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Abstract

Effects of initial and prolonged exposure to cold ambient temperatures on the behaviors of free-ranging beef cows were examined over a fall and winter season. Mean daily temperature (*MDT*) and short-term thermal stress (*STTS*) were used to express thermal stressors. Short-term thermal stress was defined as the deviation of the current day's mean temperature from a running mean temperature of previous days (an acclimation period). Twenty different acclimation periods (calculated using temperatures from the previous 1-20 days) were used to express 20 different acclimation lengths for determining *STTS*. Daily grazing time and forage intake were estimated for 15, 6-year-old gestating cows during January and February (winter trial), and for 12 of these cows during October and November (fall trial). In the winter, daily grazing time increased with increased ambient temperature and decreased with increased grazing time ($P < 0.10$). Observed fluctuations in winter daily grazing time in relation to thermal stress were less than 84 min day⁻¹. Daily grazing time was lower in the fall than winter. Cattle acclimated more quickly to *STTS* in the winter than in the fall. However, forage intake was consistent during both seasons and unresponsive to thermal stress. The thermal environment in these northern latitudes appeared to be only a minor influence upon grazing behaviors. It is likely that forage quality and availability, and accessibility of sites with moderate microclimates are more important environmental features effecting daily intake and total grazing time.

Key words: Cattle; Grazing; Feeding; Thermoregulatory behavior

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1. Introduction

The cold environment common to rangelands of temperate latitudes may be a primary stressor of rangeland livestock. Thermal stressors which affect livestock foraging behaviors could negatively impact the nutritional status of those animals. Senft and Rittenhouse (1985) hypothesized that grazing activity is reduced following short-term temperature deviations from the animal's acclimated thermal zone. Adams et al. (1986) reported that daily grazing time (*DGT*) and forage intake of beef cows grazing winter range are reduced as minimum daily temperature declines. However, other studies of foraging behavior of range beef cows indicated consistency and insensitivity to short-term thermal stress (*STTS*) despite fluctuating and cold temperatures during winter (Dunn et al., 1988; Beverlin et al., 1989).

Beverlin et al. (1989) suggested that Senft and Rittenhouse's (1985) model, and Adams et al.'s (1986) hypothesis may be appropriate during transitional periods when grazing cattle are acclimating to seasonal changes in the thermal environment, but may not apply to the consistently cold temperatures of winter. At northern latitudes, the fall season is characterized by fluctuating and declining ambient temperatures. Winters usually have prolonged periods of cold ($< 2^{\circ}\text{C}$) temperatures. The objective of our study was to test the hypothesis proposed by Beverlin et al. (1989). We examined forage intake and *DGT* of free-ranging prepartum beef cows during winter and the following fall in response to mean daily temperature (*MDT*) and *STTS*.

2. Animals, materials and methods

The study area was a 324 ha native range pasture on the Red Bluff Research Ranch (latitude $45^{\circ} 35' \text{N}$; longitude $111^{\circ} 34' \text{W}$), Norris, Montana. The pasture has sandy and silty range sites typical of the southwestern Montana foothill range. Dominant vegetation was bluebunch wheatgrass (*Agropyron spicatum*), needleandthread (*Stipa comata*), Idaho fescue (*Festuca idahoensis*) and basin wildrye (*Elymus cinereus*). Elevations ranged from 1400 to 1900 m. The prevailing southwesterly wind and naturally protected areas minimized snow cover and kept forage accessible during the study.

Fifteen pregnant Hereford \times Angus and Tarentaise \times Angus cows were selected for the winter trial. All cows were 6 years old, had similar previous grazing experience and were in the last trimester of gestation. Initial and final mean bodyweights (BW; kg) and condition scores (visual and palpable, scale of 1 (thin) to 10 (fat); LaMontagne, 1981) for the winter trial were 574 ± 11.8 (SE), 563 ± 10.9 ; 5.5 ± 0.1 and 4.2 ± 0.2 , respectively. Twelve of these cows were used for the fall trial. Initial and final mean weights and condition scores for the fall were 597 ± 10.9 , 602 ± 10.9 , 5.8 ± 0.1 and 6.0 ± 0.3 , respectively. The cows grazed in

the study area for a 2 week adjustment period and then data were collected for 53 consecutive days for each trial. A loose iodized salt mixture containing 30% dicalcium phosphate and 30% potassium chloride was provided ad libitum. No other supplementary feeds were provided during the trials.

