Assessing the Role of Copper and Zinc in the Cow-Calf Production Cycle

John Paterson[a], Connie Swenson[b], Bruce Johnson[b] and Ray Ansotegui[a]
[a]Montana State University and [b] Zinpro Corporation

INTRODUCTION

Trace minerals are needed for vitamin synthesis, hormone production, enzyme activity, collagen formation, tissue synthesis, oxygen transport, energy production, and other physiological processes related to growth, reproduction and health. The priority of use for these physiological processes varies. For example, growth, feed intake, and feed efficiency may not be altered during subclinical deficient states, although impairment of reproduction or immune-competence may occur. The requirement of trace minerals is often based upon the ability of the animal to maintain desired production performance parameters.

Table 1: Trace mineral requirements for growing and finishing cattle (NRC, 1996).

	Requirement, mg/kg	
Mineral	Growing and Finishing Cattle	Cows
Cobalt	0.1	0.1
Copper	10	10
Iodine	0.5	0.5
Iron	50	50
Manganese	20	30
Selenium	0.1	0.1
Zinc	30	30

Table 1 shows the trace mineral requirements for growing and finishing cattle, and cows (NRC, 1996). These requirements are based upon average cattle consuming average diets. Copper requirements are suggested to be 10 mg/kg of DM intake but can vary depending upon other dietary components. Table 2 describes effects of Cu, Zn and Mn deficiencies on the fertility of cattle. Because copper utilization can be low in ruminant diets, and especially when the antagonists Mo and S are present in moderate to high levels, the NRC recommendations may require adjustment. Molybdenum and sulfate form thiomolybdates in the rumen when fed in excess. Thiomolybdate complexes Cu at both the gastrointestinal and tissue level rendering it unavailable to the animal (Allen and Gawthorne, 1987; Gooneratne et al., 1989; Suttle, 1991). Disorders associated with a simple or induced (high Mo and S) Cu deficiency include anemia, diarrhea, depressed growth, change of hair color, neonatal ataxia, temporary infertility and weak, fragile long bones which break easily (Underwood, 1981). Recently, Herd (1997) indicated that there is concern that trace elements may be limiting production in better-managed herds to a much greater extent than previously recognized. Subclinical trace mineral deficiencies in cattle may be a larger problem than an acute deficiency, because specific clinical symptoms are not evident to allow the producer to recognize the deficiency (Wikse, 1992). Animals with a subclinical status can continue to reproduce or grow, but at a reduced rate, with decreased feed efficiency, and a depressed immune system (Nockles, 1994). Correcting subclinical mineral deficiencies in animals that have been nutritionally stressed may have a positive economic impact on cattle production efficiency.

Table 2: Review of the influence of Cu, Zn and Mn on fertility of beef cattle

Mineral	Female	Male	References
Cu	Delayed estrus Embryonic death Decreased conception Delayed puberty Decreased ovulation	Decreased libido Decreased spermatogenesis	Corah and Ives, 1991 Herd, 1994 Hidiroglou, 1979 Ingraham et al., 1987 Kappel et al., 1984 Phillippo et al. 1987
Zn	Increased dystocia Abnormal estrus	Impaired growth Delayed puberty Decreased testicular size Decreased libido	Duffy et al., 1977 Mass, 1987 Apgar, 1985 Pitts et al., 1966 Puls, 1990
Mn	Increased anestrus Increased abortion Decreased ovarian activity Decreased conception rates	Increase in abnormal sperm	Brown and Casillas, 1986 Corah and Ives, 1991 Pugh, 1985

ASSESSING TRACE MINERAL STATUS IN BEEF CATTLE

In reviewing the responses to trace mineral supplementation, we have asked the question "Were the responses due to level of intake, form of mineral intake (inorganic vs organic) or a response to overcoming an antagonistic effect (Mo, S or Fe)?" The approach we have followed with producers is to first test the forages, then the water and finally conduct a liver biopsy to make recommendations. The easiest and least expensive are the first two.

Forage mineral content and bioavailability varies because of factors such as soil mineral level, soil pH, climatic conditions, plant species and even stage of plant maturity (Spears, 1996). When comparing grasses to legumes grown in the same location, legumes have been shown to be higher in Ca, Cu, Zn and Co than grasses (Greene et al., 1998). Distribution of the mineral in the plant, chemical form and mineral interactions can also influence bioavailability.

Table 3 describes average values obtained from grass, grass-legume and legume hay samples collected over the past two years in Montana. The most noticeable deficiencies were for Cu and Zn.

Current NRC dietary recommendations are 10 ppm for Cu and 30 ppm for Zn. Of the forages analyzed, all had average Cu and Zn values much lower than these recommendations, indicating that supplementation would be warranted. Although, fewer samples were analyzed for Mo, concentration in grass hays were high enough to consider antagonistic effects on the utilization of Cu (Cu:Mo ratio of less than 5:1). These results would be in agreement with those reported by Corah and Dargatz (1996) who reported that 64% of forages analyzed were deficient to marginal in Cu and 97.5% were deficient to marginal in Zn. Herd (1997) published average trace mineral values for native grasses analyzed in the Texas A&M Forage Testing Lab (Table 4).

Table 3: Average nutrient concentration of grasses, forage-mixes and legumes for Montana.

Forage Type	No. Samples	Crude Protein%	TDN %	Ca %	P %	S %	Cu, ppm	Mo, ppm	Cu:Mo ratio	Zn, Ppm
Grasses	151	9.6	54.9	.62	.16	.14	5.2	1.45	3.6	18.2
Forage-Mix	163	13.1	57.9	.85	.21	.19	7.0	.81	8.6	19.2
Legumes	58	17.9	62.7	1.4	.24	.26	8.8	1.15	7.7	21.4

Table 4: Variation in forage mineral content for native grasses from Texas (adapted from Herd, 1997).

