Effects of Trace Mineral Supplementation on Fiber Digestion and Cow-Calf Production

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- **Outline**
  - **Trace minerals (Cu and Zn)**
    - ✓ **Function**
    - ✓ **Mineral requirements**
    - ✓ **Rumen fermentation**
      - **Microbial function**
      - **Solubility**
      - **Fiber digestion**
      - **Redox potential**
  - **Current and future experiments**
    - ✓ **Rumen: mineral solubility, fermentation characteristic, and binding strength to rumen digesta.**
    - ✓ **Long-term cow-calf production experiment**

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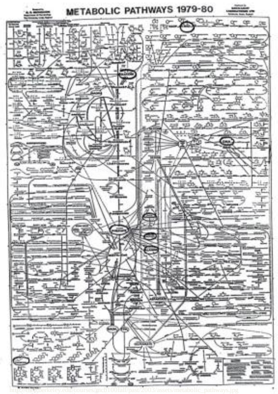
General Functions of Minerals:

- Structural (bone, cytoskeleton, connective tissue)
- Maintenance of homeostasis
  - acid base balance (RBC and kidney)
- Enzyme activity
  - metalloenzymes
  - metal activated enzymes
- Components or regulators of hormones - Iodine
- Lipid metabolism
- Gene expression
- Hormone (production, storage, and secretion)
- Vitamin metabolism
- Component of Vitamin B_{12} (prop. → succ.-CoA; methyltransferase)
- Reproduction
- Membrane stability
- Immunity



http://mcb.berkeley.edu/courses/mcb100fall/past/2003/assets/metabolic_pathways.jpg

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However, if you think you may have a mineral deficiency:

CHECK THE ENERGY AND PROTEIN CONTENT OF THE DIET <u>FIRST</u>

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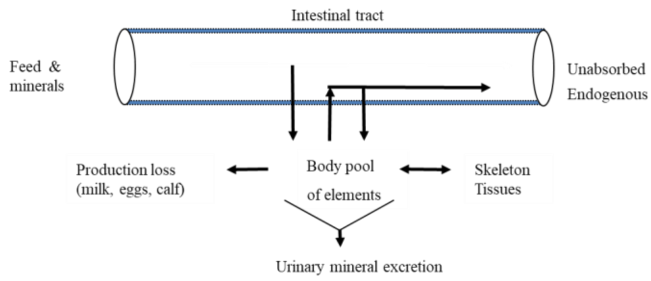
Determining Mineral Requirements

- Factorial estimates – determining gross mineral requirement: Sum of the components of net requirements for maintenance and production and divide the total by the coefficient of absorption



- **Advantages** -Requirements of a specific mineral can be estimated for a wide range of production levels and physiological stages. Works well for Ca and P measurements – high degree of accuracy.
- **Disadvantages:** Difficult to accurately measure and experiments are limited.
  - Absorption coefficients are potentially a major source of error (can be impacted by dietary components as well as physiological status of the animal).
  - Absorption coefficients for certain trace minerals are more accurately measured when dietary concentrations are at or below the animal's requirements. Elevated concentrations activate homeostatic control mechanisms that can reduce absorption.

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Determining Mineral Requirements:

Dietary experimentation estimates (most common)

- **Basic approach** – supplement a diet deficient or suspected of being deficient in a mineral with one or more concentrations of a specific mineral of interest.
- **Response variables are then measured** (e.g., growth, reproduction, bone strength, etc.)
  - **Advantages**
    - Supplementation experiments can arrive at an estimate of the requirement in the whole animal.
  - **Disadvantages**
    - Supplementation experiments rarely give precise estimates of requirements.
    - It is difficult and costly to estimate requirements using experiments for cattle of different ages and varying physiological states (growth, maintenance, reproduction, lactation, etc.).
    - Dependent on response variables measured.

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DATA COMPARISON

- **BR-CORTE** (2016)
- **ARC:** Agricultural Research Council: The Nutrient Requirements for Ruminant Livestock
- **AFRC** – Agriculture and Food Research Council (Report 6)
- **NASEM/NRC** (2016) – National Research Council Nutrient Requirements for Beef/Dairy Cattle
- **CSIRO** – Commonwealth Scientific and Industrial Research Organization
- **Costa e Silva** (2016) Macrominerals and Trace Element Requirements for Beef Cattle
- **BR CORTE** (2010) – Nutrient requirements for Zebu beef cattle. Valadares Filho et al., (2010).

Costa e Silva et al. (2015)

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Dietary Requirements

	mg/kg dry matter intake					
Item	Cu	Fe	Mn	Se	Zn	Co
NRC	10.0	50	20	0.10	30	0.15
CSIRO (2007)	---	---	---	0.05	11.6	---
Costa e Silva et al. (2015)	9.53	218	9.5	0.57	61	2.78
BR-CORTE (2016)	7.91	207.3	23.1	0.56	56.8	0.78

Costa e Silva et al. (2015); Absorption coefficients, where reported, are highly variable: Cu 6-84%; Mn 1-75%; Se 30-50%; Zn 5-80%.

Costa e Silva et al. (2015)

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Why the variation in ruminant data (Cu, Mn, Zn, dose and source)?

- The duration and concentration of mineral supplementation
- The duration of deficiency
- Environmental factors
- The absence or presence of dietary trace mineral antagonists
- Breed differences in mineral metabolism and immune response.
- Stress

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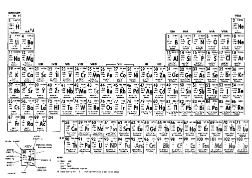
Factors Affecting Trace Mineral Requirements

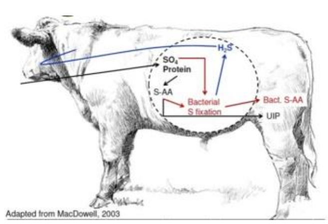
- **Interactions with other elements**
  - **Cu-Mo-S** (thiomolybdates; mono, di, tri, tetra)
    - High concentrations of Mo (10 mg Mo/kg DM) may not affect Cu status of cattle any more than moderate concentrations of Mo (5 mg Mo/kg DM).
    - **Mo in water** – does not appear to have the same influence on Cu metabolism relative to Mo in the feed/diet. (Kincaid, 1980 calves; Kistner et al., 2017 feedlot steers: Thorndyke, et. al., 2020, 2021, 2023 Cows, calves, and steers)
  - **Fe and Cu**
    - Synergistic (Enzymes)
    - Antagonistic (Gut)
  - **High Zn can decrease Cu absorption**
    - Molecular adaptation of the intestinal cells.

