt, as cobalt carbonate was added to the diet at levels of 0, 0.05, 0.10 or 1.00 mg/kg. Cobalt propionate also was evaluated at supplemental cobalt concentrations of 0.05 and 0.10 mg/kg diet. During the 56-day growing phase neither gain or feed intake was affected by level or source of cobalt. Plasma vitamin B_{12} was slightly ($P < 0.10$) lower in control steers at the end of the growing phase but liver B_{12} concentrations were not affected by dietary cobalt. Vitamin B_{12} concentrations in plasma were lower in control steers throughout the finishing phase. By day 56 of the finishing phase and at subsequent sampling days (84 and 112) plasma vitamin B_{12} concentrations were much higher in steers supplemented with 1.0 mg Co/kg diet compared to those receiving 0.05 or 0.10 mg Co/kg diet. Liver vitamin B_{12} concentrations were also increased by cobalt supplementation during the finishing study and tended to increase with increasing dietary cobalt. Feed intake and gain increased with cobalt addition and feed intake was highest in steers supplemented with 1.0 mg Co/kg from cobalt carbonate or 0.10 mg Co/kg from cobalt propionate. However, the higher intakes observed in steers fed the higher concentrations of cobalt were not associated with increased body weight gain, and gain and carcass weights at slaughter were maximized in steers supplemented with 0.05 mg cobalt (total diet cobalt of 0.09 mg/kg). Further studies are warranted to better define cobalt requirements of beef and dairy cattle.

Copper Requirements

It is well documented that copper requirements of cattle are greatly increased by high dietary concentrations of molybdenum and sulfur. High iron concentrations in feedstuffs, especially if the iron is in an available form, can reduce copper status and may increase copper requirements of cattle.

In addition to dietary factors, breed differences in copper metabolism may also affect copper requirements. Gooneratne et al. (1994) reported that biliary excretion of copper was much higher in Simmental than in Angus heifers. Angus heifers and their calves had higher plasma copper concentrations than Simmental or Charolais cattle when fed diets low in copper (Ward et al., 1995). Mullis (1997) conducted a 149-day study to examine copper requirements of Angus and Simmental heifers. Heifers were housed in confinement and fed a corn silage-based diet (analyzed 6.4 mg Cu/kg DM) supplemented with 0, 7 or 14 mg Cu/kg diet. Plasma copper concentrations in this study were affected by a treatment x breed x time ($P < 0.01$) and a treatment x breed ($P < 0.01$) interaction (Figure 2). Copper supplementation of the control diet increased plasma copper from day 37 until the end of the study in Simmental heifers. Plasma copper concentrations in Angus heifers were generally not affected by dietary copper. In non-copper supplemented heifers, Simmentals had lower plasma copper than Angus from day 37 until the end of the study. Breed differences were not found when 7 mg Cu was supplemented per kg diet. Liver copper concentrations at the end of the study also tended to be lower for control Simmental compared to control Angus heifers. When copper was supplemented at 7 or 14 mg/kg diet, liver copper concentrations were similar across breeds. Heifer performance was not affected by dietary copper in either breed. However, based on liver and plasma copper concentrations Simmental heifers required slightly more copper than Angus.

Copper metabolism also appears to differ between Holsteins and Jerseys. Two studies have indicated higher liver copper concentrations in Jersey than in Holstein cows when copper was supplemented at 80 (Du et al., 1996) or 20 mg/kg diet (Morales et al., 2000). Based on field observations, Jerseys may be more sensitive to copper toxicity than Holsteins (Du et al., 1996). It is unclear if minimal copper requirements differ between these two breeds.

