Effects of Trace Mineral Source and Growth Implants on Trace Mineral Status of Growing and Finishing Feedlot Steers[a,b,c]

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ABSTRACT : Three hundred and seventy-three steers (approximately 7 mo of age and 247±19.4 kg) were utilized to determine the effects of trace mineral (TM) source and growth implants on trace mineral status. Steers were blocked by ranch, post-weaning treatment within ranch, stratified by initial body weight, and randomly assigned to one of 36 pens (9-12 head/pen). Treatment consisted of: i) control (no supplemental Cu, Zn, Mn, and Co), ii) inorganic trace minerals, and iii) organic trace minerals. Six pens of steers per treatment received a growth implant at the beginning of the experiment and were re-implanted during the finishing phase. The remaining steers received no growth implants. Steers were fed a corn silage-based growing diet for 56 d then were gradually switched to a high concentrate finishing diet. Treatments during the finishing phase consisted of: i) control (no supplemental Zn); ii) inorganic Zn (30 mg of Zn/kg DM from $ZnSO_4$); and iii) organic Zn (iso-amounts of organic Zn). By the end of the growing and finishing phases, implanted steers had greater (p<0.01) plasma Cu concentrations than non-implanted steers. During the growing phase, liver Cu concentrations (p<0.01) and plasma Zn concentrations (p<0.02) were greater in steers supplemented with TM compared to control steers. Steers supplemented with inorganic minerals had greater liver Cu concentrations than steers supplemented with organic minerals at the beginning (p<0.01) and end (p = 0.02) of the growing phase. During both the growing (p = 0.02) and finishing phases (p = 0.05), non-implanted control steers had greater plasma Cu concentrations than non-implanted steers supplemented with TM, whereas, implanted control steers had similar plasma Cu concentrations than implanted steers supplemented with TM. Non-implanted steers that received inorganic TM had lower plasma Cu concentrations (p = 0.03) during the growing phase and ceruloplasmin activity (p<0.04) during the finishing phase than non-implanted steers that received organic TM, whereas, implanted steers supplemented with either organic or inorganic TM had similar plasma Cu concentrations. (**Key Words :** Steers, Trace Minerals, Mineral Status, Growth Implants)

INTRODUCTION

Conventional US beef production systems involve the use of anabolic implants during one or more phases of cattle production prior to harvest. The use of anabolic implants is

effective for improving growth performance and profitability of growing and finishing cattle (Apple et al., 1991; Duckett et al., 1999; Duckett and Andrae, 2001). The impact of growth implants on enhancing gain and feed efficiency is thought to occur by an increase in protein accretion. With an increase in protein accretion, dietary energy and protein utilization are altered in order to assist with protein accretion. However, little research has investigated the impact of growth implants on trace mineral status of beef cattle.

Huerta et al. (2002) reported a decrease in liver Zn concentrations in implanted heifers and steers that were fed a control diet containing 64 mg Zn/kg DM and 84 mg Zn/kg DM, respectively. This decrease in liver Zn concentrations may be due to the importance of Zn in protein metabolism. Zinc forms a tetrahedral complex with cysteine and histidine residues to form Zn finger domains in DNA binding proteins (Berg, 1963), which aid in transcription of messenger RNA and cell replication (Chester, 1978).

Increasing protein accretion with the use of growth implants may increase Zn requirements and possibly the requirement of other trace minerals of an animal. Therefore, the objective of this experiment was to determine the effects of trace mineral source and growth implants on trace mineral status of steers.

MATERIALS AND METHODS

Prior to the initiation of this experiment, the Colorado State University Institutional Animal Care and Use Committee approved care, handling, and sampling of the animals defined herein.

Three hundred and seventy three steer calves (approximately 7 mo of age and 247±19.4 kg) were utilized in this experiment. Calves were obtained from 3 different Colorado State University Research facilities: 127 Hereford×Angus calves; 135 crossbred calves; and 111 Black Angus calves.