Puls, 1994

PERIODIC TABLE OF THE ELEMENTS



Adapted form Sargent-Welch Scientific Company



Adapted from MacDowell, 2003

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Rumen Fermentation

- The role that Cu and Zn play in rumen microbial fermentation is not well understood.
- The majority of research determining microbial trace mineral requirements has been conducted *in vitro*.
- Early *in vitro* rumen simulated experiments indicate that low concentrations of Cu and Zn in artificial rumen fluid were adequate to optimize fiber digestion (Cheng et al, 1955; Hubbert et al, 1958; Durand and Kawashima, 1980).
- Requirements of the host ruminant for zinc and copper are much higher than those needed by rumen microorganisms (≈0.1 mg Cu/l; Zn 0.2 mg/l).

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Ruminal disappearance of copper and zinc from forages from dacron bags incubated for 0 or 72 hours in the rumen of cattle

	Copper		Zinc	
Forage	0[a]	72 h	0[a]	72 h
	------------ % of total	-------------		
Alfalfa	88.9	92.9	25.8	79.4
Rhizoma peanut	50.6	89.6	18.1	80.5
Dwarf elephantgrass	84.4	94.3	7.3	75.5
Bermudagrass	69.9	75.8	43.1	62.1
Bahiagrass	63.1	81.7	33.8	53.0
Limpograss	70.0	69.5	26.6	67.2

[a]**Amount disappearing following washing with water.**

Emanuele and Staples (1990)

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Rumen Microorganisms

- Bacteria metal homeostasis
- Regulated by metal sensor proteins that regulate:
  - Metal uptake
  - Metal efflux
  - Metal binding proteins
- Data would indicate that practical diets fed to ruminants without Cu and Zn supplementation are able to meet the microbial Cu and Zn requirements (Emmanuel and Staples, 1990).
- Numerous factors can impact rumen solubility of minerals such as the pH of the rumen, the concentration of dietary antagonists (Mo, Fe, S, fiber, etc.), diet type, and mineral source.
- Microenvironments and soluble minerals?

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Trace mineral source

- Copper from Cu hydroxychloride was relatively insoluble (0.6%) in water (pH 7.0) and highly soluble (81.4%) at a low pH (2.2), whereas Cu from $CuSO_4$ was almost completely soluble in both water and at a low pH (Spears 2004).
- Zinc hydroxychloride has also been reported to have low solubility in water (Cao et al. 2000) and was less soluble in the rumen of cattle when compared to Zn from $ZnSO_4$ (Shaeffer, 2006).

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Effect of trace mineral source on fiber digestion in lactating dairy cows[a]

Item	Sulfate[a]	Hydroxy[a]
NDF digestion, %[b]		
Forage diet[c]	43.0	45.9
By-product diet[d]	49.8	51.2

[a]Copper, zinc, and manganese were supplemented at 10, 32, and 30 mg/kg, respectively.
[b]Trace mineral source effect ($P < 0.02$).
[c]44% corn silage, 20% alfalfa silage.
[d]11% corn gluten feed, 15% beet pulp, 14.1% soy hulls.

Faulkner and Weiss (2017)

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Beef Cattle

- 8 crossbred steers fitted with ruminal cannulas
- Steers were fed a TMR (corn silage, steam-flaked corn-based diet) that contained appropriate trace mineral treatments.
- Treatments: 10 mg Cu/kg DM; 20 mg Mn/kg DM; 30 mg Zn/kg DM
  - 1) Sulfate
  - 2) Hydroxy
- Steer were acclimated to individual metabolism stalls for 5 d followed by a 5-d fecal and urine collection.

Caldera et al. (2019)

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Influence of trace mineral source on DM and NDF digestibility[a]

	Treatment			
Item	Sulfate[1]	Hydroxy[2]	SEM	P <
DM intake, kg/d	9.92	9.89	0.96	0.98
DM digestibility, %	65.6	70.7	2.4	0.18
NDF digestibility, %	37.8	41.2	1.7	0.09

[a]Zinc, copper, and manganese were supplemented at 30, 10, and 20 mg/kg DM, respectively.

Caldera et al. (2019)

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Rumen solubility of trace minerals

- To determine the impact of Cu and Zn source (SO_4 vs HTM) on rumen characteristics in steers fed a low-quality forage-based diet:
  - Dry matter and fiber digestibility.
  - Rumen soluble concentrations of Cu and Zn.
  - Rumen fermentation characteristics.
  - Binding strength of Cu and Zn to rumen solid digesta.

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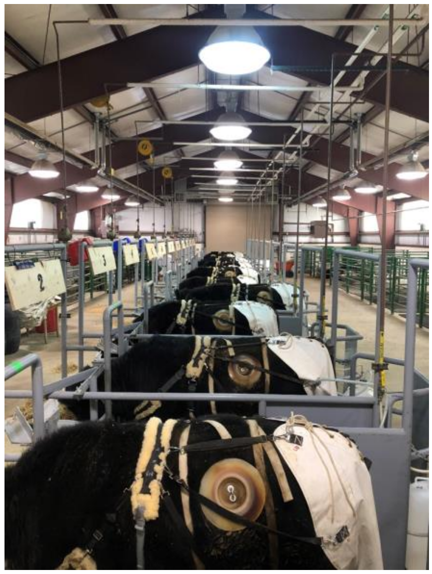
Experimental Design

- 12 crossbred steers fitted with ruminal cannulas.
- Group fed a low-quality grass hay-based diet for 60 days.
- Treatments:
  20 mg Cu/kg DM
  40 mg Mn/kg DM
  60 mg Zn/kg DM
  - 1) Sulfate
  - 2) Hydroxy

