Meeting the Trace Mineral Needs of Dairy Cows

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Take Home Messages

- Current Dairy NRC (2001) requirements for cobalt, manganese and zinc may not be sufficient to meet the needs of the cow.
- Trace mineral content of feedstuffs and mineral content of water can be quite variable.
- Antagonists and stress affect trace mineral absorption and utilization.
- Supplying a portion of the trace minerals from mineral sources, in which the metal is bound to an amino acid, reduces the effect of antagonists and stress on mineral availability.

1. Introduction

In January 2001, the Seventh Revised Edition of the Dairy NRC was introduced and in many respects was a vast improvement over previous editions. For example, in the Sixth Revised Edition of the Dairy NRC (1989), trace mineral requirements were the same for a 1700 lb mature mid-lactation cow consuming 55 lb dry matter (**DM**) and producing 70 lb milk as for a 1300 lb first calf heifer, 20 days fresh, consuming 42 lb DM and producing 100 lb milk. With the exception of cobalt (Co) and selenium (Se), the Seventh Revised Edition of the Dairy NRC (2001) introduced a factorial approach for determination of trace mineral requirements (Table 1). This consists of summing the trace mineral needs of weaned dairy cattle for maintenance, growth, pregnancy and lactation, then dividing this sum by the DM intake (**DMI**) to determine the required trace mineral concentration. An absorption coefficient is then applied to this sum to account for differences in bioavailability between trace mineral sources. This approach accounts for the impact of DMI on trace mineral intake, in addition to differences in trace mineral needs due to level of milk production, growth rate and stage of gestation (Figure 1). Trace mineral requirements for unweaned calves did not change substantially from the Sixth Revised Edition.

2. Research update on trace mineral requirements

While the Seventh Revised Edition of the Dairy NRC (2001) made vast improvements concerning trace mineral requirements of dairy cattle, recent research indicates that current NRC (2001) requirements for some trace minerals may not be sufficient.

2.1 Zinc (Zn) requirement for dry cows.

Required dietary Zn concentrations for dry and prefresh cows were reduced from 40 ppm (NRC, 1989) to 22 to 30 ppm (NRC, 2001), depending upon age and DMI. However, Tennessee researchers (Campbell and Miller, 1998), found that feeding an additional 800 mg Zn (400 mg from Zn methionine (Met; ZINPRO® zinc methionine) and 400 mg from Zn sulfate) to late gestation cows, which were already receiving a diet containing 102 ppm Zn, resulted in improved fertility and health postcalving. Cows fed additional Zn prepartum had fewer days to first estrus, less udder edema when cows were fed diets high in iron and tended to have fewer days to first service.

More recently, research with other species has found that feeding high levels of Zn to pregnant animals or injecting Zn into eggs improved gut development and health of offspring. Canadian researchers found that feeding sows an additional 250 ppm Zn from Zn amino acid (AA) complex (Availa®Zn) during the last trimester of pregnancy, resulted in improved intestinal development of pigs, as indicated by increased villous height (Caine et al., 2001). Furthermore, intestinal defenses of these pigs against pathogens appeared to have been improved as indicated by an increased number of intraepithelial lymphocytes. Similarly, North Carolina researchers found that injecting ZnMet (ZINPRO) *in ovo* at seventeen days of incubation resulted in significant increases in brush-border enzymes and transporters and in jejunal villous surface area (Tako et al., 2005). Results of these studies indicate that increasing Zn supply to pregnant dairy cattle has the potential to improve gut health and development of young calves.

2.2 Manganese (Mn) requirement

Required dietary Mn concentrations were decreased from 40 ppm (NRC, 1989) to 13 to 22 ppm (NRC, 2001). It should be noted that there was a limited amount of data available to the NRC committee to assist them in establishing a Mn requirement for dairy cattle. Since the publication of the NRC (2001), research at The Ohio State University found the average dry and lactating cow must consume 580 mg Mn/d in order to maintain a zero Mn balance (equates to 49 ppm Mn for dry cow diets and 28 ppm Mn for lactating cow diets; Weiss and Socha, 2005). While consuming 580 mg Mn/d resulted in the average dairy cow being in zero Mn balance, a number of cows consuming up to 1000 mg Mn/d were still in negative Mn balance (Figure 2). Furthermore, growing and pregnant dairy cattle should be in positive Mn balance due to tissue accretion. Therefore nutritionists should formulate diets to provide in excess of 580 mg Mn/cow/d to ensure that most cows in the dairy herd are at least maintaining Mn balance.

One potential benefit of increasing Mn supply to dairy cattle is improved reproduction. Manganese is necessary for synthesis of cholesterol, the precursor of the steroids, estrogen, progesterone and testosterone (Underwood and Suttle, 1999). Insufficient steroid production results in decreased circulating concentrations of these reproductive hormones resulting in abnormal sperm production in males and irregular estrous cycles in females (Miller et al., 1988). The ovary is relatively rich in manganese and appears to be particularly sensitive to dietary deficiencies of manganese (Hidiroglou, 1979). In addition, vaginal Mn concentrations are higher in cycling than in anestrous ruminants (Hidiroglou, 1976).

North Carolina researchers found that increasing Mn supplementation of growing beef heifers numerically improved fertility. In this study, heifers were fed a basal diet containing 15.8 ppm of Mn supplemented with 0, 10, 30 and 50 ppm Mn from Mn sulfate (Hansen et al., 2006). Increasing supplemental Mn from 0 to 50 ppm numerically increased heifers showing estrus after a prostaglandin injection from 40 to 50%, first service conception rates from 45 to 60%, and overall pregnancy rate from 60 to 75%

(Table 2). Inability to detect significant treatment effects despite sizable improvements in these measurements may be attributed to insufficient number of animals assigned to the study.

