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Supplemental trace minerals (zinc, copper, and manganese) as sulfates, organic amino acid complexes, or hydroxy trace-mineral sources for shipping-stressed calves

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ABSTRACT

Crossbred calves (n = 350; average BW 240 ± 1 kg) were obtained from regional livestock auctions. Within each set (block, n = 4), calves were stratified by BW and arrival sex into 1 of 8, 0.42-ha pens (10 to 12 calves per pen). Pens were assigned randomly to 1 of 3 treatments consisting of supplemental Zn (360 mg/d), Mn (200 mg/d), and Cu (125 mg/d) from inorganic (zinc sulfate, manganese sulfate, and copper sulfate; n = 2 pens per block), organic (zinc amino acid complex, manganese amino acid complex, and copper amino acid complex; Availa-4, Zinpro Corp., Eden Prairie, MN; n = 3 pens per block), and hydroxy (IntelliBond Z, IntelliBond C, and IntelliBond M; Micronutrients, Indianapolis, IN; n = 3 pens per block) sources. During the 42- to 45-d backgrounding period calves had ad libitum access to bermudagrass hay and were fed corn and dried distillers grain–based supplements that served as carrier for the treatments. After removal of data for chronic (n = 6) and deceased (n = 1) calves, trace-mineral source had no effect on final or intermediate BW (P = 0.86) or ADG (P ≥ 0.24). With all data included in the analysis, dietary treatments had no effect on the number treated once (P = 0.93), twice (P = 0.71), or 3 times (P = 0.53) for bovine respiratory disease or on the number of calves classified as chronic (P = 0.55). Based on these results, trace-mineral source had no effect on total BW gain, ADG, or morbidity during the receiving phase in shipping-stressed cattle.

Key words: beef cattle, copper, manganese, trace mineral, zinc

INTRODUCTION

In the beef cattle industry, calves are often weaned between 6 and 8 mo of age. At or soon after weaning, calves are often sold through local auction markets during which time they are exposed to a variety of stressors, including food and water deprivation and potentially dramatic dietary changes from forage- to concentrate-based diets. Additionally, calves from multiple sources are typically commingled after purchase and thus potentially exposed to foreign pathogens. Stress experienced by calves during transportation and weaning increases their susceptibility to infection (Breazile, 1988). In addition to medical costs due to morbidity, morbid cattle in general grow slower during the feedlot phase, are less efficient at converting feed to gain, and have both lighter BW and lower-quality carcasses after slaughter (McNeill, 1995; Gardner et al., 1999). Several factors can affect immune function, one of those being trace-mineral status (Wan et al., 1989; Erickson et al., 2000; Spears, 2000). However, different sources of trace

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minerals may vary in price and have been shown to differ in bioavailability (Wedekind et al., 1992; Kegley and Spears, 1994; Spears et al., 2004). In addition, Kegley and coworkers (2012) reported an increase in growth performance in calves supplemented with amino acid complexed trace minerals compared with inorganic sulfate trace minerals. However, results have varied; Garcia et al. (2014) reported recently that varying level and source of trace minerals did not affect growth performance or morbidity in newly received cattle. Trace minerals from hydroxy sources have not been evaluated as a trace-mineral supplement in shipping-stressed cattle. Zinc hydroxychloride, Mn hydroxychloride, and basic Cu chloride are crystalline inorganic mineral sources formed by covalent bonds between the trace mineral and a hydroxy group. These forms of trace minerals lack solubility at neutral pH and dissolution occurs at lower pH. Recently, Genther and Hansen (2015) confirmed that Mn and Cu from these hydroxy sources were relatively insoluble in the rumen but had similar solubilities to sulfate sources in the abomasum. Therefore, our objective was to evaluate the effect of trace-mineral supplementation from sulfate, organic amino acid complex or hydroxy sources on growth performance, morbidity, and immune response to vaccination for bovine viral diarrhea (**BVD**) virus in newly received stocker cattle.