Ingredient	%DM
Grass hay	90.0
Protein/mineral supplement	10.0
Analyzed composition	
Dry matter, %	89.1
Crude Protein, %	12.4
Acid detergent fiber, %	37.2
Neutral detergent fiber, %	60.4
Copper, mg/kg DM	6.6
Manganese, mg/kg DM	58.4
Zinc, mg/kg DM	27.4



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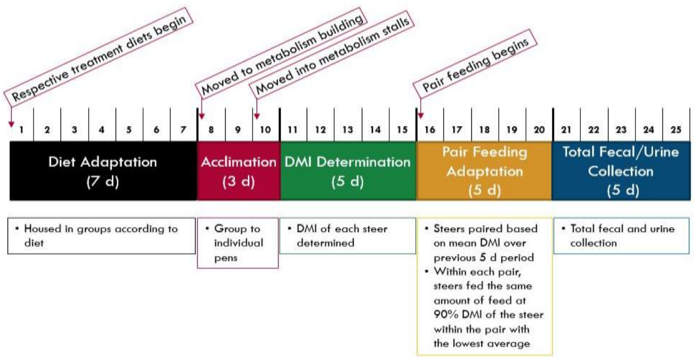
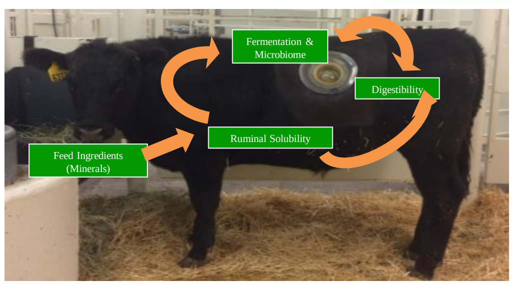
Trial Design





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Effect of trace mineral source on digestibility in steers fed a low-quality hay supplemented with protein[a]

	Sulfate	Hydroxy	P<
DMI, kg/d	7.4	7.4	-------
DM digestibility, %	51.9	53.4	0.07
NDF digestibility, %	40.4	42.7	0.04
ADF digestibility, %	32.4	34.1	0.05
CP digestibility, %	51.2	54.3	0.06

[a]Copper, manganese, and zinc were supplemented at 20, 40, and 60 mg/kg, respectively.

Guimaraes et al. (2019)

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Day 6

Influence of trace mineral source on short chain fatty acid production at 0, 2, and 4 hours post feeding.

	Treatment[a]				
Item	STM[b]	HTM[c]	Trt	Time	Trt*Time
pH	6.59	6.68	0.47	0.01	0.57
Butyric acid, mM/100mM	16.3	14.9	0.02	0.001	0.93
Total SCFA, mM	59.8	72.3	0.05	0.85	0.86

[a]Treatments: 20 mg Cu/kg DM; 40 mg Mn/kg DM; 60 mg Zn/kg DM from hydroxy or sulfate trace mineral sources.
[b]Sulfate trace minerals.
[c]Hydroxy trace minerals.
[d]Short chain fatty acids.

Guimaraes et al. (2019)

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Bolus dose experiment

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- Following the SCFA collection all steers were fed the basal diet without supplemental Cu, Mn, or Zn was fed for 14 days.
- Followed by a bolus dose in 0.23 kg of ground corn of Cu, Mn, and Zn at 2 x NASEM (2016) requirements for Cu, Mn, and Zn (20, 40, and 60 mg/kg of Cu, Mn, and Zn, respectively).
- Rumen grab samples were collected at 2-hour intervals beginning at -4 hours through 24 hours post dosing.

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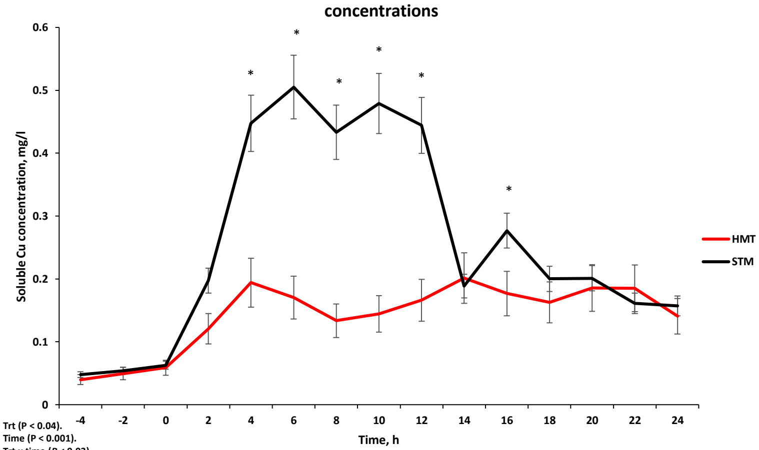
Figure 1a. Influence of trace mineral source on rumen soluble Cu concentrations



Trt (P < 0.04).
Time (P < 0.001).
Trt x time (*P* < 0.03).
*Means within a time point differ (P < 0.05).

Guimaraes et al. (2019)

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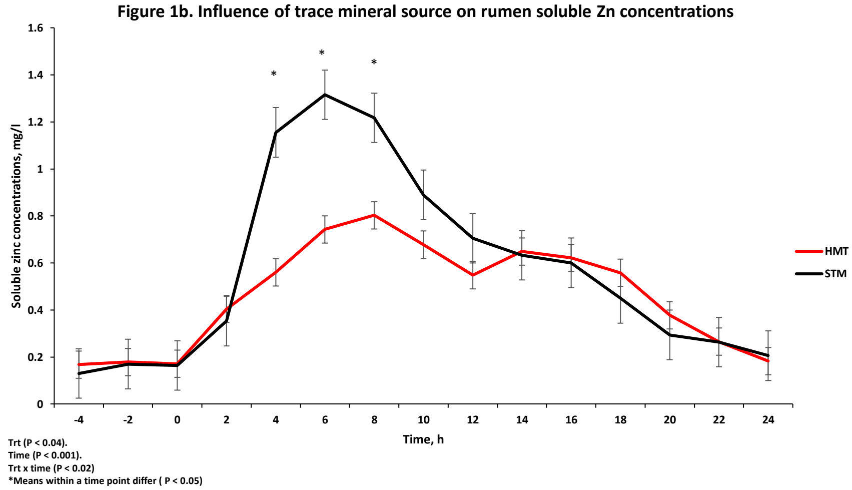
Figure 1b. Influence of trace mineral source on rumen soluble Zn concentrations