Prior to the initiation of the study, calves were backgrounded at their respective ranch locations for 30 d. Post-weaning, at each ranch location, calves were weighed on two consecutive days and stratified by body weight into six groups. Groups were then randomly assigned to one of six group pens equipped with bunk feeders and automatic waterers. Pens were then randomly assigned to treatments. Treatments consisted of: i) control (no supplemental trace minerals), ii) inorganic trace mineral (CuSO$_4$, ZnSO$_4$, MnSO$_4$, and CoCO$_3$), and iii) organic trace mineral (iso-amounts of organic Cu amino acid complex, Zn amino acid complex, Mn amino acid complex, and Co glucoheptonate; Avalia$^®$4, Zinpro Corp. Eden Prairie, MN). Mineral treatments were fed in alfalfa pellets at a rate of 0.23 kg/hd/d with control calves receiving alfalfa pellets with no supplemental Cu, Zn, Mn, or Co. Mineral treatments were fed in alfalfa pellets formulated to supply 360 mg of Zn, 200 mg of Mn, 125 mg of Cu, 12.5 mg of Co per head per day from either organic or inorganic sources. On day 30 post-weaning, calves were weighed and transported to the Agricultural Research, Development, and Education Center (ARDEC) feedlot facility in Fort Collins, CO. Pre-conditioning data is reported by Dorton et al. (2006).

Receiving/growing phase

Upon arrival, all calves were weighed (on two consecutive days), vaccinated with Ultrabac$^®$7/Somubac and Bovishield^{TM} 4+L5, and dewormed with Dectomax (Pfizer Animal Health, Exton, PA). Calves were blocked by ranch and stratified by initial body weight and backgrounding treatment and were sorted into one of thirty-six pens (9-12 head per pen) equipped with automatic waterers. Pens within ranch were then assigned to treatments. Treatments consisted of: i) control (no

supplemental trace minerals), ii) inorganic trace minerals (CuSO$_4$, ZnSO$_4$, MnSO$_4$, and CoCO$_3$), and iii) organic trace minerals (iso-amounts of organic Cu, Zn, Mn, and Co; Zinpro Corp., Eden Prairie, MN). Calves remained on the same trace mineral treatments that they received during the on-farm backgrounding phase. However, trace mineral treatments were included in the total mixed growing ration to supply the same concentrations of Zn, Mn, Cu, and Co as supplemented during the on-farm backgrounding phase. Half of the steers from each treatment (6 pens per treatment) were implanted with 200 mg progesterone and 20 mg estradiol benzoate on d 28 post arrival to the feedlot, and the remaining steers (6 pens per treatment) received no implant. Steers were fed a corn silage-based growing diet (Table 1) for 56 d. Diets were formulated to meet or exceed NRC (1996) requirements for energy, protein, macro- and micro-minerals with the exception of Cu, Zn, Mn, and Co. Diets were fed once daily in the morning in amounts adequate to allow *ad libitum* access to feed throughout the day.

Liver biopsy samples were obtained from 3 calves per pen on d 0 and d 56 of the growing phase using the true-cut technique described by Pearson and Craig (1980) as modified by Engle and Spears (2000). Briefly, hair was clipped from a 10 cm×10 cm area on the right side of the steer between the 11th and 12th ribs, and the area was scrubbed three times with betadine alternating with 70% alcohol. Five milliliters of a two percent lidocaine hydrochloride solution (Abbott Laboratories, Chicago, IL) were injected via a 20-gauge×2.5 cm needle between the 11th and 12th rib on a line from the tubercoxae to the tip of the shoulder. A small incision (approximately 1.0 cm) was made using a #11 scalpel blade. A core sample of liver was collected using a modified Jam Shide bone marrow punch (0.5 cm×14 cm; Sherwood Medical, St. Louis, MO). Following collection, samples were immediately rinsed with 0.154 M phosphate buffered saline solution (pH 7.4), placed into an acid washed polyethylene tube, capped, stored on ice and transported to the laboratory. Samples were then stored at -20°C until analysis for trace minerals.

Blood samples were collected every 28 d in hepranized trace mineral free vacutainer tubes (Becton Dickenson Co., Franklin Lakes, NJ) (from the same 3 steers per pen that were biopsied) for analysis of plasma trace mineral content. On d 0 and d 56, plasma samples were also analyzed for ceruloplasm activity.