Mineral	Average	Commonly Observed
Calcium, %	.48	.29-.67
Phosphorus, %	.10	.04-.16
Magnesium, %	.12	.07-.17
Potassium, %	.91	.28-1.54
Sulfur, %	.13	.07-.19
Iron, ppm	205	43-367
Copper, ppm	5	3-7
Manganese, ppm	50	25-75
Zinc, ppm	21	13-29

Figure 1: Analyses of water samples for sulfate concentration from twelve Montana Ranches (Livermont, 1998, unpublished).

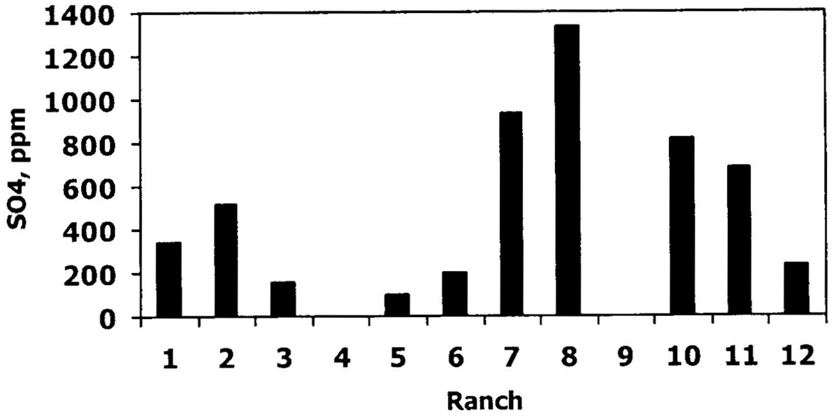
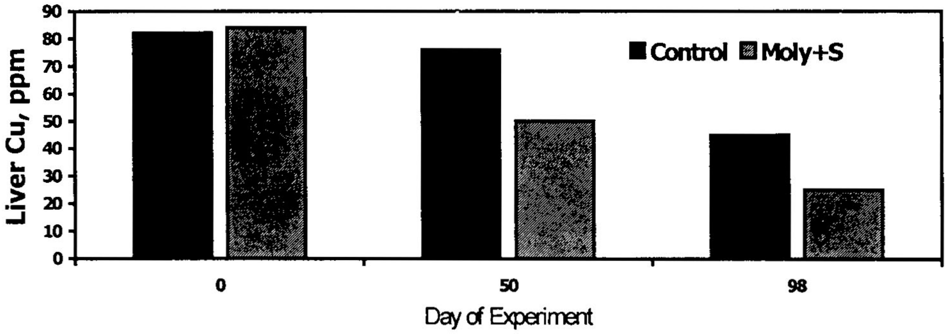


Figure 2: Change in liver copper concentration when cattle were supplemented with Mo and S (adapted from Arthington et al., 1996).



In addition to forage quality, livestock water quality is often considered in making nutritional recommendations. Figure 1 shows the variation in sulfate concentration of water for twelve ranches in Montana. The values above 400 ppm sulfate cause us to question the effects on Cu utilization. Independent of Mo, dietary S can also reduce Cu absorption (Suttle, 1974). Our concern has been the interaction that molybdenum and sulfur consumption has on the utilization of copper. This concept is demonstrated by the work of Arthington et al. (1996) who showed that copper levels in the liver were significantly reduced when molybdenum and sulfur were supplemented to beef cattle (Figure 2).

These data show that supplementing both S and Mo resulted in a reduction in liver stores of Cu. Ward et al. (1993) also demonstrated that Mo and S supplementation reduced plasma Cu concentrations in steers after 21 days of feeding, and impaired Cu metabolism.

LIVER BIOPSY TO DETERMINE CU, ZN AND MN STATUS

In diagnosing Cu status, serum may not be a good indicator of status because not all Cu circulating in the blood is available to the animal. Serum levels can be influenced by Mo, sulfate, infection, trauma and stage of production (Puls, 1990). Serum Cu levels are not highly correlated to liver Cu levels (Clark et al., 1993). For example, cattle with low plasma Cu levels had adequate liver Cu levels (Mulryan and Mason, 1992). Stoszek et al. (1986) found that animals with liver Cu levels of 25 ppm had plasma Cu levels between .07 to 1.0 ppm, while animals with liver Cu levels between 100 and 400 ppm also had plasma Cu levels close to .9 ppm. Table 5 describes the status levels for Cu, Zn, Mn and Fe in the bovine liver. For Cu and Zn, approximately 100 ppm (DM basis) is assumed to be adequate for the bovine, while 10 ppm is adequate for Mn.

To assess trace mineral levels from a regional basis, a nine-state survey was conducted to determine the variation in Cu, Zn, Mn and Mo levels of bovine liver. Twelve hundred and forty three cows were sampled by the use of liver biopsy. States included in the survey were CO, KS, MO, MT, NE, ND, OK, SD and TX. Table 6 presents the number of cows biopsied and the average, minimum and maximum liver concentrations for these trace elements.

Evaluating the average liver Cu concentrations would suggest that cows from CO, NE, ND and SD would be considered deficient to marginal in status. Manganese levels were marginal for MT, NE, ND, OK and SD. Zinc levels appeared to be adequate based on the recommendations from Table 5. The minimum and maximum values indicate wide variation in liver copper storage. However, the values were sorted by state to indicate the percentage of cattle which may be deficient, marginal or adequate in liver copper (Table 7) based on the recommendations defined in Table 5.