Guimaraes et al. (2019)

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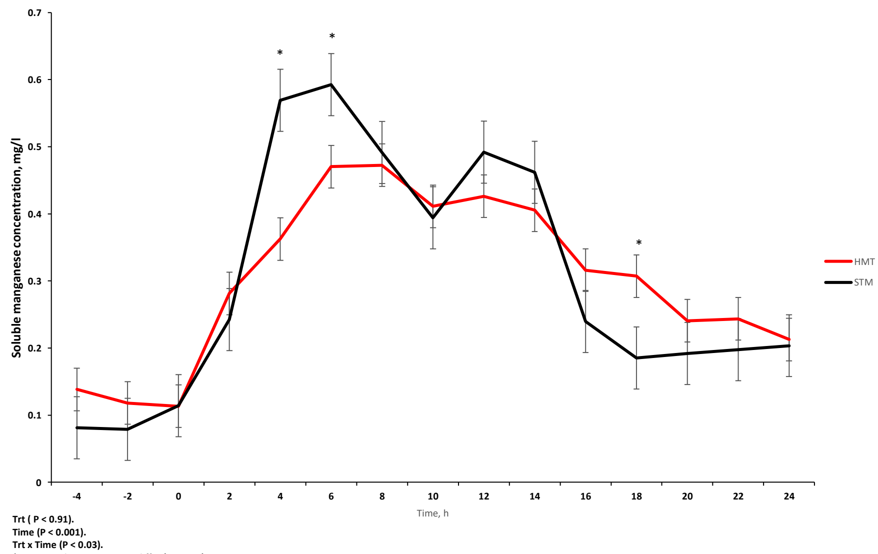
Figure 1c. Influence of trace mineral source on rumen soluble Mn concentrations



Guimaraes et al. (2019)

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Binding strength of copper, manganese, and zinc to rumen solid digesta

- Estimated using release of copper, manganese, and zinc from solid digesta by dialysis against 0.05M Tris-EDTA.

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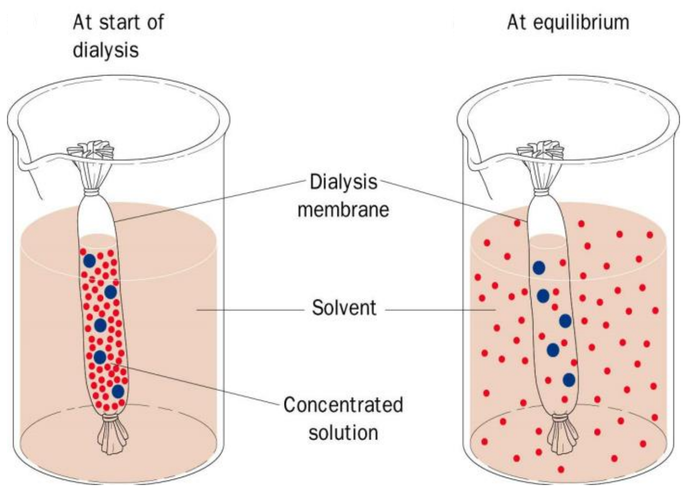

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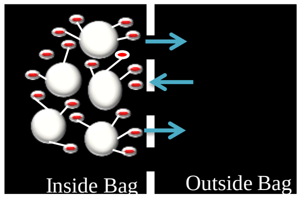

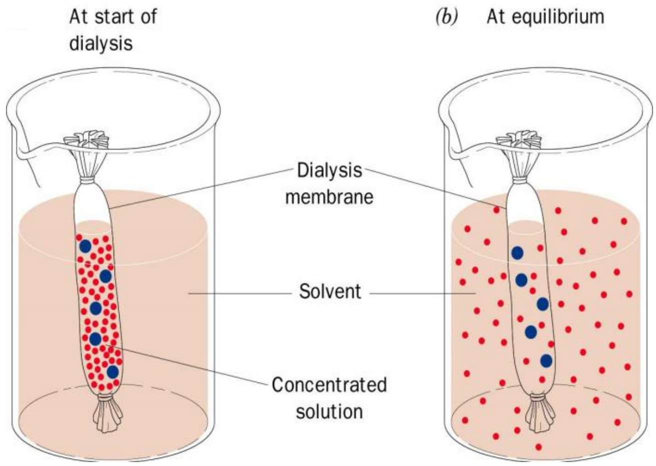

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Effect of trace mineral source on release of copper and zinc from rumen digesta at 12 hours after a pulse dose of 20 mg Cu, 40 mg Mn, and 60 mg Zn/kg DM

	Hydroxy	Sulfate	*P*<
Initial concentration in digesta, mg/kg DM			
Copper	31.6	8.1	0.001
Manganese	38.2	35.3	0.030
Zinc	129.6	37.3	0.001
Released by Tris-EDTA, %			
12h			
Copper	59.2	26.5	0.01
Manganese	63.7	77.2	0.01
Zinc	87.8	34.3	0.01

Guimaraes et al. (2019)

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Experiment 2 – Dairy diet[a]

Ingredients,%	Inclusion, % DM	
Corn Silage	64.5	
Alfalfa Hay	10.2	
Supplement	25.5	
Soybean meal		64.0
Dry distillers grain		16.2
Cracked corn		9.4
Limestone		7.5
Salt		1.9
Magnesium oxide		0.64
Trace mineral premix		0.35

[a]Formulated to provide 45.5 kg milk/day.
Treatments: Sulfate, Organic, and HTM (Cu, Zn, and Mn).