Finishing phase

At the beginning of the finishing phase, steers that had received an implant in the growing phase were re-implanted with 80 mg trenbolone acetate and 16 mg estradiol. The finishing diet was fed until the steers reached a finished weight of approximately 540 kg. Diets were formulated to

Table 1. Ingredient composition of basal diets

Ingredient	Backgrounding	Growing	Finishing
	-- %[a] --		
Corn silage	-	17.80	9.31
Alfalfa hay	94.90	17.32	7.95
Flaked corn	-	55.96	78.68
Protein supplement	5.10	8.92	4.06
Protein supplement composition			
Cottonseed meal	-	46.00	43.59
Soybean hulls	38.17	-	-
Soybean meal	-	20.00	20.16
Soybean oil	0.62	-	-
Sunflower meal 32%	10.60	4.52	7.89
Wheat midds	40.00	-	-
Molasses cane blend	3.50	-	-
Urea	-	6.98	7.03
Rumensin 80[b]	-	+	+
Bentonite	1.00	-	-
Monocalcium phosphate	0.82	3.90	3.91
Cobalt carbonate	-	-	< 0.01
Copper sulfate	-	-	0.05
Dyna-K[c]	1.47	3.93	3.96
Limestone	3.27	11.75	11.84
Manganese sulfate	-	-	0.08
Iodine 20 GM	0.02	0.06	0.06
Salt	0.45	0.90	0.91
Selenium	0.02	0.08	0.08
Sulfur flower	-	0.04	0.01
Vitamin A 30/0	-	0.07	0.07
Vitamin A and D 30/10	0.03	-	-
Vitamin E 125	0.02	0.05	0.05
Chemical composition			
DM (%)	91.10	68.82	75.62
OM (%)	92.27	94.51	96.51
CP (%)	14.28	13.60	10.65
NDF (%)	64.18	27.72	18.64
Ash (%)	7.73	5.49	3.49
Ca (%)	1.23	0.91	0.56
P (%)	0.30	0.31	0.24
K (%)	1.43	0.78	0.51
Mg (%)	0.27	0.21	0.14
Na (%)	0.10	0.06	0.04
S (%)	0.24	0.21	0.15
Fe (ppm)	270.16	188.45	126.63
Mn (ppm)	33.08	27.89	19.74
Zn (ppm)	45.17	50.68	48.42
Cu (ppm)	16.17	15.56	14.95
Mo (ppm)	0.11	0.19	0.09

[a] Dry matter basis. [b] Provided 20 and 33 mg of monensin/kg DM in the growing and finishing ration, respectively.

meet or exceed NRC (1996) requirements for energy, protein, macro- and micro-minerals with the exception of Zn. Trace mineral treatments during the finishing phase were: i) control (no supplemental Zn); ii) inorganic Zn (30 mg Zn/mg DM from $ZnSO^4$); and iii) iso-amounts of organic Zn (Zinpro Corp., Eden Prairie, MN; animals receiving treatments 1, 2, and 3 during the growing phase remained on treatments 1, 2, and 3, respectively during the

finishing phase). All other trace minerals were supplied in inorganic form during the finishing phase. On day 112, a liver biopsy was collected as previously described from the same 3 calves per pen that were biopsied during the growing phase.

During the finishing phase, blood samples were obtained every 28 d in trace mineral free hepranized vacutainer tubes (Becton Dickenson Co., Franklin Lakes, NJ) from the same three calves per pen that were biopsied and analyzed for trace mineral concentrations. On d 84 of the finishing phase, plasma samples were analyzed for ceruloplasm activity.

Analytical procedures

Blood preparation: All blood samples were centrifuged at 1,200×g for 25 min at room temperature. Plasma from blood samples collected in trace mineral free vacutainer tubes was harvested and stored in acid washed polyethylene tubes until analysis for plasma trace mineral concentrations and ceruloplasm activity.

Plasma and Liver mineral analysis: Plasma and liver samples were analyzed via inductively coupled plasma-atomic emission spectroscopy (ICP-AES) methods (Braselton et al., 1997 as described by Ahola et al., 2004) for Zn, Cu, Mo, and Mn concentrations. Briefly, liver samples were thawed, dried for 4 hours at 95°C, and then allowed to cool to room temperature. Samples were weighed and then combined with 2 ml of 3.6 N nitric acid. The mixture was allowed to digest overnight at 95°C and then cooled to room temperature. Samples were diluted in dH$_2$O to fit within a linear range of a standard curve generated by linear regression of known TM concentrations. Multielemental analysis was then carried out by the simultaneous/sequential ICP-AES, with cross flow nebulization, procedure.