It should be noted that the heifers fed 0 and 50 ppm supplemental manganese continued to receive their respective treatments through parturition. The basal diet fed during gestation contained 16.6 ppm Mn, a level slightly below NRC (2001) requirements for late gestation cows of 17.8 ppm (body. Calves born to dams fed 0 ppm supplemental manganese exhibited varying signs of a manganese deficiency including superior brachygnathism, unsteadiness, disproportionate dwarfism and swollen joints (Hansen et al., 2006). Results of the study suggest that feeding gestating heifers diets containing 16.6 ppm is not adequate for proper fetal development.

Results from Nocek et al. (2006) indicate that increasing Mn supplementation of dairy diets improves fertility. In this study, lactating dairy cattle were either supplemented with Zn, Mn, copper (Cu) and Co at 75% of NRC (2001) requirements using AA complexes and glucoheptonate (75Z), 100% of NRC (2001) requirements for these trace minerals using either AA complexes and glucoheptonate (100Z) or sulfates (100S), or a combination of sulfates, AA complexes and glucoheptonate to provide lactating dairy cattle with Zn and Cu at 100% NRC (2001) requirements and Mn and Co at 3.3 and 9.1 times NRC (2001) requirements, respectively (Z/S). Compared to the other treatments, cows fed the Z/S treatment had fewer days to first estrus in lactations one and two and increased first service conception rate and pregnancy rate in lactation two (Table 3). While there were differences in trace mineral source and cobalt concentration between the 75Z, 100Z, 100S and Z/S treatments, the most notable difference between the Z/S treatment and the other treatments was the amount of Mn supplemented during lactation.

2.3 Cobalt requirement

The Co requirement listed in the Dairy NRC (2001) is 0.11 ppm DM. However, researchers at Washington State University found that lactating cows, in particular multiparous cows, benefit from consuming diets with Co levels well in excess of NRC (2001) requirements (Kincaid et al., 2003). In the study, increasing Co supplementation from 0 to 25 mg/hd/d increased production of milk and 3.5% fat-corrected milk in multiparous cows but not in primiparous cows.

Lack of response by first calf heifers to additional Co may be due to first-calf heifers having higher Co status than mature cows, as indicated by higher liver Co and serum vitamin B_{12} concentrations (Co is required for the formation of vitamin B_{12}). Analysis of diet and milk Co concentrations indicated that cows were in negative Co balance, assuming that 2% of dietary Co was absorbed by the animal (Kincaid et al., 2003; Table 4). This assumption is consistent with cobalt absorption estimates reported in the literature (Looney et al., 1976). In order for cows to be in zero Co balance, they would need to absorb 37, 20 and 11% of dietary Co, based upon the Co intakes of 8.8, 15.6 and 29.9 mg/hd/d, respectively (Table 4).

Results of Kincaid et al. (2003) are supported by Canadian research which found that early lactation cows fed diets containing 0.66 ppm supplemental Co had low serum vitamin B_{12} concentrations (Girard et al., 2005). Injecting cows, weekly, with 10 mg vitamin B_{12} increased production of energy-corrected milk, milk solids and milk fat (Girard and Matte, 2005).

In addition to lactation being a drain on Co/vitamin B_{12}, feeding high concentrate diets, typical of those fed to lactating dairy cows, appears to increase the Co requirement. Research has demonstrated that increasing the concentrate to forage ratio reduces the amount of vitamin B_{12} flowing from continuous culture fermentors (Allen, 1986; concentrate portion of diet increased from 30 to 60%) and decreases true vitamin B_{12} content of solid and liquid associated bacteria (Santschi et al., 2005; concentrate portion of the diet increased from 40 to 60%). Increasing supplemental Co concentration from 0.0 to 0.5 ppm increased the amount of vitamin B_{12} flowing from continuous culture fermentors (Allen, 1986) when fermentors were fed a 40% forage diet.

The decrease in true vitamin B_{12} production with increasing levels of concentrate may be attributed to increasing levels of nonfiber carbohydrates (NFC). Schwab et al. (2004) found that cows fed a 40% NFC diet had lower apparent ruminal vitamin B_{12} synthesis than cows fed a 30% NFC diet (73 vs. 100 mg/d). Nonfiber carbohydrate source may also affect ruminal production of vitamin B_{12} and required dietary Co concentration. Increasing dietary Co concentration from 0 to 0.15 mg added Co/kg DM increased ruminal B_{12} concentrations of steers fed corn-based diets but not steers fed barley-based diets (Table 5; Tiffany and Spears, 2005).

Together, these studies indicate that current NRC (2001) requirements appear to be insufficient to meet the Co requirements of early lactation dairy cows and that Co requirements of dairy cattle appear to be dependent upon level of milk production, NFC content of the diet and NFC source.

3. Factors Affecting Absorption Coefficients

Other factors that need to be considered when using the NRC (2001) to determine the amount of trace minerals to add to diets of dairy cattle are the absorption coefficients. In the Seventh Revised Edition of the Dairy NRC (2001), absorption coefficients were given for feedstuffs and inorganic sources of trace minerals. Absorption coefficients used to calculate required dietary concentrations (Table 1) were those applied to endogenous trace minerals in feedstuffs. In most cases, supplemental sources of trace minerals have higher absorption coefficients, thus reducing required dietary concentrations.

In addition, absorption coefficients used to calculate requirements assume “normal” intakes of elements that affect uptake of trace minerals. A safety factor is not included to account for variations in consumption of antagonists. Nutrition advisors need to be aware of trace mineral and antagonist content of dietary ingredients and adjust their recommendations accordingly.

Adjusting trace mineral recommendations in response to changes in intakes of trace minerals and antagonists can be difficult as feedstuffs can differ substantially from lot to lot in trace mineral content. This is especially true when forages and commodities are acquired from several sources. Agronomic practices, harvest methods and soil types impact Zn, Cu and Mn as well as molybdenum (Mo), sulfur (S) and iron (Fe) content of feedstuffs and forages.