Experiment 3 –Feedlot diet[a]

Ingredients,%	Inclusion, % DM	
Steam-flaked corn	66.9	
Corn Silage	10.0	
Alfalfa hay	10.0	
Dry distillers grain	10.0	
Supplement	3.1	
Limestone		48.4
Urea		35.5
Salt		9.6
VTM premix		6.5

[a]Formulated to target 1.6 kg ADG.
Treatments: Sulfate and HTM (Cu, Zn, and Mn).

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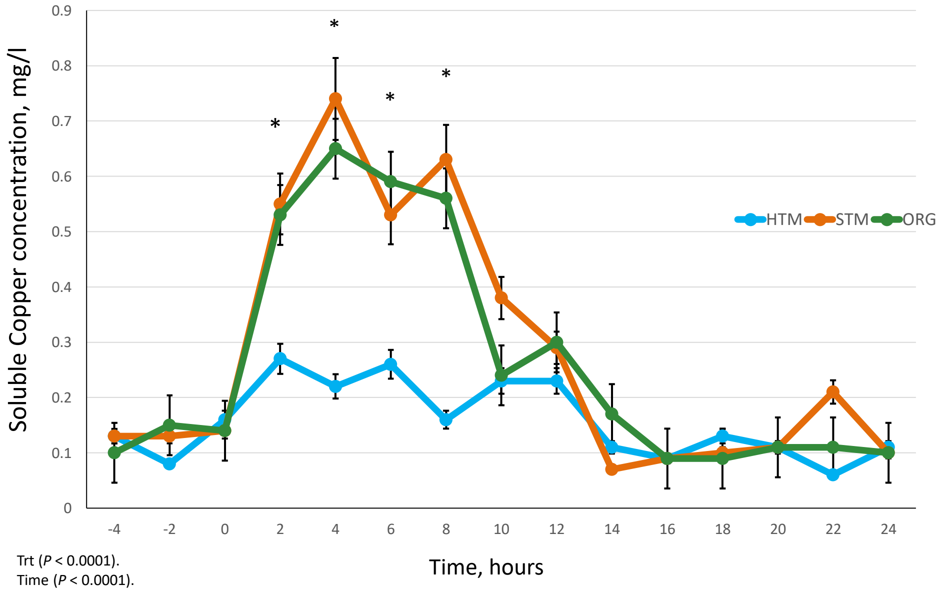
Influence of trace mineral source on rumen soluble Copper concentrations



Trt ($P < 0.0001$).
Time ($P < 0.0001$).
Trt x Time ($P < 0.0002$).
*means within a time point differ ($P < 0.05$).

Guimaraes et al. (2022)

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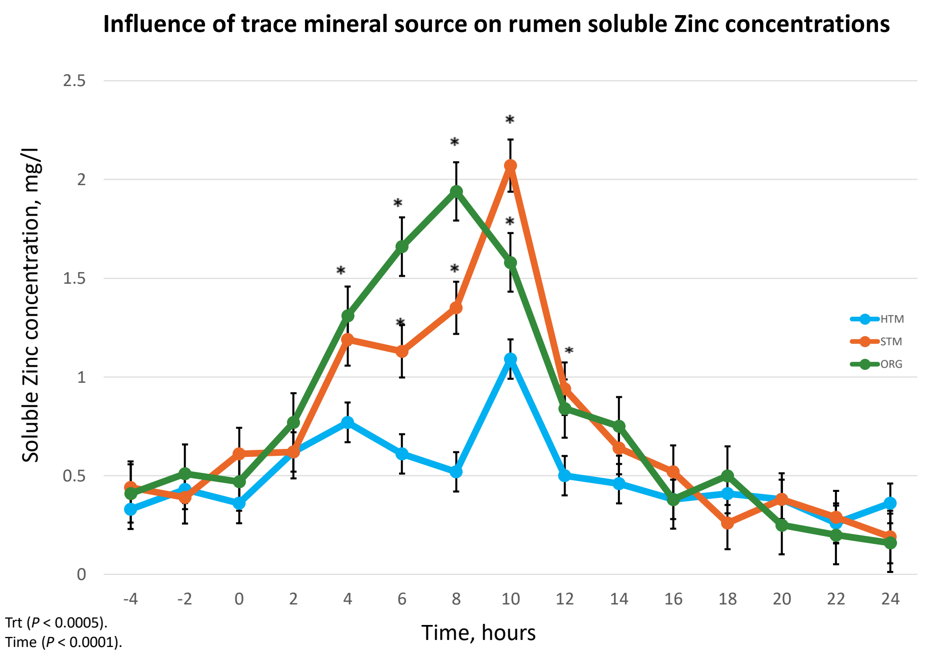

Trt ($P < 0.0005$).
Time ($P < 0.0001$).
Trt x Time ($P < 0.0001$).
*means within a time point differ ($P < 0.05$).

Guimaraes et al. (2022)

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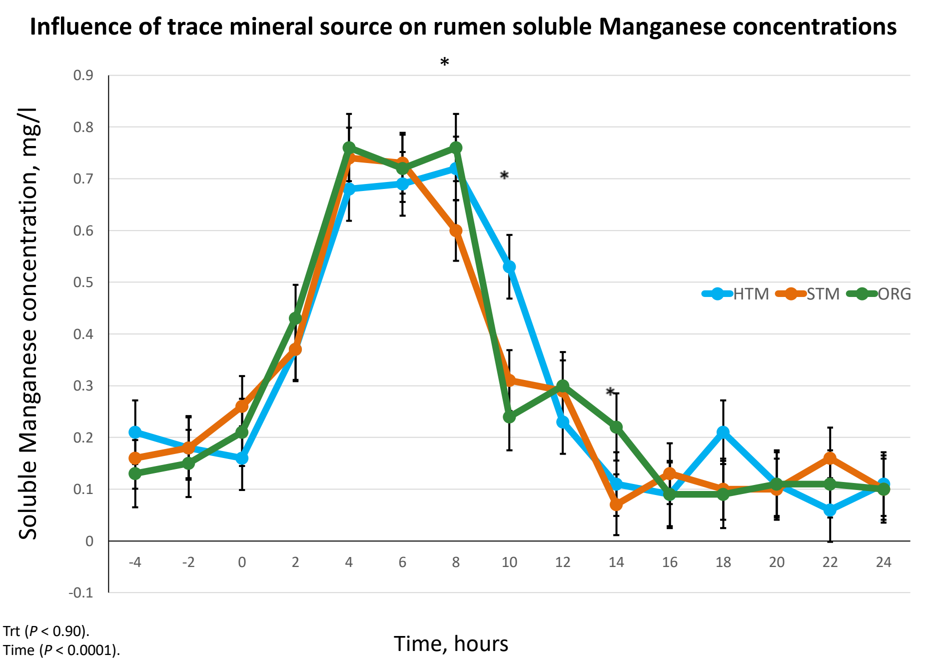

Trt ($P < 0.90$).
Time ($P < 0.0001$).
Trt x Time ($P < 0.02$).
*means within a time point differ ($P < 0.05$).

