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Effect of dietary trace mineral supplementation and a multi-element trace mineral injection on shipping response and growth performance of beef cattle

O. N. Genther* and S. L. Hansen*[1]

*Department of Animal Science, Iowa State University, Ames 50011

ABSTRACT: To examine the effect of trace mineral (TM) status and TM injection on growth performance and carcass characteristics in beef cattle, 40 steers were used in a growing and finishing study. Steers were stratified by weight (323 ± 14.8 kg) and assigned to 1 of 2 treatments for an 84-d depletion period: 1) a corn silage-based diet supplemented with Cu, Mn, Se, and Zn to meet or exceed NRC recommendations (CON), or 2) CON diet without supplemental Cu, Mn, Se, or Zn but supplemented with 300 mg Fe and 5 mg Mo/kg diet DM as dietary TM antagonists (DEF) to induce mild deficiencies. To mimic shipping stress, steers were shipped for 20 h on d 88 and were received back on d 89. On d 91 an equal number of steers from both dietary treatments were injected with sterilized saline (SAL) or Multimin 90 (MM; containing 15, 60, 10, and 5 mg/mL of Cu, Zn, Mn, and Se, respectively) at a dose of 1 mL/68 kg BW. Steers were fed a common finishing diet supplemented with 10 mg Cu, 20 mg Mn, 0.1 mg Se, and 30 mg Zn/kg diet DM for the 90-d repletion period. Steers were harvested 91 d postinjection and carcass data were collected. During the depletion period, diet did not affect BW, ADG, DMI, or G:F ($P > 0.20$). During the shipping period (defined as the time between 2-d consecutive weights on d 83 and 84 and d 90 and 91), DEF steers tended to lose more weight per day than CON steers ($P = 0.06$) and had lesser DMI ($P = 0.03$), suggesting that response to shipping stress may be modulated by TM status. During the repletion period, ADG of DEF + MM steers was greater ($P = 0.03$) compared with DEF + SAL and was not different ($P = 0.92$) among CON + MM and CON + SAL steers. There was no effect of diet or injection on HCW or dressing percentage ($P > 0.20$). Within the CON group, TM injection decreased yield grade ($P = 0.03$) but did not affect yield grade of DEF steers ($P > 0.20$). Steers given TM injection had a larger rib eye area ($P = 0.04$) regardless of previous diet. Interestingly, both diet and injection affected marbling scores (MS), where CON steers had greater MS than DEF steers ($P = 0.01$) and MM steers had greater MS than SAL steers ($P = 0.04$). These results indicate that adequate TM nutrition is essential for marbling development, during both the growing and finishing phases. Overall, an injectable mineral improved rib eye area and MS regardless of initial TM status and improved growth of mildly TM deficient steers.

Key words: beef cattle, marbling, rib eye area, shipping, trace minerals

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INTRODUCTION

Trace minerals (**TM**) are important dietary components for beef cattle and are necessary for multiple biochemical processes, including skeletal and muscular development (Suttle, 2010). Feedstuffs commonly fed to beef cattle can provide these nutrients; however, variable or inadequate concentrations (Smart et al., 1981) coupled with the formation of insoluble complexes with dietary antagonists such as Fe, Mo, and S can lead to TM deficiencies (Spears, 1996). Trace mineral deficiencies contribute to poor growth performance and lower quality carcasses (Ward and Spears, 1997; Spears and Kegley, 2002). However, it is uncommon to know the TM status of cattle coming into the feedlot, so providing TM to avoid risks associated with deficiencies may be beneficial. Supplemental TM delivered through injection bypass the gastrointestinal tract and antagonists and have been shown to improve Cu and Se concentrations in the liver through at least 15 d postinjection (Pogge et al., 2012) and health and performance in beef cattle (Richeson and Kegley, 2011). However, the effect of TM supplementation and TM injection on growth performance and carcass charac

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[1] Corresponding author: slhansen@iastate.edu

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teristics in animals with varying TM status has not been studied. The objective of this study was to evaluate the effect of varying TM status on response to a shipping event as well as TM injection on growth performance and carcass characteristics in beef feedlot cattle.

MATERIALS AND METHODS

All procedures and protocols were approved by the Iowa State University Institutional Animal Care and Use Committee (log number 3-11-7099-B).