Another factor that can affect trace mineral availability is soil consumption. British researchers found that plasma Cu levels of Cu deficient ewes increased when supplemented with Cu (Suttle et al., 1976). However, plasma Cu levels of Cu deficient ewes did not increase when supplemental Cu was added to diets containing 10% soil, indicating that the soil was reducing Cu absorption. Amount of soil consumed by cattle on dairies varies substantially depending upon harvest conditions, storage structures, conditions upon emptying of storage structures and grazing conditions. In a summary of 450 fresh, fall harvested, alfalfa silage samples, ash content ranged from 4.9 to 16.0% DM (average 10.2% DM; Figure 2; D. Taysom, Dairyland Laboratories, St. Cloud, MN; personal communication), indicating that the degree of soil contamination is variable and can be potentially quite high.

In a sampling of byproducts and forages from California and the Midwest, researchers and nutrition advisors found that Fe, Zn, Cu and Mn content of feed ingredients can deviate several fold (DePeters et al., 2000; Olson et al., 2002; Table 6). For instance, Fe content of alfalfa hay/silage ranged from 1 to 872 ppm and Cu content of wheat mill run ranged from 2 to 153 ppm (Table 6). Alfalfa silage fed at a rate of 10 lb DM/hd/d, or 20% of DM, would contribute between 0.2 and 174 ppm Fe. Feeding 4 lb/hd/d of wheat mill run would contribute between 0.2 and 12 ppm Cu. Thus mineral content of feed ingredients can, in some situations, increase the need for supplemental trace minerals and in other situations limit the amount of trace minerals that can safely be added to the diet.

Minerals supplied by water can also affect absorption of trace minerals. A summary of 5,549 water samples indicated that Ca, Cl, Na, Mg, S, Fe and Mn content of water can be variable and have a significant effect on intake of these minerals (Socha et al., 2009; Table 7). For instance, S content of water ranged from 0 to 1,553 ppm (Table 7). Lactating dairy cows drinking water containing 250 ppm S would consume 31 g of additional S (assuming cows are consuming 52.9 lb DM and 31.6 gallons of water). This translates into an additional 0.13 percentage units of dietary S. Fortunately, on most dairies, there are only one or two sources of water. Thus, most of the variation is between dairies, in contrast to feed ingredients that can vary from lot to lot within a dairy.

3.1 Absorption Coefficients are Not Static

Due to fluctuations in trace mineral and antagonist intake, true absorption coefficients of trace minerals vary. This variation impacts the amount of trace minerals needed to meet the true requirements of the animal. For example, increasing dietary S intake from 0.20% to 0.60% due to consumption of high S water reduces Cu absorption coefficient by 50% (NRC, 2001; Table 8). Changes in Mo intake also impact dietary Cu requirements, but to a lesser extent than changes in dietary S. Absorption coefficients reported for Cu in Table 8 do not reflect the antagonistic effects of high dietary levels of Fe and Zn.

4. Formulating Diets to Meet Trace Mineral Requirements of the Animal

Due to potentially large fluctuations in dietary trace minerals and antagonists, formulating diets to meet the trace mineral requirements of dairy cattle can be difficult. Nutrition advisors can employ one of three methods to compensate for these variations:

1. Implement an intensive feed analysis program, analyzing all lots of commodities, feedstuffs and forages, and alter trace mineral fortification levels accordingly. The logistics of this program would be extremely difficult;
2. Substantially increase dietary concentrations of inorganic trace mineral sources. This strategy does not account for potential trace mineral interactions and may, in reality, negatively impact animal performance and the environment; or
3. Feed levels of dietary trace minerals at or slightly above NRC (2001) requirements and include Zinpro Performance Minerals® at the recommended levels.

4.1 Feeding Lower Levels of Trace Minerals with a Portion Supplied by Performance Minerals Reduces the Risk for Trace Mineral Toxicity

Trace minerals fed in excess of requirements may not only impede absorption of other trace minerals, but may also be toxic. For most trace minerals there is a relatively large margin between amounts needed to meet requirements and the maximum tolerable level. However, for Cu, the safety margin is relatively low. Copper toxicities have been reported in Jersey cattle at dietary levels of 37 ppm Cu, approximately three times the NRC (2001) requirement (Olson et al., 1999).

4.2 Performance Minerals are Less Affected by Antagonists and Stress than Inorganic Sources

The difference in absorption of inorganic sources of trace minerals such as Zn sulfate and more bioavailable complexed sources such as ZnMet (ZINPRO) are minimal when level of antagonists are low, but increase when level of antagonists are high. This is illustrated in a study conducted by Wedekind et al. (1992). When chicks were fed diets formulated to contain only crystalline amino acids to minimize dietary fiber and phytate levels, the differences in availability of Zn from Zn sulfate and Zn from ZnMet were, although significant, minimal (Figure 4). However, when chicks were fed commercial diets formulated with soybean meal as the source of amino acids and hence contained higher dietary levels of antagonists such as fiber and phytate, the difference in availability of Zn from Zn sulfate and ZnMet increased dramatically (Figure 4).

Formulating diets containing lower levels of trace minerals with a portion of the trace minerals supplied by organic sources increases the probability that trace mineral requirements of animals will be met when dietary levels of antagonists are high but minimizes the risk of toxicity when dietary levels of antagonists are low.

The ability of animals to absorb and utilize trace minerals is affected by not only antagonists but also by stress level. In a study conducted at Colorado State University (Nockels et al., 1993), Cu balance was examined prior to subjecting calves to Cu restricted diets and induced stress. Calves then received a Cu restricted diet for nine days with stress being induced by feed and water restriction for three of the nine days.

Following the period of Cu restriction and induced stress, Cu balance was measured with calves receiving Cu supplied by either Cu sulfate or Cu lysine (CuLys; CuPLEX®). Results of the study showed that prior to the period of Cu restriction and induced stress, calves retained 3.6 mg or 8.1% of ingested Cu from Cu sulfate and 6.5 mg or 14.3% of ingested Cu from CuLys. Following the period of Cu restriction and stress, calves retained 1.5 mg or 3.3% of Cu from Cu sulfate and 6.9 mg or 15.0% of Cu from CuLys, indicating that stress had a greater impact on retention of Cu from inorganic sources than from CuLys.