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Table 1. Mineral requirements for Dairy Cows in the 2001 Nutrient Requirements of Dairy Cattle[a]

	Dry Pregnant Cow[b]			Lactating Cow[b]	
Days pregnant	240	270	279	—	—
Milk Production, kg/d	—	—	—	25	54
Calcium, %	0.44	0.45	0.48	0.62	0.60
Phosphorus, %	0.22	0.23	0.26	0.32	0.38
Magnesium, %	0.11	0.12	0.16	0.18	0.21
Chlorine, %	0.13	0.15	0.20	0.24	0.29
Potassium, %	0.51	0.52	0.62	1.00	1.07
Sodium, %	0.10	0.10	0.14	0.22	0.22
Sulfur, %	0.20	0.20	0.20	0.20	0.20
Cobalt, mg/kg	0.11	0.11	0.11	0.11	0.11
Copper, mg/kg	12	13	18	11	11
Iodine, mg/kg	0.4	0.4	0.5	0.6	0.4
Iron, mg/kg	13	13	18	12	18
Manganese, mg/kg	16	18	24	14	13
Selenium, mg/kg	0.3	0.3	0.3	0.3	0.3
Zinc, mg/kg	21	22	30	43	55

[a]From NRC (2001).

[b]Holstein cow with mature body weight of 680 kg.

Table 2. Comparison of Mineral Requirements in the 1989 and 2001 Nutrient Requirements of Dairy Cattle.

	Lactating Cow		Dry Pregnant Cow		Growing Heifer[d]	
	1989[d]	2001[b]	1989	2001[c]	1989	2001
Calcium, %	0.64	0.67	0.39	0.44	0.41	0.41
Phosphorus, %	0.41	0.36	0.24	0.22	0.30	0.28
Magnesium, %	0.25	0.20	0.16	0.11	0.16	0.11
Chlorine, %	0.25	0.28	0.20	0.13	0.20	0.11
Potassium, %	1.00	1.06	0.65	0.51	0.65	0.47
Sodium, %	0.18	0.22	0.10	0.10	0.10	0.08
Sulfur, %	0.20	0.20	0.16	0.20	0.16	0.20
Cobalt, mg/kg	0.10	0.11	0.10	0.11	0.10	0.11
Copper, mg/kg	10	11	10	12	10	10
Iodine, mg/kg	0.60	0.44	0.25	0.40	0.25	0.27
Iron, mg/kg	50	17	50	13	50	43
Manganese, mg/kg	40	13	40	16	40	22
Selenium, mg/kg	0.30	0.30	0.30	0.30	0.30	0.30
Zinc, mg/kg	40	52	40	21	40	32

[a]700 kg cow producing 48 kg/d of milk (3.5% fat).

[b]680 kg cow producing 45 kg/d of milk (3.5% fat).

[c]Dry cow 240 days pregnant.

[d]6 months of age.

Table 3. Mineral Requirements for Beef Cattle in the Nutrient Requirements of Beef Cattle[a]

	Growing and Finishing Cattle	Cows	
		Gestating	Early Lactation
Magnesium, %	0.10	0.12	0.20
Potassium, %	0.60	0.60	0.70
Sodium, %	0.06-0.08	0.06-0.08	0.10
Sulfur, %	0.15	0.15	0.15
Cobalt, mg/kg	0.10	0.10	0.10
Copper, mg/kg	10	10	10
Iodine, mg/kg	0.50	0.50	0.50
Iron, mg/kg	50	50	50
Manganese, mg/kg	20	40	40
Selenium, mg/kg	0.10	0.10	0.10
Zinc, mg/kg	30	30	30

[a]From NRC (1996).

Table 4. Effect of Dietary Cobalt on Growth and Feed Intake of German Simmental Bulls[1]

Dietary Cobalt mg/kg	Daily Gain kg/d	DM Intake kg/d	Carcass Weight kg
0.07	1.05[a]	6.01[a]	294[a]
0.09	1.13[a,b]	6.70[d]	312[a,b]
0.11	1.27[b,c]	7.01[c,d]	344[b,c]
0.15	1.24[b,c]	7.72[b]	341[b,c]
0.18	1.30[b,c]	7.99[b]	337[b,c]
0.26	1.27[b,c]	7.55[b.c]	334[b,c]
0.33	1.52[b]	8.16[b]	374[b]
0.42	1.41[b]	7.99[b]	363[b]
0.59	1.25[b,c]	7.91[b]	327[b,c]
0.69	1.30[b,c]	8.01[b]	347[b,c]

[1]From Schwarz et al. 2000.

[a,b,c,d]Means in a column with different superscript letters differ ($P < 0.05$).