Depletion Period

Forty yearling Angus crossbred steers were stratified by initial BW (323 ± 14.8 kg) and assigned randomly to 1 of 2 treatments (*n* = 20 per treatment): 1) a corn silage based diet supplemented with Cu, Mn, Se, and Zn to meet or exceed NRC recommendations (10 mg Cu/kg DM, 20 mg Mn/kg DM, 0.1 mg Se/kg DM, and 30 mg Zn/kg DM), in accordance with NRC (1996) recommendations or 2) a CON diet without supplemental Cu, Mn, Se, or Zn but supplemented with 300 mg Fe and 5 mg Mo/kg diet DM as dietary TM antagonists (**DEF**). Dietary composition can be found in Table 1. Steers were weighed before feeding every 28 d throughout the depletion period, and 2-d consecutive weights were taken at the beginning of the experiment, once every 28 d, and on d 83 and 84 at the end of the depletion period. The cattle were not implanted but were vaccinated with Pyramid 5 (Bovine Rhinotracheitis Virus Diarrhea-Parainfluenza-3-Respiratory Syncytial Virus Vaccine; Fort Dodge Animal Health, Fort Dodge, IA) and Presponse (Pasteurella Multocidia Bacterial Extract Mannhheimia Hemolytica Toxoid; Fort Dodge Animal Health) and Vision 7 (clostridial bacterin-toxoid; Merck Animal Health, Summit, NJ) 5 d before the beginning of the experiment. Steers were housed in partial confinement, south-facing open side, dirt floor pens measuring 30.6 m^2, with 6 or 7 steers penned by dietary treatment with ad libitum access to water. Steers were fed once daily at approximately 0800 h for approximately 3% feed refusal on a DM basis. If feed refusal was less than 3% of feed delivered, feed delivered was increased by 3% DM. Steer feed intake was recorded daily on an individual basis using the Iowa State University Beef Nutrition Farm's feed intake management system. Steers were fitted with electronic identification tags, which allowed for feed disappearance by a single steer to be monitored. This feed intake system is described in detail by Dahlke et al. (2008). Liver biopsy samples were taken on d 71 of the depletion period to establish TM status before shipping and start of the repletion period using the method reported by Engle and Spears (2000). Steers were fed a growing diet (either CON or DEF) through d 71 followed by a series of 3 (6 to 7 d in length each) step-up diets (with corn replacing corn silage), maintaining the same supplemental TM concentrations (CON or DEF) in preparation for the repletion period finishing diet. Steers were transitioned before shipping to minimize dietary changes confounding TM status changes in response to a TM injection administered 2 d after shipping.

Table 1. Composition of diets during depletion and repletion periods

	Depletion[1]		
Ingredient	CON	DEF	Repletion[2]
	% of diet DM		
Corn silage	50	50	15
Corn dried distillers grains with solubles	20.64	20.57	23.02
Soyhull pellets	10	10	10
Dry rolled corn	18	18	50
Limestone	0.9	0.9	1.51
Vitamin A premix[3]	0.11	0.11	0.11
Salt	0.31	0.31	0.31
Rumensin90[4]	0.01	0.01	0.01
Trace mineral premix[5]	0.001	0.001	0.001
CON premix[6]	0.035	–	0.035
DEF premix[7]	–	0.101	–
Calculated composition			
NE (g), Mcal/kg	1.2	1.2	1.3
CP, %	12.2	12.2	12.8
Analyzed,[8] mg/kg of diet DM			
Cu	13.8	4.1	12.7
Fe[9]	336	610	228
Mn	43.9	25.7	32.1
Mo[9]	0.88	4.85	0.77
Zn	56.1	33.9	62.3

[1] Depletion treatments were CON corn silage-based diet supplemented with Cu, Mn, Se, and Zn to meet or exceed NRC recommendations and DEF = CON diet without supplemental Cu, Mn, Se, or Zn but supplemented with 300 mg Fe and 5 mg Mo/kg diet DM as dietary TM antagonists.

[2] All cattle received the same diet during the repletion phase.

[3] Vitamin A premix contained 4,400,000 IU vitamin A/kg.

[4] Provided 200 mg steer^{-1} d^{-1} of the ionophore monensin (Elanco, Greenfield, IN).

[5] Provided per kilogram of diet DM: 0.5 mg I (calcium iodate) and 0.1 mg Co (cobalt carbonate).

[6] Provided per kilogram of diet DM: 10 mg Cu (copper sulfate), 20 mg Mn (manganese sulfate), 0.1 mg Se (sodium selenite), and 30 mg Zn (zinc sulfate).

[7] Provided per kilogram of diet DM: 300 mg Fe ($FeSO_4$) and 5 mg Mo (Na_2MoO_4).

[8] Analyzed mineral values reflect diet total, including supplemented mineral.

[9] Analysis of overall diet composite samples for Fe and Mo was completed by Dairyland Laboratories, Inc. (Arcadia, WI).

Shipping Period

Steers were loaded onto a tractor-trailer on d 88 (1030 h) and shipped for 20 h to simulate shipping, to evaluate the effect of TM dietary deficiency on shipping response. Each steer had 1.10 m^2 of space in the trailer, pens were randomly assigned to top or bottom compart ments, and future injection treatments were evenly distributed across compartments. Steers were received back at the Iowa State University Beef Nutrition Research Center on d 89 (0630 h) into the same pens and were allowed to rest for 24 h with ad libitum access to feed and water. Two day consecutive weights were taken before feeding on d 90 and 91, and the average of these weights was compared with the average of weights from d 83 and 84 to calculate shipping ADG (or loss). Shipping period DMI was also measured during this period from d 84 through d 90.