MATERIALS AND METHODS

Prior to initiation of this study, care, handling, and sampling of the animals were approved by the University of Arkansas Animal Care and Use Committee. A total of 350 crossbred beef calves (89 heifers, 129 steers, and 132 bulls; average BW of 240 ± 1 kg) were obtained from regional livestock auction markets in Arkansas and Oklahoma and shipped to the University of Arkansas Beef Cattle Facility at Savoy. Calves arrived in 4 shipment sets (block) with arrival dates of February 8 (n = 87, 63 bulls and 24 steers), March 1 (n = 88, 60 bulls and 28 steers), May 10 (n = 89, heifers), and September 26, 2013 (n = 86, 9 bulls and 77 steers). Upon arrival, calves were tagged in the left ear with a unique identification number, weighed, ear notched, and housed overnight in a holding pen with access to hay and water. Ear notches were sent for persistent infection with BVD virus testing (Cattle Stats LLC, Oklahoma City, OK), and no calves tested positive for the virus. The following morning, calves were administered respiratory (Pyramid 5, Boehringer Ingelheim Vetmedica, Ridgefield, CT) and clostridial (Covexin 8, Intervet Inc., Omaha, NE) vaccinations and were dewormed (Ivomec Plus, Merial Limited, Duluth, GA), and bulls were castrated by banding (California Bander, Inosol Co. LLC, El Centro, CA). All animals were branded with a hot iron on the right hip and weighed.

Within each block, cattle were stratified by BW and, if necessary, arrival sex (bulls or steers) and assigned randomly to 1 of 8 pens (10 to 12 calves per pen). Pens were assigned randomly to treatment. Calves were housed on 0.42-ha grass paddocks. Calves were fed corn and dried distillers grain–based supplements (Tables 1 and 2) that served as carriers of mineral treatments. Treatments consisted of supplemental Zn (360 mg/d), Mn (200 mg/d), and Cu (125 mg/d) from sulfate (n = 2 pens per block), organic amino acid complex (Availa-4, Zinpro Corp., Eden Prairie, MN; n = 3 pens per block), and hydroxy (IntelliBond Z, M, and C, Micronutrients Inc., Indianapolis, IN; n = 3 pens per block) trace-mineral sources. This resulted in 8 pens of cattle supplemented with sulfate sources of trace minerals and 12 pens of cattle supplemented with trace minerals as organic amino acid complex or hydroxy sources. Calves were offered a supplement formulated for feeding at 0.9 kg/d (as-fed basis) on d 0. When the majority of the calves in each pen were consuming the supplements, the pen was switched to supplements with the appropriate mineral treatment formulated for feeding at the 1.4 kg/d (as-fed basis) rate, and then to supplements formulated for feeding at the 1.8 kg/d (as-fed basis) rate, with calves receiving this supplement for the remainder of the 42- (block 4) to 45-d (block 1, 2, and 3) trial. During block 1, intakes of the 0.9 and 1.4 kg/d supplements for all treatments were deemed inadequate, and thus the supplement composition was changed before block 2. Changes in the supplement were formulated so that the new supplement was approximately equal in nutrients to the original diet but the percentage of dried distillers grain plus solubles was reduced. Calves had ad libitum access to bermudagrass hay (89.92% DM, 12.85% CP, 70% NDF, 38% ADF, 134 mg of Mn/kg, 52 mg of Zn/kg, 9 mg of Cu/kg, and 0.25% S; DM basis). Grab samples of supplement were taken daily and composited by diet within block. Grab samples of hay were taken from each bale offered and were composited within block. Samples were frozen at −20°C until analysis. Any supplement refusals were collected and weighed, and a subsample was frozen at −20°C until DM analysis. Calves received booster vaccinations on d 14 (block 4) or d 16 (block 1, 2, and 3).

Cattle were observed daily by trained personnel for signs of bovine respiratory disease (**BRD**) beginning the day after processing. Signs of BRD included depression, nasal or ocular discharge, cough, poor appetite, and respiratory distress. Cattle were given a clinical illness score of 1 to 5 (1 = normal to 5 = moribund). Calves with a score >1 were brought to the working facility and a rectal temperature was taken. If the rectal temperature was ≥40°C, the calf was treated according to a preplanned antibiotic protocol with therapy 1 (Micotil, Elanco Animal Health, Greenfield, IN) administered at 3 mL/45.45 kg of BW. Treated calves were returned to their home pen for convalescence and were re-evaluated in 72 h. If rectal temperature was ≥40°C during re-evaluation, the calf received therapy 2 (Nuflor, Intervet Inc.) at a rate of 6 mL/45.45 kg of BW. Calves receiving therapy 2 were returned to their home pen for