4.3 Performance Minerals Improve Animal Performance

Research has shown that replacing inorganic sources of trace minerals with Performance Minerals improves animal performance. In a summary of six dairy trials, replacing 360 mg Zn from inorganic Zn, 200 mg Mn from inorganic Mn, 125 mg Cu from inorganic Cu and 12 or 25 mg Co from inorganic Co with similar amounts from ZnMet, MnMet, CuLys and Co glucoheptonate (4®Plex), resulted in improved fertility and increased production of milk, energy-corrected milk and milk components (Kellogg et al., 2003; Ferguson et al., 2004; Kincaid and Socha, 2004; Table 9). Control and treatment diets in all studies met or exceeded trace mineral requirements. Liver biopsies were collected in only two of the six studies, thus it can only be assumed that cows assigned to most of these studies had adequate trace mineral status.

A study completed in Florida indicates that cows with adequate to high trace mineral status benefited when sulfate forms of Zn, Mn, Cu and Co were replaced with Zinpro Performance Minerals (Ballantine et al., 2002). Despite control and treatment diets containing 231%, 628%, 153% and 1,364% of NRC (2001) requirements for Zn, Mn, Cu and Co, respectively, cows fed Performance Minerals (Availa®4) produced more milk and energy-corrected milk, had fewer days open, tended to be more likely to be pregnant at 150 d postpartum and tended to have fewer claw lesions at 75 days postpartum.

5. Trace Mineral Recommendations

Dairy cattle trace mineral recommendations from Zinpro Corporation are provided in Table 10. As noted above, we believe that the NRC (2001) Co and Mn requirements for dairy cattle and the Zn requirements for dry and prefresh cows are lower than desired and our recommendations reflect these sentiments. For the other trace minerals, our recommendations mirror NRC (2001) requirements. Again, requirements given in the new NRC (2001) do not contain a safety factor. However, several safety factors have been built into recommendations given in Table 10 including:

1. Recommendations are supplemental, not total diet. Requirements given in NRC (2001) are total diet;
2. NRC requirements given in Table 1 and Figure 1 of this paper are calculated using absorption coefficients given for feedstuffs. Absorption coefficients given for sulfates and Performance Minerals are higher than those used for feedstuffs, reducing the amount of supplemental trace minerals needed; and
3. Recommendations include a portion of the trace minerals being supplied by Performance Minerals. Absorption of Performance Minerals is less affected by stress and antagonists.

6. Comments Regarding Iron Recommendations

In the NRC (2001), it is stated "iron deficiency in adult cattle is very rare – in part because their requirement is reduced, but also because iron is ubiquitous in the environment, and soil contamination of forages (and soil ingested by animals on pasture) generally ensures that iron needs of the adult will be met or exceeded…" Thus many nutritionists have either reduced or removed supplemental iron from diets of adult dairy cattle.

It should be noted that there is limited research available examining the effect of feeding adult dairy cattle supplemental iron. Most recently research has examined the effect of feeding steers and dairy cattle supplemental iron on gossypol absorption. Adding 150, 300, 450 and 600 ppm of iron from iron sulfate to diets of steers consuming approximately 10 g of gossypol per day, reduced plasma total gossypol concentrations by 30.7, 27.0, 41.7 and 53.3%, respectively (Santos et al., 2005). Weight gain of steers was unaffected by treatment.

Due to the potential concerns with gossypol and its effect on fertility (Santos et al., 2003), there may be beneficial effects of supplementing dairy cattle, consuming diets containing large amounts of cottonseed, with iron. McCaughey et al. (2005) found that supplementing diets of lactating dairy cattle with 250 and 500 ppm of iron from iron sulfate reduced total plasma gossypol concentrations by 23.7 and 28.2%, respectively. While adding 250 and 500 ppm of iron from iron sulfate decreased milk yield by 3.87 and 7.63%, respectively, milk energy output increased 0.7% when cows were fed the diet containing 250 ppm iron.

In humans, iron deficiency is a common nutritional problem despite iron being one of the most common elements on earth (Dallman, 1990). Possible explanations include common forms of iron being relatively insoluble and poorly absorbed and phytate and fiber, in diets containing whole grains and legumes, reducing iron availability (Dallman, 1990). In addition, iron found in soil appears to be of limited availability. New Zealand researchers found that feeding sheep diets containing 712 to 978 ppm of iron from soil for 76 days did not increase significantly iron content of liver (Grace et al., 1996).

Children and women of child bearing age appear to be most prone to iron deficiency (Dallman, 1990). With pregnancy, erythrocyte volume increases as much as 18 to 30% in the later stages of gestation (King and Weininger, 1990).

Clearly more research is needed to determine if cattle in late pregnancy are prone to iron deficiency or to determine if supplementing dairy cattle with low to moderate levels of iron can reduce gossypol absorption while maintaining or enhancing performance of cattle.

7. Comments Regarding Iodine Recommendations

In May, 2000, FDA Office of Regulatory Affairs revised the Compliance Policy Guide for ethylenediamine dihydroiodide (EDDI) allowing producers to feed cattle 49.9 mg EDDI (provides approximately 40 mg iodine) per day. However, in October, 2000, Sharon Benz from FDA sent out an email noting that while dairy producers were allowed to feed 49.9 mg of EDDI, "…it is the producer's responsibility to make sure that the milk is safe." She noted that "...up to 30 mg of EDDI/day could be fed without causing unsafe iodine levels in the milk."

In a summary of studies, Irish researchers found that dairy cattle needed to receive 30 to 60 mg iodine per day to maintain adequate iodine status as noted by plasma inorganic iodine concentrations (Rogers, 1999). It should be noted that in several of these studies, potassium iodide was the source of supplement iodine. As compared to EDDI, iodine volatilization tends to be greater with potassium iodide (NRC, 2001). Thus higher levels of iodine from potassium iodide may need to be fed to provide dairy cattle with the same amount of absorbable iodine as compared to providing supplemental iodine in the form of EDDI.