Repletion Period

On d 91, steers (441 ± 21.8 kg BW) were stratified by liver mineral status (primarily liver Cu) within depletion period diet and randomly assigned to receive an injection with sterilized saline (**SAL**) or Multimin 90 (**MM**; Multimin USA, Fort Collins, CO) at a dose of 1 mL/68 kg BW (average dose = 6.5 mL), resulting in 10 steers per treatment group. The MM injection provided 15 mg Cu/mL (as copper disodium EDTA), 10 mg Mn/mL (as manganese disodium EDTA), 5 mg Se/mL (as sodium selenite), and 60 mg Zn/mL (as zinc disodium EDTA). All steers were fed a common finishing diet supplemented with 10 mg Cu, 20 mg Mn, 0.1 mg Se, and 30 mg Zn/kg diet DM for the 90 d repletion period (Table 1). Average daily gain was calculated from 2-d consecutive weights taken at the beginning and end of each period and at 28 d intervals between. At the end of the repletion period, steers were shipped to a commercial abattoir in Dension, IA (Tyson Fresh Meats), where individual identification was maintained with each carcass following harvest and HCW data were collected. After a 24-h chill, carcasses were ribbed between the 12th and 13th ribs and graded according to USDA standards. Carcass data were collected at the plant by representatives of Tri-Country Carcass Futurity (Iowa State University Beef Extension, Lewis, IA) who were blinded to treatment. Data collected included rib eye area (**REA**), 12th rib back fat (**BF**), KPH, marbling score (**MS**), quality grade (**QG**), and yield grade (**YG**). Carcass-adjusted final BW was calculated by dividing HCW by the average dressing percentage (62.8%). A 4% pencil shrink was applied to all live BW measures before the calculation of ADG and G:F.

Feed Sampling and Analysis

Diet total mixed ration samples were collected weekly, and samples were dried in a forced air oven at 70°C for 48 h for dry matter determination. The diet samples were then ground through a 2-mm screen in a Wiley Mill (Thomas Scientfic, Swedesboro, NJ), and samples were composited within treatment by month for Cu, Mn, and Zn analysis. Composited feeds were digested using trace metal grade nitric acid (catalog number A509-P212; Fisher Scientific, Fair Lawn, NJ) before TM analysis. Feed sample concentrations of Cu, Mn, and Zn were determined using inductively coupled plasma optic emission spectroscopy (PerkinElmer, Waltham, MA) as previously described (Richter et al., 2012). A bovine liver reference sample (National Institute of Standards and Technology, Gaithersburg, MD) was included in all analyses to verify instrument accuracy. Overall diet composite samples were analyzed for Fe and Mo by Dairyland Laboratories Inc. (Acadia, WI).

Steer intake as measured by the Iowa State University individual feed intake management system was adjusted for weekly diet DM to determine DMI. Feed efficiency (G:F) was calculated every 28 d from the total gain and total DMI within that period.

Statistical Analyses

Depletion and shipping period data were analyzed by ANOVA as a randomized complete block design using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) including the fixed effect of diet (CON or DEF) and the random effect of steer. Steers were individually fed throughout the experiment and were considered the experimental unit (*n* = 20 per diet). Data from the repletion period were analyzed as a 2 × 2 factorial also using the MIXED procedure of SAS including the fixed effects of both diet (CON or DEF) and injection (SAL or MM) and the random effect of steer. Steer was the experimental unit (*n* = 10 per diet × injection treatment) in the repletion period as well. Body weights, ADG, and G:F during the depletion and repletion periods were analyzed as monthly repeated measures (based on weigh dates). The model contained the fixed effects of diet or diet and injection as described above, with month as the repeated effect. Dry matter intake was averaged on a weekly basis during both the depletion and repletion periods before statistical analysis and was analyzed as repeated measures, with week as the repeated effect. The variance structure of auto-regressive 1 (**AR(1)**) was selected based on lowest Akaike information criterion corrected, and the interaction between diet, injection, and steer was designated as the subject for all repeated measures. Degrees of freedom were approximated using the Satterthwaite method. Data were checked for normalcy and homogeneity of variance, and no data transformation were necessary. Outliers were determined using Cook's *D* statistic and removed. Data reported are least-squared means ± SEM. Significance was declared at $P \leq 0.05$ and tendencies were declared from $P = 0.06$ to 0.10.

