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Influences of increasing levels of sulfate in drinking water on the intake and use of low-quality forages by beef cattle

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ABSTRACT

Objective: This study evaluated the effects of varying sulfate concentrations of water on forage and water intake, digestibility, digestive kinetics, and rumen fermentation characteristics of cattle consuming low-quality forages provided a protein supplement, with and without salt.

Materials and Methods: Eight ruminally cannulated cows (2 yr of age) were used in 2 concurrent 4 × 4 Latin squares (4 cows per square) to test the effects of increasing water sulfate concentrations on forage and water intake, digestibility, digestive kinetics, and rumen fermentation characteristics of cattle consuming low-quality forages provided protein supplement with and without salt. Within each square, cows were randomly assigned to the following treatments: (1) control (<10 mg/L sulfate); (2) 473 mg/L; (3) 946 mg/L; and (4) 1,420 mg/L. All cattle were provided a crude protein supplement at 0.18% of BW daily (0800 h daily); however, protein supplement NaCl composition differed by square (no NaCl vs. addition of 25% NaCl). Each period consisted of a 14-d adaptation period, followed by a 7-d intake and digestion period with ruminal profiles conducted on d 22 and complete ruminal evacuations on d 23, 5 h after feeding.

Results and Discussion: There were no observed effects of sulfate (SO_4) levels on forage intake, water intake, ruminal DM and liquid fill, ruminal DM and NDF digestibility, ruminal liquid passage rate, ruminal liquid turnover, ruminal liquid flow rate, ruminal pH, ruminal ammonia, ruminal total VFA concentrations, ruminal individual VFA concentrations, or the ruminal acetate-to-propionate ratio ($P \geq 0.16$). Furthermore, the addition of 25% salt to supplement had no effect on forage intake, ruminal DM and liquid fill, DM and NDF digestibility, liquid passage rate, liquid turnover, liquid flow rate, ruminal pH, or the acetate-to-propionate ratio ($P \geq 0.24$). Conversely, water intake was greater for animals provided 25% salt in supplement compared with animals not provided salt ($P = 0.05$).

Implications and Applications: Sulfate water concentrations as high as 1,420 mg/L had minimal effects on intake, digestibility, and rumen fermentation characteristics of cattle consuming low-quality forage-based diets when provided a protein supplement containing up to 25% salt.

Key words: beef cattle, digestion, intake, sulfate, water quality

INTRODUCTION

Grazing ruminant livestock production systems often rely on natural reservoirs, springs, rivers, and streams to meet water requirements. If water quality or quantity is limited, animal wellbeing could be compromised, as water is essential for regulating core body temperature, digestion, elimination of waste materials, reproduction, and lactation (NASEM, 2016). Landscape geology, subsurface basin depth, recharge site soil chemistry, and precipitation are all factors that influence water quality (Anderson and Woosley, 2005; Petersen et al., 2015). Therefore, inorganic qualities (e.g., sulfates; SO_4) of drinking water used for grazing ruminant production systems have been reported to be highly variable (Gould et al., 2002; Anderson and Woosley, 2005; Penner et al., 2020). Additionally, livestock drinking water high in sulfate concentration (>1,000 mg/L) are common throughout rangelands in the western and north-central regions of the United States and central Canada (Gould et al., 2002; Penner et al., 2020). Furthermore, pastures in these semiarid regions often have limited or single water sources, suggesting that surface water with high sulfate concentrations may be unavoidable for livestock consumption (Petersen et al., 2015). Excessive sulfate consumption by cattle can result in elevated production of hydrogen sulfide in the rumen, which then can cause reduced DM and water intake (Weeth and Hunter,

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1971; Harper et al., 1997) and, under extreme conditions, sulfur-toxicity-induced polioencephalomalacia (Olkowski 1997). However, previous research has suggested that sulfate concentrations generally considered safe for consumption (583–1,000 mg/L) may result in decreased growth and overall performance of feedlot cattle (Loneragan et al., 2001).

Cattle grazing on semiarid rangelands are often exposed to seasonal deficiencies in nutrients (DelCurto et al., 2000). Forage resources on rangelands often require supplemental protein to meet the nutritional needs and performance expectations of grazing ruminant livestock (Lusby et al., 1967; Bowman and Sowell 1997; Bodine et al., 2001). Self-fed supplement delivery systems are among the most preferred on extensive rangeland systems due to ease of delivery and reduction of labor. Self-fed supplementation assumes that all animals consume a target quantity of supplement, and deviation from the target intake can have deleterious effects on animal performance, reflected as decreased profit for the producer (Bowman and Sowell, 1997). The most common method to limit overconsumption of self-fed supplements is by including 20 to 30% salt (NaCl) to the supplement composition (Weir and Torell, 1953; Rush and Totusek, 1975; Kunkle et al., 2000).