Cows from CO, KS, NE, ND and SD had high percentages of cows considered to be of marginal status. Three questions arise from this survey:

- When should a liver biopsy be conducted?
- How does liver copper concentrations change throughout the year?
- Does a high level of Mo in the liver influence availability of copper to the animal?

We have concentrated to date on the first two questions.

Table 5: Status and concentration of Cu, Zn, Mn and Fe in bovine liver (ppm on a DM Basis)[a].

Status	Copper	Zinc	Manganese	Iron
Deficient	<25	<40	<3.5	<30
Marginal	30-90	50-90	5-10	40-60
Adequate	100-200	100-300	9-21	75-300
High	300-550	400-800	14-80	400-700

[a] Adapted from numerous sources

Table 6: Average, minimum and maximum concentrations of liver Cu, Zn, Mn and Mo of cattle from nine states, (ppm on a DM basis)

State	No. Animals Sampled	Cu (Min-Max)	Zn (Min-Max)	Mn (Min-Max)	Mo (Min-Max)
CO	329	73 (5.3-368)	125 (2.9-299)	14.7 (1.9-1222)	5.7 (2.1-16.0)
KS	257	108 (1.3-454)	181 (13-980)	11.5 (2.0-241)	5 (2-8.2)
MO	32	122 (19-237)	109 (89-145)	16.0 (7.5-128)	3.7 (1.5-4.5)
MT	182	102 (29-304)	120 (89-196)	8.3 (5.6-11.9)	3.6 (2.2-6.1)
NE	78	20.4 (4.1-125)	126.6 (4.7-227)	8.5 (5.1-54.5)	3.5 (2.2-5.1)
ND	113	12 (3.9-78)	144 (1.4-640)	8.0 (6.2-10.0)	2.9 (1.8-3.7)
SD	162	39 (3.8-291)	123 (83-237)	8.6 (6.4-11.3)	3.5 (2.4-5.7)
TX	60	121 (6.5-458)	143 (57-759)	11.2 (1.4-60.8)	3.1 (.2-6.8)

Appreciation is expressed to Drs. Brink (NE), Corah (KS), Johnson, Whittier (CO) and Wikse (TX) who contributed data for this survey.

To answer the first question, Swenson, (1998) repeatedly biopsied sixty spring-calving cows starting at 30 days precalving, at parturition, at breeding, at weaning and again just before calving the next year. These results are presented in figure 3.

Results from this experiment indicate that the cows had adequate liver Cu stores pre-calving (110 ppm) but became marginal by the time of parturition (80 ppm). We interpreted these results to indicate a maternal transfer of Cu to the fetus during the last trimester of pregnancy. Copper reserves were increased during the summer and fall and did not appear to decline until just before calving the next year. Serum Cu changes did not appear to be indicative of liver copper changes.

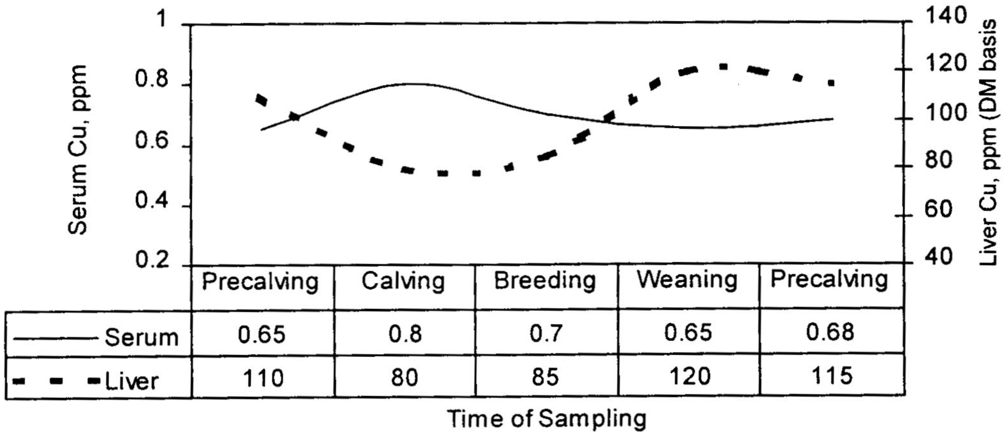
EFFECT OF FORM OF SUPPLEMENTAL MINERALS

Traditionally, supplemental trace minerals have been supplied to livestock in the form of inorganic salts, sulfates, oxides and chlorides. The use of organic trace minerals has increased due to reports of improved feed efficiency, growth, reproduction and immune response (Manspeaker et al., 1987; Chirase et al., 1991; Swenson, 1998). Power et al. (1994) showed bioavailability of zinc proteinate to be 159% of the bioavailability of zinc sulfate in rats. Lovell (1994) reported that zinc methionine had 300-400% the potency of zinc sulfate in young channel catfish. Table 8 (adapted from Greene et al., 1998) compares the bioavailability of several trace elements from different sources.

Table 7: Percentage of cattle which were classified as deficient, marginal or adequate in liver Cu concentrations.

		------------ % of cattle	---------------------	
State	No Cattle	Deficient <30 ppm	Marginal < 60 ppm	Adequate >90 ppm
CO	329	30	49	30
KS	257	16	39	51
MO	32	6	13	63
MT	182	.2	12	61
NE	78	55	77	12
ND	113	92	96	0
SD	162	65	69	27
TX	60	10	23	62

Figure 3: Changes in liver and serum copper concentrations for beef cows (Swenson, 1998).



