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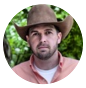

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Water temperature impacts water consumption by range cattle in winter[1]

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ABSTRACT: Water consumption and DMI have been found to be positively correlated, and both may interact with ingestion of cold water or grazed frozen forage due to transitory reductions in the temperature of ruminal contents. The hypothesis underpinning the study explores the potential that cows provided warm drinking water would have increased in situ NDF and OM disappearances and a more stable rumen temperature, drink more water, and lose less BW during the winter. This hypothesis was tested in 3 experiments. In Exp. 1, ruminal extrusa (93.1% DM, 90.2% OM, 81.1% NDF [DM], and 4.9% CP [DM]) were randomly allocated to 1 of 5 in vitro incubation temperatures. In 2 independent trials, temperatures evaluated were 39, 37, or 35°C (trial 1) and 39, 33, or 31°C (trial 2). In Exp. 2, 4 pregnant rumen cannulated cows grazing in January were fitted with Kahne (KB1000) temperature continuous recording boluses for 22 d. Two grazed in a paddock provided cold water (8.2°C) and 2 in a paddock provided warm water (31.1°C). Two in situ trials were conducted placing 6 in situ bags containing 2 g of winter range ruminal extrusa in each of the 4 ruminally cannulated cows and incubating bags for 72 h for measurement of NDF disappearance. In Exp. 3, 6 paddocks (*n* = 3/water treatment) were grazed by 10 to 13 pregnant crossbred Angus cows from December through February across 3 yr from 2009 to 2012. Water intake per paddock was measured daily and ambient temperature was recorded. Motion-activated cameras were used to determine the time of day water was consumed and the number of cow appearances at water. In Exp. 1, rate and total gas production ($P < 0.05$) and NDF disappearance ($P < 0.001$) at 48 h was reduced by each incubation temperature below 39°C. In Exp. 2, ruminal temperature for cows supplied with warm water dropped below 38°C 1.5% of the time whereas ruminal temperature for cows provided cold water dropped below 38°C 9.4% of the time ($P < 0.01$). Drinking water temperature did not alter in situ OM or NDF disappearance. In Exp. 3, cows with access to warm water consumed 30% ($P < 0.05$) more water than cows provided cold water. In this study, there were energetic costs to range cows proportional to consumption of water at temperatures less than body temperature. The magnitude of these costs were found to be less than the heat increment because no improvement to BW gain, BCS change, or calf birth weight were found for cows consuming warmed water.

Key words: in vitro, neutral detergent fiber disappearance,
range cows, rumen temperature, water intake, water temperature

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INTRODUCTION

Water is required for all life processes. Multiple factors affect water intake, such as physiological condition of the animal, DMI, water availability, quality of water, ambient temperature, and temperature of the water offered (NRC, 1981). Water consumption and DMI have been found to be positively correlated, this relationship maybe altered by the consumption of cold water or frozen grazed forage due to the effects of transitory reductions in temperature of ruminal contents. In general, water intake decreases with decreasing ambient temperature. Domestic animals alter water consumption based on water temperature (Lanham et al., 1986). In addition, ponies drank 40% more warm than ambient, near-freezing water in Pennsylvania in January (Kristula and McDonnell, 1994). During winter in Missouri, nonlactating dairy cows consumed 6.4 kg more warm water at 39°C than cold water at 1.1°C (Cunningham et al., 1964). There are numerous field reports/observations suggesting warmed artesian stock water increases herd time spent at water and appearance of fill, especially in winter (T. Patterson, Padlock Ranch, Ranchester, WY, personal communication).

Ingestion of cold water or frozen forage may decrease the temperature of ruminal contents, thus altering ruminal fermentation. Lowered temperature of rumen contents may decrease microbial activity (Hungate, 1966), which may retard forage digestion. Rumen microbial attachment to fibrous substrates has been reported to be optimal at 38°C, with lower or higher temperatures markedly reducing adhesion (Roger et al., 1990).

Our hypothesis was cows provided warm drinking water would have increased in situ NDF and OM disappearances and a more stable temperature in the rumen, would drink more water, and would lose less BW during the winter. The objectives of this study were to demonstrate the effects of in vitro incubation temperature on NDF disappearance and determine influences of drinking water temperature on range cow rumen contents temperature and in situ NDF disappearance in winter. In addition, the influence of heated drinking water on grazing range cow water consumption, cow BW change, BCS change, and calf birth weights was evaluated.

MATERIALS AND METHODS

All procedures were approved by the USDA-ARS Fort Keogh Livestock and Range Research Laboratory Animal Care and Use Committee.

Study Site

All experiments were conducted at the 22,500-ha USDA-ARS Fort Keogh Livestock and Range Research Laboratory near Miles City, MT. The research laboratory is within the mixed grass prairie of the northern Great Plains with an average elevation of 780 m. Native vegetation is predominately a grama–needle-grass–wheatgrass (*Bouteloua–Stipa–Agropyron*) mix (Kuchler, 1964) with less abundant small shrubs including silver sage (*Artemisia cana* Pursh subsp. *cana*), big sage (*Artemisia tridentata*), and winter fat (*Ceratoides lanata*) and small trees such as juniper (*Juniperus communis*). Average annual precipitation is 315 mm, of which 80% is received from April through September. For the period the study was conducted, the 30-yr normal high temperature was 0.22°C, the low temperature was −11.3°C, and the precipitation was 21.3 mm.