In the Irish studies, milk iodine levels ranged from 0.02 ppm to 0.4 ppm (Rogers, 1999). According to current guidelines, humans can safely consume up to 1000 µg I per day (Hetzel, 1990). Dairy products commonly provide about 50% of the total iodine consumed by humans (Rogers, 1999). Milk iodine concentrations greater than 0.3 ppm are considered high (Rogers, 1999) with milk processors taking action with producers when milk iodine levels exceed 0.8 ppm.

Clearly more research needs to be conducted with iodine to determine how much EDDI needs to be fed to maintain adequate iodine status in dairy cattle and how much EDDI can be fed to cows while maintaining safe levels of iodine in milk.

8. Summary

The Seventh Revised Edition of the Dairy NRC (2001) made significant positive improvements in identifying the trace mineral requirements of dairy cattle. However, more recent research indicates that (NRC, 2001) Mn and Co requirements for late gestation and lactating dairy cattle and Zn requirements for late gestation cattle may not be adequate. Furthermore, the absorption coefficients used to calculate requirements account for limited antagonistic relationships between minerals. The task of ration formulation is further complicated by substantial variation in trace mineral and antagonist content of feedstuffs and water. These fluctuations can have a significant impact on absorption coefficients, affecting the trace mineral requirements of the animal, as well as the amount of trace minerals that can safely be added to the diet.

Nutrition advisors can compensate for fluctuations in trace mineral and antagonist content of feedstuffs by either substantially increasing fortification levels with inorganic sources or by feeding trace minerals at or slightly above NRC (2001) requirements with a portion of the minerals supplied by Performance Minerals. By supplementing trace minerals at or slightly above NRC (2001) requirements and including Performance Minerals at the recommended levels, nutrition advisors:

1. Increase probability of meeting requirements of cows when cows are consuming high levels of antagonist;
2. Increase the probability of meeting requirements of cows during stress;
3. Reduce the risk of a trace mineral toxicity; and
4. Improve animal performance.

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Table 1. Example of NRC (2001) trace mineral requirements of cows in different stages of the lifecycle

Animal Description	Dry Cow[a]	Prefresh Cow[b]		Fresh Cow[c]		Lactating Cow[d]		
		Entering 1st lactation	Entering 2nd lactation					
Milk lb/d	-	-	-	55	77	77	99	120
DMI, lb/d	31.7	23.4	30.2	29.7	34.3	51.9	59.2	66
Trace Mineral, ppm DM								
Cobalt	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
Copper[e]	12	16	13	16	16	11	11	11
Iodine[f]	0.4	0.4	0.4	0.88	0.77	0.5	0.44	0.4
Iron	13	26	13	19	22	15	17	18
Manganese	16	22	18	21	21	14	13	13
Selenium	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Zinc	21	30	22	65	73	48	52	55

[a] Holstein cow: BW, with conceptus 1609 lb, mature BW without conceptus 1499 lb, body condition score (BCS) = 3.3, 57 mos. of age, 240 d pregnant, calf weight = 99 lb, gaining 1.5 lb with conceptus

[b] Holstein cow: 270 days pregnant, mature BW 1499 lb, BCS = 3.3, Entering 1st lactation, BW 1378 lb with conceptus gaining 2.1 lb with conceptus; Entering 2nd lactation or greater, BW 1656 lb with conceptus

[c] Holstein cow: BW 1499 lb, mature BW 1499 lb, BCS = 3.3, 58 mos. of age, milk fat = 3.5%, milk true protein = 3.0%, milk lactose = 4.8%, days in milk = 11

[d] Holstein cow: BW 1499 lb, mature BW 1499 lb, BCS = 3.0, 65 mos. of age, milk fat = 3.5%, milk true protein = 3.0%, milk lactose = 4.8%, days in milk = 90

[e] High dietary molybdenum, sulfur, and iron can interfere with copper absorption, increasing the requirement

[f] Diets high in goitrogenic substances or nitrates increase the iodine requirement

Table 2. Effect of dietary manganese on reproductive performance of beef heifers[a] (Hansen et al., 2006)

	Supplemental Manganese[b], mg/kg			
Item	0	10	30	50
Estrus after $PGF_{2\alpha}$[c], %	40	40	47	50
1st service conception rate, %	45	40	47	60
Overall pregnancy rate[e], %	60	50	67	75

[a] Heifers started the trial at 10 months of age; Control diet contained 15.8 mg/kg Mn

[b] Supplied by Mn sulfate

[c] Response to prostaglandin was based upon two doses of prostaglandin given at 13 mos of age

[d] Rectal palpation and/or ultrasound at d 196 of the study

Table 3. Effect of trace mineral level and source on reproductive performance (Nocek et al., 2006).

Item	Treatments[a]			
	75Z	100S	100Z	Z/S
	Lactation One[b]			
Days to first estrus	56^{z}	54^{z}	54^{z}	47^{y}
Services/conception	2.3	2.4	2.2	1.9
Days Open	120	118	115	104
	Lactation Two[b]			
Days to first estrus	57^{z}	56^{z}	56^{z}	50^{y}
First service conception rate, %	31.7^{yz}	29.6^{y}	33.5^{yz}	36.9^{z}
Services/conception	2.6	2.5	2.7	2.2
Days open	129	132	135	116
Pregnant by 159 d, %	60.7^{y}	61.4^{y}	61.0^{y}	70.6^{z}

[a] 75Z and 100Z treatments; Zn, Mn, Cu and Co supplied ZINPRO® ZnMet, MANPRO® MnMet, CuPLEX® CuLys and COPRO® Co glucoheptonate at 75 and 100% of NRC (2001) requirements for early lactation cows; 100S treatment: Zn, Mn, Cu and Co supplied by $ZnSO_4$, $MnSO_4$, $CuSO_4$ and $CoSO_4$ at 100% of NRC (2001) requirements; Z/S treatment: Zn, Mn, Cu and Co supplied by 4-Plex and $ZnSO_4$, $MnSO_4$, $CuSO_4$ and $CoSO_4$ at Zinpro Corporation recommendations; Cows received treatments beginning in the dry period through lactation 1, dry period through 200 d in lactation 2

[b] For lactation 1, includes only cows which completed lactation 1 and began lactation 2; For lactation 2, includes only cows which completed 200 d in lactation 2 and were not designated as "do not breed".