Plasma samples were prepared for analysis as follows. One ml of 10% trichloroacetic acid was added to one ml of plasma or standard and was mixed vigorously. The mixture was placed in a -20°C freezer for 30 minutes to aid in precipitation and then centrifuged at 1,200×g for 10 minutes. The supernatant was removed, placed into a clean tube and then diluted in dH$_2$0 to fit within a linear range of a standard curve generated by linear regression of known Cu concentrations. Multielemental analysis was also carried out by the simultaneous/sequential ICP-AES, with cross flow nebulization, procedure.

Ceruloplasm activity: Ceruloplasm activity was determined using a procedure described by Houchin (1958). Briefly, 100 μl of plasma were incubated at 37°C for 20 minutes. One milliliter of a 1% para-phenylenediamine solution was added. This solution was incubated for 30 minutes at 37°C and five milliliters of 0.02% sodium azide

solution was added. The sample was then read at 525 nm using a spectrophotometer (Spectronic Genesis 5, Spectronic Instruments, Rochester, NY). The results were recorded as absorbency values.

Statistical analysis

Statistical analysis of data was performed using Proc Mixed procedure of SAS (2001) for a 3×2×3 factorial arrangement in a completely randomized design. The model included the fixed effects of ranch treatment, feedlot treatment, implant, time, location (ranch), and all possible interactions. The random effect of pen within treatment× implant was included in the model. When an interaction was not significant, it was removed from the model and the reduced model was reanalyzed. Significance was declared at p<0.05 and trends were declared at 0.05<p<0.10.

RESULTS AND DISCUSSION

Liver mineral concentrations

Liver mineral concentrations are shown in Table 2 and 3 for the growing and finishing phases respectively. Liver mineral concentrations were unaffected by implant during the growing phase; and liver Zn and Cu concentrations were unaffected by implant during the finishing phase. Steers that were implanted tended (p = 0.06) to have greater liver Mn concentrations than non-implanted steers during the finishing phase. Research investigating the effects of growth implants on liver mineral concentrations is limited. Huerta et al. (2002) reported that non-implanted heifers had greater liver Zn and Cu concentrations than implanted heifers on d 50 of the study but the effect was not observed on d 120. They also reported no significant difference in liver Zn and Cu concentrations among implanted and non-implanted steers.

Trace mineral supplementation had no effect on liver Zn and Mn concentrations in either the growing or finishing phases. Similar results were reported in studies utilizing heifers (Huerta et al., 2002), steers (Mullis et al., 2003), and lactating Holstein cows (Kellogg et al., 1989) supplemented with Zn. In contrast to the present study, liver Zn concentrations have been reported to be increased in TM supplemented wethers (Rojas et al., 1995) and steers (Huerta et al., 2002). In a study utilizing ewes, Zn supplemented as either ZnSO$_4$ or a Zn amino acid complex resulted in greater liver Zn concentrations than reported in control ewes not supplemented with Zn (Hatfield et al., 2001). Ahola et al. (2004) observed varying results in a two year cow study. Cows received no supplemental Cu, Zn, or Mn or were supplemented with iso-amounts of inorganic and organic TM (50% organic and 50% inorganic Cu, Zn, and Mn) in free choice trace mineral feeders. The basal diet

Table 2. Effects of Zn source and implants on liver and plasma mineral concentrations of steers during the growing phase