	Precalving	Calving	Breeding	Weaning	Precalving
——— Serum	0.65	0.8	0.7	0.65	0.68
- - -Liver	110	80	85	120	115

Other work has suggested that the bioavailability of Cu-lysine was similar to $CuSO_4$ in chicks (Baker et al., 1990) and steers (Ward et al., 1992). Du et al. (1996) showed that the utilization of Cu from either Cu-proteinate or Cu-lysine was higher than Cu-sulfate based on rat liver Cu content. Interestingly, these data also revealed that high dietary Zn decreased the utilization of Cu, but this effect could be overcome by increasing Cu in the diet. Wellington et al. (1998) came to a similar conclusion with beef heifers (Figure 4). In this study, heifer calves were fed 5 ppm Mo and supplemented with either Cu-amino acid complex (15 ppm in the diet) or Zn-amino acid complex (90 ppm in the diet) to determine the effects on liver Cu changes over 90 days. Data indicate that Cu-supplementation alone increased liver Cu by 24%, while Zn supplementation alone decreased liver Cu levels by 41%. But, supplementing both Cu and Zn increased liver Cu by 103%.

Herd (1997) hypothesized that the usage of organic forms of trace minerals may be of greater value when an animal is under nutritional, disease or production stress. Ward et al. (1992) demonstrated that source of trace minerals may result in differences in ADG and feed intake. Their data showed improved performance for incoming feedlot calves during the first two weeks compared to feeding the sulfate form of trace minerals (Table 9).

Eckert et al. (1999) conducted a study with crossbred ewes comparing copper sulfate to copper-proteinate fed at three levels (10, 20 or 30 ppm of diet). Although no observable Cu toxicity was measured, feeding Cu-proteinate resulted in greater ceruloplasmin activity than $CuSO_4$, but liver Cu was greater when $CuSO_4$ was fed.

Recently, Bailey et al. (1999) conducted two 100-day studies with growing heifers (24 heifers in each trial with an average weight of 643 lbs) to determine if source of supplemental Cu and Zn, in the presence of the antagonists Mo, S and Fe, influenced liver Cu levels. Supplemental trace mineral treatments were: 1) basal supplement with no additional Cu or Zn (Control), 2) 250 mg/d Cu and 500 mg/d Zn in sulfate form (Sulfate), 3) same as treatment 2, but 50% of the Cu and Zn were provided from amino acid-complex form and 50% was from the sulfate form (2-Way), 4) same as treatment 2, but the ratios of Cu and Zn were 50% amino acid complex form, 25% sulfate-form and 25% from the oxide form (3-Way). In addition to the supplements all animals were individually fed the antagonists in the following DM concentrations: 10 ppm Mo, 3,000 ppm S and 450 ppm Fe. A basal diet of chopped hay and a barley-based concentrate was formulated to achieve 1.5 lb/day gain. Liver biopsies were taken on days 0, 25, 50, 75 and 100 and analyzed for trace minerals. Copper loss over the 100 day trial was slower ($P < .05$) for supplemented heifers compared to Control heifers. With the high levels of antagonists fed in these trials, rate of Cu loss was slower ($P < .05$) when heifers were fed the 2-Way supplement compared to heifers fed either the 3-Way or sulfate treatments between days 25 and 50 of the experiment. These data do suggest that form of supplemental mine ral does react differently in the presence of antagonistic minerals in the diet.

Table 8: Relative bioavailability of trace minerals from different sources (adapted from Greene et al., 1998)

Mineral	Sulfate	Oxide	Carbonate	Chloride	Organic
Co	100	31[a]	110[a]	-	85[g]
Cu	100	0[b]	-	105[c]	130[h]
Fe	100	0[d]	0-75[d]	-	-
Mn	100	58[e]	28[e]	-	176[i]
Zn	100	-	60[f]	40[f]	159[j]-206[k]

[a] Henry (1995)
[b] Kegley and Spears (1994)
[c] Ivan et al. (1990)
[d] Spears (1996)
[e] Wong-Valle et al. (1989)
[f] Kincaid (1979)
[g] Kawashima et al. (1986)
[h] Kincaid et al. (1986)
[i] Fly et al. (1989)
[j] Power et al. (1994)
[k] Wedekind et al. (1992)

EFFECTS OF TRACE MINERALS ON REPRODUCTION AND IMMUNITY

Reproduction

Doyle et al. (1988) conducted a study in which Zn, Cu and Mn supplementation were compared to no additional Cu, Zn or Mn. The average length of time from the beginning of the breeding season to conception was 22d for trace mineral supplement treatment vs. 42 d for non-supplemented cows. Manspeaker et al. (1987) compared no supplementation to supplementation with Cu, Zn, Mn, Fe and Mg (chelated forms) for dairy heifers. Results of this experiment are presented in table 10.

