Published January 20, 2015

Mineral concentrations of plasma and liver after injection with a trace mineral complex differ among Angus and Simmental cattle

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ABSTRACT: To examine the effects of cattle breed on the clearance rate of an injectable mineral product, 10 Angus and 10 Simmental steers were blocked by breed and initial BW (332 ± 33 kg) and injected with either Multimin 90 (MM) or sterilized saline (CON) at a dose of 1 mL/45 kg BW. Multimin 90 contains 15 mg Cu/mL (as Cu disodium EDTA), 60 mg Zn/mL (as Zn disodium EDTA), 10 mg Mn/mL (as Mn disodium EDTA), and 5 mg Se/mL (as sodium selenite). Steers received a corn-silage-based diet, and inorganic sources of Cu, Zn, Mn, and Se were supplemented at NRC recommended amounts. Jugular blood was collected immediately before injection and at 8 and 10 h post-injection and on days 1, 8, and 15 post-injection. Liver biopsies were collected 3 d before injection and on days 1, 8, and 15 post-injection. Liver and plasma mineral concentration and glutathione peroxidase (GSH-Px) activity data were analyzed as repeated measures. Plasma concentrations of Zn, Mn, and Se were greater ($P = 0.01$) and Cu tended to be greater ($P = 0.12$) post-injection in MM steers compared with the CON steers. Regardless of treatment, Simmental cattle had lower plasma concentrations of Cu, Zn, and Se ($P \leq 0.05$) when compared with Angus cattle. Erythrocyte GSH-Px activity was greater ($P = 0.01$) in MM steers compared with CON steers. Liver concentrations of Cu, Zn, and Se were greater ($P = 0.05$) in MM steers compared with CON steers post-injection. Liver Mn concentrations tended to be greater ($P = 0.06$) in MM steers compared with CON steers in the days post-injection. Interestingly, Simmental cattle exhibited greater ($P = 0.01$) liver Mn concentrations in the days after injection compared with Angus cattle (7.0 and 6.0 mg Mn/kg for Simmental and Angus cattle, respectively), regardless of treatment. It is unclear if this breed difference is biologically relevant; however, these data may suggest that differences in liver excretion of Mn exist between the two breeds. Overall, use of an injectable trace mineral increased liver concentrations of Cu and Se through the 15-d sampling period, suggesting that this injectable mineral is an adequate way to improve Cu and Se status of cattle through at least 15 d.

Key words: breed, cattle, copper, manganese, selenium, zinc

 J. Anim. Sci. 2012.90:2692–2698
doi:10.2527/jas2012-4482

INTRODUCTION

Trace minerals are essential to multiple biochemical processes in the body, including skeletal development, immune response, and reproductive performance (Underwood and Suttle, 1999). Unfortunately, cattle diets do not always contain sufficient trace minerals to adequately meet body demands. Also, though cattle may be provided with a free-choice mineral supplement, this is not always sufficient to overcome mineral antagonists that may be present in the diet. Use of an injectable mineral may be beneficial to bypass negative interactions that may occur during the process of digestion and absorption of minerals or to increase the mineral status of an animal before a period of increased need such as breeding or shipping. Upon injection, minerals are circulated throughout the body and incorporated into cells as needed, with the remainder being filtered through the liver, where minerals are either bound to storage proteins for long-term use or excreted from the body (Suttle, 2010).

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Received July 18, 2011.
Accepted February 5, 2012.

Research into the efficacy of a trace mineral (**TM**) injection in cattle has included aspects of cattle production such as reproductive performance of cows and heifers, health of newly received calves, and performance of feedlot cattle. These studies have suggested a TM injection is an effective way to improve Cu status in beef cows (Daugherty et al., 2002) and growing steers (Kurz, 2004), whereas minimal differences in Zn and Se status were noted in these studies. Data available concerning breed differences in mineral metabolism indicate notable differences in liver and plasma concentrations of elements, such as Cu, between Continental and British breeds of cattle (Ward et al., 1995; Mullis et al., 2003a,b). Because of the limited information concerning influence of cattle breed on the clearance rate of TM, in the present study we hypothesized the plasma and liver concentrations of Cu, Zn, Mn, and Se in Angus and Simmental cattle after injection with a TM product differ.

MATERIALS AND METHODS

Procedures and protocols for cattle experiments were approved by the Iowa State University Institutional Animal Care and Use Committee (protocol number 10-09-6816-B).

