Effects of organic or inorganic cobalt, copper, manganese, and zinc supplementation to late-gestating beef cows on productive and physiological responses of the offspring[1]

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ABSTRACT: Eighty-four multiparous, nonlactating, pregnant Angus × Hereford cows were ranked by pregnancy type (56 AI and 28 natural service), BW, and BCS and allocated to 21 drylot pens at the end of their second trimester of gestation (d 0). Pens were assigned to receive forage-based diets containing 1) sulfate sources of Cu, Co, Mn, and Zn (INR); 2) an organic complexed source of Cu, Mn, Co, and Zn (AAC; Availa 4; Zinpro Corporation, Eden Prairie, MN); or 3) no supplemental Cu, Co, Mn, and Zn (CON). Diets were offered from d 0 until calving and formulated to meet requirements for energy, protein, macrominerals, Se, I, and vitamins. The INR and AAC diets provided the same daily amount of Cu, Co, Mn, and Zn. Cow BW and BCS were recorded and liver samples were collected on d –10 and 2 wk (d 75) before the calving season. Within 3 h after calving, calf BW was recorded, liver samples were collected, and the expelled placenta was retrieved ($n = 47$ placentas). Calves were weaned on d 283 of the experiment, preconditioned for 45 d (d 283 to 328), transferred to a growing lot on d 328, and moved to a finishing lot on d 440 where they remained until slaughter. Liver Co, Cu, and Zn concentrations on d 75 were greater ($P \leq 0.05$) for INR and AAC cows compared with CON cows, whereas INR cows had reduced ($P = 0.04$) liver Co but greater ($P = 0.03$) liver Cu compared with AAC cows. In placental cotyledons, Co concentrations were greater ($P \leq 0.05$) in AAC and INR cows compared with CON cows, whereas Cu concentrations were increased ($P = 0.05$) only in AAC cows compared with CON cows. Calves from INR and AAC cows had greater ($P < 0.01$) liver Co concentrations at birth compared with calves from CON cows. Liver Cu and Zn concentrations at birth were greater ($P \leq 0.05$) in calves from AAC cows compared with cohorts from CON cows. Weaning BW was greater ($P \leq 0.05$) in calves from AAC cows compared with cohorts from CON cows, and this difference was maintained until slaughter. In the growing lot, calves from AAC cows had reduced ($P < 0.01$) incidence of bovine respiratory disease compared with CON and INR cohorts. Collectively, these results suggest that feeding the AAC diet to late-gestating beef cows stimulated programming effects on postnatal offspring growth and health compared with the CON diet. Therefore, supplementing late-gestating beef cows with an organic complexed source of Co, Cu, Zn, and Mn instead of no supplementation appears to optimize offspring productivity in beef production systems.

Key words: beef cows, offspring, pregnancy, supplementation, trace minerals

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INTRODUCTION

Nutritional management of beef cows during late gestation, particularly energy and CP intake, impacts offspring performance via fetal programming (Funston et al., 2010; Bohnert et al., 2013). However, little is known about the effects of trace mineral status of late-gestating cows on offspring productivity. Trace minerals

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are essential for fetal development (Hostetler et al., 2003), and the fetus depends completely on the dam for proper supply of these elements (Hidiroglou and Knipfel, 1981). If maternal supply is inadequate, fetal development and postnatal performance might be impaired (Weiss et al., 1983). For example, Zn, Cu, Mn, and Co are required for adequate development of the fetal nervous, reproductive, and immune systems (Hostetler et al., 2003; Pepper and Black, 2011). Moreover, Cu concentration in bovine fetal liver is greater than maternal liver Cu concentration, suggesting that the maternal system shunts Cu to support fetal development (Gooneratne and Christensen, 1989). Therefore, we hypothesized that supplementing Cu, Mn, Zn, and Co to late-gestating cows will result in increased postnatal offspring productivity.

One strategy to enhance trace mineral status in cattle is to feed organic complexed sources (Spears, 1996). Hostetler et al. (2003) reported that Cu, Mn, and Zn concentrations in tissues of fetuses collected from sows supplemented with organic sources of these elements were greater compared with fetuses from sows supplemented with inorganic sources, which resulted in reduced fetal loss by 30 d of gestation. Hence, we also theorized that supplementing organic complexed sources of Cu, Mn, Zn, and Co to beef cows during late gestation is an alternative to further optimize postnatal offspring productivity. Based on these hypotheses, this experiment evaluated the effects of organic and inorganic Cu, Mn, Zn, and Co supplementation to beef cows during late gestation on performance and physiological responses of the offspring.

MATERIALS AND METHODS

This experiment was conducted at the Oregon State University – Eastern Oregon Agricultural Research Center (Burns station; Burns, OR). The animals used were cared for in accordance with acceptable practices and experimental protocols reviewed and approved by the Oregon State University Institutional Animal Care and Use Committee (number 4496).

Cow–Calf Management and Dietary Treatments

Eighty-four multiparous, nonlactating, pregnant Angus × Hereford cows (512 ± 6 kg BW, 5.1 ± 0.2 yr of age, and 5.11 ± 0.04 BCS according to Wagner et al., 1988) were assigned to the experiment at the end of their second trimester of gestation (d 0 of the experiment). Cows were pregnant to AI using semen from a single Angus sire ($n = 56$) or pregnant to Hereford bulls via natural breeding ($n = 28$; cows were exposed to bulls for 50 d beginning 17 d after AI), according to the breeding management and pregnancy diagnosis described by Cooke et al. (2014). At the beginning of the experiment (d 0), pregnancy length was expected to be 206 d for cows pregnant to AI and 189 d or less for cows pregnant via natural breeding.

Before the beginning of the experiment (d –10), cows were ranked by pregnancy type (AI or natural service), BW, and BCS and allocated to 21 drylot pens (4 cows/pen; 7 pens/treatment; 7 by 15 m) in a manner such that pens had equivalent BW and BCS and either 3 or 2 cows pregnant to AI. Pens were ranked by proportion of cows pregnant to AI or natural service and alternatingly assigned to receive diets containing 1 of 3 treatments: 1) sulfate sources of Cu, Co, Mn, and Zn (**INR**; custom blend manufactured by Performix Nutrition Systems, Nampa, ID); 2) organic complexed source of Cu, Mn, Co, and Zn (**AAC**; Availa 4; Zinpro Corporation, Eden Prairie, MN); or 3) no supplemental Cu, Co, Mn, and Zn (**CON**). The AAC trace mineral source was based on a metal:AA complex ratio of 1:1 for Zn, Cu, and Mn in addition to cobalt glucoheptonate (Zinpro Corporation). All diets were isocaloric and isonitrogenous and formulated to meet requirements for energy, protein, macrominerals, Se, I, and vitamins (Table 1) of pregnant cows during the last trimester of gestation (NRC, 2000). The INR and AAC sources were mixed with the corn; formulated to provide the same daily amount of Cu, Co, Mn, and Zn (based on 7 g/cow daily of Availa 4; Siciliano-Jones et al., 2008; Kegley et al., 2012) as described in Table 1; and offered separately from hay in a different section of the same feed bunk. All diets (forage + concentrate) were limit fed at 10.8 kg of DM/cow daily, offered once daily (0700 h) from d 0 of the experiment until calving, and completely consumed within 6 h after feeding.