Research specific to the effects of water quality and intake of salt-limited self-fed protein supplements and cattle digestive kinetics is limited. Therefore, our research objectives were to evaluate the effects of varying water sulfate concentrations commonly found across the western and north-central regions of the United States and Canada on forage and water intake, digestibility, digestive kinetics, and rumen fermentation characteristics of cattle consuming low-quality forages provided a protein supplement, with and without salt. We hypothesized that the water sulfate concentration and salt inclusion rate in a self-limited supplement could have direct effects on intake and ruminal digestion of cattle consuming low-quality forage.

MATERIALS AND METHODS

The use of animals and research protocols for this study were approved by the Agricultural Animal Care and Use Committee of Montana State University (2020-AA04). Research was conducted at the Bozeman Agriculture Research and Teaching farm (45°39′N 111°04′W) at Montana State University in Bozeman, Montana, from June 23 to September 30, 2020. All animals were provided by the Montana Agricultural Experiment Station.

Eight ruminally cannulated cows (2 yr of age) were used in 2 concurrent 4 × 4 Latin squares (4 cows per square) to test the effects of increasing water sulfate concentrations on forage and water intake, digestibility, digestive kinetics, and rumen fermentation characteristics of cattle consuming low-quality forages provided protein supplement with and without salt. Within each square, cows were randomly assigned to the following treatments: (1) control (mean ± SE) <10 ± 1.95 mg/L sulfate; (2) 473 ± 2.93 mg/L; (3) 946 ± 26.91 mg/L; and (4) 1,420 ± 26.99 mg/L. Cattle were weighed following a 16-h shrink prior to the start of each period (mean ± SE): period 1 = 529.52 ± 18.33, period 2 = 548.48 ± 16.27, period 3 = 566.18 ± 15.83, and period 4 = 619.00 ± 16.57 kg. All cattle were individually penned outdoors (concrete floor, 14 × 6 m), with each pen containing a feed bunk and water trough mounted to a digital scale for measuring individual animal DM and water intake. Sulfate was added to water as Na_2SO_4 on a weight-to-volume basis, and individual animal water troughs were checked and agitated twice daily to ensure Na_2SO_4 remained in suspension. Water troughs were then sampled daily with a digital conductivity meter (REED SD-4307; Reed Instruments) for total dissolved solids, with subsamples collected and sent to a commercial laboratory for water quality analysis (Midwest Laboratories Omaha) to verify that the water quality treatments were accurate. A rain gauge and control trough (no animal access) were put in place to account for potential gains of rainwater and losses by evaporation. Ambient daily temperature conditions, along with historic normal temperatures, were recorded for each period and are presented in Table 1.

All cattle were fed low-quality chopped grass hay (>60% NDF, <8% CP; 5–10 cm length; Table 2) at 0800 h daily, provided at 120% of the previous 3-d average as-fed intake. Water for each sulfate treatment was offered ad libitum. All cattle were provided a crude protein supplement to meet the maintenance requirements of mature, nonlactating, beef cows; however, protein supplement NaCl composition differed by square (no NaCl vs. 25% NaCl). In square 1, cattle were hand fed a canola-based supplement containing no NaCl at 0.18% of BW daily (0800 h daily). In square 2, cattle were hand fed the same supplement at 0.18% of BW with the addition of 25% NaCl, resulting in the total supplement mixture (supplement + salt) being provided at 0.24% of BW (Table 2). Supplement and salt were thoroughly mixed before feeding (0800 h daily).