Table 1. Ingredient composition of supplements used, as-fed basis

	Fed at 0.9 kg/d[1]			Fed at 1.4 kg/d[1]			Fed at 1.8 kg/d[2]		
Item	**Sulfate**	**Organic**	**Hydroxy**	**Sulfate**	**Organic**	**Hydroxy**	**Sulfate**	**Organic**	**Hydroxy**
Dried distillers grains with solubles, %	46.2	46.2	46.2	49.6	49.6	49.6	47.2	47.2	47.2
Corn, cracked, %	37.8	37.2	37.8	43.2	42.9	43.3	46.5	46.2	46.5
Soybean meal, %	7.7	7.7	7.7	—	—	—	—	—	—
Limestone, %	3.3	3.3	3.3	3.2	3.2	3.2	2.9	2.9	2.9
Molasses, %	2	2	2	2	2	2	2	2	2
Salt, white, %	1.7	1.7	1.7	1.1	1.1	1.1	0.9	0.9	0.9
Availa-4,[3] g/907 kg	—	6,984	—	—	4,668	—	—	3,500	—
Zinc sulfate (35.5% Zn), g/907 kg	1,012	—	—	676	—	—	508	—	—
Manganese sulfate (32% Mn), g/907 kg	628	—	—	418	—	—	313	—	—
Copper sulfate (25.2% Cu), g/907 kg	492	—	—	328	—	—	245	—	—
IntelliBond Z,[4] g/907 kg	—	—	652	—	—	436	—	—	349
IntelliBond M,[4] g/907 kg	—	—	456	—	—	304	—	—	227
IntelliBond C,[4] g/907 kg	—	—	212	—	—	146	—	—	109
Cobalt glucoheptonate (2.5% Co), g/907 kg	504	—	504	336	—	336	251	—	251
Sodium selenite (0.99% Se), g/907 kg	100	100	100	68	68	68	50.5	50.5	50.5
Vitamin ADE premix,[5] %	0.2	0.2	0.2	0.14	0.14	0.14	0.1	0.1	0.1
Vitamin E premix,[6] %	0.1	0.1	0.1	0.07	0.07	0.07	0.05	0.05	0.05
Rumensin mix,[7] %	0.8	0.8	0.8	0.54	0.54	0.54	0.4	0.4	0.4

[1]Fed to blocks 2, 3, and 4.

[2]Fed to all blocks.

[3]Availa-4 contains 5.15% Zn as Zn amino acid complex, 2.86% Mn as Mn amino acid complex, 1.8% Cu as Cu amino acid complex, and 0.18% Co as Co glucoheptonate (Zinpro Corp., Eden Prairie, MN).

[4]IntelliBond Z contains 55% Zn as Zn hydroxychloride, IntelliBond M contains 44% Mn as Mn hydroxychloride, IntelliBond C contains 58% Cu as basic Cu chloride (Micronutrients, Inc., Indianapolis, IN).

[5]Vitamin ADE premix contains 8,800,000 IU of vitamin A, 1,760,000 IU of vitamin D, and 1,100 IU of vitamin E/kg.

[6]Vitamin E premix contains 44,000 IU/kg.

[7]To provide 160 mg of monensin per day when supplement is fed at listed rate (Rumensin, Elanco Animal Health, Greenfield, IN).

Table 2. Ingredient composition of supplements used for block 1, as-fed basis

	Fed at 0.9 kg/d			Fed at 1.4 kg/d		
Ingredient	Sulfate	Organic	Hydroxy	Sulfate	Organic	Hydroxy
Dried distillers grains with solubles, %	84.6	84.6	84.6	59.1	59.1	59.1
Corn, cracked, %	6.5	6	6.6	33.6	33.3	33.7
Limestone, %	3.9	3.9	3.9	3.3	3.3	3.3
Molasses, %	2	2	2	2	2	2
Salt, white, %	1.7	1.7	1.7	1.1	1.1	1.1
Availa-4,[1] g/907 kg	—	6,984	—	—	4,668	—
Zinc sulfate (35.5% Zn), g/907 kg	1,012	—	—	676	—	—
Manganese sulfate (32% Mn), g/907 kg	628	—	—	418	—	—
Copper sulfate (25.2% Cu), g/907 kg	492	—	—	328	—	—
IntelliBond Z,[2] g/907 kg	—	—	652	—	—	436
IntelliBond M,[2] g/907 kg	—	—	456	—	—	304
IntelliBond C,[2] g/907 kg	—	—	212	—	—	146
Cobalt glucoheptonate (2.5% Co), g/907 kg	504	—	504	336	—	336
Sodium selenite (0.99% Se), g/907 kg	100	100	100	68	68	68
Vitamin ADE premix,[3] %	0.2	0.2	0.2	0.14	0.14	0.14
Vitamin E premix,[4] %	0.1	0.1	0.1	0.07	0.07	0.07
Rumensin mix,[5] %	0.8	0.8	0.8	0.54	0.54	0.54