Animals and Experimental Design

Angus (n = 10) and Simmental (n = 10) steers from the Iowa State University beef teaching farm, approximately 9 mo of age, were stratified by initial BW (332 ± 33 kg) and used in a 2 × 2 factorial experiment with 2 breeds (Angus and Simmental) and 2 treatments: injection with either Multimin 90 (**MM**; Multimin USA, Fort Collins, CO) or sterilized saline (**CON**) at a dose of 1 mL/45 kg BW. The Multimin 90 contained 15 mg Cu/mL (as Cu disodium EDTA), 60 mg Zn/mL (as Zn disodium EDTA), 10 mg Mn/mL (as Mn disodium EDTA), and 5 mg Se/mL (as sodium selenite). To avoid pen effects, steers were housed in pens of 2, with both treatments and breeds represented in each pen. In addition to a corn-silage-based diet cattle also received a supplement containing, per kilogram of diet, 10 mg Cu, 30 mg Zn, 20 mg Mn, and 0.1 mg Se, in accordance with NRC (1996) recommended values (Tables 1 and 2). Cattle were adapted to the diet for 15 d before the start of the study, were fed at 0800 h daily, and were allowed to consume the diet on an ad libitum basis. The daily DMI for the 15-d period post-injection averaged 5.5 $kg \cdot h^{-1} \cdot d^{-1}$; this value is calculated based on pen mean basis.

Table 1. Composition and chemical analysis of diet

Item	Percent DM
Ingredient	
Corn silage	80.0
Dried distillers grains with solubles	15.0
Cracked corn	4.45
Limestone	0.50
Bovatec91[1]	0.02
Trace mineral premix[2]	0.03
Chemical composition[3]	
CP, %	9.1
ADF, %	26.1
NE_g, Mcal/kg	1.04
NE_m, Mcal/kg	1.63

[1]Provided Lasalocid at 200 $mg \cdot h^{-1} \cdot d^{-1}$, Alpharma Inc., Bridgewater, NJ.

[2]Provided per kilogram of diet: 30 mg Zn as $ZnSO_4$, 20 mg Mn as $MnSO_4$, 0.5 mg I as $Ca(IO_3)2(H_2O)$, 0.1 mg Se as Na_2SeO_3, 10 mg Cu as $CuSO_4$, and 0.1 mg Co as $CoCO_3$.

[3]Dairyland, Inc., Arcadia, WI.

Sample Collection and Analytical Procedures

Steer BW were collected before the morning feeding and immediately before injection (0630 h) to determine proper dosage for the injectable mineral or saline. Jugular blood for plasma mineral analysis was collected in vacuum tubes designed for TM analysis (potassium EDTA, Becton Dickenson, Rutherford, NJ) immediately before injection (time 0), at 8 and 10 h post-injection, and on d 1 (24 h), 8, and 15 post-injection. Blood was transported to the laboratory on ice and centrifuged at 1,200 × *g* for 20 min at 4°C. Plasma was removed and stored at −20°C until further analysis. Liver biopsies were conducted 3 d before injection (time 0) and on d 1, 8, and 15 post-injection using the method of Engle and Spears (2000). Biopsy samples were transported on ice to the laboratory and frozen at −20°C until further analysis. Liver samples were dried in a forced-air oven and digested using trace metal grade nitric acid before mineral analysis. Liver and plasma analysis for Cu, Zn, Mn, and Se was conducted

Table 2. Mineral composition of the diet

Composition	Percent DM
Ca,[1] %	0.33
P,[1] %	0.29
Mg,[1] %	0.19
K,[1] %	0.70
S,[1] %	0.28
Cu,[2–4] mg/kg	15.5
Fe,[2] mg/kg	175.5
Mn,[2–4] mg/kg	38.0
Se,[2–4] mg/kg	0.37
Zn,[2–4] mg/kg	60.1

[1]Dairyland, Inc., Arcadia, WI.

[2]Iowa State University, Ames.

[3]Provided per kilogram of diet: 30 mg Zn as $ZnSO_4$, 20 mg Mn as $MnSO_4$, 0.5 mg I as $Ca(IO_3)2(H_2O)$, 0.1 mg Se as Na_2SeO_3, 10 mg Cu as $CuSO_4$, and 0.1 mg Co as $CoCO_3$.

[4]Mineral values reflect diet total plus supplemented mineral.

using inductively coupled plasma spectroscopy (**ICP**; Varian 820-MS, Agilent Technologies, Palo Alto, CA). Standards consisting of National Institute of Standards and Technology (**NIST**, Gaithersburg, MD) bovine muscle and liver were included in each session to verify instrument accuracy. Proximate and macromineral analysis was determined of the corn silage and dried distillers grains with solubles (**DDGS**) by Dairyland Laboratory, Inc. (Arcadia, WI), and diet TM analysis was conducted at the Iowa State University Veterinary Diagnostic laboratory using ICP mass spectroscopy (PerkinElmer, Waltham, MA).