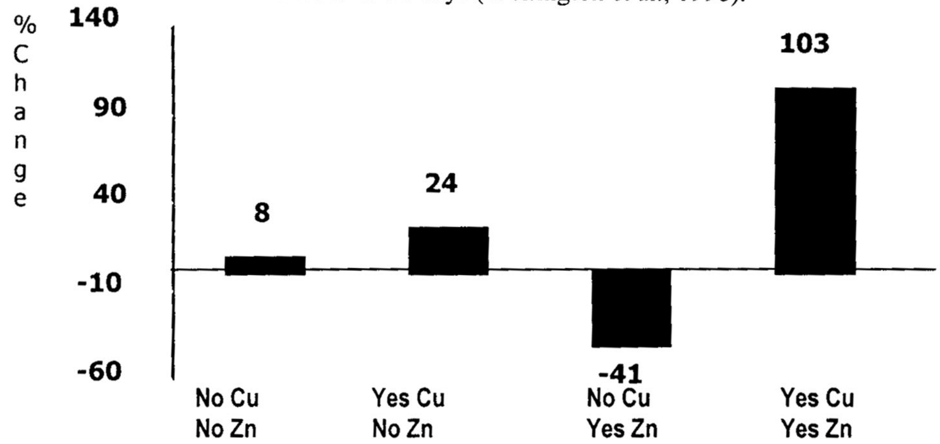
Supplementation reduced the percentage of infections, embryonic mortality, endometrial scarring and improved postpartum involution and tone of the pregnant horn. Swenson (1998) supplemented Cu, Zn, Co and Mn in either the inorganic-sulfate form or in a complexed-form to first calf heifers. These results showed that even though the percentage of significant structures and cows exhibiting estrus by day 45 was lower when complexed minerals were supplemented, the percentage of cows bred by AI was improved (Table 11). In another study (Swenson, 1998), days to conception were reduced by ten in first calf heifers supplemented with amino acid complex forms of Cu, Zn, Mn and Co compared to sulfate forms and controls with no additional trace minerals.

Phillipo et al. (1987) conducted two heifer studies with barley grain- straw based diets containing 4 ppm Cu and 5 ppm Mo (.80:1 Cu:Mo ratio). Molybdenum supplementation resulted in delayed onset of puberty, decreased conception rate and caused anestrus in cattle without accompanying changes in Cu status or in liveweight gain. It was proposed that the effects of Mo were associated with a decreased release of luteinizing hormone that might be due to an altered ovarian steroid secretion. Earlier work by Case et al. (1973) found that cattle grazing pasture on soil with an elevated Mo content had reduced fertility, while Peterson and Waldern (1977) described a negative association between the Cu:Mo ratio of silage and fertility in dairy herds in Canada.

Immunity

Trace mineral requirements are determined largely by animal growth or reproductive response, and not by the ability of the immune system to respond to a challenge. There is increasing evidence that the concentrations of trace elements required for healthy animals are often below what is required for animals experiencing an immunological challenge (Berger, 1997; Beisel, 1982.). Research (Stabel et al., 1993) has indicated that Cu deficiency affects various physiological characteristics that may be important in immunological defense to pathogenic challenge. Woolliams et al. (1986) showed that Cu supplementation affected the resistance of sheep to bacterial infections. Genglebach and Spears (1998) showed that when Mo was supplemented to a diet containing adequate Cu, no differences were apparent in plasma or liver Cu. However, calves fed

Figure 4: Effect of supplementing Cu, Zn or Cu+ Zn on change in liver Cu concentrations in beef heifers after 90 days (Wellington et al., 1998).



the Mo had a more severe Cu deficiency based on depressed humoral-immune response and super-oxide dismutase activity. In another study, Ward and Spears (1999) concluded that Cu deficiency and 5 ppm Mo in the diet did not dramatically alter the specific immunity of stressed cattle. Genglebach et al. (1997) showed that when diets were marginally deficient in Cu with supplemental Fe and Mo added, body temperature and feed intake responses to disease were affected. Ward et al. (1997) concluded that Cu deficiency and Cu deficiency coupled with high dietary Mo or Fe intake produced inconsistent immune function responses, indicating Cu deficiency may not affect specific immune function in calves. Ansotegui et al. (1994; Figure 5) found that cell mediated immune response was faster and significantly higher when complexed-forms of Cu, Zn, Co and Mn were fed compared to sulfate forms of the same minerals or to cows which were not supplemented. This study was conducted without additional antagonists added to the diet. Subsequent responses have been much more variable when antagonists have been provided.

Zinc has been shown to have a positive impact on immunity in stocker and feedlot cattle with limited research in beef cows. Weaned calves normally experience stress due to transportation, changes in feed and handling, which increase susceptibility to infectious diseases. During this period of stress, providing adequate dietary Zn may be critical, because stress has been shown to have a negative impact on Zn retention (Nockels et al., 1994). Infection can also have a detrimental effect on Zn status in cattle. Infecting cattle with a bovine rhinotracheitis challenge increased urinary Zn excretion, which caused a negative balance (Orr et al., 1990). Feed intake is often depressed when feeder cattle are stressed and the reduction in intake results in decreased trace mineral ingestion Supplying Zn to steer calves which had undergone stress (weaning, transportation, exposure to new cattle and vaccination) was shown to increase feed intake (Spears and Kegley, 1991), while Chirase et al. (1991) showed that dietary Zn enhanced the recovery rate of IBR-stressed cattle.

SUMMARY

Data from Montana and Texas indicate that copper and zinc are deficient in many of the forages cattle consume. Coupled with the antagonistic effects of Mo and S, this may require additional supplementation with copper, because it would also appear that there are a fairly large number of cows who have the potential to be deficient to marginal in liver Cu and Mn stores. However, experimental results do suggest that single trace element supplementation can be antagonistic (e.g. excessive Zn depressing liver Cu stores) or symbiotic (Cu and Zn both supplemented). Supplemental trace minerals have been shown to have positive effects on reproduction, immune status, disease resistance and feed intake of incoming feeder cattle. Although the data is somewhat variable among experiments, it has been shown that complexed minerals are more available than inorganic minerals and have application in the presence of dietary antagonists, and when the animal is stressed.