RESULTS

Table 2. Effect of depletion period dietary trace mineral supplementation on depletion period growth performance in yearling steers[1]

Variable	Treatment		SEM	*P*-value		
	CON	DEF		Diet	Time	Diet × time
BW,[2,4] kg	374.4	374.7	3.87	0.96	<0.001	0.03
d 0 (initial)	311.2	308.4	3.21	0.54	–	–
d 28	355.1	355.1	4.50	0.99	–	–
d 56	398.6	404.5	4.55	0.37	–	–
d 84 (final)[3]	432.9	431.9	4.89	0.89	–	–
DMI,[4,5] kg/d	10.61	10.14	0.328	0.32	<0.001	0.13
ADG,[4] kg/d	1.45	1.47	0.047	0.71	<0.001	0.007
d 1–28	1.57	1.63	0.101	0.65	–	–
d 29–56	1.56	1.80	0.065	0.01	–	–
d 57–84	1.22	0.98	0.066	0.01	–	–
G:F[4]	0.141	0.148	0.0085	0.56	<0.001	0.22

[1] Means are based on 20 steers per dietary treatment. CON = corn silage-based diet supplemented with Cu, Mn, Se, and Zn to meet or exceed NRC recommendations; DEF = CON diet without supplemental Cu, Mn, Se, or Zn but supplemented with 300 mg Fe and 5 mg Mo/kg diet DM as dietary TM antagonists.

[2] A 4% pencil shrink was applied to all live BW measures as well as those used in the calculation of ADG and G:F.

[3] Final BW is from d 83 and 84 of the experiment.

[4] Least-square means are based on overall repeated measures analysis from d 0 through 84 in the depletion period.

[5] DMI was averaged on a weekly basis before statistical analysis.

Trace mineral status of all steers was assessed throughout the study by analysis of liver and plasma TM concentration and data are reported elsewhere (Genther and Hansen, 2014). Briefly, after 71 d consuming a TM deficient diet, liver Cu and Se concentrations in DEF steers (79.0 ± 11.60 mg Cu/kg DM and 1.66 ± 0.080 mg Se/kg DM) were lesser than CON steers (229 ± 11.6 mg Cu/kg DM and 2.41 ± 0.080 mg Se/kg DM). Liver Cu in DEF steers would be classified as marginally deficient according to Kincaid (2000). Liver Mn tended to be lesser in DEF steers (8.71 ± 0.261 mg/kg DM) than CON steers (9.37 ± 0.261 mg/kg DM), while liver Zn was greater in DEF than CON steers (79.3 ± 1.45 mg/kg DM and 68.8 ± 1.40 mg/kg DM for DEF and CON, respectively) at the beginning of the repletion period. After TM injection, both liver Cu and Se concentrations of MM steers were greater than SAL steers for at least 30 d regardless of previous diet, while liver Mn and Zn were not affected by injection.

Growth Performance

During the 85 d depletion period, there were no overall differences in DMI or G:F between the DEF and CON steers ($P > 0.10$; Table 2). An interaction between diet and day was observed for ADG where DEF steers had greater ADG than CON from d 29 to 56 ($P = 0.01$) but lesser ADG from d 57 to 85 ($P = 0.01$). Diet had no impact on BW ($P > 0.20$), but there was an interaction between diet and day ($P = 0.03$) with likely minimal biological meaning as DEF and CON measures on individual days were not different ($P > 0.30$).

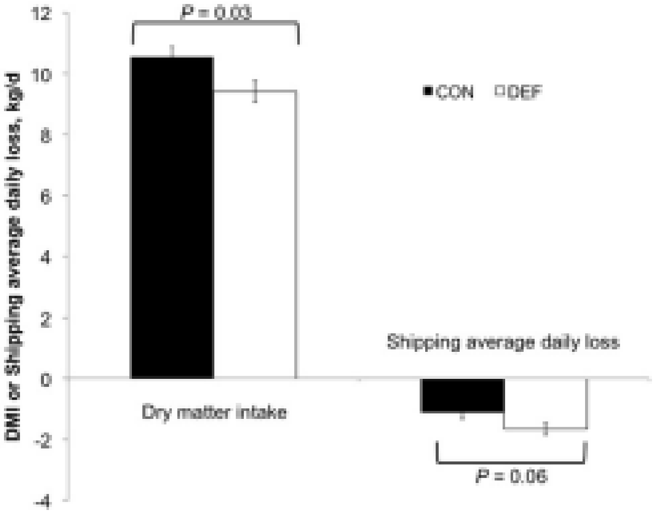

Figure 1. Shipping period DMI and average daily BW loss of steers fed either (CON) control corn silage-based diets supplemented with Cu, Mn, Se, and Zn to meet or exceed NRC recommendations ($n = 20$) or CON diet without supplemental Cu, Mn, Se, or Zn but supplemented with 300 mg Fe and 5 mg Mo/kg diet DM as dietary TM antagonists (DEF; $n = 20$) during the depletion period (85 d). Error bars represent SEM values.