Each square included four 24-d periods, where cows were abruptly exposed and adapted to their respective water sulfate treatment for 14 d before initiating intake and digestion data collection. Feed, orts, water disappearance, and fecal output were measured for each individual animal during the following 7-d sample collection period (d 15–21). Feed and ort samples were collected daily at 0800 h, and individual subsamples were dried at 55°C for 48 h to determine dry mater intake. Daily fecal output was measured by manually collecting the total fecal material from the floor of each concrete pen, weighing the total content and subsampling in duplicate. Fecal subsamples were dried at 55°C for 96 h in a forced-air oven to calculate total fecal output on a DM basis. All dried feed, ort, and fecal samples were then ground to pass through a 1-mm screen using a Wiley mill. Immediately following the 7-d sample collection period (d 22), each cow was intraruminally pulse-dosed with 286.25-mg/mL of a liquid marker (CrEDTA) in a 250-mL aqueous solution (71.5

Table 1. Mean, minimum, and maximum daily temperature (°C) and mean, minimum, and maximum daily normal temperatures (°C) for a 4 × 4 Latin square design digestion trial conducted in Bozeman, Montana

Item	Period 1[1]	Period 2[2]	Period 3[3]	Period 4[4]
Actual temperature, °C				
Mean	16.63	20.53	20.10	13.77
Minimum	9.17	15.83	12.50	9.44
Maximum	20.00	24.44	24.72	19.72
Historic normal temperature,[5] °C				
Mean	17.63	20.35	18.06	13.36
Minimum	9.32	11.24	8.99	5.23
Maximum	25.93	29.34	27.10	21.44

[1]June 23 to July 14.

[2]July 17 to August 7.

[3]August 12 to September 2.

[4]September 9 to September 30.

[5]Historic normal temperature data retrieved from NOAA National Weather Service (https://www.weather.gov/wrh/climate).

g/dose; Udén et al., 1980) just before feeding (0800 h). Rumen fluid samples were then obtained using a suction strainer (Raun and Burroughs, 1962) just before feeding and dosing (0 h) and at 4, 8, 12, 18, and 24 h after feeding to determine liquid kinetics and rumen fermentation characteristics. Ruminal fluid samples were measured for pH immediately after extraction; then samples were stored at −20°C. Rumen fluid samples were analyzed for ammonia (NH_3) concentrations using methods described by Sigma Technical Bulletin no. 640 (Chaney and Marbach, 1962; Horn and Squire, 1967; Weichselbaum et al., 1969). Individual VFA concentrations were analyzed using a gas chromatography procedure (Baumgardt, 1964; Byers, 1979; Fritz and Schenk, 1987). Chromium concentrations of rumen samples were analyzed by removing particulate matter via centrifuge (20 min at 4,000 × g at 20°C) and using atomic absorption spectroscopy with a Perkin Elmer AAnalyst 300 equipped with an air/acetylene flame following the procedures described by Galyean (1997). Ruminal liquid volume and liquid dilution rates were estimated by regressing the natural logarithm of Cr concentrations against sampling time (Galyean, 1997).

Table 2. Nutrient analysis of hay and supplement offered to cannulated 2-yr-old beef cows

Nutrient composition, % DM basis	Hay[1]	Supplement[2]
CP	7.21	46.32
ADF	31.23	11.95
NDF	61.01	25.28
Nonfiber carbohydrates	22.57	11.21
TDN	57.58	—
Ca	0.26	2.74
P	0.14	1.46
K	1.62	1.03
Na	0.03	0.07
S	0.12	0.55

[1]Hay was fed ad libitum.

[2]Supplement was fed daily at 0.18% of BW to meet nutrient requirements for nonlactating beef cows.

Ruminal contents were manually evacuated via the ruminal cannula on d 23, 5 h after feeding. Total contents were weighed, thoroughly mixed, and subsampled in duplicate (Van Soest, 1994). Ruminal subsamples were then weighed and dried in a forced-air oven at 55°C for 96 h to determine liquid and DM fill. Feed, orts, and fecal samples were then analyzed for NDF (Ankom 200 Fiber Analyzer, Ankom Co.) for estimation of total-tract DM and NDF digestibility.

The effects of sulfate level and supplement salt content on DM and water intake, digestibility, and fermentation characteristics were analyzed using an ANOVA with a generalized linear mixed model for a 4 × 4 Latin square design, including sulfate treatment and salt in the supplement (square) as fixed effects and individual animal and period as random intercepts. Individual cow was used as a random intercept to account for autocorrelation of multiple measurements for each individual over the course of the study. Volatile fatty acids, pH, and ammonia were also analyzed using an ANOVA with a generalized linear mixed model for a 4 × 4 Latin square design with repeated measures, including sulfate treatment, salt in the supplement (square), hour, treatment × hour, and salt in the supplement (square) × hour as fixed effects and individual

Table 3. Effects of increasing water sulfate levels on intake, digestibility, and rumen fill of 2-yr-old cows consuming low-quality forages and hand-fed a protein supplement