Item	Dietary treatments						SEM[a]	p-value				
	Control		Inorganic TM		Organic TM			Implant	TM	Implant ×TM	TM Source[b]	TM Source × Implant
	-[c]	+[d]	-[c]	+[d]	-[c]	+[d]						
Liver Zn												
Initial	90.19	91.52	101.84	89.79	113.72	98.26	8.28	-	0.14	-	0.17	-
Final	105.21	105.79	82.04	113.03	113.28	106.03	8.28	0.31	0.76	0.68	0.22	0.10
Liver Cu												
Initial	49.63	62.38	197.67	190.19	134.42	122.90	37.51	-	<0.0001	-	<0.0001	-
Final	192.62	225.90	299.36	306.40	248.64	263.44	37.51	0.26	0.0002	0.0026	0.02	0.20
Liver Mn												
Initial	6.88	6.30	7.12	6.74	6.58	7.04	0.73	-	0.37	-	0.69	-
Final	7.32	7.11	7.67	7.32	7.59	7.18	0.73	0.39	0.56	0.78	0.81	0.89
Plasma Zn												
Initial	0.84	0.78	0.89	0.94	0.97	0.99	0.066	-	0.02	-	0.30	-
Final	1.01	0.96	1.02	0.95	1.10	1.07	0.065	0.36	0.36	0.66	0.14	0.41
Plasma Cu												
Initial	1.16	1.30	1.18	1.25	1.17	1.26	0.073	-	0.84	-	0.94	-
Final	1.01	1.18	0.92	1.30	1.03	1.21	0.092	0.0029	0.86	0.02	0.92	0.03

[a] Standard error of the mean. [b] Inorganic TM vs. Organic TM. [c] Non-implanted. [d] Implanted with Synovex-S[R.].

contained native pasture consisting of blue grama, prairie sandreed, and needle-and-thread grass (13.1 mg Cu/kg DM, 16.1 mg Zn/kg DM, and 36.6 mg Mn/kg DM) and millet hay (19.6 mg Cu/kg DM, 32.1 mg Zn/kg DM, and 52.2 mg Mn/kg DM). In year 1, they reported that trace mineral supplementation increased liver Mn concentrations. However, in year 2, trace mineral supplementation decreased liver Mn concentrations, both of which were in contrast to results of the present study. Ahola et al. (2004) suggested that liver Mn concentrations may not be a good indicator of Mn status in the body. Ivan and Hidiroglou (1980) and Watson et al. (1973) reported that liver Mn only increased 3 to 4 fold when dietary Mn was increase 130 to 140 fold. The reason why liver Zn and Mn concentrations were unaffected by trace mineral supplementation in the present study may be similar. Furthermore, Zn concentrations in tissues shows little change when dietary Zn changes (Miller et al., 1968) because there is little

Table 3. Effects of Zn source and implants on liver and plasma mineral concentrations of steers during the finishing phase

Item	Dietary treatments						SEM[a]	p-value				
	Control		Inorganic TM		Organic TM			Implant	TM	Implant× TM	TM Source[b]	TM Source ×Implant
	-[c]	+[d]	-[c]	+[d]	-[c]	+[d]						
Liver Zn												
Initial	105.21	105.79	82.04	113.03	113.28	106.03	8.28	0.31	0.76	0.68	0.22	0.10
Final	96.61	88.55	95.09	108.97	95.60	90.72	8.57	0.96	0.55	0.82	0.31	0.50
Liver Cu												
Initial	192.62	225.90	299.36	306.40	248.64	263.44	37.51	0.26	0.0002	0.0026	0.02	0.20
Final	231.90	267.13	318.86	220.46	255.26	239.00	40.68	0.66	0.82	0.82	0.76	0.84
Liver Mn												
Initial	7.32	7.11	7.67	7.32	7.59	7.18	0.73	0.39	0.56	0.78	0.81	0.89
Final	7.99	9.76	7.16	7.84	8.31	10.88	0.75	0.06	0.71	0.36	0.07	0.18
Plasma Zn												
Initial	1.01	0.96	1.02	0.95	1.10	1.07	0.065	0.36	0.36	0.66	0.14	0.41
Final	1.10	1.14	1.16	1.10	1.18	1.06	0.061	0.36	0.93	0.51	0.89	0.51
Plasma Cu												
Initial	1.01	1.18	0.92	1.30	1.03	1.21	0.092	0.0029	0.86	0.02	0.92	0.03
Final	1.02	1.15	0.91	1.11	1.04	1.13	0.060	0.0069	0.45	0.05	0.21	0.10

[a] Standard error of the mean. [b] Inorganic TM vs. Organic TM. [c] Non-implanted.
[d] Implanted with Synovex-S[R.] in the growing phase and Revalor IS in the finishing phase.

readily available Zn in tissues (McDowell, 1992). Bone may be a better indicator of Zn status than liver (Underwood and Suttle, 1999) but again Zn in bone is not readily available for use by the body (McDowell, 1992). Therefore, the liver may not be the best tissue to examine in order to determine the Zn and Mn status of an animal.