During the shipping period, DEF steers tended to lose more weight per day than CON steers ($P = 0.06$) and had lesser DMI ($P = 0.03$; Fig. 1). Interestingly, ADG during the shipping period was positively correlated with initial liver Cu ($r = 0.324$, $P = 0.04$) and Se concentrations ($r = 0.396$, $P = 0.01$), based on liver samples collected 21 d before shipping, suggesting that greater Cu and Se status conveyed some protection against shipping stress-induced weight loss. During the initial 3 wk of the repletion period DEF steers had lesser DMI than CON steers ($P < 0.05$; Fig. 2) and tended to have lesser DMI at wk 5 and 6 ($P < 0.10$), while there was no overall injection effect on DMI over the repletion period. Body weights were not impacted by diet or injection ($P > 0.20$; Table 3). A tendency for an interaction between diet and injection was observed ($P < 0.10$) where MM improved ADG in DEF steers, but MM did not affect ADG within CON animals (Table 3). Efficiency, as determined using live animal performance variables, was not affected by previous depletion diet or injection treatment ($P \geq 0.14$). Carcass adjusted final BW was not influenced by either diet or injection ($P \geq 0.35$), but there was a tendency for MM steers to have greater carcass-adjusted ADG ($P = 0.08$) when compared with SAL steers. Additionally, there was an effect of diet ($P = 0.03$) on G:F, where steers that received the DEF diet during the depletion period were more efficient than CON steers; however, this effect was mainly driven by increased efficiency of the DEF + MM steers, as pairwise comparisons revealed that DEF + SAL steer G:F was not different from other treatments ($P > 0.20$).

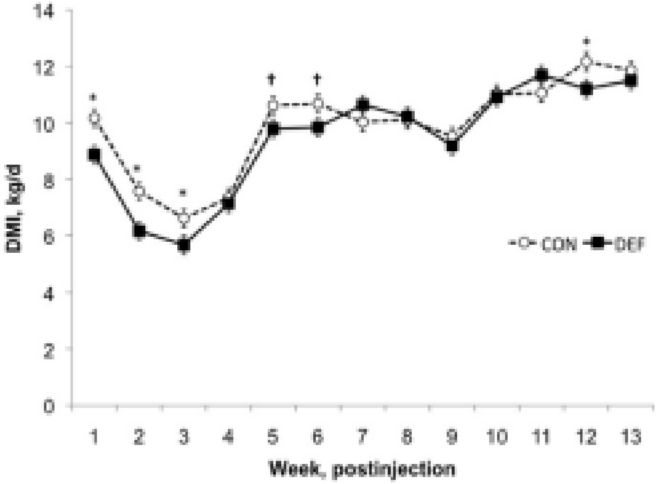

Figure 2. Repletion period DMI of steers fed either control (CON) corn silage-based diet supplemented with Cu, Mn, Se, and Zn to meet or exceed NRC recommendations ($n = 20$) or CON diet without supplemental Cu, Mn, Se, or Zn but supplemented with 300 mg Fe and 5 mg Mo/kg diet DM as dietary TM antagonists (DEF; $n = 20$) during the depletion period (85 d). Diet × week: $P < 0.001$, asterisks (*) denote differences ($P < 0.05$) between depletion diets and daggers (†) denote tendencies for differences ($P < 0.10$) between depletion diets, within week of the experiment. Error bars represent SEM values.

Carcass Characteristics

There was no effect of diet or injection on HCW or dressing percentage ($P > 0.20$; Table 4). There was an interaction ($P = 0.03$) between depletion and repletion treatments on calculated YG, where DEF + MM steers had higher YG than DEF + SAL steers ($P < 0.05$), yet within CON steers, MM decreased YG. Cattle treated with the injectable mineral had less KPH ($P = 0.01$) and had numerically lesser 12th rib BF ($P = 0.13$) than animals treated with saline. Trace mineral injection increased REA ($P = 0.04$) regardless of previous diet. Both diet and injection affected MS, where DEF steers had lesser MS than CON steers ($P = 0.01$) and MM steers had greater MS than SAL steers ($P = 0.04$). Receiving an injectable TM improved QG distribution of steers as more MM steers achieved a QG of low choice, while fewer MM steers graded high select ($P < 0.01$) when compared with SAL steers (Table 5). There was a tendency for more DEF steers to grade low choice than CON steers ($P = 0.08$), due to fewer DEF steers grading average choice than CON steers ($P = 0.02$).

DISCUSSION

Although limited differences in performance due to dietary TM supplementation were noted during the depletion phase, steers that consumed the CON diet during the depletion period were better able to recover from transit stress than steers receiving the DEF diet, as indicated by the lesser daily weight loss and greater DMI on return to the feedlot. Based on the liver biopsy samples collected shortly before shipping, liver Cu and Se concentrations in DEF steers were lesser than CON steers before injection (Genther and Hansen, 2014) suggesting these minerals may be critical in the response to shipping. Although 2-d consecutive weights were taken on either side of the shipping period to minimize variation, measuring weights over such a short period of time can increase the variation contributed by gut fill differences and certainly limits the interpretation of the these data. The positive correlation between weight gain during the shipping period and liver Cu and Se concentrations also supports this theory. However, the lack of correlation between liver Mn and Zn concentrations and shipping response does not necessarily indicate that Mn and Zn can be dismissed in relation to shipping response as liver concentrations of Mn or Zn are poor biomarkers for whole-body Mn and Zn status (Kincaid, 2000). Trace minerals are vital to the antioxidant system because they are components of enzymes such as Se-containing glutathione peroxidase and copper/zinc or manganese superoxide dismutase (Weisiger and Fridovich, 1937; Sordillo and Aitken, 2009). Stress, such as heat stress or shipping stress, can increase production of free radicals (Ganaie et al., 2013); therefore, antioxidant enzyme activity is very important to prevent oxidative damage to lipids, DNA, or other sensitive biological substrates. Other shipping studies have shown that transit stress of beef cattle increases serum malondialdehyde (**MDA**) concentrations (a marker of lipid peroxidation) and lowers total antioxidant capacity (Chirase et al., 2004). Through not measured directly in this study, nutritional support of these antioxidant enzymes may have improved shipping response by decreasing oxidative stress in CON cattle vs. DEF cattle.