Guimaraes et al. (2022)

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Influence of trace mineral source on dry matter and neutral detergent fiber digestibility (dairy diet).

ITEM	Treatment STM	ORG	HTM	SEM	P<
DMI, kg/day	8.2	8.2	8.2	---	---
DM dig., %	64.6	65.7	66.5	0.57	0.11
NDF dig., %	43.0[a]	47.0[b]	47.6[b]	1.2	0.05
ADF dig., %	29.8.0[a]	31.6[b]	32.4[b]	0.49	0.05
CP dig., %	63.5	63.7	64.3	0.31	0.20

[a,b] Means within a row with different superscripts differ ($P < 0.04$).

Guimaraes et al. (2022)

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Influence of trace mineral source on short chain fatty acid (SCFA) production post feeding (dairy diet).

ITEM	Treatment ZTM	ORG	HTM	SEM	*P* value Trt	Time	Trt x Time
Rumen pH	6.38	6.42	6.59	0.09	0.26	0.01	0.17
Total VFA, mM	73.3	78.0	77.4	0.8	0.01	0.01	0.05

Guimaraes et al. (2022)

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Conclusion

- Results indicate that ruminal solubility of copper and zinc differs between sulfate, organic, and hydroxy sources.
- It appears that rumen copper and zinc solubility from sulfate forms may impact rumen fermentation of cattle fed high forage and dairy-type diets. Metal ion release in the rumen may influence fiber digestibility (sulfate compared to ORG and HTM).
- Future analysis
  - Completed additional experiments with a feedlot type diet. Microbiome analysis. Directly measure the free ion load in the rumen and rumen redox potential.

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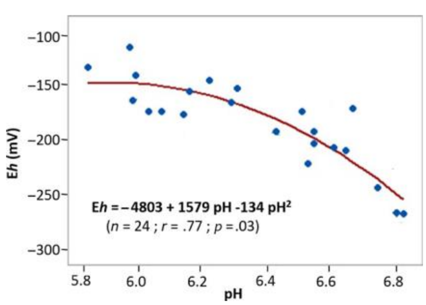
Rumen Redox (oxidation-reduction) Potential



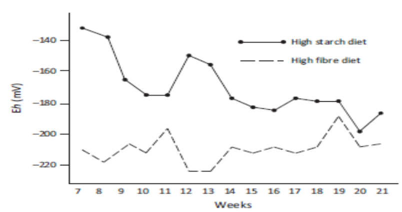
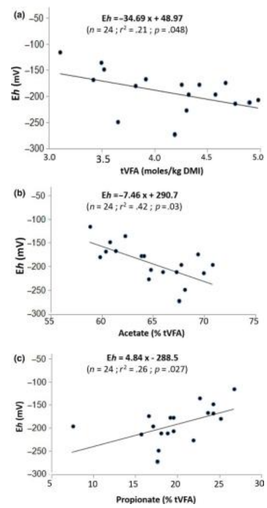


FIGURE 2 Changes in ruminal Eh in heifers fed high starch-diet or fed high fibre diet (from Monteils et al., 2009). Eh, redox potential



Huang et al. (2017)

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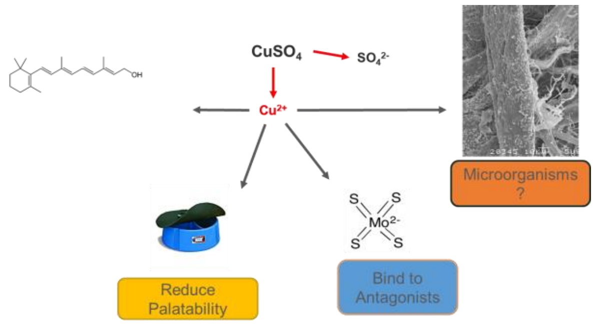
Question: Can soluble ions of trace elements impact rumen redox potential?

- DCAD/EB and Redox potential in soil can influence mineral availability.
- What can free metal ions do? Alter redox potential?



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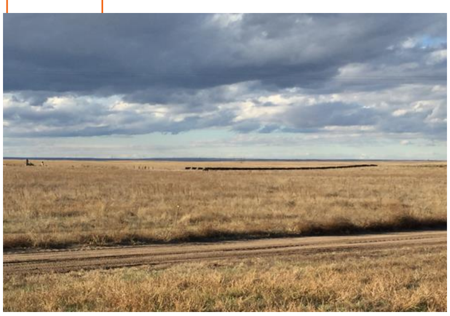
Influence of supplemental copper, manganese, and zinc source on reproduction, mineral status, and performance in a grazing beef cow-calf herd over a four-year period.



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Materials and Methods

- 180 Angus x Hereford cows (3 years old)
- 9 pastures with 20 cow per pasture (rotated monthly across 18 pastures).
- Replicates: 3 pasture replicates per treatment
- 3 free-choice trace mineral treatments.

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Materials and Methods (Cont.)

- Free-choice trace mineral treatments

Free-choice mineral supplement ingredient composition on a DM basis.