In the present study, initial liver Cu concentrations were greater (p<0.0001) in TM supplemented steers than controls at the beginning of the growing phase, which may be the result of TM supplementation during the background phase at the ranch. By the end of the growing phase, this difference was still apparent (p = 0.0002). Similar results were reported in studies using steers that were supplemented with Zn, Cu, Mn, and Co (Stanton et al., 1988) and cows that were supplemented with either inorganic or organic TM (Ahola et al., 2004). Huerta et al. (2002) reported contrasting results where control steers tended (p<0.14) to have greater liver Cu concentrations than Zn supplemented steers. In other studies, similar liver Cu concentrations were seen among control and Zn supplemented heifers (Kincaid et al., 1997), steers (Huerta et al., 2002; Mullis et al., 2003), and sheep (Rojas et al., 1995; Hatfield et al., 2001). Trace mineral supplementation had no effect on liver Cu concentrations in the finishing phase. The reason that liver Cu concentrations were affected by TM supplementation and Zn and Mn were not may be due to the livers ability to store and repartition Cu to the rest of the body (Owen, 1980; McDowell, 1992). There was no effect of TM supplementation on liver TM concentrations during the finishing phase.

Trace mineral source had no effect on liver Zn and Mn concentrations in the growing phase and liver Zn in the finishing phase. In contrast to the present study, Hatfield et al. (2001) reported a TM source effect in ewes. Ewes that were supplemented with organic TM tended to have greater liver Zn concentrations than ewes supplemented with inorganic TM. Huerta et al. (2002) also reported a TM source effect in feedlot heifers. Heifers supplemented with 200 mg Zn/kg DM from $ZnSO_4$ had greater liver Zn concentrations than heifers supplemented with 200 mg Zn/kg DM from Zn methionine. The reason for the discrepancies in results reported in these two studies and the present study is unknown. The difference could possibly be due to the type of animals utilized in each study (steers vs. ewes vs. heifers) or possibly could be the result of the total amount of TM being supplemented.

Trace mineral source had an effect on liver Cu concentrations. Steers that were supplemented with inorganic minerals had greater liver Cu concentrations than steers supplemented with organic minerals at the beginning (p<0.0001) and end (p = 0.02) of the growing phase. However, this difference was not present at the end of the finishing phase. In contrast to the present study, ewes supplemented with organic Zn (Zn amino acid complex) tended to have greater liver Cu concentrations than ewes supplemented with $ZnSO_4$ (Hatfield et al., 2001). This effect was also reported in cows (Ahola et al., 2004).

Steers supplemented with organic Zn tended (p<0.07) to have greater liver Mn concentrations than steers supplemented with inorganic Zn in the finishing phase. Spears (1996) proposed a theory that organic sources of minerals were more bioavailable than inorganic sources because the organic sources are more similar to biologically active forms of minerals in the body and in feed. Organic forms of minerals may prevent binding of antagonists or other molecules in the body because they are already bound to a molecule and have fewer or no binding sites available. Animals fed inorganic sources of minerals have to first convert the minerals to biologically active forms before they can be utilized (Spears, 1996). This may be why steers had greater liver Mn concentrations when supplemented with organic TM. The reason liver Cu concentrations were greater when supplemented with inorganic TM is unclear.

There was a TM×implant interaction (p = 0.0026) for liver Cu concentrations at the end of the growing phase. Non-implanted control steers had lower liver Cu concentrations than non-implanted steers supplemented with TM. This difference was also observed between implanted control and implanted steers supplemented with TM, where the implanted control steers had lower liver Cu concentrations than steers supplemented with TM, but the difference was more prominent in the non-implanted cattle.