	Water sulfate concentration (mg/L)					*P*-value		
Item	**<10**	**473**	**946**	**1,420**	**SEM**	**TRT[1]**	**LIN[2]**	**QUAD[3]**
Forage intake, kg	12.07	12.04	12.68	12.17	0.54	0.18	0.38	0.32
Forage intake, g/kg of BW	23.62	23.28	24.56	23.88	0.66	0.24	0.33	0.71
Water intake, L	50.31	50.58	51.76	50.41	4.75	0.68	0.73	0.40
Water intake, mL/kg of BW	99.43	99.10	101.14	99.99	11.11	0.92	0.71	0.85
DM digestibility, %	56.28	56.71	57.16	56.98	1.41	0.95	0.63	0.80
NDF digestibility, %	56.23	57.95	57.72	56.94	1.65	0.76	0.74	0.33
Ruminal digestive kinetics								
DM fill, kg	15.45	14.76	15.05	14.57	0.99	0.43	0.21	0.79
DM fill, g/kg of BW	30.34	28.45	29.24	28.49	1.61	0.36	0.23	0.51
Liquid fill, kg	97.80	98.05	98.64	97.12	6.57	0.97	0.88	0.69
Liquid fill, g/kg of BW	192.18	189.00	191.04	188.82	8.39	0.95	0.71	0.92
Liquid passage, %	5.49	5.98	6.45	6.46	0.45	0.16	0.04	0.51
Liquid turnover, h	18.95	17.21	17.18	15.74	1.58	0.34	0.11	0.90
Liquid flow, L/h	9.76	9.84	10.34	8.72	2.49	0.26	0.34	0.17

[1]Treatment main effect.

[2]Linear preplanned contrast

[3]Quadratic preplanned contrast

animal and period as random intercepts. Preliminary data analysis included sulfate treatment, salt in the supplement, and a sulfate treatment × salt in the supplement interaction as main effects. Although the sulfate treatment × salt contained in the supplement interaction was significant for water intake and isovalerate ($P < 0.05$), post hoc mean separation of water sulfate levels within supplement type did not differ ($P > 0.05$; Supplemental Table S1, https://doi.org/10.15232/aas.2022-02336). Therefore, the sulfate treatment × salt interaction term was removed from the final model to increase statistical power for detecting main effect differences. All data were plotted and log-transformed and re-plotted if needed to meet the assumptions of normality and homogeneity of variance. An $\alpha \leq 0.05$ was considered significant, and tendencies were considered between 0.05 and 0.10. Orthogonal polynomial contrasts were used to determine linear and quadratic effects of sulfate level for each analysis, and means were separated using the Tukey method when $P < 0.05$. All statistical analyses were performed in R (R Core Team, 2017).

RESULTS AND DISCUSSION

We observed no effects of sulfate levels of drinking water on forage intake, expressed as either kilograms per day or grams per kilogram of BW ($P \geq 0.24$), averaging 12.24 kg and 23.85 g/kg daily (Table 3). Additionally, water intake, expressed as either liters per day or milliliters per kilogram of BW, did not differ across sulfate water concentrations ($P \geq 0.68$; 50.77 L, 99.92 mL/kg). Ruminal DM (kg, and g/kg of BW) and liquid fill (L, L/kg of BW) were also not influenced by sulfate water concentrations ($P \geq 0.36$). Likewise, DM and NDF digestibility were not affected by sulfate levels of drinking water ($P \geq 0.76$), averaging 56.78 and 57.21%, respectively. Furthermore, there was no effect ($P \geq 0.16$) of water sulfate concentration on liquid passage rate, turnover, or flow, averaging 6.10%, 17.27 h, and 9.67 L/h, respectively. No treatment × time interaction was observed for ruminal fermentation characteristics ($P \geq 0.36$); therefore, data are presented by sulfate treatment levels averaged across time (Table 4). Water sulfate concentrations had no effect on ruminal pH, ammonia, or total VFA concentrations ($P \geq 0.21$). Individual VFA concentrations and the acetate-to-propionate ratio were also not influenced by sulfate water concentrations ($P \geq 0.17$).