Adequate TM nutrition may help stressed cattle recover previous feed consumption rates more quickly after a stressful event, as in this study CON steers had greater DMI on arrival back to the feedlot after shipping when compared with DEF steers. Beyond the shipping period, DMI continued to be greater in CON steers through the initial 6 wk of the repletion period suggesting that supplementation with TM may improve DMI in response to other potentially stressful situations. This study was conducted in the summer of 2011, and some of the hottest weather of the summer occurred during the repletion period of this study. During the initial 4 wk of the repletion period, the average temperature–humidity index was 26.1 ± 4.57°C with an average maximum temperature–humidity index of 34.4 ± 6.88°C. High daily temperatures and humidity and poor silage quality (mold due to excessive heat causing the silage to dry out very quickly) caused poor intakes during the first 3 wk of the repletion period. In another study, steers challenged with infectious bovine rhinotracheitis virus and supplemented with 54 mg zinc methionine/kg DM (89 mg Zn/kg total diet DM) had a slower rate of DMI decline and a lesser overall decrease in DMI when compared with steers fed 35 mg Zn/kg from zinc oxide (Chirase et al., 1991). These data suggest that during a potential stressor, such as disease or shipping, adequate TM status may be critical in maintenance of DMI by cattle. Cattle in feedlots frequently experience heat stress in the summer and economics dictate that these animals must not only survive but also continue to convert feed to gain as efficiently as possible.

Table 3. Effects of depletion dietary trace mineral supplementation and repletion saline or trace mineral injection on repletion period performance of yearling steers[1]

	Treatment							
	CON		DEF			*P*-value		
Variable	SAL	MM	SAL	MM	SEM	Diet	Injection	D × I[2]
Live measures								
Initial BW,[3,4] kg	424.4	428.8	416.0	424.7	6.72	0.36	0.33	0.76
Final BW,[4] kg	544.5	549.4	537.1	548.0	9.15	0.64	0.40	0.74
Repeated measures[5]								
BW,[4,6] kg	477.7	482.2	466.0	484.6	8.93	0.61	0.20	0.43
ADG,[6] kg/d	1.32	1.31	1.24	1.46	0.068	0.59	0.13	0.10
DMI,[7] kg/d	9.94	9.88	9.06	9.85	0.294	0.13	0.22	0.15
G:F[6]	0.132	0.132	0.139	0.145	0.0062	0.14	0.63	0.64
Carcass adjusted measures[8]								
Final BW, kg	547.1	548.5	533.3	551.1	10.21	0.59	0.35	0.43
ADG, kg/d	1.28	1.33	1.30	1.49	0.065	0.17	0.08	0.28
G:F	0.133	0.133	0.143	0.150	0.0058	0.03	0.49	0.59

[1] Means are based on 10 steers per diet × injection treatment combination. Depletion period dietary treatments included control corn silage-based diet (CON) supplemented with Cu, Mn, Se, and Zn to meet or exceed NRC recommendations and DEF = CON diet without supplemental Cu, Mn, Se, or Zn but supplemented with 300 mg Fe and 5 mg Mo/kg diet DM as dietary TM antagonists. Cattle received either sterilized saline (SAL) solution (1 mL/68 kg BW) or Multimin 90 (MM; 1 mL/68 kg BW) on d 1 of the repletion period.

[2] D × I represents the interaction between diet (D) and injection (I).

[3] Initial BW measures are from d 90 and 91 of the experiment.

[4] A 4% pencil shrink was applied to all live BW measures as well as in the calculation of ADG and G:F.

[5] Least-squared means are based on repeated measures.

[6] Day: $P < 0.001$ and all interactions including day: $P > 0.20$.

[7] DMI was averaged by week before repeated measures analysis. Week: $P < 0.001$, diet × week: $P < 0.001$, and injection × week and diet × injection × week: $P > 0.15$.

[8] Carcass-adjusted performance was calculated by dividing HCW with the average dressing percentage (62.8%).