[1]Availa-4 contains 5.15% Zn as Zn amino acid complex, 2.86% Mn as Mn amino acid complex, 1.8% Cu as Cu amino acid complex, and 0.18% Co as Co glucoheptonate (Zinpro Corp., Eden Prairie, MN).

[2]IntelliBond Z contains 55% Zn as Zn hydroxychloride, IntelliBond M contains 44% Mn as Mn hydroxychloride, IntelliBond C contains 58% Cu as basic Cu chloride (Micronutrients Inc., Indianapolis, IN).

[3]Vitamin ADE premix contains 8,800,000 IU of vitamin A, 1,760,000 IU of vitamin D, and 1,100 IU of vitamin E/kg.

[4]Vitamin E premix contains 44,000 IU/kg.

[5]To provide 160 mg of monensin per day when supplement is fed at listed rate (Rumensin, Elanco Animal Health, Greenfield, IN).

convalescence and re-evaluated in 72 h, and if rectal temperature was ≥40°C, calves received a final therapy 3 (Excenel, Zoetis, Florham Park, NJ) administered at 2 mL/45.45 kg of BW dosage for 3 consecutive days, returning to their home pen each day. After administering therapy 3, if the clinical illness score was greater than time 0 or ≥2 and rectal temperature was ≥40°C, then the calf was considered nonresponsive and no further treatments were given. If BRD symptoms reoccurred >21 d after administration of the previous therapy, symptoms were considered a new BRD episode and treatment began with therapy 1. Records were kept of all antibiotics administered, and medication cost reported is the drug cost with no additional fees assessed. Calves that received all 3 drug therapies and gained less than 0.23 kg/d were deemed chronic (n = 6).

Body weights were recorded initially (d −1 and 0) and before supplement feeding on d 14, 28, 41, and 42 (block 4) or d 16, 30, 44, and 45 (block 1, 2, and 3). Average daily gain was calculated for interim and final periods based on averages of initial and final BW that were taken on 2 consecutive days. Blood was collected from all calves on d −1 and the final day (d 42 or 45) via jugular venipuncture for plasma trace-mineral analysis, into vacuum tubes (7 mL) specifically made for trace-mineral analysis (Kendall Monoject 307014, Tyco Healthcare Group, Mansfield, MA), inverted to mix, and placed on ice. Calves in the final 2 blocks were bled on d −1, 16, 30, and 45 (block 3) or d −1, 14, 28, and 42 (block 4) for antibody titer response to vaccination. Blood (10 mL) was collected via jugular venipuncture in tubes containing a clot activator (BD Vacutainer 367985, BD, Franklin Lakes, NJ) and allowed to sit at room temperature for at least 30 min to allow clot formation. All blood was spun at 2,060 × *g* for 20 min at 20°C, and plasma and serum was stored at −20°C. Plasma was deproteinated by mixing 1 mL of plasma with 7 mL of 1 *N* trace metal grade nitric acid for 24 h, and then centrifuged at 2,060 × *g* for 20 min at 20°C. The supernatant was taken to the University of Arkansas–Division of Agriculture Altheimer Laboratory for trace-mineral analysis by inductively coupled plasma spectroscopy (Model 3560, Applied Research Laboratory, Sunland, CA). Serum was analyzed for BVD type 1 antibody titers at the Iowa State University Veterinary Diagnostic Laboratory (Ames, IA).