[yz] LSmeans lacking a common superscript letter differ, $P \leq 0.05$

Table 4. Cobalt (Co) balance of early lactation dairy cows fed varying amounts of Co (Kincaid et al., 2003)

Measurement	Dietary Treatments[a]		
	Low Cobalt	Medium Cobalt	High Cobalt
Cobalt intake, mg/d	8.8	15.6	29.9
Milk cobalt output, mg/d	3.3	3.1	3.3
Absorbed cobalt at 2% efficiency, mg/d	0.18	0.31	0.60
Absorbed cobalt minus milk cobalt, mg/d	-3.1	-2.8	-2.7
Absorption efficiency needed to = output, %	37	20	11

[a] Low Co diet supplied 8.8 mg Co/d; medium Co diet, 15.6 mg Co/d; and high Co diet, 29.9 mg Co/d. Additional Co supplied by COPRO Co glucoheptonate.

Table 5. Effect of cobalt (Co) supplementation and grain source on ruminal vitamin B_{12} concentration of finishing steers (Tiffany and Spears, 2005)

Item	Added Co, mg/kg DM[a]		
	0	0.05	0.15
Overall ruminal B_{12}[b], pmol/mL	1.35	1.40	2.28
Corn based diets, ruminal B_{12}, pmol/mL	1.37	1.70	3.37
Barley based diets, ruminal B_{12}, pmol/mL	1.34	1.10	1.18

[a] Added in the form of Co carbonate. Corn-based diet contained 0.04 ppm Co and the barley based diet contained 0.02 ppm Co.

[b] Grain source effect, $P \leq 0.05$; Level effect, 0.05 vs. 0.15 mg Co/kg DM, $P \leq 0.05$

Table 6. Iron (Fe), zinc (Zn), copper (Cu) and manganese (Mn) content of selected feedstuffs[a].

Ingredient	Number of Samples	Iron Range, ppm	Zinc Range, ppm	Copper Range, ppm	Manganese Range, ppm
Alfalfa hay/silage	96	1 – 872	16 – 368	1 – 32	1 – 169
Almond hulls	22	74 – 709	7 – 30	1 – 15	11 – 35
Beet pulp	20	183 – 447	18 – 43	0 – 7	41 – 94
Brewers grain	21	103 – 163	75 – 161	7 – 21	43 – 71
Canola meal	10	203 – 295	56 – 65	3 – 5	56 – 60
Citrus pulp, wet	10	46 – 79	6 – 11	2 – 4	5 – 13
Corn	6	1 - 241	19 - 29	0 - 8	4 - 10
Corn gluten feed	10	80 – 152	46 – 76	3 – 5	14 – 27
Corn silage	213	1 – 1714	9 – 57	1 – 37	9 – 67
Distillers grain, dried	10	141 – 217	50 – 55	0 – 6	33 – 45
Grass hay/silage	3077	1 – 1400	8 – 74	2 – 18	1 – 195
Hominy feed	10	75 – 182	33 – 53	1 – 4	11 – 22
Mixed forage hay/haylage	331	1 - 1282	1 - 107	1 - 28	11 - 97
Molasses	10	123 – 277	4 – 77	2 – 13	22 – 121
Small grain silage	91	1 - 1005	14 – 52	3 – 49	9 – 67
Rice bran	10	74 – 266	51 – 61	1 – 9	172 – 219
Safflower meal	10	258 – 414	76 – 346	20 – 46	27 – 510
Soy hulls	10	145 – 847	15 – 44	4 – 9	11 – 43
Wheat mill run	10	58 – 433	22 – 82	2 – 153	34 - 151

[a] From DePeters et al., 2000, Olson et al., 2002, and www.dairylandlabs.com/pages/interpretations/forage_2008.php, accessed 5/6/09

Table 7. Variation in mineral content of 5,549 water samples and amount of mineral supplied by water as a percent of mineral requirements (Socha et al., 2009).

Mineral	Mineral Content of Water, ppm		% of NRC (2001) Requirements Supplied By Water[a]	
	Median	Maximum	Mean	Maximum
Calcium	61	689	4.5	51
Magnesium	20	682	4.6	155
Chloride	24	3712	4.0	620
Potassium	3	759	0.1	37
Sodium	14	1556	2.8	314
Sulfur	10	1553	3.0	444
Copper	0.01	13.00	0.4	545
Iron	0.10	123.00	2.8	3487
Manganese	0.03	12.70	1.0	425

[a] NRC (2001) requirements for a lactating cow, BW 1499 lb, 0 d pregnant, body condition score 3, 30 days in milk, third lactation, 13 month calving interval, 110 lb milk/d, 3.8% fat, 3.0% true protein, 68 °F, no grazing.

Table 8. Impact of varying sulfur and molybdenum concentration on absorption coefficient of copper (NRC 2001).

Sulfur, % DM	Molybdenum, ppm DM	Absorption Coefficient for Dietary Copper
0.20	1	0.046
0.40	1	0.031
0.60	1	0.021
0.25	0.5	0.043
0.25	1	0.042
0.25	2	0.039
0.25	5	0.031
0.25	10	0.022
0.25	20	0.010
0.25	100	0.003

Table 9. Summary of dairy trials evaluating Performance Minerals[a], iso trials (Kellogg et al., 2003; Ferguson et al., 2004; Kincaid and Socha, 2004).