Experiment 1

Experiment 1 was designed to determine the impact of lower body temperatures on in vitro NDF disappearance to demonstrate potential impacts of ruminal temperature changes in the winter dormant forage fermentation. To determine the impact of incubation temperature on in vitro disappearance, ruminal extrusa was collected from 4 ruminally cannulated cows grazing native pasture in November 2010. Prior to collection, ruminal contents were manually removed from cows and reserved in 150-L plastic tubs. The ruminal walls were sponged dry to remove moisture, as described by Lesperance et al. (1960). An aliquot of ruminal extrusa was frozen at −20°C, lyophilized, and milled to pass through a 1-mm screen. Samples were analyzed for DM, OM, NDF (Goering and Van Soest, 1970), and CP (AOAC, 1990). The extrusa sample collected was 93.1% DM, 90.2% OM, 81.1% NDF, and 4.9% CP (DM). This sample of winter range extrusa and a laboratory forage control were weighed (0.25 g) into 100-mL glass syringes according to the procedure described by Blümmel and Becker (1997). Immediately prior to incubation, rumen liquor was collected from 2 winter-grazing ruminally cannulated cows, blended, saturated with CO_2, and strained through cheesecloth. McDougall's buffer was mixed 4:1 with rumen liquor and 20 mL was added to each syringe. Syringes were placed upright in a 39°C water bath for 12 h to simulate fermentation at normal body temperature. At 12 h of incubation, gas production was recorded and 8 syringes per temperature treatment were randomly placed in water baths (Brinkman Luada Circulator model RC6; Brinkmann Lauda, Westbury, NY) of 39, 37, or 35°C (trial 1) and 39, 33, or 31°C (trial 2) water for an additional 36 h of incubation. Both trials followed the same protocol. Water bath temperatures were set to mimic potential changes in ruminal temperature during the winter after ingestion of snow, frozen forage, and water/ice mixture. Gas production was recorded after 15, 18, 21, 24, 30, 36, 42, and 48 h of incubation. At 48 h, syringes were emptied into Berzelius beakers and rinsed with 50 mL heated neutral detergent solution to stop fermentation. Samples were refluxed in NDF solution for 1 h and filtered, dried, weighed, ashed, and reweighed. In vitro disappearance of NDF was calculated on an OM basis. Due to restrictions in water bath capacity, the second trial was conducted 1 wk later using the same methods as trial 1, using water bath temperatures of 39, 33, and 31°C.

Statistical Analysis. Rate of gas production was calculated using a linear model in GraphPad Prism (GraphPad Software, Inc., La Jolla, CA). Data was analyzed by MIXED procedures of SAS (SAS Inst. Inc., Cary, NC) using individual syringe as the experimental unit. The Kenward–Roger degrees of freedom method was used to adjust SE and calculate denominator degrees of freedom. Gas production and NDF disappearance data were analyzed as a split-plot design with repeated measures. Water temperature was the whole plot and hour and hour × treatment were the subplot. Separation of least squares means was performed by the PDIFF option of SAS when a significant ($P \leq 0.05$) effect was detected.

Experiment 2

To validate the responses found in the in vitro segment, an in situ trial was conducted. Two adjacent paddocks (77 ha average area) of winter range were grazed from December through February in 2010/2011 by 24 pregnant range cows, of which 4 were fitted with rumen cannulae. One paddock was provided ambient temperature water pumped from a well and was available to cows at 8.2 ± 0.4°C (cold). An adjoining paddock was provided water from the same source but heated by a Rheem RTG-95XN (Rheem Manufacturing Company, Atlanta, GA) outdoor tankless propane water heater to 31.1 ± 1.3°C (warm). Stock water in both paddocks was delivered in water lots at the terminal eastern end of each paddock into a float-controlled on-demand Ritchie water trough (Omni 3 number 18270; Ritchie Industries, Conrad, IA). The 4 cannulated cows received Kahne (Auckland, New Zealand) rumen temperature continuous recording boluses (KB1000; recorded temperature at 5 min intervals) for 22 d starting January 4. Boluses were hand placed in the rumen by a technician below the floating mat. When boluses were recovered, they were retrieved in suspension above of the ventral sac of the rumen. Assuming the position of the boluses remained below the fiber mat, the bolus rarely came in contact with water entering the rumen after consumption. Two cannulated cows grazed each paddock with 12 herd mates and had access to either cold or warm water. The recorded data were used to determine the occurrence of rumen contents temperature below 38°C. Additionally, a Bushnell Trophy Cam XLT (Bushnell Outdoor Products, Overland Park, KS) motion-activated trail camera was mounted within 9 m of each water source delivering cold or warm water to record time of day and number of trips each cannulated cow dipped their head in the water trough. These measurements were collected to ensure the cannulated cows represented behavior similar to their herd mates. Data is not presented.

Two consecutive in situ NDF disappearance trials were conducted within 7 d after temperature boluses were recovered. Extrusa placed into in situ bags was collected in November as previously described. Ground extrusa samples (5 g) were weighed in triplicate Dacron bags (10 by 20 cm; 53 ± 10 μm pore size; Ankom Technology Corp., Fairport, NY). Triplicate bags containing ground extrusa as well as empty, sealed Dacron bags (i.e., blanks) were placed into 60 by 60 cm zippered laundry bags with an attached cord. Dacron bags (3/cow) containing ground extrusa samples and blank bags (2/cow) were placed into the rumen and immersed in rumen contents for approximately 72 h. Upon removal from the rumen, the bags were rinsed by submerging them 3 times in a 19-L bucket filled with cold water to stop fermentation. Bags were individually rinsed in cold tap water until the effluent was clear, after which the bags were frozen (−20°C), lyophilized, and weighed. The amount of residue in the blank Dacron bag was subtracted from each sample bag. Residue remaining in the bag was analyzed for DM, OM, and NDF, and NDF and OM disappearance were calculated.