In our study, water sulfate concentrations under 1,420 mg/L had little effect on intake and digestibility of 2-yr-old nonlactating cows consuming a forage-based diet. Conversely, other works evaluating sulfate water concentration have shown dramatic reductions in feed and water intake with increasing water sulfate concentrations (Weeth and Hunter, 1971; Patterson et al., 2003; Cammack et al., 2010); however, such work used greater levels of sulfate in water than the present study (up to 4,654 mg SO_4/L). Other studies using similar sulfate concentrations to the present study (1,462–2,500 mg of SO_4/L) have shown little effects of water sulfate concentration on DM and water intake (Weeth and Capps, 1972; Digesti and Weeth, 1976; Kessler et al., 2012).

Sulfate consumed in the diet (feed and water) by cattle is reduced in the rumen to H_2S by dissimilatory sulfate-re-

Table 4. Effects of increasing water sulfate levels on rumen fermentation characteristics of 2-yr-old cows consuming low-quality forages fed a protein supplement

	Water sulfate concentration (mg/L)					*P*-value		
Item	**<10**	**473**	**946**	**1,420**	**SEM**	**TRT[1]**	**LIN[2]**	**QUAD[3]**
pH	6.55	6.49	6.48	6.52	0.07	0.94	0.43	0.04
Ammonia, mg/dL	3.85	3.36	3.48	3.43	0.67	0.67	0.41	0.47
Total VFA, m*M*	87.26	95.14	96.47	93.71	5.70	0.21	0.06	0.03
Acetate:propionate ratio	4.28	4.15	4.19	4.18	0.40	0.99	0.78	0.74
Acetate, mol/100 mol	67.56	67.24	67.57	67.65	1.85	0.93	0.69	0.56
Propionate, mol/100 mol	17.16	17.68	17.36	17.54	0.56	0.94	0.16	0.20
Isobutyrate, mol/100 mol	1.36	1.26	1.29	1.30	0.22	0.17	0.29	0.15
Butyrate, mol/100 mol	10.51	10.58	10.49	10.44	0.91	0.99	0.76	0.80
Isovalerate, mol/100 mol	1.49	1.32	1.39	1.31	0.16	0.30	0.04	0.41

[1]Treatment main effect.

[2]Linear preplanned contrast

[3]Quadratic preplanned contrast

ducing bacteria (Cummings et al., 1995; Wu et al., 2012). Accumulation of H_2S in the rumen can be toxic; thus, it has been well documented that increased dietary intake of S can result in decreased intake and average daily gains and, although unlikely with the sulfate concentrations used in this study, can lead to sulfur-induced polioencephalomalacia (Weeth and Hunter, 1971; Harper et al., 1997; Olkowski, 1997). Generally, a large portion of the H_2S disassociates to $HS-$ in the ruminal fluid; however, this disassociation is a pH-dependent process, where the rate of disassociation of H_2S decreases as ruminal pH decreases (Beauchamp et al., 1984; Schoonmaker and Beitz, 2012; Drewnoski et al., 2014). Numerous early recorded cases of polioencephalomalacia were a result of cattle consuming water containing greater than 1,000 mg sulfate/L (NASEM, 2016). Additionally, it has been reported that sulfate concentrations generally considered safe for consumption (583–1,000 mg/L) can lead to decreased growth and performance of cattle (Loneragan et al., 2001). Thus, the National Animal Health Monitoring System (NAHMS; USDA-APHIS, 2000) considers drinking water less than 300 mg sulfate/L safe for livestock consumption, with a general recommendation that water containing >1,000 mg sulfate/L be avoided (NASEM, 2016). However, the ma-

Table 5. Effects of salt provided in supplement on intake, digestibility, and rumen fill of 2-yr-old cows consuming low-quality forages hand-fed a protein supplement containing no salt and 25% salt

	Supplement			
Item	**0% salt**	**25% salt**	**SEM**	***P*-value**
Forage intake, kg	12.43	12.04	0.56	0.45
Forage intake, g/kg of BW	24.02	23.65	0.62	0.56
Water intake, L	48.24	53.28	4.85	0.05
Water intake, mL/kg of BW	94.34	105.49	11.32	0.05
DM digestibility, %	57.24	56.34	1.15	0.44
NDF digestibility, %	57.95	56.47	1.39	0.24
Ruminal digestive kinetics				
DM fill, kg	14.42	15.5	1.18	0.46
DM fill, g/kg of BW	27.96	30.3	1.87	0.33
Liquid fill, kg	95.77	100.03	7.77	0.64
Liquid fill, g/kg of BW	185.22	195.3	6.46	0.47
Liquid passage, %	6.01	6.18	0.43	0.76
Liquid turnover, h	17.89	16.65	1.45	0.49
Liquid flow, L/h	9.31	10.03	2.48	0.42