Immediately after calving, cow–calf pairs were removed from their respective pens and assigned to the general management of the research herd (described by Francisco et al., 2012) that included free-choice inorganic trace mineral supplementation (Cattleman's Choice; Performix Nutrition Systems; containing 14% Ca, 10% P, 16% NaCl, 1.5% Mg, 6,000 mg/kg Zn, 3,200 mg/kg Cu, 65 mg/kg I, 900 mg/kg Mn, 140 mg/kg Se, 136 IU/g of vitamin A, 13 IU/g of vitamin D_3, and 0.05 IU/g of vitamin E). All calves were administered Clostrishield 7 and Virashield 6 + Somnus (Novartis Animal Health, Bucyrus, KS) at approximately 30 d of age. Cows were assigned to the same reproductive management (d 172 to 242 of the experiment) and pregnancy diagnosis (d 284 of the experiment) described by Cooke et al. (2014).

Calf Management

Preconditioning (d 283 to 328). Calves were weaned on d 283 of the experiment and transferred to a 6-ha meadow foxtail (*Alopecurus pratensis* L.) pasture, which had been previously harvested for hay, for a 45-d preconditioning period as a single group. All calves were administered One Shot Ultra 7, Bovi-Shield Gold 5, TSV-2, and Dectomax (Zoetis Inc., Florham Park, NJ) at weaning and received a booster of Bovi-Shield Gold 5, UltraChoice 7, and TSV-2 (Zoetis Inc.) 28 d after weaning (d 311 of the experiment). During preconditioning, calves received mixed alfalfa–grass hay (14% CP and 56% TDN, DM basis), water, and the same commercial mineral and vitamin mix previously described (Cattleman's Choice) for ad libitum consumption.

Growing (d 328 to 440) and Finishing (d 440 until Slaughter). On d 328, all calves were loaded into a commercial livestock trailer and transported for 480 km to the growing lot (Top Cut Feedlot, Echo, OR), where they remained for 112 d and managed as a single group. On d 440, calves were moved to an adjacent finishing lot (Beef Northwest, Boardman, OR), where they continued to be managed as a single group until slaughter at a commercial packing facility (Tyson Fresh Meats Inc., Pasco, WA). Upon arrival to the finishing lot, all calves were administered Bovi-Shield Gold 5 (Zoetis Inc.), Vizion 7 (Merck Animal Health, Kenilworth, NJ), Valbazen (Zoetis Inc.), and Bimectin pour-on (Bimeda Animal Health Inc., Oakbrook Terrace, IL). Steers were implanted with Revalor IS (Merck Animal Health) and heifers were implanted with Revalor IH (Merck Animal Health) on arrival. Growing and finishing diets were fed ad libitum and are described in Table 2. Slaughter date was determined according to the availability of the commercial packing facility (Tyson Fresh Meats Inc.). As a result, calves were randomly assigned to slaughter on 2 separate dates, 13 d apart, regardless of treatment group (*n* = 11 AAC, *n* = 5 CON, and *n* = 6 INR calves after 147 d on feed [**DOF**]; *n* = 11 AAC, *n* = 18 CON, and *n* = 15 INR calves after 160 DOF).

Sampling

Feedstuffs. Two samples of all dietary ingredients fed to late-gestating cows (Table 1) were collected before the beginning of the experiment and analyzed for nutrient content by a commercial laboratory (Dairy One Forage Laboratory, Ithaca, NY). Each sample was analyzed in triplicate by wet chemistry procedures for concentrations of CP (method 984.13; AOAC, 2006), ADF (method 973.18 modified for use in an Ankom 200 fiber analyzer; Ankom Technology Corp., Fairport, NY; AOAC, 2006), NDF (Van Soest et al., 1991; modified for an Ankom 200 fiber analyzer), and macro- and trace minerals using inductively coupled plasma emission spectroscopy (Sirois et al., 1991) as well as Se according to method 996.16 of the AOAC (2006). Calculations for TDN used the equation proposed by Weiss et al. (1992), whereas NEm was calculated with the equations proposed by the NRC (2000).

Table 1. Ingredient composition and nutrient profile of diets containing no supplemental Cu, Co, Mn, and Zn (CON); sulfate sources of Cu, Co, Mn, and Zn (INR); or organic complexed source of Cu, Mn, Co, and Zn (AAC) as well as nutrient requirements (REQ; as % diet DM) of pregnant cows during last trimester of gestation

Item	CON	INR	AAC	REQ[1]
Ingredients, kg/d (as-fed basis)				
Alfalfa hay	6.8	6.8	6.8	
Grass-seed straw	2.7	2.7	2.7	
Whole corn	2.3	2.3	2.3	
Macromineral mix[2]	0.060	0.060	0.060	
Inorganic trace mix[3]	–	0.004	–	
Organic trace mix[4]	–	–	0.007	
DM intake, kg/d	10.8	10.8	10.8	11.0
Nutrient profile[5] (DM basis)				
TDN,[6] %	61	61	61	53
NEm,[7] Mcal/kg	1.45	1.45	1.45	1.10
CP, %	14.4	14.4	14.4	7.8
Ca, %	0.59	0.59	0.59	0.26
P, %	0.35	0.35	0.35	0.21
Mg, %	0.32	0.32	0.32	0.12
K, %	1.86	1.86	1.86	0.60
Na, %	0.44	0.44	0.44	0.07
S, %	0.24	0.24	0.24	0.15
Co, mg/kg	1.03	2.18	2.14	0.10
Cu, mg/kg	10.3	20.8	20.6	10.0
I, mg/kg	0.54	0. 54	0.54	0.50
Fe, mg/kg	522	522	522	50
Mn, mg/kg	56	74	74	40
Se, mg/kg	1.07	1.07	1.07	0.10
Zn, mg/kg	31	64	64	30
Vitamin A, IU/kg	21,780	21,780	21,780	13,552
Vitamin D, IU/kg	2,420	2,420	2,420	1,331
Vitamin E, IU/kg	11.6	11.6	11.6	22

[1] Based on requirements of the NRC (2000).