Statistical Analysis. Rumen temperatures were analyzed as a completely randomized design as the percentage of time above 38°C using the Freq procedure of SAS. Neutral detergent fiber and OM disappearance data were analyzed using the MIXED procedure of SAS. The model for NDF and OM disappearances included pasture and water temperature and their interaction. Separation of least squares means was performed by the PDIFF option of SAS when a significant ($P \leq 0.05$) effect was detected.

Experiment 3

This experiment was conducted to assess the impacts of warm water availability in a winter grazing setting on drinking behavior, cow BW change, and calf birth weights from December through February across 3 yr (during 2009 to 2010, 2010 to 2011, and 2011 to 2012). Six paddocks (68 ha average area) were grazed by randomly assigning a nearly balanced number of pregnant crossbred Angus range cattle to paddock and treatment with a total of 75, 65, and 65 cows in yr 1, 2, and 3, respectively. Cows provided cold water for all 3 yr had an average BW of 509 +/- 7.5 kg and those provided warm water had an average body weight of 510 +/- 7.5 kg. Mean daily high temperature for yr 1, 2, and 3 was −4.6, −3.2, and 3.8°C, respectively. Mean daily low temperatures for yr 1, 2, and 3 was −18.6, −14.3, and −10.3°C, respectively. Precipitation for December 1 to March 1 for yr 1, 2, and 3 was 12.2, 16.5, and 24.9 mm, respectively. Paddocks (*n* = 3 for each temperature) were provided either cold (8.2 ± 0.4°C) or warm (31.1 ± 1.3°C) stock water delivered in Ritchie water troughs (the same as those used in Exp. 2). Warm water was heated by a Rheem outdoor tankless propane water heater (Rheem Manufacturing Company) as described in Exp. 2. Water intake per paddock was measured daily (at approximately 0830 h) by an electronic water flow meter (number TM050-N 1.27 cm; Great Plains Industries, Inc., Wichita, Kansas) as was water temperature using a mercury thermometer. The energy required to warm unheated water to a temperature equal to that of heated water was calculated as Δkcal = [(L H_2O drank in yr 1, 2, and 3 heated) − (L H2O drank in yr 1, 2, and 3 unheated)] × (temperature ΔC° × 1 kcal/L H2O $1C^{\circ-1}$) Water intake from snow consumption was not measured. Bushnell Trophy Cam XLT motion-activated trail cameras were mounted within 9 m of each water source in every paddock to record individual animal time of day and the number of trips that each animal visited the water troughs, as in Exp. 2. Daily temperature was recorded onsite by a 2000 Series WatchDog Weather Station manufactured by Spectrum Technologies, Inc. (Aurora, IL). Days were categorized into groups by daily high temperature: warm (greater than −3°C), cool (−9.5 to −3°C), and cold (less than −9.5°C). The number of days categorized as warm daily high temperature in yr 1, 2, and 3 was 38, 42, and 77, respectively. The number of days categorized as cool daily high temperature in yr 1, 2, and 3 was 24, 16, and 8, respectively. The number of days categorized as cold daily high temperature in yr 1, 2, and 3 was 18, 17, and 4, respectively. Days were also categorized by daily low temperature: warm (greater than −9°C), cool (−17.7 to −9.5°C), and cold (less than −17.7°C). The number of days categorized as warm daily low temperature in yr 1, 2, and 3 was 13, 23, and 43, respectively. The number of days categorized as cool daily low temperature in yr 1, 2, and 3 was 30, 30, and 37, respectively. The number of days categorized as cold daily low temperature yr 1, 2, and 3 was 37, 22, and 9, respectively. If snow cover restricted access to grazable forage, then mature dryland mixed grass hay was fed to ensure a minimum DMI. In 2009, cows received 0.45 kg animal/d of a 36% CP supplement, whereas in 2010, cows received 5 to 6 kg of grass hay twice weekly (Monday and Friday) for 76 d. In 2011, cows were not fed any supplemental feed. Water samples were collected each year and sent to Midwest Laboratories, Inc. (Omaha, NE) for domestic water quality analysis panel. Water quality was considered adequate for yr 1, 2, and 3 (Table 1) and therefore not expected to influence water ingestion (Petersen et al., 2015).

Table 1. Yearly water quality measurements of ground sourced water at study site

	Date		
Item	Dec. 4, 2009	Jan. 7, 2011	Jan. 25, 2012
Calcium, mg/L	1.1	1.2	1.4
Chloride, mg/L	22.0	19.0	21.0
Fluoride, mg/L	2.7	2.3	2.5
Iron, mg/L	0.03	0.02	0.01
Magnesium, mg/L	0.3	0.3	0.5
Nitrate, mg/L	0	0	0.3
Manganese, mg/L	0	0	0
pH	9.3	8.6	9.1
Sodium, mg/L	367.0	358.0	357.0
Sulfate, mg/L	42.0	38.0	39.0
Total dissolved solids, mg/L	1,013.0	907.0	959.0

Statistical Analysis. Data were analyzed as a completely randomized design with paddock as the experimental unit using the Kenward–Roger degrees of freedom method. The MIXED procedure (of SAS) was used to test all main effects and all possible interactions. The model included fixed effects of water temperature, year, and air temperature and their interactions. All interactions remained in the model regardless of significance. Daily high and low air temperature classes were not analyzed in the same model. Separation of least squares means was performed by the PDIFF option of SAS when a significant ($P \leq 0.05$) effect was detected.