Table 9: Effect of form of mineral on performance of calves (adapted from Ward et al. 1992)

Parameter	Control	Oxide	Sulfate	Complex	SE
Number of animals	31	31	31	31	
Initial weight (lbs)	454	454	456	452	6.3
Daily gain, lb/d					
Day 0-14	2.93^{ab}	2.76^{ab}	2.69^{b}	3.44^{a}	0.29
Day 0-28	2.00	1.76	1.74	2.09	0.18
DM Intake, lb/d					
Day 0 – 14	7.3^{ab}	7.1^{ab}	6.7^{b}	7.4^{a}	0.24
Day 0 – 28	9.9	10.1	10.0	10.4	0.35

^{a,b} Values within a row with different superscripts differ ($P<0.01$)

Table 10: Influence of mineral supplementation on heifer post-partum fertility (adapted from Manspeaker et al., 1987).

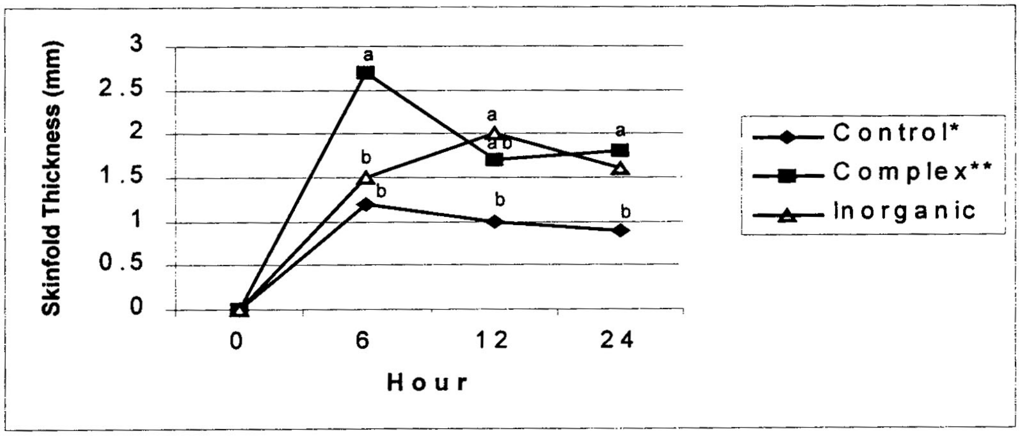
Item	Supplemented	No Supplement
Infections		
Bacteria isolated from cervix & uterus, %	5	25
Ovarian activity		
Mature follicles 30-80 d post-partum, %	35	20
Embryonic mortality		
Palpated embryonic depression 35-55 d post-Insemination, %	0	20
Incidence of endometrial scarring, %	10	58
Post-partum involution and tone of pregnant horn compared to nonpregnant horn	Indistinguishable3 0-35 d	Distinguishable5 0-55 d

Table 11: Influence of trace mineral supplementationa on reproduction parameters in first-calf beef heifers Swenson, 1998).

Reproduction parameters	Control	Sulfate	Complex
Significant structuresb by 45 d,%	86.7x	88.9x	50.0w
Exhibited estrusc by 45 d,%	46.7xw	66.7x	27.8w
Bred AI,%	46.7yz	33.3y	61.1z

aComplex contained Zn methionine, Cu lysine, Co glucoheptonate and Mn methionine; Sulfate provided Zn, Cu, Co and Mn sulfate forms; and Control had no additional Zn, Cu, Co, or Mn.
bSignificant structures include follicles greater than 12mm and/or corpra lutea as determined by rectal palpation.
cThe presence of a corpra lutea indicated that a heifer had exhibited estrus.
xwMeans in the same row with uncommon superscripts differ ($P<.05$).
yzMeans in the same row with uncommon superscripts differ ($P=.09$).

Figure 5: Effects of mineral supplementation on skinfold thickness at 6, 12 and 24 hr post injection with PHA-P (Ansotegui et al., 1994).



Zinc methionine, manganese methionine, copper lysine and cobalt glucoheptonate
**Sulfate forms fed in equal amounts to organic treatment
^{a,b} (P<0.01)

Our recommendations presently are to use a blend of inorganic-organic minerals in front of an expected stress (calving to breeding and pre-weaning) and then use an inorganic based trace mineral supplement the rest of the year. This approach is only part of a program to provide balanced nutrition with emphasis on supplying adequate protein, energy and trace minerals to prevent loss of beef cattle productivity.

LITERATURE

Allen , J.D. and J.M. Gawthorne. 1987. Involvement of the solid phase of rumen digesta in the interaction between copper, molybdenum, and sulfur in sheep. Br. J. Nutr. 58:265.

Ansotegui, R.P., C.K. Swenson, E.J. Swennson, T.J. Milner, K.S. Bryan, and J.A. Paterson . 1994. Effects of chemical form and intake of mineral supplementation on blood profiles and inflammatory reaction to phytohemagglutin (PHA-P) in pregnant heifers. Proc. of West. Sec. American Soc. Anim. Sci. 45:222.

Apgar, J. 1985. Zinc and reproduction. Ann. Rev. Nutr. 5:43-68.

Arthington, J.D., L.R. Corah, and F. Blecha. 1996. The effect of molybdenum-induced copper deficiency on acute-phase protein concentrations, superoxide dismutase activity, leukocyte numbers, and lymphocyte proliferation in beef heifers inoculated with bovine herpesvirus-1. J. Anim. Sci. 74:211-217.

Bailey, J.D., R.P. Ansotegui, J.A. Paterson, J.G. Berardinelli, and A.B. Johnson. 1999. Effects of supplemental trace mineral form on trace mineral status and performance of beef heifers. In: Proc. West. Sec. Amer. Soc. Anim. Sci. (in press).