	Free-choice mineral supplement treatment		
Item, %*	Sulfate[1]	Hydroxy 1X[2]	Hydroxy 0.5X[3]
Monocalcium Phosphate 21%	28.45	28.43	28.47
Salt, NaCl[4]	25.55	25.55	25.45
Calcium Carbonate $CaCO_3$	20.75	21.45	22.00
Elemental sulfur, S	11.65	11.65	11.65
Corn Distillers Dried Grains	4.90	4.90	5.00
Magnesium Oxide, MgO	3.07	3.07	3.07
Selenium 0.16%, Se	1.88	1.88	1.88
Soybean Oil	1.00	1.00	1.00
Copper Sulfate (25%, Cu)	0.40	-	-
Zinc Sulfate (36%, Zn)	0.83	-	-
Manganese (32%, Mn)	0.63	-	-
Intellibond Cu	-	0.18	0.09
Intellibond Mn	-	0.46	0.23
Intellibond Zn	-	0.55	0.27
Cobalt Carbonate 2%, $CoCO_3$	0.08	0.08	0.08
Calcium Iodate 8%, CaI	0.06	0.06	0.06
Vitamin A		0.62	0.62
Vitamin D_3	0.05	0.05	0.05
Vitamin E	0.11	0.11	0.11

[1] Sulfate= 1 times NASEM (2016) requirements for Cu, Zn, and Mn – Sulfate source mineral containing 1,000, 2,000, and 3,000 mg/kg of Cu, Mn, and Zn.

[2]Hydroxy 1X= 1 times NASEM (2016) requirements for Cu, Zn, and Mn – Hydroxychloride source mineral containing 1,000, 2,000, and 3,000 mg/kg of Cu, Mn, and Zn (Intellibond C, Z, M, Micronutrients USA LLC (Indianapolis, IN) .

[3]Hydroxy 0.5X= 0.5 times NASEM (2016) requirements for Cu, Zn, and Mn – Hydroxychloride source mineral containing 500, 1,000, and 1,500 mg/kg of Cu, Mn, and Zn (Intellibond C, Z, M, Micronutrients USA LLC (Indianapolis, IN).

[4]On month 10 of the experiment, an additional 16.6% salt was added to each free-choice mineral feeder at the time of mineral delivery and thoroughly mixed by hand.

Ahola et al., 2004. 82-2375-2383. Negative control; ING; ORG – No supplemental Cu, Mn, and Zn for greater than 2 years decreased pregnancy rates,

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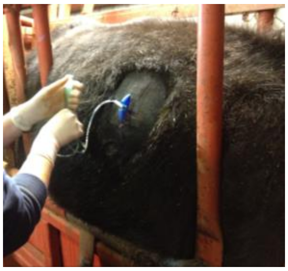
Materials and Methods (Cont.)

- BW, BCS, weaning weights.
- Monthly forage and water samples.
- Blood and liver biopsies were collected at the end of each year.
- Weaning weights, reproductive performance, offspring feedlot performance and carcass characteristics.
- Monitored monthly free-choice mineral intake.



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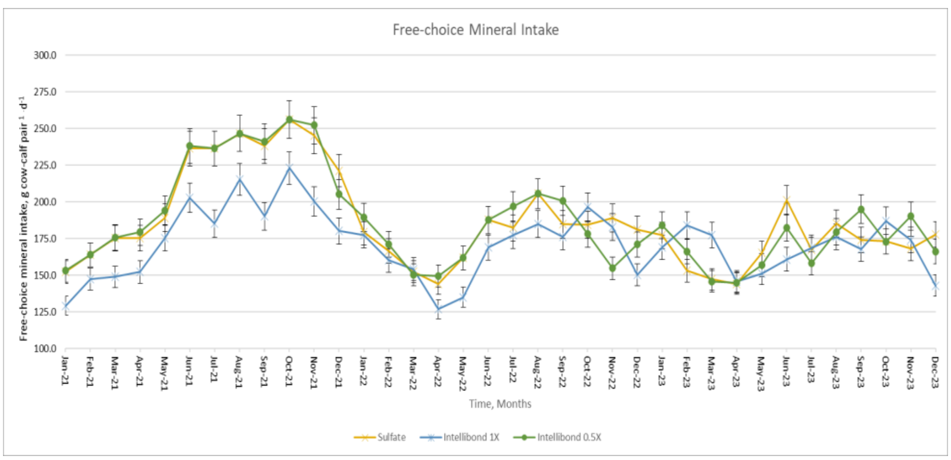
Free-choice trace mineral intakes



Calving: Feb/Mar
Breeding: July
Weaning: October

Unpublished data

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Effects of trace mineral supplement on cow BW, BCS, reproductive performance, and actual and 205 day adjusted weaning weights (Year 1, 2, and 3; Preliminary Data).

Item	Treatment			SEM	Contrast	
	Sulfate[1]	Intellibond 1x[2]	Intellibond 0.5x[3]		Sulfate vs. Intellibond 1x	Intellibond 1x vs. Intellibond 0.5x
BW, kg						
d 0	562.6	568.0	569.2	14.2	0.94	0.87
d 314, yr. 1	607.5	616.0	613.1	17.8	0.89	0.94
d 659, yr. 2	618.9	621.3	622.4	18.0	0.90	0.91
d 984, yr. 3	622.3	624.1	625.3	19.7	0.84	0.92
BCS[4]						
d 0	5.9	5.9	5.9	0.08	0.88	0.91
d 314, yr. 1	5.7	5.8	5.8	0.04	0.91	0.92
d 659, yr. 2	5.4	5.5	5.5	0.06	0.94	0.94
d 984, yr. 3	5.1	5.4	5.3	0.05	0.91	0.94

[1] Sulfate= 1 times NASEM (2016) requirements for Cu, Zn, and Mn – Sulfate source mineral containing 1,000, 2,000, and 3,000 mg/kg of Cu, Mn, and Zn.
[2] Hydroxy 1X= 1 times NASEM (2016) requirements for Cu, Zn, and Mn – Hydroxychloride source mineral containing 1,000, 2,000, and 3,000 mg/kg of Cu, Mn, and Zn (Intellibond C, Z, M, Micronutrients USA LLC (Indianapolis, IN) .
[3] Hydroxy 0.5X= 0.5 times NASEM (2016) requirements for Cu, Zn, and Mn – Hydroxychloride source mineral containing 500, 1,000, and 1,500 mg/kg of Cu, Mn, and Zn (Intellibond C, Z, M, Micronutrients USA LLC (Indianapolis, IN).
[4] 1=emaciated, 9= obese; Richards eat al., 1986.
[5] Artificial insemination.
[6] Adjusted for sex.