Animal Performance

Animal performance measurements were recorded during the 3-yr experiment. Measurements of cow BW and BCS were made at the beginning of treatment in December and the end of treatment in February of each year of the study to evaluate treatment effects on change of BW and BCS. In addition, measurements of cow BW and BCS were taken before calving in April. Measures of calf BW were taken at birth in April or May and weaning in November. Calving interval was calculated as the number of days between the current and the following year dates of calving. An average BCS (1 = emaciated and 9 = obese; Wagner et al., 1988) was determined for scores assigned by 2 trained employees using palpation to assess fat cover.

Statistical Analysis. Production data were analyzed as a completely randomized design with paddock as the experimental unit using the Kenward–Roger degrees of freedom method. The MIXED procedure (of SAS) was used to test all main effects and all possible interactions. The model included fixed effects of

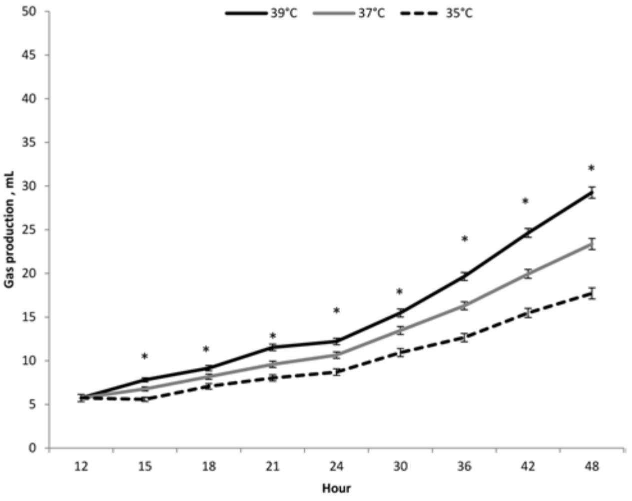

Figure 1. In vitro gas production over a 48-h incubation period with 3 different water bath temperatures. A water temperature × hour interaction occurred ($P < 0.01$). *$P < 0.05$.

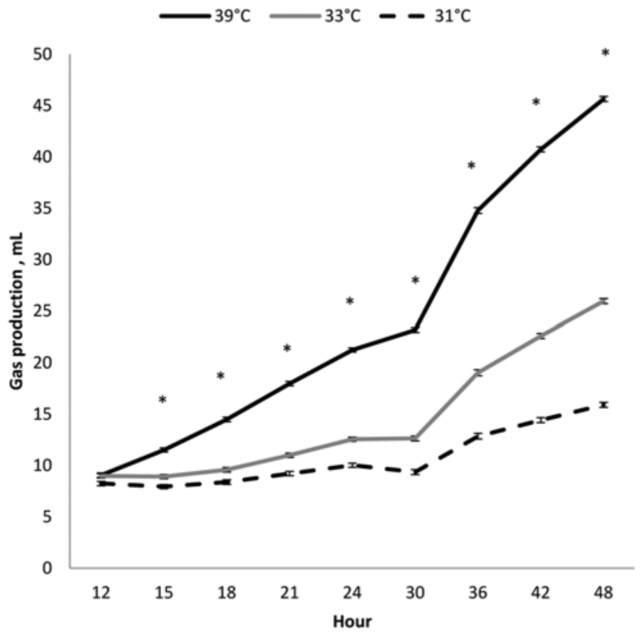

Figure 2. In vitro gas production over a 48-h incubation period with 3 different water bath temperatures. A water temperature × hour interaction occurred ($P < 0.01$). *$P < 0.05$.

treatment and year with pasture as the random term. All interactions remained in the model regardless of significance. Separation of least squares means was performed by the PDIFF option of SAS when a significant ($P \leq 0.05$) effect was detected.

RESULTS

Experiment 1

Comparison of total gas production at 39, 37, and 35°C incubation temperatures resulted in an incubation temperature × hour interaction ($P < 0.05$; Fig. 1). Therefore, gas production means were compared at each hour. At 12 h, all syringes produced the same ($P = 0.99$) quantity of gas (5.73 mL ± 0.41), demonstrating comparable and active fermentation prior to implementation of temperature treatments at h 12. The rate of gas production from 12 to 48 h was reduced ($P < 0.001$; 0.63 ± 0.01, 0.49 ± 0.01, and 0.34 ± 0.01 mL/h for 39, 37, and 35°C, respectively) in the 37 and 35°C water baths compared with the 39°C water bath. Therefore, total gas production per gram of substrate was also decreased ($P < 0.001$) in 37 and 35°C water compared with 39°C water. Total and rate of gas production were reduced at 15 h and every incubation interval thereafter ($P < 0.01$). In vitro NDF disappearance was reduced ($P < 0.001$) by 15% or more with lower incubation temperatures compared with 39°C incubation temperature (21.7 ± 0.49%). The NDF disappearance for in vitro cultures incubated at 37 and 35°C were 18.6 ± 0.6% and 17.2 ± 0.6, ($P = 0.07$).