Erythrocyte glutathione peroxidase activity (**GSH-Px**) was determined in samples collected at hours 0 and 10 and d 1, 8, and 15 post-injection. Packed red blood cells were lysed with 4 volumes of ice-cold molecular-grade water, mixed thoroughly, and centrifuged at 10,000 × *g* for 15 min at 4°C. The supernatant was removed and stored at −80°C until analysis using a commercial glutathione peroxidase activity kit (Cayman Chemical, Ann Arbor, MI; Catalog number 703102). The hemoglobin concentration of the cell lysate was determined as previously described (Hansen et al., 2010). Erythrocyte GSH-Px activity is reported as units GSH-Px per gram of hemoglobin, and a unit of GSH-Px is defined as the substrate amount that will cause the oxidation of 1.0 nmol of NADPH to $NADP^+$ per minute at 25°C.

Statistical Analysis

Data were analyzed by ANOVA as a complete randomized design using the MIXED procedure (SAS Inst. Inc., Cary, NC). Data were analyzed as a 2 × 2 factorial design, with the 2 factors being breed (Angus or Simmental) and treatment (CON or MM). Repeated measures analysis included time of sampling as the repeated effect, and baseline values determined before injection were used in a covariate analysis for all variables except plasma Mn because d 0 values were at or below ICP detection limits. The covariance structure was variance components (**VC**). The model included the fixed effects of treatment, breed, and time of sampling and the interactions. No data were found to have significant treatment by breed by time interactions, and thus these were removed from all models. When the *P*-value associated with a 2-way interaction was greater than 0.20, the interaction was removed from the model. Because the response of each steer was based on the individual injection of mineral or saline, the individual animal was considered the experimental unit for all data presented. Significance was declared at $P \leq 0.05$, and tendencies of $P \leq 0.15$ are reported. All data shown are least squares means adjusted for baseline values in covariate analysis with the exception of plasma Mn.

RESULTS AND DISCUSSION

The objective of the present study was to determine the effects of an injectable TM product on liver and plasma concentrations of Cu, Zn, Mn, and Se in Angus and Simmental cattle. Trace minerals are essential for a variety of physiological processes within the body, such as vitamin synthesis, hormone production, enzyme activity, tissue synthesis, oxygen transport, and energy production (Underwood and Suttle, 1999). Many of the trace elements required for growth and performance of cattle are found naturally in feedstuffs; however, mineral concentrations of those feedstuffs may be inadequate to maintain growth and optimal production. The present study diet was not designed to be antagonistic, and NRC (1996) recommended concentrations of TM were supplemented in addition to those already present in the diet, as recommended by Multimin 90 manufacturers. Trace mineral supplementation of cattle has been proven to have beneficial effects on reproduction, immune status, disease resistance, and feed intake (Paterson and Engle, 2005).

In this study, plasma Cu concentrations in MM steers demonstrated a tendency ($P = 0.12$) to be greater than CON steers over the 15-d post-injection period (Table 3). Regardless of treatment, Simmental cattle exhibited decreased ($P = 0.05$) plasma Cu concentrations compared with Angus cattle. Mullis et al. (2003a) also reported decreased plasma Cu concentrations in Simmental heifers compared with Angus heifers when cattle were fed a diet supplemented with 5 or 10 mg Cu/kg DM, and Ward et al. (1995) found that calves born to Simmental heifers displayed decreased plasma Cu concentrations compared with calves born to Angus heifers when the diet was supplemented with 10 mg Cu/kg DM. In the present study, liver Cu concentrations were increased ($P = 0.01$) in MM calves compared with CON calves over the 15-d post-injection period, but there was no difference among Angus and Simmental cattle (Table 4). Mullis et al. (2003a) also reported no difference in liver Cu concentrations among Simmental and Angus heifers when supplemented with 0, 7, or 14 mg Cu/kg. However, in another study by Mullis et al. (2003b), examining the effect of breed and differing sources of Cu and Zn on mineral status, the authors reported Simmental steers expressed decreased liver Cu concentrations compared with Angus steers throughout the 140-d study. Discrepancies between our study and that of Mullis et al. (2003b) may be due to the length of study as the present study was only 15 d compared with 140 d in the Mullis et al. (2003b) study.