[2] Containing (DM basis) 571.1 g/kg $CaHPO_4$, 190 g/kg NaCl, 164.1 g/kg $CaCO_3$, 31.3 g/kg MgO, 16.8 g/kg Na_2O_3Se 1%, 15 g/kg KCl, 10 g/kg MgC_{l2}.

0.8 g/kg Vit A 1000, 0.6 g/kg Vit E 50%, 0.2 g/kg Vit D 500, and 0.1 g/kg C2H10I2N2 79.5%.

[3] Containing (DM basis) 500 g/kg of ground corn, 231 g/kg $ZnSO_4$, 147 g/kg $MnSO_4$, 114 g/kg $CuSO_4$, and 8 g/kg of $CoSO_4$.

[4] Availa 4 (Zinpro Corporation, Eden Prairie, MN), which contained (DM basis) 5.15% Zn from 1:1 Zn and AA complex, 2.86% Mn from 1:1 Mn and AA complex, 1.80% Cu from 1:1 Cu and AA complex, and 0.18% Co from cobalt glucoheptonate.

[5] Values obtained via wet chemistry analysis (Dairy One Forage Laboratory, Ithaca, NY).

[6] Calculated according to the equations described by Weiss et al. (1992).

[7] Calculated with the equation (NRC, 2000): $NE_m = 1.37\ ME - 0.138\ ME^2 + 0.0105\ ME^3 - 1.12$. Given that ME = DE × 0.82, and 1 kg of TDN = 4.4 Mcal of DE.

Cows and Newborn Calves. Individual cow BW and BCS (Wagner et al., 1988) were recorded and

Table 2. Ingredient composition (as-fed basis) of growing and finishing diets offered to cattle

	Growing lot[1]		Finishing lot[2]				
Ingredients, % as-fed basis	A	B	A	B	C	D	E
Alfalfa hay	0.0	0.0	23.3	16.7	8.4	6.6	6.6
Barley	18.0	17.0	0.0	0.0	0.0	0.0	0.0
Corn cobs	0.0	5.3	0.0	0.0	0.0	0.0	0.0
Corn silage	10.0	15.0	0.0	0.0	0.0	0.0	0.0
Corn stover	0.0	10.0	0.0	0.0	0.0	0.0	0.0
Culled french fries	0.0	0.0	0.0	5.0	6.7	8.0	8.0
High-moisture corn	0.0	0.0	0.0	0.0	7.7	15.0	15.0
Mineral and vitamin mix[3,4]	3.0	3.4	11.3	7.2	6.5	3.0	3.0
Mixed pea/wheat/barley hay	34.0	5.3	0.0	0.0	0.0	0.0	0.0
Potato slurry	13.0	23.0	0.0	10.0	12.1	15.0	15.0
Rolled corn	0.0	0.0	40.4	40.0	40.0	36.0	36.0
Ryegrass silage	22.0	15.0	0.0	0.0	0.0	0.0	0.0
Vegetable oil	0.0	0.0	0.0	0.5	0.9	1.4	1.4
Wet distillers grain	0.0	6.0	25.0	20.6	17.7	15.0	15.0

[1] A = offered for 10 d on receiving; B = offered for 102 d after diet A and until transfer to the finishing lot.

[2] A = offered for 10 d on receiving; B = offered for 10 d after diet A; C = offered for 10 d after diet B; D = offered for 30 d after diet C; E = offered until slaughter.

[3] Growing diets included Rumax (Performix Nutrition Systems, Nampa, ID), containing corn soy blend, cane molasses, corn steep, NH_4 PO_3, NaCl, CaCO, Attaflow (BASF Corporation, Florham Park, NJ), whey, water, fat, NH_3, Deccox 6% (Zoetis, Florham Park, NJ), $ZnSO_4$, $MnSO_4$, $CuSO_4$, vitamin E premix 60%, sodium selenite 4%, vitamin A, $CoSO_4$, $C_2H_{10}I_2N_2$, and vitamin D_3.

[4] Finishing diets included a customized blend of minerals, vitamins, and feed additives (Westway Feed Products, Tomball, TX, and Land O'Lakes, Inc., Saint Paul, MN), which contained one-third of Zn, Mn, and Cu as metal:AA complex ratio (Zinpro Corporation, Eden Prairie, MN) and two-thirds as sulfate sources.

averaged over 2 consecutive days before the beginning of the experiment (d –11 and –10; initial measurement) to establish initial BW and BCS and 2 wk before the beginning of the estimated calving season (d 75 and 76; precalving measurement). On d –10 and 75, liver biopsies were performed in all cows via needle biopsy (Tru-Cut biopsy needle; CareFusion Corporation, San Diego, CA) according to procedures described by Arthington and Corah (1995), and liver samples were immediately stored at –80°C. Within 3 h after calving and before the first nursing event, calf birth BW, birth date, and gender were recorded, and a liver sample was collected via needle biopsy (Tru-Cut biopsy needle; CareFusion Corporation) and immediately stored at –80°C. When feasible, the expelled placenta was retrieved and immediately rinsed with nanopure water for 5 min. A total of 47 placentas were retrieved, with at least 1 placenta per experimental pen (18, 14, and 15 placentas retrieved from INR, CON, and ACC cows, respectively). All collected placentas were expelled within 12 h after calving and therefore not considered as retained fetal membranes (Takagi et al., 2002). The 5 largest cotyledons were dissected from each placenta using curved scissors, given that the largest cotyledons are expected to be the most active regarding nutrient transfer from the dam to the fetus (Senger, 2003). Cotyledons from each placenta were pooled and dried for 24 h at 65°C and subsequently stored at –80°C.

Preconditioning. Cow BW and BCS (Wagner et al., 1988) were recorded at weaning (d 283). Calf BW was recorded and blood samples were collected via jugular venipuncture into commercial heparinized blood collection tubes (Vacutainer, 10 mL; Becton, Dickinson and Company, Franklin Lakes, NJ), on d 283, 284, 286, 288, and 290 of the experiment. Calf BW on d 283 and 284 were averaged and considered as calf weaning BW. Calves were observed daily for bovine respiratory disease (**BRD**) symptoms according to the subjective criteria described by Berry et al. (2004) and received 0.1 mL/kg of BW of Hexasol LA Solution (Norbrook Inc., Overland Park, KS) when symptoms were observed.