Comparison of gas production rate and total gas production at incubation temperatures of 39, 33, and 31°C resulted in a temperature × hour interaction ($P < 0.01$; Fig. 2). Therefore, gas production means were compared at each time point. The rate of gas production and total gas produced at 12 h were, for all syringe cultures, similar to those in the first trial. Total gas production was reduced ($P < 0.01$) at 48 h for syringes in the 33 and 31°C water baths compared with the 39°C water bath. The rate of gas production was reduced ($P < 0.01$) at 48 h for syringes in the 33 and 31°C water baths compared with the 39°C water bath (0.94 ± 0.003, 0.45 ± 0.003, and 0.2 ± 0.003 mL/h for 39, 33, and 31°C, respectively). Disappearance of NDF was reduced at least 33% at the lower incubation temperatures. The extent of NDF disappearance was greater ($P < 0.01$) for culture incubated at 39°C compared with cultures incubated at 33 and (42.3 ± 0.3%, 28.2 ± 0.3%, and 21.3 ± 0.3%). The extent of NDF disappearance also differed ($P < 0.01$) between 33 and 31°C.

Experiment 2

Cows provided warm water had less ($P < 0.01$; Table 2) variability in ruminal temperature than cows provided cold water. The 72-h in situ NDF and OM disappearances of winter range extrusa were not influenced by the temperature of the water provided ($P \geq 0.63$; Table 2). The proportion of time that the ruminal temperature dropped below 38°C during a 22-d period was 1.5% for cows with access to warm water and 9.4% for cows that had access to cold water ($P < 0.01$). The range in rumen temperature for cows provided cold water was 31.6 to 40.8°C, whereas the rumen temperature in cows provided warm water ranged from 34.5 to 40.6°C (Fig. 3).

Table 2. Effect of drinker water temperature on variability of rumen temperature and extent of in situ NDF and OM disappearance during winter in grazing range cows

Measurement	Water temperature[1] Warm	Cold	SEM	P-value
Frequency above 38°C, %	98.5	90.6	–	<0.01
NDF disappearance, %	57.5	58.9	2.9	0.77
OM disappearance, %	57.8	59.7	2.4	0.64

[1] Drinker water temperature: warm = 31.1 ± 1.3°C and cold = 8.2 ± 0.4°C.

Experiment 3

A year × treatment interaction ($P < 0.01$) was observed for water intake (Table 3). In yr 1 and 2, cows consuming warmer water drank a 32% greater volume, whereas in yr 3, the cows supplied with warm water drank 14% less. Water intake was not influenced by category of daily high ($P = 0.78$) or daily low temperatures ($P = 0.49$). The calculated energy required to bring the average quantity of water drank in yr 1, 2, and 3 from consumption temperature to body temperature was 60.4 kcal for cold and 18.7 kcal for warm water consumers.

The percentage of cows appearing at the water trough each day was not influenced by water temperature ($P = 0.67$). The percent of cows recorded at the water troughs differed by year ($P < 0.01$). More cows appeared at the troughs daily in yr 3 than in yr 1 and 2 (Table 4).

Year × water temperature × category of daily high temperature interactions ($P < 0.0001$; Tables 5 and 6) were observed for the number of trips to water and the time at water per day. In yr 1, cows made the same number of daily trips to water regardless of water temperature or daily high temperature. In yr 2, cows provided warm water made more daily trips on cool days than all other water temperature and category of daily high temperature combinations. In yr 3, cows made the least number of daily trips when drinking cold water on cold days and warm water on warm days. In yr 3, cows provided warm water on cool and cold days and cold water on cool days came in earlier in the day than all other year × water temperature × category of daily high temperature combinations. Year × water temperature × category of daily low temperature interactions ($P < 0.001$; Tables 7 and 8) were also observed for the number of trips to water and the time at water per day. In yr 1, cows provided warm water made more trips per day on days with cool daily low temperatures. In yr 2, cows provided cold water on cool low temperature days and cows provided warm water on cool and warm low temperature days made the most trips to water. In yr 3, cows provided warm water on cold and cool low temperature days made the least number of daily trips. In yr 1, the category of daily low temperatures did not affect the time of day cows came in to drink, regardless of water temperature. In yr 2, cows came in earlier to drink in paddocks provided cold water on days with cold low temperatures, whereas the opposite was true in yr 3.

Table 3. Treatment × year interaction for water intake[1]

Treatment	Year 1	2	3	SEM
Cold,[2] L/d	14.7^{d}	17.8^{c}	26.0^{a}	1.17
Warm,[3] L/d	21.4^{b}	26.2^{a}	22.4^{b}	1.12

[a–d] Within row and columns, means without a common superscript differ ($P < 0.05$).

[1] Daily water intake = flow per drinker in 24 h/animals per paddock.

[2] Cold treatment refers to water temperature available to cows at 8.2 ± 0.4°C.

[3] Warm treatment refers to water temperature available to cows at 31.1 ± 1.3°C.

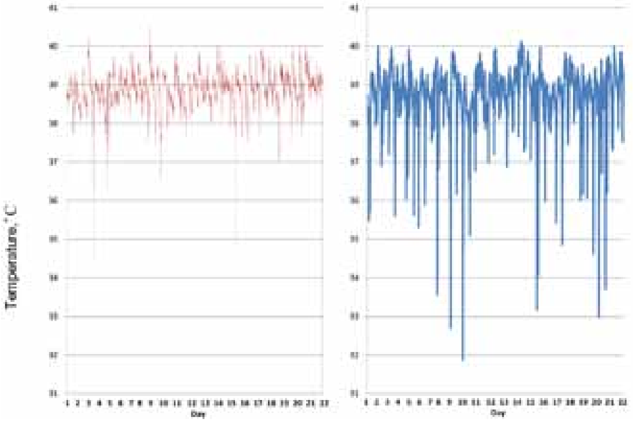

Figure 3. Temperature of ruminal contents over a 22-d period for representative cows grazing winter forage and provided water at 31.1 ± 1.3°C (left panel) or 8.2 ± 0.4°C (right panel). Frequency of temperature above 38°C was greater ($P < 0.01$) for cows provided water at 31.1 ± 1.3°C.