Baker, D.H., J. Odle, M.A. Funk, and T.M. Wieland. 1990. Research note: bioavailability of copper in cupric oxide, cuprous oxide and in a copper-lysine complex. Poult. Sci. 70:177.

Beisel, W. 1982. Single nutrients and immunity. Am. J. Clin. Nutr. 35:417.

Berger, L.L. 1997. Trace minerals play important role in immune system. Feedstuffs, April 22, 1997.

Brown, M.A. and E.R. Casillas. 1986. Manganese and manganese-ATP interactions with bovine sperm adenylate cyclase. Arch. Biochem. Biophys. 244:719-726.

Case, A.A., L.A. Shelby, D.P. Hutcheson, R. Ebens, J.A. Erdman, and G.L. Feder. 1973. Infertility and growth suppression in beef cattle associated with abnormalities in their geochemical environment. Trace Substances in Environmental Health. VI, 15-21.

Chirase, N.K., D.P. Hutcheson, and G.B. Thompson. 1991. Feed intake, rectal temperature and serum mineral concentrations of feedlot cattle fed zinc oxide or zinc methionine and challenged with infectious bovine rhinotracheitis virus. J. Anim. Sci. 69:4137.

Clark, T.W., Z. Xin, Z. Du, and R.W. Hempken. 1993. A field trial comparing copper sulfate, copper proteinate and copper oxide as copper sources for beef cattle. J. Dairy Sci. 76(Suppl.):462.

Corah, L.R. and D. Dargatz. 1996. Forage analyses from cow/calf herds in 18 states. Beef Cow/Calf Health and Productivity Audit (CHAPA). USDA Animal and Plant Health Inspection Services, National Health Monitoring System.

Corah, L. R. and S. Ives. 1991. The effects of essential trace minerals on reproduction in beef cattle. Vet. Clin. Of N. America Food Anim. Prac. 7:41-57.

Doyle, J.C., J.E. Huston, and D.W. Spiller. 1988. Influence of phosphorus and trace mineral supplementation on reproductive performance of beef cattle under range conditions. J. Anim. Sci. 66 (Suppl. 1):462.

Du, Z., R. Hempken, J. Jackson, and D. Trammell. 1996. Utilization of copper in copper proteinate, copper lysine and cupric sulfate using the rat as an experimental model. J. Anim. Sci. 74:1657.1663.

Duffy, J.H., J.B. Bingley, and L.Y. Cove. 1977. The plasma zinc concentration of nonpregnant, pregnant and parturient Hereford cattle. Aust. Vet. J. 53:519-522.

Eckert, G., W. Greene, G. Carstens, and W. Ramsey. 1999. Copper status of ewes fed increasing amounts of copper from copper sulfate or copper proteinate. J. Anim. Sci. 77:244-249.

Fly, A.D., O.J. Izquierdo, K.R. Lowry, and D.H. Baker. 1989. Manganese bioavailability in an Mn-methionine chelate. Nutr. Res. 9:901.

Genglebach, G. and Spears.1998. Effects of dietary copper and molybdenum on copper status, cytokine production and humoral immune response of calves. J. Dairy Sci. 81: 3286-3292.

Genglebach, G., J. Ward, J. Spears, and T. Brown. 1997. Effects of copper deficiency and copper deficiency coupled with high dietary iron or molybdenum on phagocytic cell function and response of calves to a respiratory disease challenge. J. Anim. Sci. 75:1112-1118.

Gooneratne, S.R., W.T Cuckly, and D.A. Christensen. 1989. Review of copper deficiency and metabolism in ruminants. Can. J. Anim Sci. 69: 819-845.

Greene, L.W., A. B. Johnson, J.A. Paterson, and R.P. Ansotegui. 1998. Role of trace minerals in cow-calf cycle examined. Feedstuffs. 70:34.

Henry, P.R. 1995. Cobalt bioavailability. In: Bioavailability of nutrients for animals: Amino acids, minerals and vitamins. (Ed.) C. Ammerman, D. Baker, A. Lewis) Academic Press, NY

Herd, D.B. 1994. Identifying copper deficiencies under field conditions. In: Proc. Florida Ruminant Nutr. Symp. p. 76.

Herd, D.B. 1997. Mineral supplementation of beef cows in Texas. Texas Agric. Extension Service Publ. B-6056.

Hidiroglou, M. 1979. Trace element deficiencies and fertility in ruminants: a review. J. Dairy Sci. 62:1195

Ingraham, R.H., L.C. Kappel, E.B. Morgan, and A. Srikandakumar. 1987. Correction of subnormal fertility with copper and magnesium supplementation. J. Dairy Sci. 70:167-180.

Ivan, M.J., F. Proulx, R. Morales, C. Codagone, and M.de S. Dayrell. 1990. Copper accumulation in the liver of sheep and cattle fed diets supplemented with copper sulfate or copper chloride. Can. J. Anim. Sci. 70:727.

Kappel, L.C., R.H. Ingraham, and E.B. Morgan. 1984. Plasma copper concentration and packed cell volume and their relationships to fertility and milk production in Holstein cows. Am. J. Vet. Res. 45:346-350.

Kawashima, T., C. B. Ammerman, and P. R. Henry. 1986. Tissue uptake of cobalt from glucoheptonate in sheep. J. Anim. Sci. 67 (Suppl. 1): 503.

Kegley, E.B. and J.W. Spears. 1994. Bioavailability of feed grade copper sources (oxide, sulfate or lysine) in growing cattle. J. Anim. Sci. 72:2728.

Kincaid, R. L. 1979. Biological availability of zinc from inorganic sources with excess dietary calcium. J. Dairy Sci. 62:1081.