Growing and Finishing. Calf BW was recorded on arrival at the growing lot (d 328) and the finishing lot (d 440). Calves were observed daily for BRD symptoms according to the DART system (Zoetis Inc.) and received medication according to the management criteria of the growing and finishing yards. At the commercial packing plant, HCW was collected on slaughter. Final finishing BW was estimated based on HCW adjusted to a 63% dressing percentage (Loza et al., 2010). After a 24-h chill, trained personnel assessed carcass back fat thickness at the 12th-rib and LM area, whereas all other carcass measures were recorded by a USDA grader.

Preconditioning ADG was determined using BW obtained at weaning (average d 283 and 284) and on growing lot arrival (d 328). Growing lot ADG was determined using BW values obtained on growing lot and finishing lot arrival (d 440). Finishing lot ADG was determined using BW values obtained on finishing lot arrival and final finishing BW estimated from HCW (Loza et al., 2010).

Blood and Tissue Analysis

Liver and cotyledon samples were analyzed via inductively coupled plasma mass spectrometry for concentrations of Co, Cu, Mn, and Zn by the Michigan State University Diagnostic Center for Population and Animal Health (East Lansing, MI) according to Braselton et al. (1997). Blood samples were collected, centrifuged at 2,500 × *g* for 30 min at 4°C for plasma collection, and stored at –80°C on the same day of collection. Plasma samples were analyzed for haptoglobin (Cooke and Arthington, 2013) and cortisol (Immulite 1000; Siemens Medical Solutions Diagnostics, Los Angeles, CA) concentrations. The intra- and interassay CV for haptoglobin were 2.6 and 5.6%, respectively. Plasma cortisol was analyzed within a single assay, and the intra-assay CV was 4.4%.

Statistical Analysis

All cow and calf variables were analyzed with pen as the experimental unit and pen(treatment) and cow(pen) as random variables. Quantitative data were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) and binary data were analyzed using the GLIMMIX procedure of SAS and Satterthwaite approximation to determine the denominator degrees of freedom for tests of fixed effects. Model statements for cow-related responses included the effects of treatment. Model statements for calf-related responses and placental cotyledons analysis included the effects of treatment and calf gender as an independent covariate as well as day and treatment × day interaction for plasma variables. In addition, DOF was included as an independent covariate for all finishing lot and carcass variables. The specified term used in the repeated statement for plasma variables was day, the subject was cow(pen), and the covariance structure used was autoregressive, which provided the best fit for these analyses according to the lowest Akaike information criterion. Results are reported as least squares means, covariately adjusted to calf gender and DOF when applicable, and separated using PDIFF. Significance was set at $P \leq 0.05$, and tendencies were determined if $P > 0.05$ and $P \leq 0.10$.

RESULTS AND DISCUSSION

Nutrient composition and profile of diets offered to CON, INR, and AAC cows are described in Table 1. All diets provided adequate amounts of macronutrients and trace minerals, based on the requirements of pregnant cows during last trimester of gestation (NRC, 2000). As expected, including the inorganic or organic sources of Cu, Co, Mn, and Zn equally increased concentration of these trace elements in INR and AAC diets (Table 1). It is important to note that minimum requirements for Cu, Co, Mn, and Zn were met in the CON diet, whereas the INR and ACC diets provided nearly 200% of NRC requirements for Zn, Cu, and Mn and over 2,000% of NRC requirements for Co (Table 1; NRC, 2000). Therefore, results from this experiment should not be associated with trace mineral deficiency in the CON diet but with potential fetal programming effects of additional Cu, Co, Mn, and Zn intake by AAC and INR cows.

Cow Parameters

Cow age at the beginning of the experiment as well as length of treatment administration were similar ($P \geq 0.36$) among CON, INR, and AAC cows (Table 3). Based on the experimental design, initial cow BW and BCS were also similar ($P \geq 0.41$) among treatments (Table 3). No treatment differences were detected ($P \geq 0.61$) for BW change or precalving BW (Table 3). Cows receiving CON gained less ($P \leq 0.05$) BCS during the last trimester of gestation compared with INR and AAC cohorts (Table 3; main treatment effect, $P = 0.10$). However, such increase was insufficient to impact precalving BCS, which was similar ($P = 0.61$) among treatments and adequate to promote offspring productivity according to Bohnert et al. (2013). Similarly, others reported that Cu, Co, Mn, and Zn supplementation, either as organic or inorganic sources, failed to substantially benefit BW and BCS during gestation in cows receiving diets with adequate content of these trace minerals (Stanton et al., 2000; Ahola et al., 2004).

No differences were detected ($P \geq 0.38$) among CON, INR, and AAC cows for initial (d –10) liver Co, Cu, Mn, and Zn concentrations (Table 4), indicating that all treatments had similar and adequate (Kincaid, 2000; McDowell, 2003) Co, Cu, Mn, and Zn liver status before the beginning of the experiment. In precalving (d 75) samples, liver concentrations of Co, Cu, and Zn were greater ($P \leq 0.05$) for INR and AAC cows compared with CON cows, whereas INR cows had reduced ($P = 0.04$) liver Co and similar ($P = 0.62$) liver Zn but greater ($P = 0.03$) liver Cu compared with AAC cows (Table 4). No treatment differences were detected ($P = 0.67$) on precalving liver Mn concentration (Table 4). These results indicate that the INR and AAC diets successfully increased liver Co, Cu, and Zn concentrations but not Mn concentration. Underwood and Suttle (1999) reported that liver Mn concentration in ruminants is not influenced by increased dietary Mn intake, suggesting that the liver may not be an appropriate tissue to evalu-

Table 3. Performance of beef cows receiving diets containing no supplemental Cu, Co, Mn, and Zn (CON); sulfate sources of Cu, Co, Mn, and Zn (INR); or organic complexed source of Cu, Mn, Co, and Zn (AAC) during the last trimester of gestation[1,2]

Item	CON	INR	AAC	SEM	*P*-value
Cow age, yr	5.2	5.1	5.1	0.2	0.87
Days receiving diets, d	99	94	93	3	0.36
BW, kg					
Initial (d –10)	520	511	505	11	0.60
Precalving (d 75)	643	645	634	14	0.85
BW change	127	134	134	6	0.61
Weaning (d 283)	591	577	569	12	0.40
BW change	–60	–69	–71	9	0.67
BCS					
Initial (d –10)	5.19	5.10	5.04	0.08	0.41
Precalving (d 75)	5.75	5.93	5.94	0.14	0.61
BCS change	0.55[a]	0.83[b]	0.82[b]	0.09	0.10
Weaning (d 283)	5.0	5.0	5.0	0.1	0.79
BCS change	–0.73	–0.85	–0.97	0.16	0.54
Pregnancy rates,[3] %					
To AI	65.1 (17/26)	48.9 (11/23)	52.9 (13/24)	11.6	0.59
To bull	100 (9/9)	100 (12/12)	100 (11/11)	0	1.00
Overall	100 (26/26)	100 (23/23)	100 (24/24)	0	1.00

[a,b] Within rows, means with different superscripts differ ($P \leq 0.05$).