In the present study, the injectable TM was an effective way to increase liver Cu concentrations of cattle, similar to the increases reported by others using injectable TM (Daugherty et al., 2002; Kurz, 2004). It should be noted

Table 3. Effect of injectable mineral on bovine plasma mineral concentration and red blood cell glutathione peroxidase activity

Item	Treatment[1]			Breed			*P*-Value	
	CON	MM	SEM	Angus	Simmental	SEM	Trt[2]	Breed
Plasma mineral	n = 10	n = 10		n = 10	n = 10			
Cu,[3] mg/L	1.2	1.3	0.03	1.3	1.2	0.03	0.12	0.05
Zn,[3–5] mg/L	1.0	1.2	0.04	1.2	1.0	0.04	0.01	0.01
Mn,[3–5] μg/L	2.0	7.9	0.4	4.7	5.2	0.4	0.01	0.30
Se,[3–6] μg/L	77.6	175.3	6.2	138.0	115.0	6.1	0.01	0.01
Red blood cell								
Glutathione peroxidase activity, [3,7] U/g Hb	160.4	226.2	15.5	186.2	200.4	15.6	0.01	0.5

[1]Control cattle (CON) received a sterilized saline solution at 1 mL/45 kg BW, and Multimin 90 (MM) cattle received injectable mineral at 1 mL/45 kg BW.

[2]Trt = treatment.

[3]Overall means based on repeated measures analysis; day 0 values as covariates, except Mn.

[4]Day ($P < 0.001$).

[5]Day × treatment ($P < 0.001$).

[6]Day × breed ($P \leq 0.05$).

[7]Day ($P < 0.10$).

that steers used in the present study were not deficient in Cu before the initiation of this experiment as evidenced by adequate liver Cu concentrations averaging 99 mg/kg DM on d 0 (range of 46 to 170 mg Cu/kg DM). However, Cu deficiency in beef cattle has been previously noted in the United States [NAHMS Beef 1997 USDA Animal and Plant Health Inspection Service (**APHIS**); USDA:APHIS:VS, 2000] even when cows receive supplemental Cu. Copper status may be particularly influenced because of the many antagonistic interactions that commonly occur between Cu and other minerals, including Fe, Mo, S, and Zn (Davis and Mertz, 1987; Phillippo et al., 1987). An injectable TM that contains Cu may help bypass antagonisms that occur in the gastrointestinal tract, such as formation of thiomolybdate complexes in the rumen, thereby providing more Cu for metabolic processes that require Cu. In cattle, Cu-dependent enzymes play an important role in maintaining health status, as Xin et al. (1991) reported a decrease in bactericidal capacity and superoxide dismutase (**SOD**) activity of neutrophils in Cu-deficient steers. Neutrophils, the primary phagocytes in the innate immune response, are responsible for the first line of defense against pathogen invasion and generate superoxide ions as a mechanism to destroy pathogenic cells. Xin et al. (1991) hypothesized that the decreased SOD activity observed in their study may be the cause of impaired neutrophil function in Cu-deficient steers, thus resulting in the risk of increased susceptibility to pathogenic infections.

Zinc is another TM that is critical to cattle health and growth. A deficiency of Zn has been characterized in all domestic species, with symptoms including loss of appetite, growth depression, abnormalities of the skin and appendages, and reproductive failure (Suttle, 2010). Plasma Zn concentrations were increased ($P = 0.01$) in MM steers over the 15-d post-injection period compared with CON steers (Table 3). Plasma Zn concentrations displayed a treatment by day interaction ($P < 0.001$) as concentrations in MM steers were increased through 24 h but were comparable with CON cattle for the remainder of the 15-d post-injection period (Figure 1A). Similar to breed differences observed in plasma Cu, Simmentals exhibited decreased ($P = 0.05$) plasma Zn concentrations compared with Angus cattle regardless of treatment (Table 3). Mullis et al. (2003b) also reported lower plasma Zn concentrations in Simmental vs.

Table 4. Effect of injectable mineral on bovine liver mineral concentration

Item	Treatment[1]			Breed			*P*-Value	
	CON	MM	SEM	Angus	Simmental	SEM	Trt[2]	Breed
Liver mineral, mg/kg DM	n = 10	n =10		n = 10	n = 10			
Cu[3,4]	113.5	177.6	5.3	140.9	150.2	5.3	0.01	0.2
Zn[3]	77.8	88.3	3.0	83.2	82.8	3.0	0.02	0.9
Mn[3]	6.2	6.8	0.19	6.0	7.0	0.19	0.06	0.01
Se[3–5]	1.7	6.2	0.37	3.7	4.3	0.38	0.01	0.3

[1]Control cattle (CON) received a sterilized saline solution at 1 mL/45 kg BW, and Multimin 90 (MM) cattle received injectable mineral at 1 mL/45 kg BW.