Measurement	n[b]	Control	Performance Minerals[c]	*P* =[d]
Milk, lb/d	6	79.7	81.4	0.07
ECM[e], lb/d	6	80.6	82.6	0.01
3.5% FCM[f], lb/d	6	80.8	82.7	0.02
Fat, lb/d	6	2.86	2.92	0.04
Protein, lb/d	6	2.43	2.50	0.01
Solids (fat+protein), lb/d	6	5.29	5.43	0.01
Fat, %	6	3.61	3.62	0.82
Protein, %	6	3.06	3.09	0.33
SCC, 1000s/mL	4	256	267	0.64
Days to first service	4	71	66	0.07
Days open	5	143	130	0.10
Services/conception	4	2.7	2.4	0.18
Cows pregnant at 150 d postpartum, %	2	56.5	69.5	0.07

[a] 4-Plex®, Zinpro Corporation, Eden Prairie, MN

[b] Number of trials in which data were available on selected parameter, averages presented as LSmeans

[c] In two studies, the control diet provided 360 mg Zn/hd/d from zinc methionine; in five studies, both diets contained equivalent amounts of Zn, Mn, Cu and Co; in one study, both diets supplied equivalent amounts of Zn, Mn and Cu, but the 4-Plex diet supplied an additional 13 mg Co/hd/d

[d] Model for statistical analysis included effect of trial (block) and treatment within trial (experimental unit)

[e] Energy-corrected milk, 3.5% fat and 3.0% true protein

[f] Fat-corrected milk, 3.5% fat

Table 10. Trace mineral recommendations for dry and early, mid and late lactation cows[a].

Trace Mineral	Supplemental, ppm DM		Performance/Organic
	Dry or Early Lactation Cows	Mid to Late Lactation Cows	
Zinc	75 to 85	55 to 65	360 mg
Manganese	55 to 75	40 to 55	200 mg
Copper	14 to 16	10 to 12	125 mg
Cobalt	0.8 to 1.2	0.6 to 0.9	25 mg
Iodine	0.9 to 1.1	0.7 to 0.8	100% (EDDI)
Iron	0 to 10	0 to 10	0
Selenium	0.3	0.3	

[a] Holstein cow, calving BW, 1400 lb; peak milk, 110 lb; 8% decline in milk yield after peak, peak milk 2 months after calving, 365 d milk yield, 30,714 lb; NRC predicted DMI; default environmental conditions; conception date, 5 months after calving; average milk fat, 3.5%; average daily gain with conceptus, 0.4 lb/d.

Figure 1. Effect of lactation and gestation on Zn, Mn, Cu and Fe requirements (ppm DM basis). Requirements based upon a Holstein cow, calving BW, 1400 lb; peak milk, 110 lb/d; peak milk two months after calving; 365 day milk yield, 30,174 lb; NRC predicted DMI; default environmental conditions; conception date five months after calving; average milk fat, 3.5%; average daily gain with conceptus, 0.4 kg. Cows are dried off at 12 months postcalving.

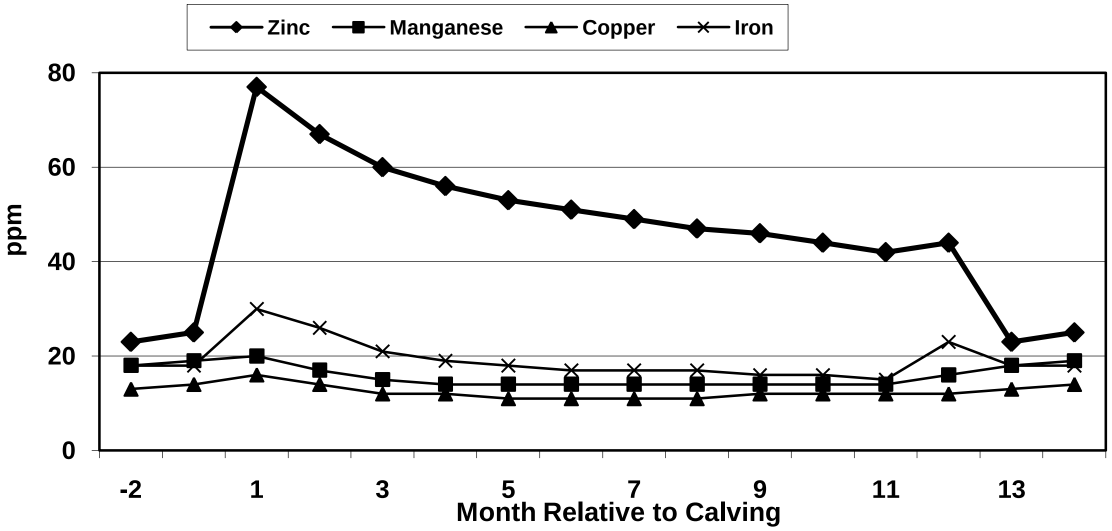


Figure 2. The relationship between Mn intake and apparent Mn balance in dry and lactating dairy cows. Each point represents a cow or cow-period and are adjusted for random trial effects. The circles represent lactating cows and the triangles represent dry cows. The red line represents the relationship between Mn intake and Mn balance. Analysis indicates that Mn balance equals zero when Mn intake equals 580 mg/d (Weiss and Socha, 2005).