Table 6. Effects of salt provided in supplement on rumen fermentation characteristics of 2-yr-old cows consuming low-quality forages hand-fed a protein supplement containing no salt and 25% salt

	Supplement			
Item	**0% salt**	**25% salt**	**SEM**	***P*-value**
pH	6.53	6.50	0.07	0.86
Acetate:propionate ratio	4.13	4.26	0.38	0.91
Acetate, mol/100 mol	67.36	67.66	1.84	0.56
Propionate, mol/100 mol	17.58	17.29	0.57	0.64
Isobutyrate, mol/100 mol	1.27	1.33	0.21	0.26
Butyrate, mol/100 mol	10.59	10.42	0.9	0.79
Isovalerate, mol/100 mol	1.30	1.46	0.15	0.02

jority of research used to develop these guidelines has been conducted with feedlot cattle consuming high-concentrate diets. Cattle consuming high-forage diets have been shown to tolerate greater concentrations of S in the water (Weeth and Hunter, 1971; Weeth and Capps, 1972), likely related to the increased ruminal pH associated with forage-based diets. Therefore, water containing up to 2,000 to 2,500 mg sulfate/L may be safe for cattle consumption when provided a forage-based diet (Digesti and Weeth, 1976; Harper et al., 1997; NASEM, 2016). However, the works used to develop these recommendations did not evaluate the effects of sulfate water concentration on total-tract digestion and rumen function with low-quality forage-based diets. Nevertheless, the results from our study support previous research and recommendations that suggest cattle intake and digestibility are relatively unaffected by water sulfate concentrations up to 1,420 mg/L when consuming a forage-based diet.

The addition of 25% salt to supplement had no effect on forage intake when expressed as either kilograms per