[2]Trt = treatment.

[3]Overall means based on repeated measures analysis; day 0 values as covariates.

[4]Day ($P < 0.05$).

[5]Day × treatment ($P < 0.05$).

Angus cattle when supplemented with 25 mg Zn/kg DM. Liver Zn concentrations were higher (P = 0.02) in MM steers compared with CON steers (Table 4) but were not affected by breed. The increases in liver Zn concentration in MM steers vs. CON steers were statistically significant but probably not large enough to be biologically important. Had steers in the present study been Zn deficient before TM injections, it is likely that a greater increase in liver Zn would have been observed as the animal would have greater biological need for supplemental Zn.

Manganese is an essential TM that serves as an enzyme activator for glyosyltransferases in cartilage formation and aids in prevention of oxidative stress through its role in mitochondrial SOD (Suttle, 2010). In the present study, plasma Mn concentrations were greater (P = 0.01) in the MM steers compared with CON steers during the 15-d post-injection period (Table 3). On the basis of repeated measures, a treatment by day interaction (P < 0.01) was detected, in which plasma Mn concentrations in MM cattle were increased above CON cattle through d 1 and returned to baseline values similar to CON cattle by d 8 (Figure 1B). Manganese concentrations in plasma were not affected by breed. Similarly, Hansen et al. (2006) reported no differences in plasma Mn concentrations among Angus or Simmental heifers of a similar age to the steers used in the present study, fed varying concentrations of dietary Mn.

Liver Mn concentrations in the present study tended to be greater (P = 0.06) in MM steers compared with CON steers over the 15-d post-injection period (Table 4). Limited research is available concerning Mn storage in tissues. In situations where excess Mn is supplemented to animals, the initial pass through the liver is the only opportunity for storage in this organ, and the excess is often excreted in the bile (Suttle, 2010). Interestingly, in the current study Simmental cattle exhibited greater (P = 0.01) liver Mn concentrations compared with Angus cattle, regardless of treatment. There was also a tendency for a day by