Unpublished data

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Effects of trace mineral supplement on cow BW, BCS, reproductive performance, and actual and 205 day adjusted weaning weights (Year 1, 2, and 3; Preliminary Data).

Item	Treatment			SEM	Contrast	
	Sulfate[1]	Intellibond 1x[2]	Intellibond 0.5x[3]		Sulfate vs. Intellibond 1x	Intellibond 1x vs. Intellibond 0.5x
Pregnancy rate to AI[5], %						
Year 1	55.0	63.3	56.7	5.1	0.64	0.63
Year 2	30.0	57.5	51.7	6.2	0.05	0.41
Year 3	40.4	60.9	57.3	5.3	0.07	0.40
Overall Pregnancy Rate, %						
Year 1	91.7	93.3	93.1	2.3	0.86	0.92
Year 2	95.0	95.0	96.7	5.9	0.98	0.87
Year 3	94.8	95.0	96.1	6.3	0.97	0.83
WW, kg						
Year 1	236.4	240.1	235.9	6.1	0.87	0.91
Year 2	242.2	249.9	244.2	3.8	0.10	0.29
Year 3	242.1	248.3	250.3	4.9	0.07	0.17

[1] Sulfate= 1 times NASEM (2016) requirements for Cu, Zn, and Mn – Sulfate source mineral containing 1,000, 2,000, and 3,000 mg/kg of Cu, Mn, and Zn.
[2] Hydroxy 1X= 1 times NASEM (2016) requirements for Cu, Zn, and Mn – Hydroxychloride source mineral containing 1,000, 2,000, and 3,000 mg/kg of Cu, Mn, and Zn (Intellibond C, Z, M, Micronutrients USA LLC (Indianapolis, IN) .
[3] Hydroxy 0.5X= 0.5 times NASEM (2016) requirements for Cu, Zn, and Mn – Hydroxychloride source mineral containing 500, 1,000, and 1,500 mg/kg of Cu, Mn, and Zn (Intellibond C, Z, M, Micronutrients USA LLC (Indianapolis, IN).
[4] 1=emaciated, 9= obese; Richards eat al., 1986.
[5] Artificial insemination.

Unpublished data

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Effects of pasture trace mineral supplement on offspring feedlot performance and carcass characteristics (Year 1, and 2; Preliminary Data).

	Treatment				Contrast	
Item	Sulfate[1]	Intellibond 1x[2]	Intellibond 0.5x[3]	SEM	Sulfate vs. Intellibond 1x	Intellibond 1x vs. Intellibond 0.5x
Year 1 (2022)						
Feedlot initial BW, kg	240.1	243.3	241.9	5.3	0.86	0.86
Feedlot Final BW, kg	634.2	637.1	638.9	7.9	0.60	0.79
Feedlot ADG, $kg \cdot animal^{-1} \cdot d^{-1}$	1.76	1.77	1.78	0.07	0.91	0.94
Hot carcass weight, kg	384.2	385.3	385.2	6.4	0.87	0.88
Dressing percentage[4]	63.1	63.0	62.8	0.24	0.74	0.78
Marbling score[5]	634.2	648.3	644.8	9.3	0.36	0.37
Fat thickness, cm.	1.38	1.30	1.19	0.54	0.76	0.84
Ribeye area, $cm.^2$	83.2	84.1	82.9	1.97	0.91	0.87
USDA YG	2.78	2.69	2.81	0.07	0.62	0.55
Year 2 (2023)						
Feedlot initial BW, kg	240.4	244.7	243.9	5.9	0.74	0.81
Feedlot Final BW, kg	637.2	648.3	647.1	6.7	0.21	0.73
Feedlot ADG, $kg \cdot animal^{-1} \cdot d^{-1}$	1.73	1.75	1.76	0.08	0.92	0.94
Hot carcass weight, kg	387.2	391.2	395.6	5.2	0.64	0.88
Dressing percentage[4]	63.3	62.9	63.6	0.31	0.42	0.38
Marbling score[5]	638.7	654.1	632.1	10.3	0.67	0.58
Fat thickness, cm.	1.41	1.30	1.29	0.11	0.47	0.38
Ribeye area, $cm.^2$	84.1	85.2	82.9	0.94	0.85	0.19
USDA YG	2.89	2.58	2.84	0.09	0.05	0.04

[1] Sulfate= 1 times NASEM (2016) requirements for Cu, Zn, and Mn – Sulfate source mineral containing 1,000, 2,000, and 3,000 mg/kg of Cu, Mn, and Zn.
[2]Hydroxy 1X= 1 times NASEM (2016) requirements for Cu, Zn, and Mn – Hydroxychloride source mineral containing 1,000, 2,000, and 3,000 mg/kg of Cu, Mn, and Zn (Intellibond C, Z, M, Micronutrients USA LLC (Indianapolis, IN).
[3]Hydroxy 0.5X= 0.5 times NASEM (2016) requirements for Cu, Zn, and Mn – Hydroxychloride source mineral containing 500, 1,000, and 1,500 mg/kg of Cu, Mn, and Zn (Intellibond C, Z, M, Micronutrients USA LLC (Indianapolis, IN).
[4]Final live body weight pencil-shrunk by 4% prior to dressing percentage calculation.
[5]Slightly Abundant=800, Moderate=700, Modest=600, Small=500, Slight=400.
[a,b]Means in a row with different superscripts differ $P < 0.05$.

Unpublished data

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Future Challenges/Opportunities:

- Mineral availability from basal feed ingredients.
- Mineral solubility throughout the gastrointestinal tract.
- Rumen pH, reducing potential, and abomasal retention time.
- Minerals and growth (Zn, Cr, Cu, etc.).
- Cow production efficiency.
- Bacterial and protozoal uptake and metabolism of trace minerals.

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Thank You!

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