The DEF + MM steers maintained greater ADG during the repletion period, suggesting that injectable TM at the start of the finishing period could help alleviate some negative impacts of prior TM deprivation. Additionally, DEF + MM animals had numerically greater DMI than DEF + SAL during the first few weeks of the trial, which

Table 4. Effects of depletion dietary trace mineral supplementation and repletion saline or trace mineral injection on carcass characteristics of yearling steers[1]

	Treatment							
	Diet: CON		DEF			*P*-value		
Variable	Injection: SAL	MM	SAL	MM	SEM	Diet	Injection	D × I[2]
HCW, kg	343.8	344.7	335.2	346.3	6.59	0.59	0.36	0.43
Dressing percentage, %	62.9	62.8	63.3	63.0	0.001	0.56	0.74	0.82
Yield grade	3.28	2.95	2.98	3.12	0.107	0.54	0.35	0.03
Rib eye area, cm^2	78.19	80.72	77.20	80.14	1.304	0.55	0.04	0.87
KPH	2.55	2.06	2.50	2.35	0.114	0.29	0.008	0.14
Backfat, cm	1.26	1.07	1.17	1.17	0.063	0.87	0.13	0.13
Marbling score[3]	558	588	509	550	15.9	0.01	0.04	0.72

[1] Means are based on 10 steers per diet × injection treatment combination. Depletion period dietary treatments included control (CON) corn silage-based diet supplemented with Cu, Mn, Se, and Zn to meet or exceed NRC recommendations and DEF = CON diet without supplemental Cu, Mn, Se, or Zn but supplemented with 300 mg Fe and 5 mg Mo/kg diet DM as dietary TM antagonists. Cattle received either sterilized saline (SAL) solution (1 mL/68 kg BW) or Multimin 90 (MM; 1 mL/68 kg BW) on d 1 of the repletion period.

[2] D × I represents the interaction between diet (D) and injection (I).

[3] Slight: 300, small: 400, and modest: 500.

Table 5. Effect of depletion dietary trace mineral supplementation and repletion saline or trace mineral injection on quality grade distribution of yearling steers[1]

	Treatment						
	CON		DEF		*P*-value		
Variable	SAL	MM	SAL	MM	Diet	Injection	D × I[2]
USDA quality grade,[3] %							
Prime	10	0	0	0	0.23	0.23	0.99
Choice	70	100	60	100	0.99	0.001	0.99
High	10	0	0	0	0.23	0.23	0.99
Average	30	30	0	10	0.02	0.26	0.26
Low	30	70	60	90	0.08	0.02	0.95
Select	20	0	40	0	0.99	0.003	0.99
High	20	0	30	0	0.99	0.006	0.99
Low	0	0	10	0	0.23	0.23	0.99

[1] Means are based on 10 steers per diet × injection treatment combination. Depletion period dietary treatments included control (CON) corn silage-based diet supplemented with Cu, Mn, Se, and Zn to meet or exceed NRC recommendations and DEF = CON diet without supplemental Cu, Mn, Se, or Zn but supplemented with 300 mg Fe and 5 mg Mo/kg diet DM as dietary TM antagonists. Cattle received either sterilized saline (SAL) solution (1 mL/68 kg BW) or Multimin 90 (MM; 1 mL/68 kg BW) on d 1 of the repletion period.

[2] D × I represents the interaction between diet (D) and injection (I).

[3] Quality grades are based on percentages within treatment.

may help explain the improved ADG in DEF–MM steers compared with DEF–SAL steers. Similarly, 2 different multi-element injections (containing either 20 mg Zn, 20 mg Mn, 10 mg Cu, and 5 mg Se/mL or 48 mg Zn, 10 mg Mn, 16 mg Cu, and 5 mg Se/mL from various inorganic sources) both improved ADG of highly stressed, newly received beef heifers when administered at a rate of 1 mL/45 kg of BW to heifers weighing 200 kg (Richeson and Kegley, 2011). In heat stress, as Sahin and Kucuk (2003) demonstrated, Zn supplementation to laying Japanese quail can increase feed intake and feed efficiency and decrease serum MDA concentrations (Kucuk et al., 2003; Sahin and Kucuk, 2003). These results suggest that Zn supplemented through injection may have played an important role in improving the DEF + MM steers response to the stressors that occurred early in the repletion period. Injectable TM in combination with supplemental dietary TM also improved TM liver stores more rapidly than adding supplemental TM to the diet alone at the beginning of the repletion period in the current study (Genther and Hansen, 2014), which may have aided in the improved performance of the DEF + MM steers.

Using a TM injection improved carcass-adjusted ADG compared to SAL, suggesting that providing a rapidly available source of TM to cattle may support carcass gain. This effect was mainly driven by the DEF + MM steers having greater gain than DEF + SAL. Although there was no difference in BW between CON and DEF steers at the end of the depletion period, DEF steers had lesser ADG at the end of the depletion period and lost more weight during shipping, suggesting that DEF animal performance was beginning to be limited by diet. However, DEF + MM steers had greater carcass-adjusted ADG and also greater carcass-adjusted efficiency after rapidly improving TM status with TM injection after a period of mild deficiency and ended the experiment having similar performance to CON steers. Carcass adjusted performance was calculated using a common dressing percentage, which allowed for lesser variation within measurement, likely contributing to the slight differences in statistical significance of these analyses.