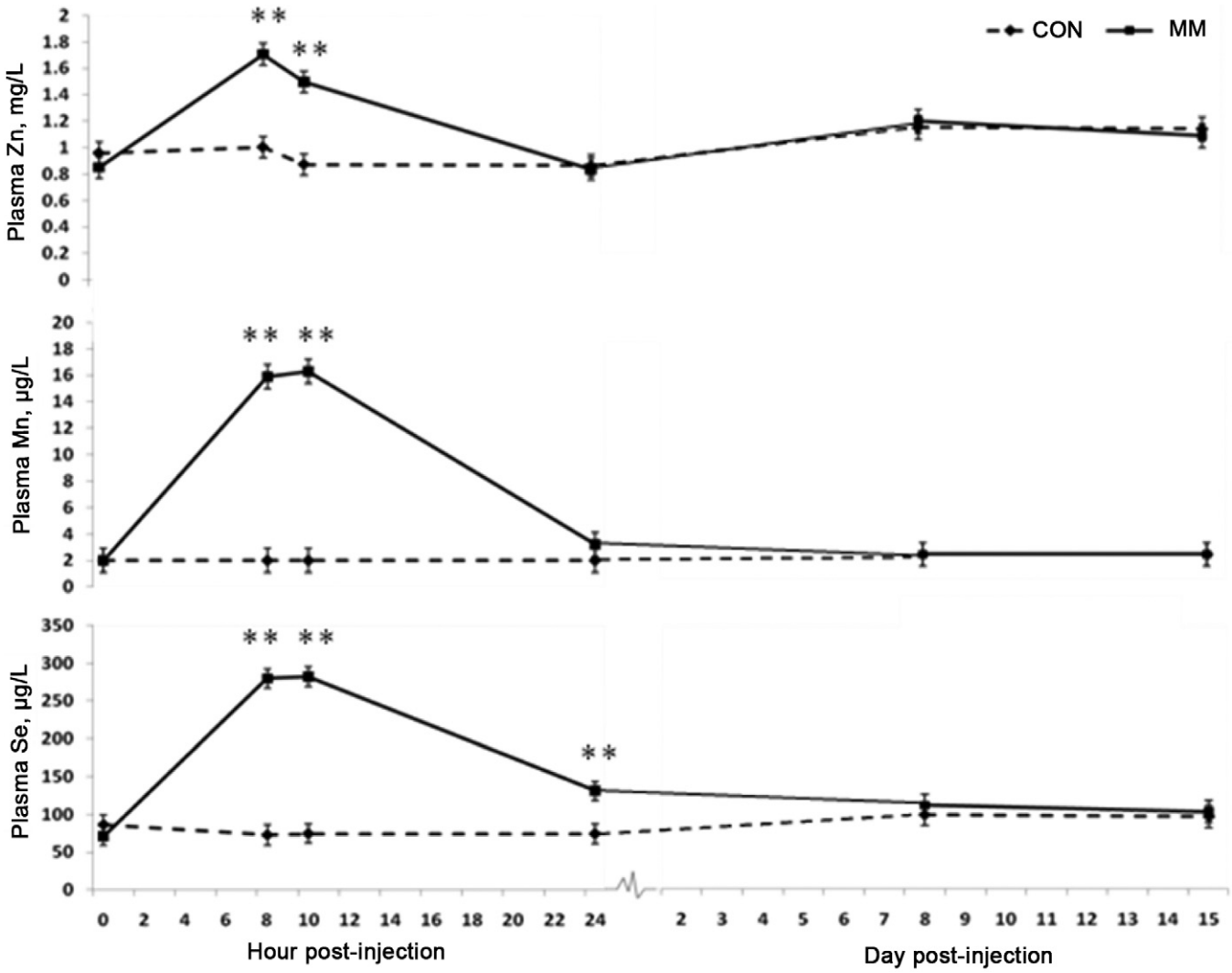

Figure 1. Effect of an injectable trace mineral on plasma concentrations of (A) Zn, (B) Mn, and (C) Se over the 15-d post-injection period; treatment (P < 0.05) and treatment × day (P < 0.001). Asterisks denote differences (P < 0.001) between treatments within day of experiment; n = 10 steers per treatment at each time point. Treatments are sterilized saline (CON) and Multimin 90 (MM).

breed interaction ($P = 0.07$) in which Angus cattle exhibited lower liver Mn concentration regardless of treatment across all time points (6.09, 5.88, and 6.01 mg Mn/kg on d 1, 8, and 15, respectively) compared with Simmental cattle (6.38, 6.77, and 7.81 mg Mn/kg on d 1, 8, 15, respectively), which increased liver Mn concentrations over the period between d 1 and 15 post-injection, regardless of treatment. It is unclear if the difference between breeds is biologically relevant, but the difference may suggest that clearance from the liver differs between the 2 breeds. Alternately, Hansen et al. (2006) found no difference in liver Mn concentrations among Simmental or Angus heifers; however, it is possible that breed differences are dependent upon the sex of the animal as steers were used in the present study.

Deficiencies and marginal deficiencies of Se are prevalent across the United States, particularly in the northwestern, northeastern, and southeastern portions of the country (Mortimer et al., 1999). Supplementation of dietary Se has been deemed a preventative measure against incidences of white-muscle disease in cattle and sheep, a degeneration of cardiac and striated muscle (Muth et al., 1958). A deficiency in Se may result in growth suppression, especially in a concurrent insufficiency of Cu (Gleed et al., 1983; Koh and Judson, 1987). In the present study, plasma Se concentrations were greater ($P = 0.01$) over the 15-d post-injection period in MM steers compared with CON steers (Table 3). A treatment by day interaction ($P < 0.01$) was observed where plasma Se increased by 8 h after injection in MM steers and remained increased above the CON cattle through 24 h, after which plasma Se returned to near-baseline amounts, similar to CON cattle (Figure 1C).

Angus cattle exhibited greater ($P = 0.01$) plasma Se concentrations compared with Simmental cattle (Table 1). A treatment by breed interaction ($P = 0.05$) was observed in which Angus cattle injected with the TM exhibited a greater increase in plasma Se concentrations over Angus CON than did Simmental MM steers when compared with Simmental CON steers.

Liver Se was greater ($P = 0.01$) in MM steers compared with CON steers through the 15-d post-injection period, and there was no evidence of a breed effect on Se concentrations in the liver. A treatment by day interaction ($P < 0.01$) was observed for Se concentrations in the liver, as liver Se in MM cattle peaked on d 1 and decreased from d 1 to d 8 but did not differ between d 8 and 15, whereas CON cattle liver Se concentrations did not differ by day (Figure 2). In addition to improving liver Cu concentrations, the injectable TM used in this study appears to be an effective way to increase liver Se concentrations of cattle over at least a 15-d period.