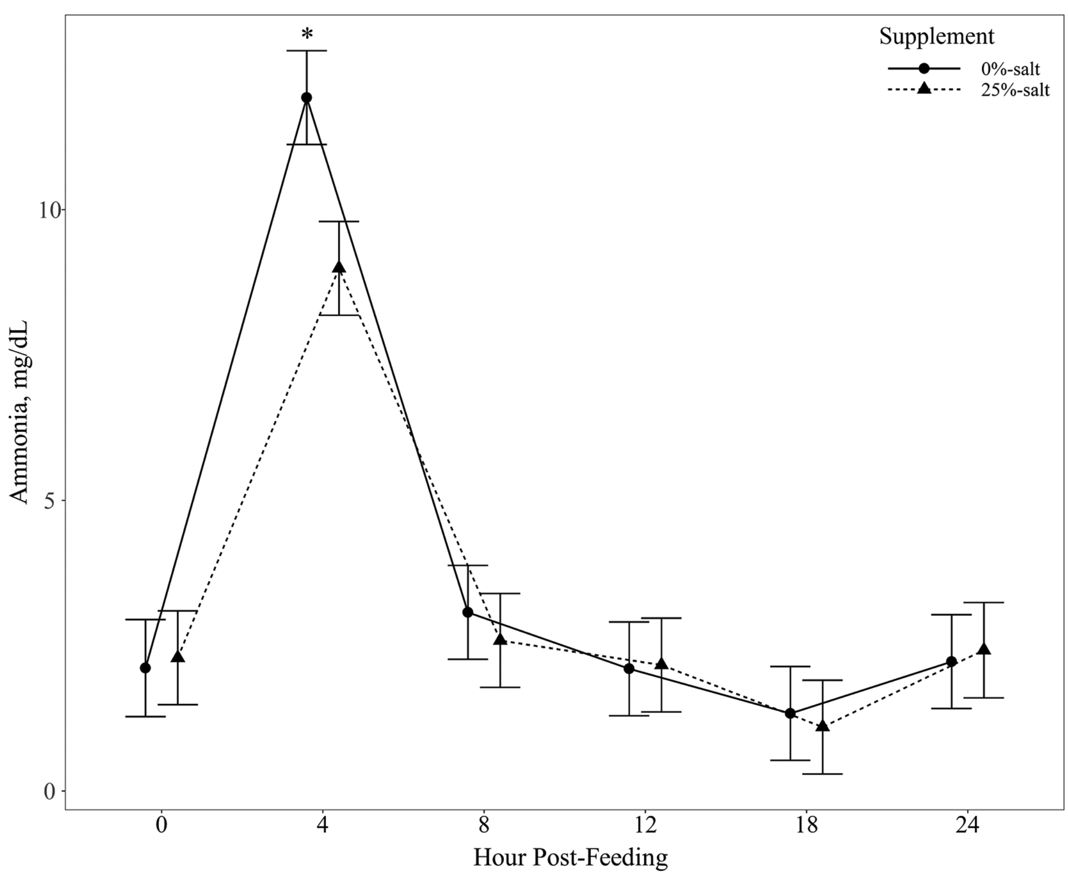

Figure 1. Influence of supplement salt concentration and hours after feeding (P = 0.03) on ruminal ammonia concentration (mg/dL ± SE) of cattle consuming a low-quality forage-based diet. Differences ($P \le 0.05$) within hour after feeding are denoted by *.

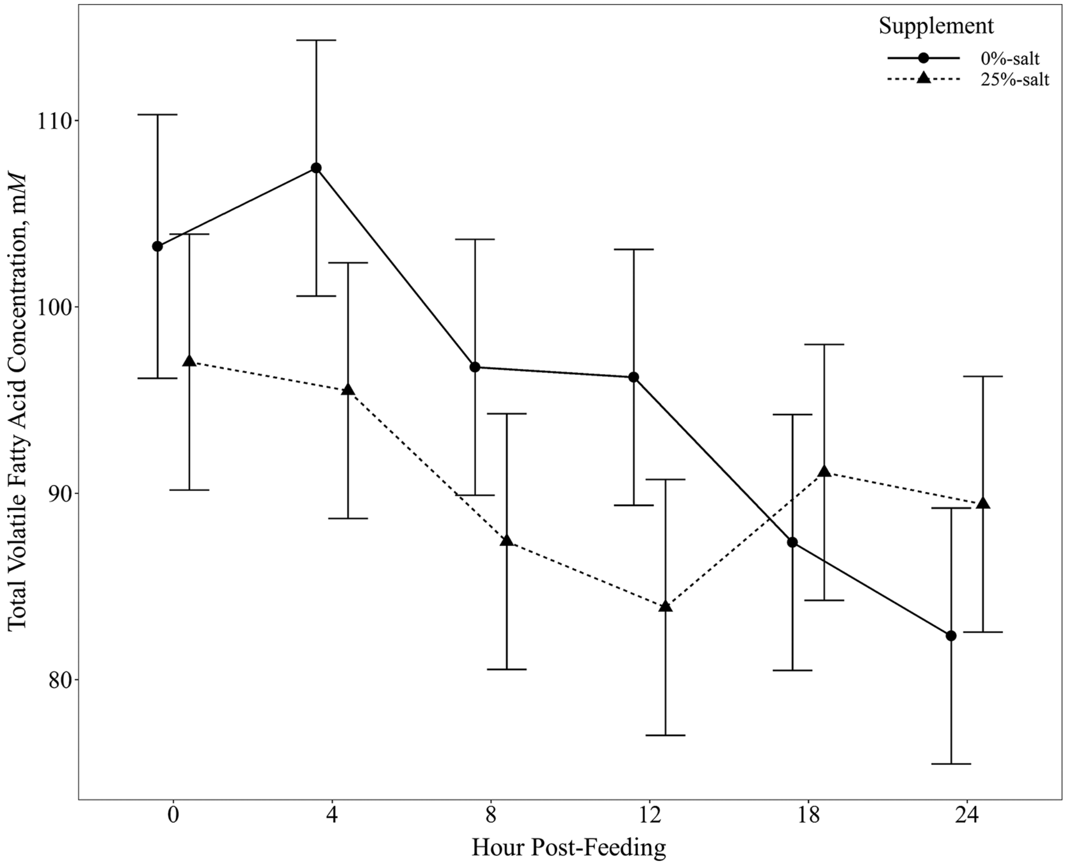

Figure 2. Influence of supplement salt concentration and hour after feeding (P = 0.03) on total VFA concentration (mM ± SE) of cattle consuming a low-quality forage-based diet. No differences ($P \leq 0.05$) between supplement salt concentrations were observed within hour after feeding.