[1] INR and AAC cows received the same amount of Cu, Co, Mn, and Zn from sulfate sources or Availa 4 (Zinpro Corporation, Eden Prairie, MN).

[2] BW and BCS (Wagner et. al., 1988) were recorded before the beginning of the experiment (initial; d –10), 2 wk before the beginning of the calving season (precalving BW; d 75), and at weaning (d 283).

[3] Cows that weaned a live calf were assigned to an estrus synchronization + AI protocol beginning 63 ± 2 d after calving (Cooke et al., 2014) and exposed to mature Angus and Hereford bulls (1:25 bull:cow ratio) for 50 d (18 to 68 d after AI). Cow pregnancy status to AI was verified by detecting a fetus via transrectal ultrasonography (5.0-MHz transducer, 500 V; Aloka, Wallingford, CT) 80 d after AI. During the subsequent calving season, calf birth date, sex, and birth BW were recorded. Calf paternity (AI or bull breeding) was determined according to transrectal ultrasonography and birth date. Only cows that were diagnosed as pregnant during the transrectal ultrasonography exam and gave birth during the initial 2 wk of the calving season were considered pregnant to AI. Values within parenthesis report number of pregnant cows divided by total cows exposed to AI, number of cows nonpregnant to AI that became pregnant to natural service, and number of pregnant cows divided by total cows exposed to breeding (AI + natural service), respectively.

ate dietary impacts on Mn status of beef cattle (Ahola et al., 2004). Others also reported that cows supplemented with Co, Cu, and Zn via inorganic or organic sources had greater liver concentrations of these trace minerals compared with nonsupplemented cohorts (Stanton et al., 2000; Ahola et al., 2004; Akins et al., 2013). Although organic mineral forms are expected to have enhanced absorption, retention, and biological activity compared with sulfate minerals (Spears, 1996; Ward et al., 1996; Hostetler et al., 2003), only liver Co supported this rationale in the present experiment. Nevertheless, the effects of supplementing organic Zn, Cu, and Co on liver mineral status of beef cows has been variable (Stanton et al., 2000; Ahola et al., 2004; Arthington and Swenson, 2004), agreeing with the inconsistency in treatments effects detected for Cu, Co, and Zn in precalving liver samples of AAC and INR cows. Yet all treatments had adequate Co, Cu, Mn, and Zn liver status before calving (Kincaid, 2000; McDowell, 2003), corroborating that the CON, INR, and AAC diets provided the minimum recommended amount of these trace minerals to gestating beef cows (NRC, 2000).

No treatment effects were detected ($P \geq 0.40$) for cow BW and BCS at weaning as well as BW and BCS change from precalving to weaning (Table 3). No treatment effects were also detected ($P \geq 0.59$) for pregnancy rates to AI, bull breeding, and overall (AI + bull breeding; Table 3). These results can be attributed to the similar nutritional management that all treatments groups received from calving until weaning and indicate that Cu, Zn, Mn, and Co supplementation during late gestation, as organic or inorganic sources, did not impact postcalving BW, BCS, and cow reproductive performance (Stanton et al., 2000; Muehlenbein et al., 2001).

Calf Birth and Weaning Parameters

In the placental cotyledons (Table 5), Co concentrations were greater ($P \leq 0.05$) in AAC and INR cows compared with CON cows and similar between INR and ACC cows ($P = 0.25$). Concentrations of Cu in placental cotyledons were greater ($P = 0.05$) in AAC cows compared with CON cows and similar when comparing INR and CON cows ($P = 0.16$) or INR and ACC cows

Table 4. Liver concentrations of Co, Cu, Mn, and Zn of beef cows receiving diets containing no supplemental Cu, Co, Mn, and Zn (CON); sulfate sources of Cu, Co, Mn, and Zn (INR); or organic complexed source of Cu, Mn, Co, and Zn (AAC) during the last trimester of gestation[1,2]

Item	CON	INR	AAC	SEM	*P*-value
Co, mg/kg					
Initial (d –10)	0.29	0.28	0.27	0.01	0.38
Precalving (d 75)	0.21^{a}	0.40^{b}	0.44^{c}	0.01	<0.01
Cu, mg/kg					
Initial (d –10)	93	106	95	10	0.68
Precalving (d 75)	69^{a}	155^{b}	129^{c}	9	<0.01
Mn, mg/kg					
Initial (d –10)	12.8	12.8	12.2	0.5	0.58
Precalving (d 75)	8.7	9.0	8.7	0.3	0.67
Zn, mg/kg					
Initial (d –10)	171	176	171	5	0.70
Precalving (d 75)	211^{a}	230^{b}	235^{b}	7	0.05

[a–c]Within rows, means with different superscripts differ ($P \leq 0.05$).

[1] INR and AAC cows received the same amount of Cu, Co, Mn, and Zn from sulfate sources or Availa 4 (Zinpro Corporation, Eden Prairie, MN).

[2] Liver samples were collected before the beginning of the experiment (initial; d –10) or 2 wk before the beginning of the calving season (precalving; d 75) via needle biopsy (Arthington and Corah, 1995). Concentrations of Co, Cu, Mn, and Zn were determined by the Michigan State University Diagnostic Center for Population and Animal Health (East Lansing, MI; Braselton et al., 1997).

Table 5. Concentrations of Co, Cu, Mn, and Zn in cotyledons and liver from newborn calves born from beef cows that received diets containing no supplemental Cu, Co, Mn, and Zn (CON); sulfate sources of Cu, Co, Mn, and Zn (INR); or organic complexed source of Cu, Mn, Co, and Zn (AAC) during the last trimester of gestation[1,2]

Item	CON	INR	AAC	SEM	*P*-value
Co, mg/kg					
Cotyledon	0.13^{a}	0.20^{b}	0.24^{b}	0.03	0.02
Calf	0.09^{a}	0.12^{b}	0.13^{b}	0.01	<0.01
Cu, mg/kg					
Cotyledon	3.88^{a}	4.75^{ab}	5.12^{b}	0.39	0.09
Calf	362^{a}	428^{ab}	450^{b}	30	0.10
Mn, mg/kg					
Cotyledon	22.0	18.2	22.9	4.5	0.73
Calf	5.82	5.22	5.83	0.36	0.43
Zn, mg/kg					
Cotyledon	65	66	68	4	0.87
Calf	456^{a}	562^{ab}	660^{b}	57	0.01

[a,b]Within rows, means with different superscripts differ ($P \leq 0.05$).