At the end of the growing phase, there was a tendency for a TM source×implant interaction (p<0.10) for liver Zn concentrations. Non-implanted steers that were supplemented with inorganic TM tended to have lower liver Zn concentrations than non-implanted steers supplemented with organic TM, whereas, implanted steers supplemented with inorganic TM had similar liver Zn concentrations than implanted steers supplemented with organic Zn. This interaction was not observed by Huerta et al. (2002).

Plasma mineral concentrations

Growth implants had no effect on plasma Zn concentrations during the growing and finishing phase (Table 2 and 3, respectively). By the end of the growing phase, implanted steers had greater (p<0.01) plasma Cu concentrations than non-implanted steers. This effect was also observed during the finishing phase (p = 0.0069). In contrast, Huerta et al. (2002) found no effect of growth implants on serum Cu concentrations in heifers and steers, but implanted heifers had greater serum Zn concentration than non-implanted heifers.

Trace mineral supplementation had no effect on plasma

Cu concentrations during the growing or finishing phase. At the beginning of the growing phase, steers that were supplemented with TM had greater (p<0.02) plasma Zn concentrations than control steers, but were similar throughout the remainder of the study. Plasma and serum mineral concentrations have varied in studies in which cattle and sheep have received a TM supplement vs. a non-supplemented control diet. Mayland et al. (1980) reported that cows and calves supplemented with TM had greater plasma Zn concentrations than cows and calves fed the non-supplemented control diet. Steers and heifers supplemented with either $ZnSO_4$ or an organic Zn source had greater serum Zn concentrations than non-supplemented steers and heifers. However, serum Cu concentrations were unaffected by TM supplementation in this study (Huerta et al., 2002). Spears et al. (1991) observed no effect of TM supplementation on serum Zn and Cu concentrations when supplementing steers with Zn oxide or Zn methionine. Various studies have reported contrasting results where Zn supplementation had no effect on serum Zn and Cu concentrations in sheep (Droke et al., 1988) and steers (Chirase et al., 1991; Malcolm and Callis, 2002; Spears and Kegley, 2002). Plasma Zn and Cu concentrations have also been reported to be unaffected by TM supplementation in sheep (Spears, 1989; Kegley and Spears, 1994) and steers (Chirase et al., 1994).

The initial difference in plasma Zn concentrations may be due to the animals having been backgrounded on TM before arriving at the feedlot. Plasma mineral concentrations are stabilized or maintained at adequate concentrations by the mobilization of these minerals from storage depots from the liver when plasma mineral concentrations decrease below adequate levels. In the present study, plasma Zn and Cu concentrations were adequate (Zn<0.4 mg/L; Cu<0.6 mg/L; Mills, 1987; Pulz, 1994). Plasma mineral concentrations may have been unaffected by TM supplementation because plasma mineral concentrations were at adequate concentrations (Mills, 1987).

Trace mineral source had no effect on plasma mineral concentrations during the growing phase and the finishing phase. Serum Zn and Cu concentrations were unaffected by TM source ($ZnSO_4$ and $CuSO_4$ or organic Zn and Cu) in steers (Mullis et al., 2003). In contrast to the present study, Chirase et al. (1994) reported an increase in plasma Zn concentrations in steers supplemented with Zn methionine rather than Zn oxide. Heifers supplemented with Zn methionine had a greater serum Zn concentration than heifers supplemented with $ZnSO_4$ (Huerta et al., 2002). Contrasting results were reported in lambs. Lambs supplemented with Zn oxide had greater serum Cu concentrations than lambs supplemented with Zn

methionine (Kegley and Spears, 1995). The reason that plasma mineral concentrations were unaffected by TM source in this study is unknown but may be due to plasma mineral concentrations being at adequate concentrations.

There was a TM×implant interaction during the growing phase (p<0.02) and the finishing phase (p<0.05) for plasma Cu concentrations. Non-implanted control steers had greater plasma Cu concentrations than non-implanted steers supplemented with TM; whereas, implanted control steers had similar plasma Cu concentrations than implanted steers supplemented with TM. Huerta et al. (2002) reported a TM×implant interaction for serum Cu concentrations. Non-implanted control heifers had lower serum Cu concentrations than non-implanted heifers supplemented with TM; whereas, implanted control steers had greater serum Cu concentrations than implanted heifers supplemented with TM. This effect was not observed in steers (Huerta et al., 2002).