Samples of supplements (Table 3) and hay were dried at 50°C in a forced-air oven until a constant weight to determine dry matter. Dried samples were ground in a Wiley Mill (Thomas Scientific, Swedesboro, NJ) through a 1-mm screen. Samples were analyzed for CP via total combustion (Rapid Combustion Method, Elementar Americas Inc., Mt. Laurel, NJ)

Table 3. Analyzed nutrient composition of supplements, DM basis

		Fed at 0.9 kg/d			Fed at 1.4 kg/d			Fed at 1.8 kg/d		
Nutrient	**Unit**	**Sulfate**	**Organic**	**Hydroxy**	**Sulfate**	**Organic**	**Hydroxy**	**Sulfate**	**Organic**	**Hydroxy**
DM	%	90	90.2	90.1	90.2	90.2	89.7	90.1	89.8	90
CP	%	22	21.1	22.3	19.8	20.5	19.9	20.3	20.6	19.9
NE_m[1]	Mcal/45.4 kg	94	94	94	95	95	95	96	96	96
NE_g[1]	Mcal/45.4 kg	65	65	65	65	65	65	66	66	66
Zn	mg/kg	415	408	429	248	324	320	301	316	316
Mn	mg/kg	225	234	249	114	221	183	203	183	174
Cu	mg/kg	139	152	140	71	126	99	103	122	90
Co	mg/kg	17	16	17	8	13	12	10	13	11
S	%	0.47	0.43	0.43	0.39	0.44	0.41	0.44	0.44	0.42

[1]Values calculated with University of Arkansas Cattle Grower Ration Balancer software.

and sequentially for NDF and ADF (Van Soest method, ANKOM Technology Corp., Fairport, NY). Mineral concentrations were determined via inductively coupled plasma spectroscopy at the University of Arkansas–Division of Agriculture Altheimer Laboratory after wet ashing duplicate 0.5-g samples with 15 mL of trace metal grade nitric acid (J.T. Baker 9598–34, Avantor Performance Materials, Center Valley, PA) in 50-mL centrifuge tubes. Samples were predigested in a heating block at 80°C for 30 min followed by digestion at 115°C for 1 h. Samples were brought to a constant 45-mL volume with deionized water following digestion.

Pen was used as the experimental unit and incorporated in a randomized complete block design. The model included treatment as a fixed effect and block as a random effect. Growth performance, morbidity data (if calves were treated 1, 2, or 3 times with antibiotics), and antibiotic costs were analyzed using the MIXED procedure of SAS (SAS Institute Inc., Cary, NC). Plasma minerals, antibody titer response, and BW were analyzed using the MIXED procedure with repeated measure statement. The covariance structure of the repeated measure was variance components and the subject was pen within block. Data are reported as least squares means with standard errors. The LIFETEST procedure was used to compare the day when calves received their first, second, third, or last antibiotic treatment with calf as the experimental unit.

RESULTS AND DISCUSSION

For growth performance data, after removal of chronics (n = 6) and animals that died (n = 1), trace-mineral source had no effect on d 14, 28, or final BW ($P = 0.87$) or ADG ($P \geq 0.24$; Table 4). This concurs with Sharman et al. (2008), who reported no differences in ADG during a 28-d receiving period in newly received steers supplemented with either sulfate or organic amino acid complex trace minerals at levels equal to those used in the present study. Because a hydroxy source was not included, a comparison for the hydroxy source is not possible. Garcia et al. (2014) reported no difference in ADG of newly received calves fed either NRC-recommended trace-mineral levels or 3 times those levels as inorganic or 50:50 inorganic:organic sources. Engle and Spears (2000) also found no difference in ADG among growing steers individually fed various levels of Cu from sulfate, citrate, hydroxy, or proteinate sources over a 56-d growing phase. Arthington and Spears (2007) investigated the effects of Cu supplemented at 100 mg/d from either sulfate or hydroxy sources in growing heifers and likewise reported similar ADG for both treatments. However, in regard to trace-mineral supplementation from sulfate or organic sources, results have not been consistent. Kegley et al. (2012) observed an increase in ADG and final BW over a 42-d backgrounding period in newly received calves supplemented with organic trace minerals versus calves supplemented with sulfate sources at levels identical to those fed in the current study.

Average DM consumption of the corn dried distillers grain supplement did not differ ($P \geq 0.35$) for any period during the experiment (Table 5). Recent research indicated that young calves consumed more creep feed fortified with hydroxy trace minerals compared with creep feed supplemented with sulfate sources of trace minerals (Saran Neto et al., 2014). In an additional project, when given a choice between supplements, early weaned calves preferred supplements formulated with hydroxy trace minerals versus supplements containing organic and sulfate sources of trace minerals (Caramalac et al., 2014). However, the trace-mineral concentrations in the supplements in the preference study were 5 to 13 times greater than those in the current project, and in this project no differences were observed in how rapidly the cattle consumed these receiving supplements.