day or grams per kilogram of BW ($P \geq 0.45$), averaging 12.24 kg and 23.84 g/kg daily (Table 5). Conversely, water intake, expressed as liters per day and milliliters per kilogram of BW, was greater for animals provided 25% salt in supplement compared with animals not provided salt ($P =$ 0.05; 53.28 vs. 48.24 L/d and 105.49 vs. 94.34 mL/kg, respectively). Ruminal DM (kg, and g/kg of BW) and liquid fill (L, L/kg of BW) were also not influenced by the addition of salt to the supplement ($P \geq 0.33$). Likewise, DM and NDF digestibility were not affected by the inclusion of salt ($P \geq 0.24$), averaging 56.79 and 57.21%, respectively. Furthermore, there was no effect ($P \geq 0.42$) of salt in the supplement on liquid passage rate, turnover, or flow, averaging 6.10%, 17.27 h, and 9.67 L/h, respectively. We found no effects of salt inclusion on ruminal pH ($P = 0.86$; Table 6). Ruminal ammonia concentrations displayed a square × time interaction ($P = 0.03$); however, differences were limited to greater ammonia concentrations 4 h after feeding in cattle provided supplement with no salt compared with cattle fed supplement with 25% salt ($P < 0.01$; Figure 1). Total VFA concentrations tended ($P = 0.09$) to also display a square × time interaction, with cattle fed supplement with no salt tending to have greater total VFA concentrations 4 h ($P = 0.09$) and 12 h ($P = 0.08$) after feeding compared with cattle fed supplement containing 25% salt (Figure 2). There were no effects of salt being added to the supplement on acetate, propionate, acetate-to-propionate ratio, isobutyrate, or butyrate ($P \geq 0.26$). In contrast, ruminal isovalerate concentrations were influenced by salt in the supplement ($P = 0.02$), where ruminal isovalerate increased with the addition of 25% salt in the supplement (1.30 vs. 1.46 mol/100 mol).

Although we saw little effect of sulfate concentration of drinking water on cattle intake and digestibility when consuming a forage-based diet, the inclusion of 25% salt increased water intake. Our findings are similar to previous research that reported increased water intake in response to the addition of salt in the diet; however, the magnitude reported in our study is less than previously described (2.5 vs. ≥10 L/d; Meyer et al., 1955; Croom et al., 1982; White et al., 2019). Increased water consumption in response to dietary salt is likely related to maintaining fluid homeostasis, as increased total salt intake often results in increased urinary output (Weeth et al., 1968; Weeth and Hunter, 1971). Therefore, it has been proposed that cattle will consume Na to meet a metabolic balance (Petersen et al., 2015).

Water requirements for cattle increase with environmental temperature (NASEM, 2016). In many regions of the western United States, increased environmental temperatures coincide with a dry season that is associated with a decrease in vegetation quality as well as surface water availability (DelCurto et al., 2000; Petersen et al., 2015). Many pastures in semiarid regions have limited or single water sources that often decrease in quality as the dry season progresses, suggesting that low-quality surface water may be unavoidable for livestock consumption (Petersen et al., 2015). Thus, when provided a salt-limited supplement on rangelands, cattle may increase intake of poor-quality water or refuse the supplement to maintain fluid homeostasis; either scenario can result in decreased animal performance. Therefore, livestock water quality should be tested when grazing rangelands and providing a salt-limited supplement.

APPLICATIONS

Livestock grazing on semiarid rangelands are often limited by water availability. Additionally, sulfate contents of surface water across rangelands in the north-central regions of the United States and central Canada are highly variable and commonly found in greater concentrations than the recommendation for livestock consumption. Therefore, surface water with high sulfate concentrations may be unavoidable for livestock consumption. Additionally, self-fed supplements including 20 to 30% salt (NaCl) in the supplement composition are often provided to livestock during times of seasonal forage quality deficiencies. Although we saw little effect of up to 1,420 mg/L sulfate concentration of drinking water on cattle intake and digestibility, the inclusion of a 25% salt-limited supplement increased daily water intake. The potential for water quality to interact with supplement or water intake, or both, could subsequently impact animal performance, especially at greater sulfate concentrations or longer duration of exposure than the present study. However, under the conditions of this study, we found little evidence that water sulfate levels interacted with salt-containing supplements. Thus, the maximum sulfate concentration in livestock drinking water could be raised to 1,420 mg/L with little short-term effect on forage intake and ruminal digestion when consuming a low-quality forage-based diet. However, these recommendations are also contingent on a relatively low S concentration in the feed (<0.5% dietary S). Further research during times of greater environmental temperature, with greater levels of sulfate or higher-quality diets, is warranted. Additionally, further research on the interaction of salt-containing supplements with water quality is needed.

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