Overall, winter water temperature did not have any effects ($P > 0.05$) on cow productivity measures (Table 9). A year influence ($P < 0.01$) was found for cow BCS at beginning and end of study, cow BW change during the study, and calf BW at weaning. Cow pregnancy rates were similar ($P = 0.4$) among cows provided warm water (92 ± 3.0%) and cows provided cold water (89 ± 3.0%).

DISCUSSION

Experiment 1 demonstrated that as little as a 3°C drop from normal rumen (incubation) temperature within 3 h reduced the rate of gas production and extent of NDF disappearance. When grazing in the winter,

Table 4. Year effect on percent of cattle drinking per day[1]

Measurement	Year 1	2	3	SEM	P-value
Daily drinkers,[1] %	63^{b}	70^{b}	85^{a}	4	0.003

[a,b] Means without a common superscript differ ($P < 0.05$).

[1] Calculation determined by number of cows recorded at drinker daily divided by total number of cows.

Table 5. Effect of water temperature and average daily high air temperature categorization on average daily trips a cow makes to water

Treatment	Daily high temperature, °C	Year 1	Year 2	Year 3	SEM
Cold[1]	Less than −9.5	0.88^{cd}	0.93^{c}	0.91^{cd}	0.09
	−9.5 to −3	0.78^{d}	1.22^{b}	1.1^{b}	0.06
	Greater than −3	0.82^{cd}	0.88^{cd}	1.15^{b}	0.09
Warm[2]	Less than −9.5	0.83^{cd}	0.88^{cd}	1.29^{ab}	0.09
	−9.5 to −3	0.84^{cd}	1.39^{a}	1.11^{b}	0.06
	Greater than −3	0.88^{cd}	1.17^{b}	0.93^{c}	0.03

[a–d] Within a row and column, means without a common superscript differ ($P < 0.05$).

[1] Cold treatment refers to water temperature available to cows at 8.2 ± 0.4°C.

[2] Warm treatment refers to water temperature available to cows at 31.1 ± 1.3°C.

Table 6. Effect of water temperature and average daily high air temperature categorization on time of day (hour) of first daily drink

Treatment	Daily high temperature, °C	Year 1	Year 2	Year 3	SEM
Cold[1]	Less than −9.5	$1{,}224^{cde}$	$1{,}112^{b}$	$1{,}123^{bc}$	17
	−9.5 to −3	$1{,}204^{cd}$	$1{,}225^{de}$	$1{,}013^{a}$	11
	Greater than −3	$1{,}157^{c}$	$1{,}218^{cd}$	$1{,}114^{b}$	6
Warm[2]	Less than −9.5	$1{,}304^{e}$	$1{,}115^{b}$	954^{a}	18
	−9.5 to −3	$1{,}204^{cd}$	$1{,}226^{de}$	$1{,}004^{a}$	11
	Greater than −3	$1{,}153^{c}$	$1{,}248^{e}$	$1{,}112^{b}$	19

[a–e] Within a row and column, means without a common superscript differ ($P < 0.05$).

[1] Cold treatment refers to water temperature available to cows at 8.2 ± 0.4°C.

[2] Warm treatment refers to water temperature available to cows at 31.1 ± 1.3°C.

musk ox consume cold water and food, which increases costs of thermoregulation and may affect fermentation (Crater and Barboza, 2007). Dehority (2003) and Hungate (1966) reported when domestic species graze in a temperate climate, the temperature of the rumen varies only 2°C. Cold water has been reported to drop the rumen temperature by 5 to 10°C in domestic cattle and sheep (Cunningham et al., 1964; Dehority, 2003). This reported range is similar to the treatments tested. Brod et al. (1982) reported no change in digestibility in sheep when consuming 0°C water compared with 30°C water (56.4 ± 0.3% and 58.3 ± 0.3% DM, respectively). Conversely, Butcher (1966) reported no differences in feed consumed or ADG of sheep consuming ambient temperature water compared with sheep consuming only snow. Bewley et al. (2008) also showed that water consumption by dairy cattle instantaneously effects reticulum contents temperature. Therefore, microbial activity in the rumen would be speculated to be impaired in the animal as ruminal content temperature drops in association with feed and water consumed, potentially depressing NDF digestion. The result of Exp. 1 illustrates the impact small differences in ruminal temperature due to cold water ingestion may have on rumen function.

In Exp. 1, incubation temperature was reduced for a continuous 36 h. This experimental protocol most likely does not duplicate conditions animals experience in a free roaming winter grazing situation. Experiment 2 shows that lower temperatures in the rumens of cannulated cows were within the ranges tested in Exp. 1. Figure 4 illustrates the changes in ruminal contents temperature on the same day (January 12, 2011) after cows consumed water. The cows that consumed unheated water showed a recorded drop in temperature by the boluses 30 to 60 min after estimated ingestion of water. However, the time of day that the coldest rumen temperatures were measured did not coincide with cow appearances at water troughs as recorded by the time stamp motion sensor digital camera images. This was likely due to ingestion of snow or possibly frozen grazed forage. In comparison to the 36 h of lower temperature used in Exp. 1, the duration of colder ruminal temperatures measured were short lived (average 20 min). According to Roger et al. (1990), warm drinking water allowed rumen temperature to be more stable while providing a consistent optimal temperature for microbial attachment to forage. Cunningham et al. (1964) reported no effects on digestion when cows consumed either cold (1.1°C) or warm (39.4°C) water. Brod et al. (1982) reported that water temperature (0, 10,