Sixty-two percent of the calves in the current trial were treated with the initial antibiotic for BRD (Table 6). Dietary treatment had no effect

Table 4. Performance of cattle supplemented with sulfate, organic complexes, or hydroxy trace minerals,[1] least squares means ± SE

				P-value		
Item	Sulfate	Organic	Hydroxy	Treatment	Day	Treatment × day
BW, kg						
Initial wt	240 ± 4.3	240 ± 3.5	240 ± 3.5			
d 14 wt	256 ± 4.3	260 ± 3.5	258 ± 3.5			
d 28 wt	268 ± 4.3	272 ± 3.5	269 ± 3.5			
Final wt[2]	280 ± 4.3	283 ± 3.5	280 ± 3.5	0.87	<0.0001	0.63
ADG, kg						
d 0 to 14	1.07 ± 0.08	1.25 ± 0.07	1.17 ± 0.07	0.24		
d 14 to 28	0.86 ± 0.13	0.90 ± 0.11	0.81 ± 0.11	0.84		
d 28 to 42	0.86 ± 0.11	0.75 ± 0.09	0.78 ± 0.09	0.80		
d 0 to 28	0.97 ± 0.05	1.09 ± 0.05	1.00 ± 0.05	0.25		
d 0 to 42	0.94 ± 0.05	0.99 ± 0.04	0.93 ± 0.04	0.49		

[1]Data exclude measurements from cattle labeled as chronic (n = 6) or dead (n = 1). "Chronic animals" defined as having received all drug therapies and gaining <0.23 kg/d.

[2]d 42 (blocks 1, 2, and 3) or d 45 (block 4).

on the number of calves treated once ($P = 0.95$), twice ($P = 0.71$), or 3 times ($P = 0.55$) for BRD. Numerically, one calf fed sulfate sources was deemed chronic versus 2 and 3 calves fed organic and hydroxy trace-mineral sources, respectively; however, the difference was not significant ($P = 0.81$). One calf fed hydroxy trace minerals died. Dietary treatment had no effect ($P = 0.81$) on the average antibiotic cost per calf, the percentage of calves that relapsed ($P = 0.64$), or the percentage of calves treated twice ($P = 0.71$; Table 6). The day calves received their first, second, third, or last antibiotic treatment was not affected ($P \geq 0.39$) by trace-mineral source (Table 6).

Dorton and coworkers (2006) reported similar morbidity results in calves supplemented with either sulfate or organic Cu, Zn, Mn, and Co sources beginning at the ranch after weaning and continuing through a 28-d feedlot receiving phase. Likewise, Sharman et al. (2008) observed no effect on total morbidity in newly received steers supplemented with Zn, Mn, or Cu from either sulfate or amino acid complexes. However, these authors reported a tendency for an increase in percentage repulls (defined as when an animal is treated more than once for morbidity) in steers supplemented with amino-acid-complex trace minerals compared with no difference in percentage relapse observed in the current study. It is important to note that Sharman et al. (2008) used a point scoring system to assess morbidity in which 1 point was assigned for exhibiting each of the following respiratory symptoms: ocular discharge, nasal discharge, coughing, rapid breathing, and depressed appetite. In addition, 2 additional points were assigned if rectal temperature exceeded 39.5°C, and any steers with a total of 4 or more points were considered morbid and treated with an antibiotic. In the current study, animals were not considered morbid and treated with an antibiotic unless their rectal temperature was ≥40°C regardless of the type or number of symptoms exhibited. These differences in morbidity scoring systems could play a role in the difference between the studies. As was the case with growth

Table 5. Average supplement DMI in cattle supplemented with sulfate, organic complexes, or hydroxy trace minerals, least squares means ± SE[1]

Avg supplement DMI, kg	Sulfate	Organic	Hydroxy	*P*-value
d 0 to 7	0.60 ± 0.06	0.65 ± 0.05	0.65 ± 0.05	0.76
d 0 to 14	0.89 ± 0.06	0.99 ± 0.05	1.00 ± 0.05	0.35
d 0 to 28	1.23 ± 0.04	1.30 ± 0.03	1.30 ± 0.03	0.36
d 0 to final[2]	1.37 ± 0.03	1.41 ± 0.02	1.41 ± 0.02	0.36

[1]Transition to 1.4 kg/d supplementation rate (as-fed basis) occurred when the majority of the calves in each pen were consuming the supplements at the 0.9 kg/d rate (d 8, block 1; d 8, block 2; d 9, block 3; d 8, block 4). Transition to 1.8 kg/d supplementation rate (as-fed basis) occurred when the majority of the calves in each pen were consuming the supplements at the 1.4 kg/d rate (d 16, block 1; d 12, block 2; d 11, block 3; d 11, block 4).