There was also a TM source x implant interaction (p = 0.03) during the growing phase and a tendency (p<0.10) for an interaction during the finishing phase. Non-implanted steers that received inorganic TM had lower plasma Cu concentrations than non-implanted steers that received organic TM; whereas, implanted steers supplemented with either organic or inorganic TM had similar plasma Cu concentrations. Huerta et al. (2002) reported no TM source ×implant interaction in neither heifers nor steers.

Ceruloplasm activity

Ceruloplasm, an enzyme that contains Cu, is necessary for oxidation of Fe (McDowell, 1992). Ceruloplasm catalyzes the conversion of Fe^{2+} (ferrous Fe) to Fe^{3+} (ferric Fe), which is necessary for Fe to be transported as transferrin throughout the body or for Fe to be mobilized from ferritin, the storage form of Fe, and utilized by the body (McDowell, 1992). Growth implants, TM supplementation, and TM source had no effect on ceruloplasm activity during the growing and finishing phases (Table 4). During the finishing phase, there was a TM source×implant interaction (p<0.04) for ceruloplasm activity. Implanted steers supplemented with organic TM had greater ceruloplasm activity than implanted steers supplemented with inorganic minerals; whereas, non-implanted steers supplemented with organic TM had similar ceruloplasm concentrations to non-implanted steers supplemented with inorganic TM. Trace mineral supplementation and source had no effect on ceruloplasm activity in a study utilizing steers that received a control diet containing no supplemental TM or that were supplemented with TM (Arthington et al., 2003). In a study utilizing heifers, TM supplementation increased ceruloplasm concentrations, but TM source had no effect on ceruloplasm

Table 4. Effects of Zn source and implants on ceruloplasm activity (abs) of steers during the growing and finishing phase.

	Dietary treatments							p-value				
	Control		Inorganic TM		Organic TM		SEM[a]	Implant	TM	Implant ×TM	TM Source[b]	TM Source ×Implant
	-[c]	+[d]	-[c]	+[d]	-[c]	+[d]						
Growing												
Day 0	0.178	0.224	0.261	0.230	0.178	0.230	0.033	-	0.38	-	0.19	-
Day 56	0.223	0.211	0.206	0.274	0.155	0.242	0.033	0.18	0.97	0.30	0.32	0.18
Finishing												
Day 84	0.176	0.114	0.111	0.105	0.099	0.190	0.033	0.69	0.38	0.12	0.15	0.04

[a] Standard error of the mean. [b] Inorganic TM vs. Organic TM. [c] Non-implanted.
[d] Implanted with Synovex-S[R.] in the growing phase and Revalor IS in the finishing phase.

concentrations (Arthington et al., 2003). Mullis et al. (2003) also reported that TM source (inorganic vs. organic) had no effect on ceruloplasm concentrations. It seems that TM supplementation and source have little or no effect on ceruloplasm activity. The effects of implants on ceruloplasm activity are unknown because the present study seems to be the first experiment to investigate the effects of implants on ceruloplasm activity. From the present study, it seems ceruloplasm activity is unaffected by growth implants or TM supplementation alone, but an interaction between implants and TM supplementation exists.

CONCLUSION

The effects of TM supplementation and source on TM concentrations in the body are variable. In the present study, TM supplementation and source had no effect on liver Zn and Mn concentrations, plasma mineral concentrations, and ceruloplasm activity. As mentioned previously, the liver is not always a good indicator of trace mineral status because the liver is not the main storage vessel for all minerals. Plasma trace mineral concentrations are often very stable unless there is a severe deficiency in a certain minerals because the trace minerals will be released from storage to maintain plasma trace mineral concentration at adequate levels. This may be the reason why TM concentrations in plasma were unaffected. Trace mineral supplementation increased liver Cu concentrations. Growth implants had little effect on liver mineral and ceruloplasm activity, but increased plasma Cu concentrations. The effect of growth implants on mineral concentrations has not been widely studied and it is unclear how growth implants impact trace mineral status in the body. Further research is needed to determine the effects of growth implants and TM supplementation and source on performance and trace mineral status of beef cattle.

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