Table 7. Effect of water temperature and average daily low air temperature categorization on daily trips to water

Treatment	Daily low temperature, °C	Year 1	Year 2	Year 3	SEM
Cold	Less than −17.7	0.81^{e}	0.76^{e}	1.1^{bc}	0.05
	−17.7 to −9.5	0.81^{e}	1.19^{ab}	1.18^{ab}	0.04
	Greater than −9	0.81^{e}	0.87^{de}	1.12^{b}	0.04
Warm	Less than −17.7	0.81^{e}	0.87^{de}	0.83^{de}	0.05
	−17.7 to −9.5	0.98^{cd}	1.2^{ab}	0.93^{d}	0.04
	Greater than −9	0.76^{e}	1.26^{a}	1.01^{c}	0.05

[a–e] Within a row and column, means without a common superscript differ ($P < 0.05$).

Table 8. Effect of water temperature and average daily low air temperature categorization on time of day of first daily drink

Treatment	Daily low temperature, °C	Year 1	Year 2	Year 3	SEM
Cold	Less than −17.7	$1{,}210^{de}$	$1{,}134^{c}$	$1{,}225^{def}$	10
	−17.7 to −9.5	$1{,}154^{cd}$	$1{,}212^{de}$	$1{,}102^{ab}$	8
	Greater than −9	$1{,}200^{cde}$	$1{,}217^{def}$	$1{,}053^{ab}$	10
Warm	Less than −17.7	$1{,}220^{def}$	$1{,}233^{ef}$	$1{,}124^{bc}$	11
	−17.7 to −9.5	$1{,}152^{cd}$	$1{,}237^{f}$	$1{,}049^{a}$	9
	Greater than −9	$1{,}153^{cd}$	$1{,}223^{def}$	$1{,}104^{ab}$	10

[a–f] Within a row and column, means without a common superscript differ ($P < 0.05$).

Table 9. Effect of water temperature and year on cow and calf BW, cow BCS, and calving interval

	Water treatment[1]				Year				
Item	Cold	Warm	SEM	*P*-value	1	2	3	SEM	*P*-value
Cow BW, kg									
Initial[2]	509	510	7.5	0.88	506	508	514	6.4	0.81
Final[3]	518	515	7.4	0.80	491^{b}	512^{b}	547^{a}	9.0	<0.01
Before calving	528	532	9.0	0.80	531	529	–	9.0	0.86
Cow BW change, kg									
Initial[2] to final[3]	9.4	5.1	1.9	0.11	−15^{c}	4^{b}	32^{a}	2.3	<0.01
Cow BCS									
Initial[2]	4.9	4.9	0.06	0.82	5.1^{a}	4.9^{a}	4.6^{b}	0.07	<0.01
Final[3]	4.6	4.6	0.05	0.60	4.3^{b}	4.7^{a}	4.8^{a}	0.06	<0.01
Before calving	4.4	4.3	0.06	0.92	4.3	4.4	–	0.06	0.85
Calf BW, kg									
Birth	36	38	1.1	0.21	35	37	38	1.3	0.21
Weaning	186	185	2.7	0.86	221^{a}	198^{b}	137^{c}	3.3	<0.01
Calving interval,[4] d	358	357	1.6	0.87	–	360	356	1.6	0.10

[a–c]Within a row, means without a common superscript differ ($P < 0.05$).

[1]Drinker water temperature: warm = 31.1 ± 1.3°C and cold = 8.2 ± 0.4°C.

[2]Initial is the start of the study each year in December.

[3]Final is the end of the study each year in February.

[4]Days from calf born in current year to previous year.

20, or 30°C) did not significantly influence crude fiber digestibility; however, results showed a trend for digestion coefficients to be lowest in the 0°C water treatment. Experiment 1 showed that in vitro NDF disappearance decreases from 41 to 14% when water bath temperature decreases from 39 to 31°C. However, in Exp. 2, the duration of time when the rumen temperature was below 38°C was not sufficient to reduce NDF degradation. Results from this experiment show that cows grazing range and coping with low winter temperatures are found to have a daily rumen temperature above 38°C for 91% of the time when unheated well water was provided to cows grazing winter range with no influence on extent of in situ NDF disappearance.

Daily water intake for a 409-kg wintering pregnant beef cow with ambient temperature at 4.4°C is predicted to be 22.7 L (NRC, 2000). Our measurements for daily water intake for cows in winter are within 65 to 115% of the predicted consumption amount during the 3 yr of this experiment. Adams et al. (1995) measured daily water consumption for 3 winters at the USDA-ARS Fort Keogh Livestock and Range Research Laboratory in similar range and winter conditions and reported that daily water intake ranged from 16.9 to 20.5 L. With growing steers, Arias and Mader (2011) reported daily water intake of 17.3 L in a Nebraska feedlot in winter with an average water temperature of 10°C.