[2]d 42 (blocks 1, 2, and 3) or 45 (block 4).

Table 6. Morbidity from bovine respiratory disease for cattle supplemented with sulfate, organic complexes, or hydroxy trace minerals

Item	Sulfate	Organic	Hydroxy	*P*-value
Treated once,[1,2] %	60.8 ± 6.6	60.7 ± 5.4	63.0 ± 5.4	0.95
Day of first treatment[3]	6.8 ± 0.4	10.5 ± 0.7	9.1 ± 0.60	0.89
Treated twice,[1,2] %	29.6 ± 7.2	21.9 ± 5.8	25.2 ± 5.8	0.71
Relapse,[2,4] %	44.3 ± 0.1	32.9 ± 0.1	39.6 ± 0.1	0.64
Day of second treatment[3]	15.9 ± 0.6	16.6 ± 0.4	18.7 ± 0.5	0.45
Treated thrice,[1,2] %	8.0 ± 2.9	3.9 ± 2.3	5.3 ± 2.3	0.55
Day of third treatment[3]	21.1 ± 0.4	30.5 ± 0.3	20.5 ± 0.2	0.39
Day of last treatment[3]	12.8 ± 0.9	16.5 ± 1.1	12.8 ± 0.7	0.97
Chronic,[1,2] %	1.1 ± 1.6	1.5 ± 1.3	2.4 ± 1.3	0.81
Antibiotic cost,[2] $/calf	18.66 ± 2.75	16.49 ± 2.24	17.95 ± 2.24	0.81

[1]Percentage of total number of calves.

[2]Least squares means ± SE.

[3]Mean ± SE from LIFETEST procedure (SAS Institute Inc., Cary, NC).

[4]"Relapse" defined as when animal is treated more than once for bovine respiratory disease, percentage of calves treated twice of those treated once.

performance, morbidity results have not been consistent across trials. In a previous study, Kegley et al. (2012) reported a tendency for a decrease in the percentage of calves receiving a second antibiotic treatment and a tendency for the second treatment to be administered 1-d later in calves that were supplemented with amino-acid-complex trace minerals versus those supplemented with sulfate sources.

A total of 175 calves were measured for BVD type 1 antibody titer response to respiratory vaccination. Antibody titer response was compared in all calves as well as the subpopulation that had no detectable antibody titers on d 0 (naïve calves; n = 117). There was a day of sampling effect ($P < 0.0001$) in all groups as most calves developed antibodies in response to vaccination. However, dietary treatment had no effect on antibody titer response in all cattle ($P \geq 0.70$) or in naïve cattle ($P \geq 0.83$) nor was there a treatment × day interaction in either group ($P \geq 0.95$; Figure 1). Bovine viral diarrhea type 1 virus is only 1 of 5 viral agents that were present in the respiratory vaccine, which also included BVD type 2, infectious bovine rhinotracheitis virus, bovine parainfluenza 3, and bovine respiratory syncytial virus; all viral agents present in the vaccine have been associated with respiratory-tract disease in feedlot calves (Plummer et al., 2004). Thus, BVD type 1 antibody titer response alone cannot be used to describe trace-mineral source effect on vaccine response. Kegley et al. (2012) reported no difference in BVD virus (which encompasses both BVD type 1 and 2), bovine respiratory syncytial virus, or bovine parainfluenza 3 after vaccination but did observe increases in infectious bovine rhinotracheitis virus antibody titers in calves supplemented with sulfate sources of Zn, Mn, Cu, and Co compared with those supplemented with amino-acid-complex sources of Zn, Mn, and Cu, and Co glucoheptonate. Because the current study did not examine any virus other than BVD type 1 titers, a direct comparison cannot be made. However, George et al. (1997) reported improved antibody titer response 14 and 28 d after vaccination to infectious bovine rhinotracheitis virus vaccination in calves supplemented with organic trace min-