[1] INR and AAC cows received the same amount of Cu, Co, Mn, and Zn from sulfate sources or Availa 4 (Zinpro Corporation, Eden Prairie, MN).

[2] Cotyledon and calf liver samples (via needle biopsy; according to Arthington and Corah, 1995) were collected within 3 h after calving. Concentrations of Co, Cu, Mn, and Zn were determined by the Michigan State University Diagnostic Center for Population and Animal Health (East Lansing, MI; Braselton et al., 1997).

($P = 0.51$). No treatment effects were detected for Mn and Zn concentrations in placental cotyledons ($P \geq 0.73$; Table 5). Upon calving, calves from INR and AAC cows had similar ($P = 0.21$) liver Co concentrations but greater liver Co concentrations ($P < 0.01$) compared with calves from CON cows (Table 5). Liver Cu and Zn concentrations (Table 5) were greater ($P = 0.05$) in calves from AAC cows compared with cohorts from CON cows but were similar when comparing calves from INR and CON cows ($P = 0.19$) or calves from AAC and INR cows ($P = 0.30$). No treatment effect was detected for calf liver Mn concentration ($P = 0.43$; Table 5). Given that the fetus relies completely on the dam for proper supply of trace minerals (Hidiroglou and Knipfel, 1981), treatment effects detected for cotyledon and calf liver Co concentrations suggest increased passage of this trace mineral through the placenta to the fetus when INR and AAC diets were offered to late-gestating cows instead of the CON diet (Pepper and Black, 2011). However, treatment differences in cotyledon Cu and calf liver Cu and Zn suggest that transfer of these elements from maternal to fetal tissues was enhanced only when the AAC diet was offered instead of the CON diet (Hostetler et al., 2003). The lack of treatment effects on cotyledon and calf liver Mn further corroborates that Mn concentrations in these tissues are also not impacted by dietary Mn intake by the dam during gestation (Underwood and Suttle, 1999; Ahola et al., 2004).

No treatment effects were detected ($P \geq 0.27$) for calving rate and calf birth BW (adjusted or not; BIF, 2010) as well as kilograms of calf born per cow assigned to the experiment (Table 6). Stanton et al. (2000) and Sprinkle et al. (2006) also reported that supplementing trace minerals, as organic or inorganic sources, to late-gestating beef cows did not impact calf birth BW. Therefore, AAC and INR diets did not impact fetal growth, despite treatment differences detected on cotyledon Co and Cu as well as calf liver Co, Cu, and Zn concentrations. At weaning, no treatment differences were detected ($P \geq 0.17$) for weaning rate and weaning age (Table 6). Weaning BW and 205-d adjusted weaning BW (BIF, 2010) were greater ($P \leq 0.04$) for calves from AAC cows compared with calves from CON cows and similar ($P \geq 0.18$) between calves from INR vs. AAC cows and INR vs. CON cows (Table 6). However, no treatment effects were detected ($P \geq 0.41$) for kilograms of calf weaned (actual or 205-d adjusted BW) per cow assigned to the experiment, which can be associated with the unexpected numerical decrease in weaning rate of INR cows (Table 6).

Weaning results indicate that supplementing late-gestating beef cows with the AAC diet increased weaning BW by more than 20 kg compared with CON cows.

Table 6. Calving, weaning, and preconditioning outcomes from beef cows that received diets containing no supplemental Cu, Co, Mn, and Zn (CON); sulfate sources of Cu, Co, Mn, and Zn (INR); or organic complexed source of Cu, Mn, Co, and Zn (AAC) during the last trimester of gestation[1]

Item	CON	INR	AAC	SEM	*P*-value
Calving results					
Calving rate, %	96.4	85.7	96.4	5.2	0.27
Percent of male calves born	25.9^{a}	58.3^{b}	48.2^{b}	9.5	0.05
Percent of AI-sired calves born	63.0	70.8	70.4	9.5	0.80
Calf birth BW, kg	42.1	41.6	40.8	1.0	0.63
Kilograms of calf born per cow[3]	39.8	35.9	39.3	2.2	0.41
Adjusted calf birth BW,[2] kg	42.9	42.7	41.8	1.0	0.69
Adjusted kilograms of calf born per cow[3]	40.6	36.9	40.2	2.3	0.44
Weaning results					
Weaning rate, %	92.9	85.7	89.3	5.9	0.70
Percent of AI-sired calves weaned	61.5	70.8	72.0	9.4	0.70
Percent of male calves weaned	23.1^{a}	58.3^{b}	52.0^{b}	9.6	0.04
Calf weaning age, d	178	183	186	3	0.17
Calf weaning BW, kg	212^{a}	223^{ab}	236^{b}	6	0.04
Kilograms of calf weaned per cow[4]	198	191	210	14	0.64
Calf 205-d adjusted weaning BW,[2] kg	244^{a}	252^{ab}	263^{b}	6	0.05
Adjusted kilograms of calf weaned per cow[4]	227	216	235	16	0.71
Preconditioning results					
Treated for BRD symptoms,[5] %	34.9	36.4	31.5	11.7	0.95
Calf mortality, %	0.0	7.5	0.0	6.2	0.42
End of preconditioning BW,[6] kg	226^{a}	236^{ab}	246^{b}	6	0.05
Preconditioning ADG, kg/d	0.23	0.14	0.19	0.04	0.34
Kilograms of preconditioned calf produced per cow[7]	208	186	220	16	0.31
Overall calf loss,[8] %	7.1	21.4	10.7	6.4	0.27

[a,b]Within rows, means with different superscripts differ ($P \leq 0.05$).

[1]INR and AAC cows received the same amount of Cu, Co, Mn, and Zn from sulfate sources or Availa 4 (Zinpro Corporation, Eden Prairie, MN).

[2]Calculated according to the Beef Improvement Federation (2010).

[3]Calculated based on calving rate and calf birth BW.

[4]Calculated based on weaning rate and calf weaning BW.

[5]BRD = bovine respiratory disease. Calves were classified as positive for BRD symptoms according to the subjective criteria described by Berry et al. (2004) and received 1 mL/10 kg of BW of Hexasol LA Solution (Norbrook Inc., Overland Park, KS).

[6]Collected on growing lot (Top Cut Feedlot, Echo, OR) arrival.

[7]Calculated based on preconditioning rate and end of preconditioning BW.

[8]Calculated based number of calves lost during gestation and until the end of preconditioning divided by the number of pregnant cows assigned to the experiment.