In regards to the year × category × water temperature interactions on drinking time of day and appearance at the waterers, field observations reported that cows with access to geothermal heated well water would congregate at water troughs earlier in the day and would loaf around the water longer and at a higher frequency on colder days. The interpretation of this behavior suggested that cows replaced calories acquired from forage with increased water intake of geothermal water. We did not find consistent results to support this hypothesis. The findings did show that in yr 2 when temperatures were coldest and snow cover was the deepest and persistent, cows provided warm water made more trips to water on cool days. Greater use of drinkers in yr 3 may be an artifact of a warmer winter driving greater respiratory water losses. In a previous study at the USDA-ARS Fort Keogh Livestock and Range Research Laboratory (Adams et al., 1995), when cows did not consume water during 1 d, 13.6% of those cows did not consume water the next day. In our study, snow probably impacted drinking behavior of cows in yr 1 and 2. In yr 1, snow fell in mid December and covered the ground throughout the study; however, the cows had sufficient access to vegetation and were able to graze winter range. In yr 2, snow was on the ground throughout the study and was of greater depth than in yr 1, restricting accessibility to vegetation. It was determined that cows would be unable to depend on winter grazing to meet energy needs so hay was fed. In yr 3, very little snow fell and cows had unobstructed access to range vegetation throughout the study period with no supplemental feed provided. A study conducted in Alberta, Canada, reported that pregnant cows relied on snow as their primary water source for 3 mo with no detrimental effects on body mass change, water influx,

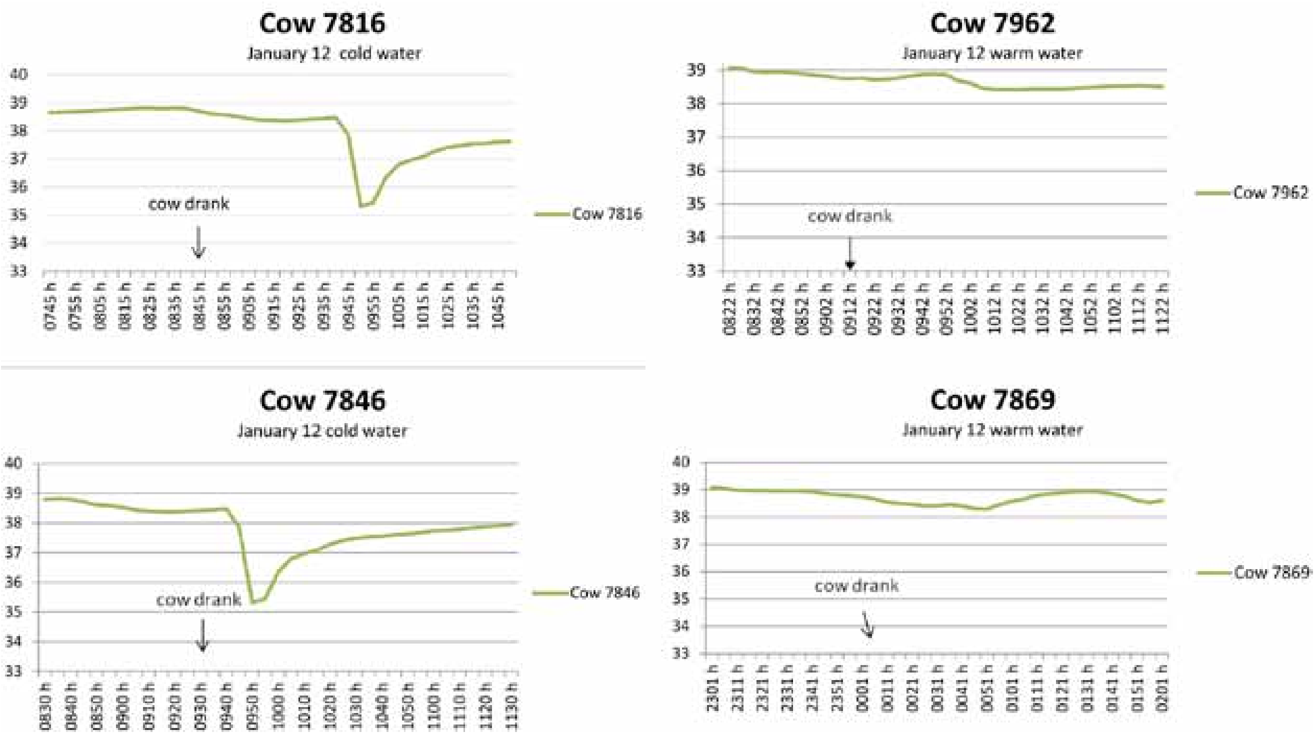

Figure 4. Pattern of rumen contents temperature change 1 h before drinking and 2 h after drinking on January 12, 2011, for cows consuming cold and warm temperature water.

calf BW at birth, or calculated energy requirements (Degen and Young, 1990).

A study conducted during winter in Nebraska found that maximum daily temperature and temperature humidity index were the best predictors of daily water intake (Arias and Mader, 2011). Economically important benefits from increased water intake in beef cattle supplied with warm water during winter have not been established. Increased water intake has been shown to have a positive relationship to DMI. Greater water consumption in musk oxen (*Ovibos moschatus*) in winter in Alaska was positively related to time spent feeding, whether the water was available as liquid or as snow (Crater and Barboza, 2007). Sexson et al. (2012) also found that as DMI increased in yearling steers in a feedlot in summer, water intake increased. In dairy cows, daily water intake increased up to 65.2 L, mainly due to increased intake of DM and milk production (Woodford et al., 1984). Results of this study showed that cows on native range in the winter with access to warm water consumed 30% more water in 2 out of 3 yr compared with cows with access to unheated water. More stable rumen temperatures in cows supplied with warm water did not support greater NDF extent of disappearance. Therefore, DMI of grazed winter vegetation would not be expected to increase, and without an increase in DMI, BCS or BW change would not increase. This study suggests that the heat increment associated with digestion and metabolism is a large enough pool of heat to warm ingested snow, cold water, and vegetation to body temperature, averting BW and BCS reductions due to partitioning of daily ME lost to consumed cold water or forage.

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