Kincaid, R. L., R. M. Blauwiekel, and J. D. Cronrath. 1986. Supplementation of copper as copper sulfate or copper proteinate for growing calves fed forages containing molybdenum. J. Dairy Sci. 69:160.

Manspeaker, J.E., M.G. Robl, G.H. Edwards, and L.W. Douglas. 1987. Chelated minerals: Their role in bovine fertility. Vet. Med. 82:91-957.

Mass, J. 1987. Relationship between nutrition and reproduction in beef cattle. Vet. Clin. N. Amer. Food Anim. Pract. 3:633-646.

Mulryan, G. and F. Mason. 1992. Assessment of liver copper status in cattle from plasma copper and plasma copper enzymes. Ann. Rech. Vet. 23:233.

Nockles, C.F. 1994. Micronutrients and the immune response. In: Montana Nutrition Conference Proceedings. Montana State University, p 3.1.

NRC, 1996. Nutrient requirements of beef cattle (7th Ed.) National Academy Press. Washington, D.C.

Orr, C.L. D.P. Hutcheson, R.B. Grainger, J.M Cummins, and R.E. Mock. 1990. Serum copper, zinc, calcium and phosphorus concentration of calves stressed by bovine respiratory disease and infectious bovine rhinotrachetis. J. Anim. Sci. 68:2893.

Peterson, R.G. and D.E. Waldern. 1977. A survey of dairy herds in the Fraser Valley of British Columbia to determine possible causes of unsatisfactory reproductive performance. Canadian J. Anim. Sci. 57:395-404.

Phillippo, M., W.R. Humphries, T. Atkinson, G.D. Henderson, and P.H. Garthwaite. 1987. The effect of dietary molybdenum and iron on copper status, puberty, fertility and estrous cycles in cattle. J. Agric. Sci. Camb. 109:321-336.

Pitts, W.J., W.J. Millers, O.T. Fosgate, J.D. Morton, and C.M. Clifton. 1966. Effects of zinc deficiencies and restricted feeding from two to five months of age on reproduction in Holstein bulls. J. Dairy Sci. 49:995-1000.

Power R., K. Cashman, and A. Flynn. 1994. Tissue deposition of zinc for a zinc chelate and from inorganic zinc in rats. Alltech, Inc. Nicholasville, KY.

Pugh, D.G. 1985. A review of the relationship between mineral nutrition and reproduction in beef cattle. Bovine Pract. 20:10.

Puls, R. 1990. Mineral levels in animal health. Sherpa International. Clearbrook, British Columbia, Canada.

Spears, J.W. 1996. Organic trace minerals in ruminant nutrition. Anim. Feed Sci. Tech. 58:151-163.

Spears, J.W. and E.B. Kegley. 1991. Effect of zinc and manganese methionine on performance of beef cows and calves. J. Anim. Sci. 69(Suppl. 1):59.

Stabel., J.R., J.W. Spears, and T.T. Brown. 1993. Effect of copper deficiency on tissue, blood characteristics, and immune function of calves challenged with infectious bovine rhinotrachetis virus and pasturella hemolytica. J. Anim. Sci. 71:1247-1255.

Stoszek, M.J., P.G. Mika, J.E. Oldfield, and P.H. Weswig. 1986. Influence of copper supplementation on blood and liver copper fed tall fescue and quackgrass. J. Anim. Sci. 62:263.

Suttle, N. F. 1991. The interactions between copper, molybdenum and sulfur in ruminant nutrition. Annu. Rev. Nutr. II: 12 1.

Swenson, C.K. 1998. Influence of mineral supplementation on blood serum and liver mineral concentrations in first calf beef heifers. Ph.D. Dissertation. NM State Univ., Las Cruces.

Underwood, E.J. 1981. The mineral nutrition of livestock. Commonwealth Agriculture Bureaux, London.

Ward, J. and J. Spears. 1999. The effects of low-copper diets with or without supplemental molybdenum on specific immune responses of stressed cattle. J. Anim. Sci. 77:230-237.

Ward, J., G. Genglebach, and J. Spears. 1997. The effects of copper deficiency with or without high dietary iron or molybdenum on immune function of cattle. J. Anim. Sci. 75:1400-1408.

Ward, J.D., J.W. Spears, and E.B. Kegley. 1992. Effect of trace mineral source on mineral metabolism, performance and immune response in stressed cattle. J. Anim. Sci. 70: (Supplement 1):642.

Wedekind, K., A. Hortin , and D. Baker. 1992. Methodology for assessing zinc bioavailability: efficacy estimates for zinc-methionine, zinc sulfate and zinc oxide. J. Anim. Sci. 70:178-187.

Wellington, B. K.., J. A. Paterson, C.K. Swenson, R.P. Ansotegui, P.G. Hatfield, and A.B. Johnson. 1998. The influence of supplemental copper and zinc on beef heifer performance and changes in liver copper. In: Proc. West. Sect. Amer. Soc. Anim. Sci. 49:323-326.

Wikse, S.E. 1992. The relationship of trace elements deficiencies to infectious diseases of beef cattle. Proceedings of the 1992 TAMU Beef Cattle Shortcourse.

Woolliams, C., N. Suttle, J. Woolliams, D. Jones, and G. Wierner. 1986. Studies on lambs genetically selected for low and high copper status. I. Differences in mortality. Anim. Prod. 43:293.

Wong-Valle, J., P. R. Henry, C. B. Ammennan, and P. V. Rao. 1989. Estimation of the relative bioavailability of manganese sources for sheep. J. Anim. Sci. 67:2409.