Given that Cu, Zn, Mn, and Co (as a component of vitamin B_{12}; NRC, 2000) play important roles on enzymatic and metabolic functions during fetal growth (Hostetler et al., 2003; Griffiths et al., 2007) and the AAC diet increased Cu, Zn, and Co concentrations in the newborn calf liver compared with CON cohorts, these results suggest that feeding the AAC diet to late-gestating beef cows resulted in programming effects on postnatal offspring development. Nevertheless, these results are novel and further research is warranted to understand the physiological mechanism underlying these outcomes. It is important to note that the proportion of AI-sired calves that were born and weaned was similar ($P \geq 0.70$) among treatments (Table 6), indicating that treatment differences in weaning outcomes were independent of calf sire. Conversely, CON cows gave birth and weaned a reduced ($P \leq 0.05$) proportion of male calves compared with INR and AAC cows (Table 6). Calf gender was not controlled in the experimental design because cows were assigned to treatments without knowledge of their fetal gender. For this reason, all calf variables were analyzed using calf gender as an independent covariate, whereas the treatment × gender interaction was not tested because the experimental units were not blocked by calf gender. Nevertheless, gender was not a significant covariate for weaning variables ($P \geq 0.45$). Although steers are expected to have greater weaning BW compared with heifers (Koger and Knox, 1945), steers and heifers had similar ($P \geq 0.45$) weaning age (182 vs. 183 d [SEM 3], respectively), weaning BW (223 vs. 224 kg [SEM 5], respectively), and 205-d adjusted weaning BW (254 vs. 252 kg [SEM 5], respectively) in the present experiment. Therefore, treatment effects detected for weaning BW variables should also not be associated with the greater ($P \leq 0.05$) proportion of male calves born from INR and AAC cows (Table 6).

Calf Preconditioning Parameters

Upon weaning, a treatment × day interaction was detected ($P < 0.01$) for plasma cortisol (Fig. 1). Cortisol concentrations increased in calves from all treatments after weaning (day effect, $P < 0.01$). However, cortisol concentrations were greater ($P < 0.01$) in calves from AAC and INR cows compared with CON cohorts and similar between calves from AAC and INR cows ($P = 0.61$) 3 d after weaning (d 286 of the experiment). Accordingly, Long et al. (2010) reported that maternal nutrition during gestation influences adrenal steroidogenesis of the offspring. No treatment effects were detected for plasma haptoglobin concentrations, which increased (day effect, $P < 0.01$) for all treatments on weaning (0.37, 1.31, 1.19, 0.93, and 0.72 μg/mL on d 283, 284, 286, 288, and 290 [SEM 0.05], respectively). The day effects reported herein for plasma cortisol and haptoglobin concentrations were expected, based on the neuroendocrine stress response and acute-phase protein reaction elicited by weaning and vaccination against BRD pathogens (Arthington et al., 2013; Rodrigues et al., 2015). Nevertheless, elevated cortisol has been positively associated with plasma haptoglobin concentrations (Cooke and Bohnert, 2011; Cooke et al., 2012), whereas the greater plasma cortisol concentration in AAC and INR calves on d 283 did not yield a similar haptoglobin response. These outcomes suggest that Co, Cu, Zn, and Mn supplementation to late-gestating cows impacted the steroidogenesis required to cope with the stress of weaning procedures in the offspring without impacting the resultant acute-phase protein response (Carroll and Forsberg, 2007).

During the 45-d preconditioning, no treatment effects were detected ($P \geq 0.42$) for incidence of calves that required treatment for BRD, calf mortality, and ADG (Table 6), indicating that treatments did not influence calf preconditioning performance and health parameters despite treatment differences detected for weaning BW (Table 6) and plasma cortisol (Fig. 1). At the end of preconditioning, BW was still greater ($P = 0.03$) for calves from AAC cows compared with calves from CON cows and similar among calves from INR cows compared with AAC and CON cohorts ($P \geq 0.25$). Gender was also not a significant covariate for preconditioning variables ($P \geq 0.34$), whereas steers and heifers had similar ($P = 0.63$) preconditioning final BW (232 vs. 227 kg [SEM 8], respectively). These outcomes corroborate with treatment effects reported for weaning variables, indicating that supplementing an organic source of Co, Cu, Zn, and Mn to late-gestating beef cows enhanced postnatal offspring performance compared with nonsupplemented cohorts. Still, kilograms of preconditioning calf produced/cow assigned to the experiment were similar ($P = 0.35$) among treatments, which can again be attributed to the unexpected numerical increase in overall calf loss of INR cows (Table 6).

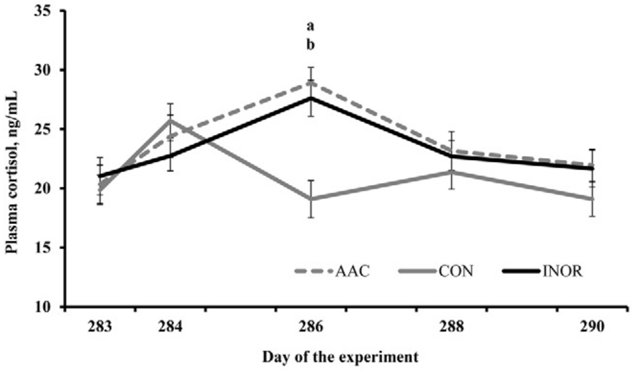

Figure 1. Plasma cortisol concentration from weaned calves (d 283 of the experiment) born from beef cows that received diets containing no supplemental Cu, Co, Mn, and Zn (CON); sulfate sources of Cu, Co, Mn, and Zn (INOR); or organic complexed source of Cu, Mn, Co, and Zn (AAC) during the last trimester of gestation. A treatment × day interaction was detected ($P < 0.01$). Within days, letters indicate following treatment differences ($P < 0.01$): a = INOR vs. CON and b = AAC vs. CON.

Calf Feedlot and Carcass Parameters

During the growing lot phase, when BRD incidence is elevated in feeder cattle (Snowder et al., 2006), the proportion of calves treated for BRD symptoms was reduced ($P < 0.01$) in calves from AAC cows compared with calves from INR and CON cohorts (Table 7). During gestation, Zn, Cu, Mn, and Co are also essential for development of the fetal immune system (Hostetler et al., 2003; Pepper and Black, 2011), suggesting that feeding the AAC diet to late-gestating cows also resulted in programming effects on postnatal offspring health. Nevertheless, no treatment effects were detected ($P \geq 0.63$) for calf mortality and ADG in the growing lot (Table 7). Calf BW at the end of the growing lot phase was still greater ($P = 0.04$) for calves from AAC cows compared with calves from CON cows and similar among calves from INR cows compared with AAC and CON cohorts ($P \geq 0.17$). Gender was also not a significant covariate for growing lot variables ($P \geq 0.39$); steers and heifers had similar ($P = 0.63$) growing lot final BW (364 vs. 359 kg [SEM 7], respectively) although feedlot performance is often impacted by calf gender (Hassen et al., 1999).