Data from this study suggest that mineral status can influence marbling development during both the growing and finishing periods. Receiving a TM deficient diet, along with Fe and Mo as antagonists, during the grow ing period negatively influenced marbling at harvest. Cattle previously on the CON diet had a greater MS and QG than steers on the DEF diet signifying the importance of TM during the growing phase for intramuscular fat development. It has been previously noted that the intramuscular fat cells essential for future marbling are already developed before the growing and finishing phases, specifically between early weaning (often 90 d of age or younger) and approximately 250 d of age (Du et al., 2013), while filling of these cells occurs later in the finishing period (Hocquette et al., 2010). However, in this study, providing TM through the diet in the growing period (approximately 350 to 430 kg BW) or providing TM through injectable mineral in the finishing period (approximately 430 to 540 kg BW) improved MS. Zinc has been implicated in the synthesis and secretion of insulin, and Zn supplementation to obese mice can enhance insulin activity and decrease plasma glucose and increase lipogenesis (Chen et al., 1998). Zinc increases glucose transport (Tang and Shay, 2001) and as glucose appears to be an important substrate for intramuscular fat development (Smith and Crouse, 1984), this suggests that TM may be needed to support marbling.

In previous research, supplementation of Zn to growing and finishing cattle increased MS and YG when compared with non-Zn supplemented steers (Spears and Kegley, 2002), suggesting an effect of Zn on overall fat metabolism of the steers. However, steers that received a TM injection in the present study not only had greater MS and QG but also had a lesser YG, KPH, and BF. These data indicate that TM injection potentially caused a repartitioning of energy from fat synthesis to protein accretion, as demonstrated by the increased REA. Previous research also suggests that Cu supplementation may have a significant impact on lipid metabolism, as supplementing Cu to cattle during the growing or finishing phases has been shown increase REA (Ward and Spears, 1997) and to decrease 12th rib BF while not impacting MS (Engle and Spears, 2000; Engle et al., 2000). Neither dietary Mn nor Se concentrations have been shown to impact carcass characteristics (Legleiter et al., 2005; Lawler et al., 2004), although research in these areas is limited. Because the treatments in this study involved multiple TM, no single TM can be implicated in the changes in carcass composition. One hundred percent of the cattle that received TM injection, regardless of previous treatment, graded USDA Choice, whereas between 20 and 40% of SAL cattle graded USDA Select. These data suggest that providing TM through injection may increase QG, and depending on the USDA Choice–Select spread this may represent a significant source of income.

Alternatively, the increase in MS in response to dietary TM supplementation may be explained by the fact that DEF animals lost more weight during the shipping period and took longer to reach previous DMI amounts. These factors may have negatively impacted overall carcass quality, despite being potentially similar before shipping. Long-term (3-h) transport of broilers increases reactive oxygen species production and MDA content in thigh muscles and changes ATP:ADP ratios, suggesting changes in muscle metabolism and increases in lipid peroxidation may occur in response to transit stress (Zhang et al., 2010). While reactive oxygen species and overall cellular metabolism were not measured in this study, greater TM stores in CON steers (Genther and Hansen, 2014) may have assisted in the response to a stressor by potentially improving antioxidant enzyme activities and allowing for improvements in MS. Additionally, MM steers, regardless of previous depletion diet, had increased activity of Mn superoxide dismutase (SOD; Genther and Hansen, 2014) and this may have improved the response to the heat experienced at the beginning of the repletion period as mentioned previously. Heat-stressed broilers also have increased mitochondrial superoxide production and inefficient mitochondrial energy production (Mujahid et al., 2006) that could negatively impact muscle growth and overall meat quality and it is possible that increased Mn SOD may have allowed for improvements in muscle and fat deposition in the present study. However, as the heat was unexpected and not a part of the experimental design, heat responsive measures were not taken and this potential response cannot be quantified.

In conclusion, although 1 single TM cannot be identified as the cause of any of the individual results of this study, it is clear that adequate TM nutrition is vital for optimum beef cattle performance. Trace mineral status of finishing cattle proved to have important impacts on growth and carcass characteristics. The results of this study suggest that both the growing and finishing phases of feedlot cattle production are biologically important times for a beef steer to have adequate TM status. Additionally, use of a TM injection 91 d before harvest helped overcome the negative effects of a poor plane of TM nutrition during the growing period on final carcass quality while also improving REA regardless of TM adequacy of the growing diet. The mechanisms by which supplementation with Cu, Zn, Mn, and/or Se may be impacting carcass characteristics of feedlot cattle remain to be elucidated. Future research is also needed to clarify the value of incorporation of a TM injection into a feedlot program, including optimal time for delivery.

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