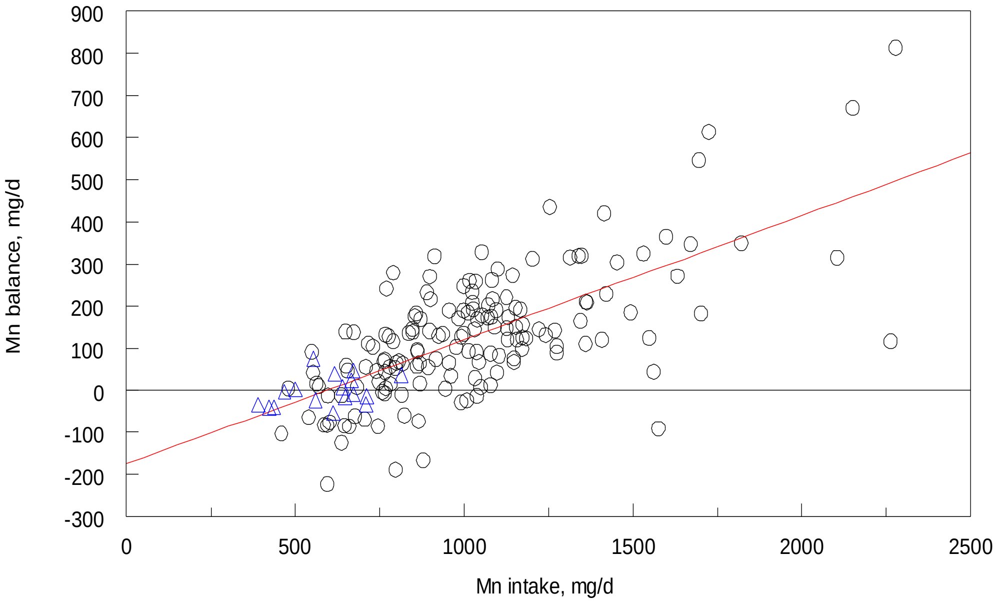
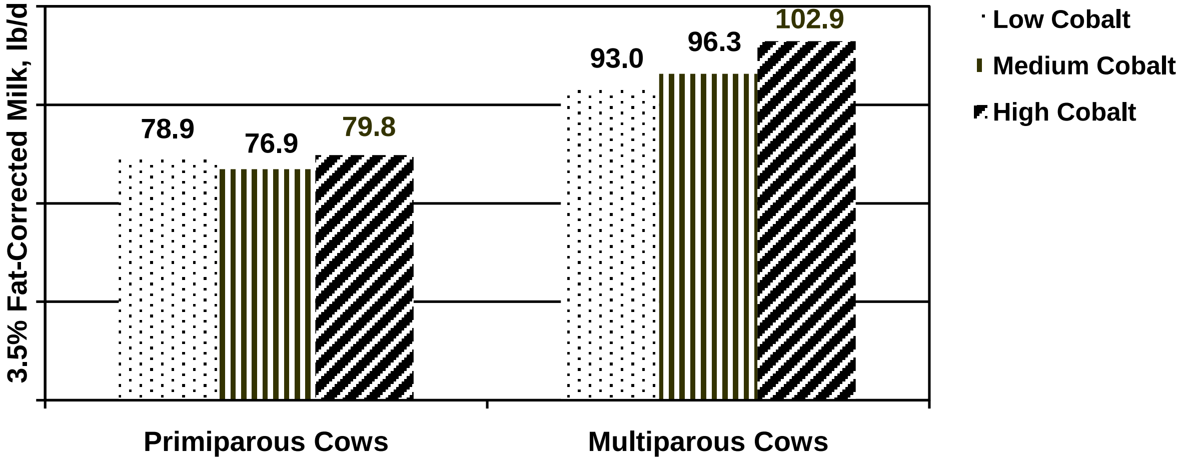


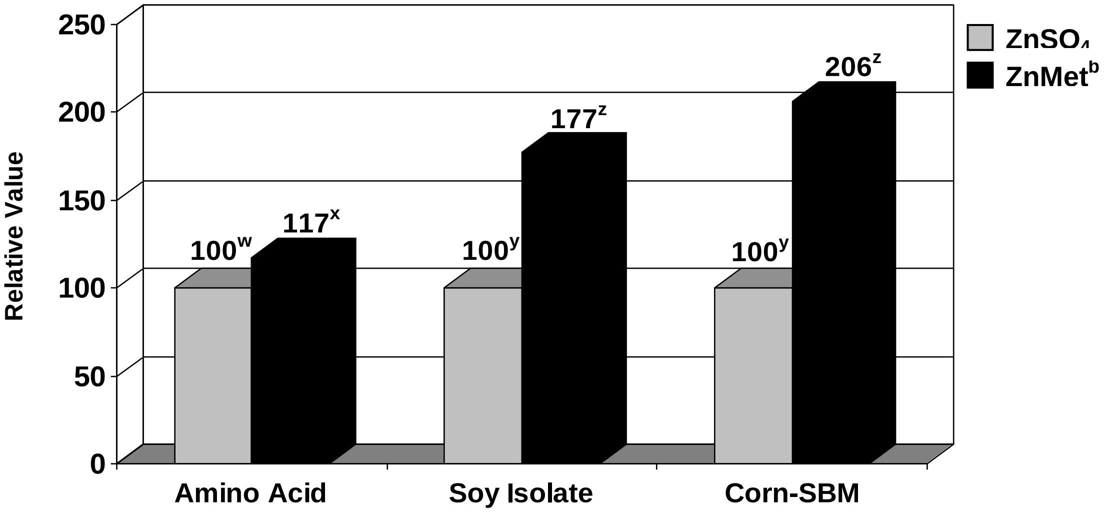
Figure 3. Effect of parity and level of cobalt supplementation on 3.5% FCM yield (Kincaid et al., 2003)[az]



[a] During lactation, amount of Co/d were low Co diet, 8.8 mg, medium Co diet, 15.6 mg, and high Co diet, 29.9 mg. Additional Co supplied by CoPRO Co glucoheptonate.

[z] Treatment X parity X week interaction ($P \leq 0.01$)

Figure 4. Bioavailability[a] of zinc (Zn) from Zn methionine (Met) relative to Zn from Zn sulfate (Wedekind et al., 1992)



[a] Bioavailability estimated using multiple regression analyses of total tibia Zn in chicks; zinc sulfate set to 100

[b] Zinpro Corporation, Eden Prairie, MN

[wx] Means lacking a common superscript letter differ ($P \leq 0.05$)

[yz] Within diet type, means lacking a common superscript letter differ ($P \leq 0.01$)