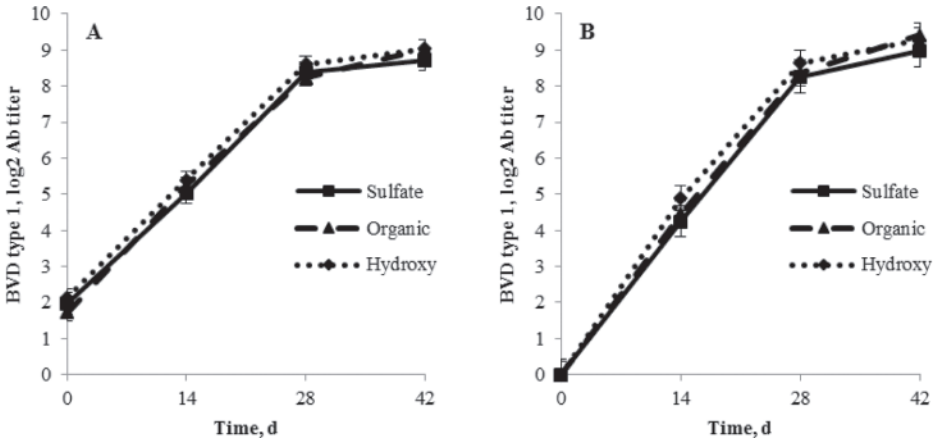

Figure 1. Bovine viral diarrhea (BVD) type 1 antibody (Ab) titer response to vaccination with modified live vaccine for respiratory virus (A) in all cattle (n = 175; treatment × day interaction, $P = 1.00$) and (B) in naïve cattle (n = 117; treatment × day interaction, $P = 0.95$).

Table 7. Plasma mineral concentrations for cattle supplemented with sulfate, organic complexes, or hydroxy trace minerals, least squares means ± SE

				P-value		
Item	Sulfate	Organic	Hydroxy	Treatment	Day	Treatment × day
Copper, mg/L				0.92	0.45	0.96
d −1	0.88 ± 0.03	0.89 ± 0.02	0.89 ± 0.02			
Final d[1]	0.89 ± 0.03	0.90 ± 0.02	0.90 ± 0.02			
Zinc, mg/L				0.83	0.15	0.65
d −1	0.93 ± 0.07	0.85 ± 0.06	0.89 ± 0.06			
Final d[1]	0.82 ± 0.07	0.82 ± 0.06	0.86 ± 0.06			

[1]d 42 (blocks 1, 2, and 3) or 45 (block 4).

erals versus inorganic minerals. Thus, as seen in previously discussed results, the variability that exists in growth performance and morbidity results for supplemental trace-mineral sources extends to antibody titer response to vaccination.

Trace-mineral source had no effect on plasma Cu ($P = 0.92$) or Zn ($P = 0.83$) concentrations (Table 7). All dietary treatments exceeded current NRC (1996) recommendations for Cu and Zn; therefore, differences in plasma concentrations of these trace minerals were not anticipated. Both Cu and Zn plasma concentrations were in the adequate range (0.7 to 0.9 mg/L for Cu and 0.8 to 1.4 mg/L for Zn; Kincaid, 1999) on both sampling days. However, plasma concentrations of Cu are not particularly sensitive to deficient Cu intake as plasma concentrations are not consistently reduced until liver Cu is <40 mg/kg (Claypool et al., 1975). Thus, it is possible that animals can be marginal in Cu, especially in the short term, without changes in plasma Cu. Plasma Zn concentrations are sensitive to Zn intake, especially if fed at extremely low or extremely high levels, but Zn can also be affected by age, stress, infections, and feed restriction (Kincaid, 1999). In addition, Engle et al. (1997) reported a reduced cell-mediated response to phytohemagglutinin injection in calves fed 17 mg/kg Zn compared with calves fed 40 mg/kg Zn with no changes in either plasma or liver Zn concentrations, concluding that cell-mediated immune response may be decreased before functional Zn deficiency symptoms are present.

IMPLICATIONS

In the current study, trace-mineral source had no effect on growth performance, morbidity, average antibiotic cost, plasma Cu and Zn concentrations, or antibody titer response to bovine viral diarrhea virus vaccination in shipping-stressed cattle over a 42- to 45-d backgrounding phase. However, additional research is needed regarding the use of hydroxy trace minerals in diets for backgrounding cattle because little research currently exists.

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