Calves from AAC cows were slaughtered with less ($P = 0.03$) DOF compared with CON cohorts (265, 269, and 268 DOF [SEM 1.3] for AAC, CON, and INR, respectively; main treatment effect, $P = 0.08$) due to the management decisions of the finishing lot and packing

Table 7. Feedlot performance and carcass characteristics of feeder cattle born from beef cows that received diets containing no supplemental Cu, Co, Mn, and Zn (CON); sulfate sources of Cu, Co, Mn, and Zn (INR); or organic complexed source of Cu, Mn, Co, and Zn (AAC) during the last trimester of gestation[1]

Item	CON	INR	AAC	SEM	*P*-value
Growing lot performance					
Treated for BRD symptoms,[2] %	42.3^{a}	59.1^{a}	20.0^{b}	9.6	0.02
Mortality, %	9.9	0.0	4.6	6.9	0.63
BW at the end of growing lot, kg	352^{a}	359^{ab}	374^{b}	8	0.09
Growing lot ADG, kg/d	1.11	1.09	1.13	0.04	0.86
Finishing lot performance					
Treated for BRD symptoms,[2] %	0.0	5.2	4.4	3.6	0.37
BW at the end of finishing lot,[3] kg	649^{a}	663^{ab}	680^{b}	11	0.10
Finishing lot ADG, kg/d	1.89	1.95	1.97	0.05	0.57
Percent calves slaughtered	82.1	78.6	85.7	8.9	0.85
Percent of male calves slaughtered	26.1^{a}	59.1^{b}	54.2^{b}	10.2	0.05
Percent of AI-sired calves slaughtered	65.2	68.2	70.8	9.9	0.92
Carcass characteristics[4]					
HCW, kg	409^{a}	418^{ab}	428^{b}	7	0.10
Back fat, cm	2.18	2.23	2.21	0.14	0.97
LM area, cm	96.0	95.8	98.4	1.8	0.53
KPH, %	2.71	2.94	2.73	0.14	0.46
Marbling	513	509	508	21	0.99
Yield grade	3.89	4.06	3.94	0.19	0.81
Retail product, %	47.7	47.3	47.5	0.45	0.80
Choice, %	87.7	97.1	92.1	5.2	0.46
Kilograms of carcass produced per cow,[5] kg	330	330	368	36	0.69

[a,b] Within rows, means with different superscripts differ ($P \leq 0.05$).

[1] INR and AAC cows received the same amount of Cu, Co, Mn, and Zn from sulfate sources or Availa 4 (Zinpro Corporation, Eden Prairie, MN). Cattle were in the growing lot (Top Cut Feedlot, Echo, OR) for 112 d and moved to an adjacent finishing lot where they remained for an average of 153 d until slaughter at a commercial packing facility (Tyson Fresh Meats Inc., Pasco, WA).

[2] BRD = bovine respiratory disease. Calves were classified as positive for BRD symptoms according to the DART system (Zoetis Inc., Florham Park, NJ) and received medication according to the feed yard management criteria.

[3] Calculated based on HCW (assuming 63% dressing; Loza et al., 2010).

[4] Back fat thickness measured at the 12th rib. Marbling score: 400 = Small^{00}, 500 = Modest^{00}; 600 = Medium^{00}. United States Department of Agriculture retail yield equation: 51.34 – (5.78 × back fat) – (0.0093 × HCW) – (0.462 × KPH) + (0.74 × LM area).

[5] Calculated based on total kilograms of carcass harvested divided by number of pregnant cows assigned to the experiment.

facility (Table 7), although DOF was not a significant covariate ($P \geq 0.16$) for finishing performance and carcass traits. Similar to weaning outcomes, the proportion of AI-sired calves that were slaughtered did not differ ($P = 0.92$) among treatments, whereas a reduced ($P \leq 0.05$) proportion of male calves were slaughtered from CON cows compared with INR and AAC cohorts (Table 7). However, calf gender was a significant covariate ($P \leq 0.04$) for all finishing and carcass variables, given that steers and heifers often have different feedlot growth rates and carcass merit (Hassen et al., 1999). As an example, steers had greater ($P < 0.01$) HCW compared with heifers (432 vs. 405 kg [SEM 7], respectively) in the present experiment. Therefore, it is important to emphasize that all finishing and carcass results were adjusted to the significant ($P \leq 0.04$) calf gender covariate. No treatment effects were detected ($P \geq 0.59$) for calf ADG and BRD incidence (Table 7) during the finishing period, which was minor due to calf age and DOF during this phase (Snowder et al., 2006), and no calf mortality was observed. Moreover, no treatment effects were detected for percentage of calves slaughtered per cow assigned to the experiment ($P = 0.85$; Table 1), indicating that mortality rate among treatments was similar throughout the entire offspring productive life. Final finishing BW and HCW were again greater ($P = 0.05$) for calves from AAC cows compared with calves from CON cows and similar among calves from INR cows compared with AAC and CON cohorts ($P \geq 0.19$). No treatment effects were detected ($P \geq 0.46$) for any of the other carcass merit traits evaluated or kilograms of carcass produced per cow assigned to the experiment (Table 7). Collectively, these outcomes suggest that treatment effects on finishing BW and HCW resulted from the greater weaning BW in calves from AAC cows compared with CON cohorts, whereas treatments and differences in finishing BW failed to impact carcass merit traits.

Overall Conclusion

Supplementing beef cows during late gestation with organic or inorganic sources of Co, Cu, Zn, and Mn effectively increased cow liver concentrations of Co, Cu, and Zn compared with CON cohorts. Liver Cu and Zn concentrations in the neonatal calf were increased only in AAC cows compared with CON cows. Calves from AAC cows were >20 kg heavier from weaning until slaughter and had reduced BRD incidence during the growing phase compared with calves from CON cows, which is suggestive of programming effects on postnatal offspring growth and health resultant from the AAC treatment (Funston et al., 2010). However, the physiological mechanism underlying these effects, including the role of each specific trace mineral supplemented herein on fetal development and programming, still requires investigation. In addition, these outcomes should not be specifically attributed to Cu and Zn, which were increased in neonatal liver when comparing ACC and CON treatments, given that liver concentration is not the absolute indicator of Co, Mn, and Zn status in livestock (McDowell, 2003). Nevertheless, results from this experiment are novel and suggest that supplementing late-gestating beef cows with an organic complexed source of Co, Cu, Zn, and Mn instead of no supplementation may be an alternative to optimize offspring productivity in beef production systems.

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