As a component of GSH-Px, Se has an important function in the protection of cellular membranes and tissues from free radical damage through GSH-Px activity, and as a result, GSH-Px activity has become a valuable measure of Se status within cattle (Kincaid, 1995). Erythrocyte GSH-Px activity was greater ($P = 0.01$) in MM compared with CON steers on the basis of repeated measures analysis over the 15-d period (Table 3), suggesting the injected Se was successfully incorporated into a biochemical process. Activity of GSH-Px was not different because of breed, suggesting that although circulating Se measured in plasma was different between breeds, both breeds of cattle were able to use the injectable Se in a similar manner.

Cattle in the present study were receiving a dietary TM supplement, at NRC (1996) recommended concentrations, in addition to minerals present in the diet. Incorporation of an injectable TM supplement into cattle production systems has an advantage over additional free-choice TM supplements or total mixed ration beyond animal requirement by ensuring the individual animal is receiving adequate TM for growth and production. Trace mineral supplementation during times of stress and critical production periods may prove beneficial to overall animal health and performance. Decreased TM status may negatively impact reproduction, immunity, and general performance of the animal. Because the ruminant diet is often forage based, the concentrations of TM in forages are often a determining factor in the need for TM supplementation. Mortimer et al., (1999) reported that across the United States, TM classification of forages sampled indicates that Se, Zn, and Cu concentrations were deficient in 69.8%, 77.0%, and 66.7% of 709 samples, respectively, whereas only 0.6% of samples were deficient in Mn. Although cattle in the present study were not stressed or deficient in TM, an increase in mineral status was observed in cattle receiving the injectable TM product. These data suggest a TM injection may improve the TM status of animals and may

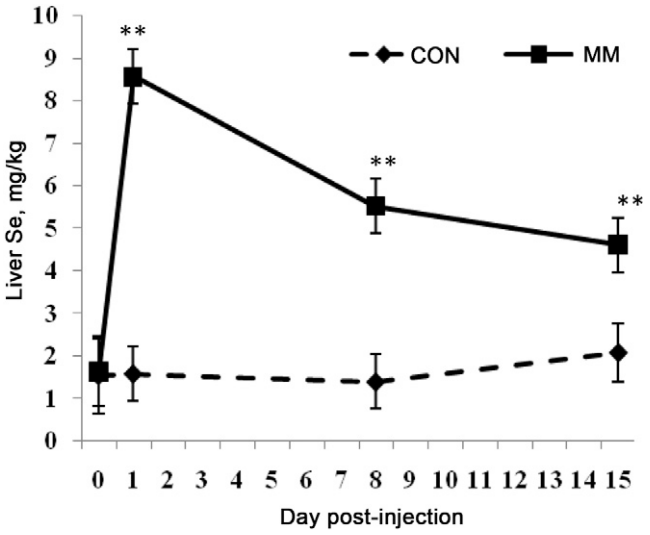

Figure 2. Effect of an injectable trace mineral on liver Se concentrations of cattle over the 15-d post-injection period; treatment × day interaction ($P = 0.004$). Asterisks denote differences ($P < 0.001$) between treatments within day of experiment; n = 10 steers per treatment at each time point. Treatments are sterilized saline (CON) and Multimin 90 (MM).

be particularly useful during times of stress or low-quality diets or in the presence of a dietary antagonist, particularly when Cu and Se are of concern.

In conclusion, Multimin 90 improved the TM status of Angus and Simmental steers when compared with controls receiving sterilized saline. In particular, liver Cu and Se were increased through d 15 post-injection. Future research should extend sampling beyond 15 d to determine the length of expected mineral status improvement. It should be noted that on the basis of liver mineral concentrations cattle used in this study were not deficient in any of the TM investigated. Though this approach has value because cattle do not often experience deficiencies of all 4 of these minerals at the same time, this may have contributed to an increased liver clearance rate as the steers did not have an excessive need for these TM. Therefore, future research should examine impacts of injectable TM on status of cattle experiencing mild to moderate deficiencies of Cu, Se, Zn, and Mn. The present study also identified breed differences among Angus and Simmental cattle in the clearance rate of an injectable TM, suggesting that cattle of different breeds may have differing TM requirements, and producers may benefit from specialized mineral supplementation programs designed to minimize producer costs and limit excessive mineral excretion due to over supplementation.