Figure 1. Effect of dietary cobalt on plasma (▲) and liver (•) vitamin B_{12} concentrations in German Simmental male cattle. From Stangl et al., 2000.

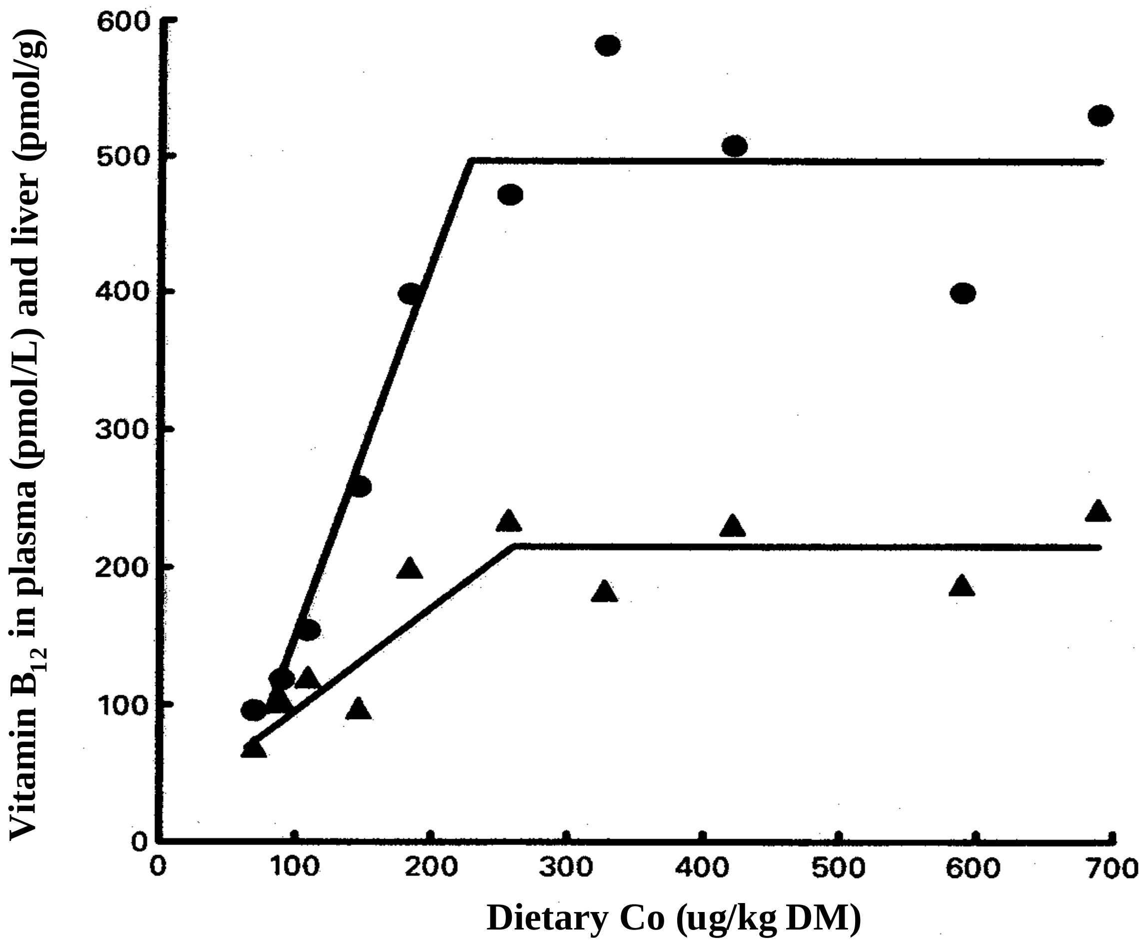

Figure 2. Effect of dietary Cu level on plasma Cu concentrations of Simmental and Angus heifers. Pooled SEM = .04. Treatment x breed x time interaction (P < .01). Treatment x breed interaction (P < .01). a = 0 ppm Cu vs 7 or 14 ppm Cu (P < .05), b = 7 ppm Cu vs 14 ppm Cu (P < .05).