LITERATURE CITED

Daugherty, S. R., G. E. Carstens, D. B. Herd, K. S. Barling, and R. D. Randel. 2002. Effects of prenatal and prebreeding trace mineral/vitamin E injections on calf health and reproductive performance of beef cows. Beef Cattle Research in Texas Report. Dep. Anim. Sci., Texas A&M Univ., College Station. http://www.multiminusa.com/sites/www.multiminusa.com/files/pdfs/multimin_in_beef_cows.pdf

Davis, K. G., and W. Mertz. 1987. Copper. Pages 301–364 in Trace Elements in Human and Animal Nutrition. 5th ed. W. Mertz, ed. Academic Press, New York.

Engle, T. E., and J. W. Spears. 2000. Effects of dietary copper concentration and source on performance and copper status of growing and finishing steers. J. Anim. Sci. 78:2446–2451.

Gleed, P. T., W. M. Allen, C. B. Mallenson, G. J. Rowlands, B. F. Sanson, M. J. Vagg, and R. D. Caswell. 1983. Effects of selenium and copper supplementation in the growth of beef steers. Vet. Rec. 113:388–392.

Hansen, S. L., M. S Ashwell, A. J. Moeser, R. S. Fry, M. D. Knutson, and J. W. Spears. 2010. High dietary iron reduces transporters involved in iron and manganese metabolism and increased intestinal permeability in calves. J. Dairy Sci. 93:656–665.

Hansen, S. L., J. W. Spears, K. E. Lloyd, and C. S. Whisnant. 2006. Growth, reproductive performance, and manganese status of heifers fed varying concentrations of manganese. J. Anim. Sci. 84:3375–3380.

Kincaid, R. L. 1995. The biological basis for selenium requirements of animals. Prof. Anim. Sci. 11:26-29.

Koh, T.-S., and G. J. Judson. 1987. Copper and selenium deficiency in cattle: An evaluation of methods of oral therapy and an observation of a copper-selenium interaction. Vet. Res. Commun. 11:133–148.

Kurz, M. W. 2004. Nutritional modulation of immunity and physiological responses in beef calves. M.S. thesis. Texas A&M Univ., College Station.

Mortimer, R. G., D. A. Dargatz, and L. R. Corah. 1999. Forage analyses from cow-calf herds in 23 states. Rep. No. N303.499. USDA:APHIS:VS, Cent. for Epidemiol. and Anim. Health. Fort Collins, CO.

Mullis, L. A., J. W. Spears, and R. L. McCraw. 2003a. Effects of breed (Angus vs Simmental) and copper and zinc source on mineral status of steers fed high dietary iron. J. Anim. Sci. 81:318–322.

Mullis, L. A, J. W. Spears, and R. L. McCraw. 2003b. Estimated copper requirements of Angus and Simmental heifers. J. Anim. Sci. 81:865–873.

Muth, O. H., J. E. Oldfield, L. F. Remmert, and J. R. Schubert. 1958. Effects of selenium and vitamin E on white muscle disease. *Science* 128:1090.

NRC. 1996. Nutrient Requirements of Beef Cattle. 7th rev. ed. Natl. Acad. Press, Washington, DC.

Paterson, J. A., and T. E. Engle. 2005. Trace mineral nutrition in beef cattle. Nutr. Conf. Proc. Dep. of Anim. Sci., UT Ext. and Univ. Prof. Dev., Univ. of Tennessee, Knoxville.

Phillippo, M., W. R. Humphries, and P. H. Garthwaite. 1987. The effect of dietary molybdenum and iron on copper status and growth in cattle. J. Agric. Sci. 99: 359–364.

Suttle, N. F. 2010. Mineral Nutrition of Livestock. 4th ed. CABI Publishing, New York.

Underwood, E. J., and N. F. Suttle. 1999. The Mineral Nutrition of Livestock. 3rd ed. CABI Publishing, New York.

USDA:APHIS:VS. 2000. Serum copper concentrations of US beef cattle, information sheet. http://www.aphis.usda.gov/animal_health/nahms/beefcowcalf/downloads/beef97/Beef97_is_SerumCopper.pdf

Ward, J. D., J. W. Spears, and G. P. Gengelbach. 1995. Difference in copper status and copper metabolism among Angus, Simmental, and Charolais cattle. J. Anim. Sci. 73:571–577.

Xin, Z., D. F. Waterman, R. W. Hemken, and R. J. Harmon. 1991. Effects of copper status on neutrophil function, superoxide dismutase, and copper distribution in steers. J. Dairy Sci. 47:3078–3085.