Fecal organic matter output (*FO*) was estimated by a Cr_2O_3 dilution technique (Raleigh et al., 1980), based on daily rectal grab samples and total fecal collections. Each cow was bolused daily at 11:30 h with 10 g Cr_2O_3 in a gelatin capsule (size No. 10), and rectal fecal grab samples were collected for Cr_2O_3 analysis. The marker was administered for 6 days before sampling began to establish steady state conditions (Pond et al., 1987). Total fecal collections (24 h for 4 consecutive days) were obtained from each cow using fecal bags. Two total collections were made from each cow during each trial. Fecal bags were changed daily during collection periods at the time of bolusing (11:30 h). A prior study at the site indicated that 11:00–13:30 h was a regular non-grazing period (Dunn et al., 1988).

Rectal grab samples were frozen immediately after collection. Total collected feces were weighed, mixed and a subsample was frozen. Dry matter and organic matter of each fecal sample was determined following Association of Official Agriculture Chemists (AOAC; 1980) procedures. The remaining fecal material was dried at 100°C for not less than 3 days and ground through a 2 mm screen in a Wiley mill (Thomas Scientific, Swedesboro, NJ, USA). Spectrophotometry was used to determine Cr_2O_3 concentration in each sample following procedures adapted from Fenton and Fenton (1979), and Costigan and Ellis (1986). Rectal grab samples were adjusted individually for each cow based on total fecal collections to account for diurnal variation in Cr_2O_3 excretion. An average percentage recovery of Cr_2O_3 [(g recovered in feces per g fed) \times 100] was calculated for each cow. Fecal output per day was estimated from rectal grab samples based on the following equation:

$$FO(\text{g per day}) = \frac{(\text{Cr}_2\text{O}_3 \text{ fed per day} \times \% \text{ recovery})}{\text{Cr}_2\text{O}_3 \% \text{ in dry fecal sample}} \quad (1)$$

Four rumen cannulated cows grazed concurrently in the study pasture and extrusa samples were collected weekly from these animals using a total evacuation technique (Lesperance et al., 1960). Two of the cows were penned overnight without feed or water. Ruminal contents were removed the following morning, the interior ruminal walls were rinsed with water and the excess removed. Animals were then allowed to graze freely for 1–1.5 h after which the grazed ingesta was removed, mixed, subsampled and frozen. The original ruminal contents were returned to the rumen and the animals were released. The procedure was repeated on the other two cows the following day. Each sample was freeze dried and ground through a 1 mm screen using a Wiley mill. In vitro organic matter digestibility (*IVOMD*) of the diet was determined using the Barnes modification of the Tilley and Terry technique (Harris, 1970). Forage organic matter intake (*OMI*) was estimated using the following equation:

$$OMI = (\text{daily } FO \text{ (kg)}) / (1 - IVOMD) \quad (2)$$

Each cow was fitted with a vibracorder to record grazing events (Stobbs, 1970) over 53 continuous days. Daily grazing time was estimated to the nearest 15 min for the period 07:01–07:00 h. Animals wore the same vibracorder during each trial.

Components of a model developed by Senft and Rittenhouse (1985) were used to express the effect of the ambient air temperature of previous days on *OMI* and *DGT*. Ambient air temperature was measured continuously with a meteorograph. Mean daily temperature was calculated for the period 07:01–07:00 h for the present day (i). Mean daily temperature is the weighted mean of daily maximum temperature ($T_{\max i}$), daily minimum temperature ($T_{\min i}$) and minimum temperature of the following day ($T_{\min(i+1)}$)

$$MDT = [2(T_{\max i}) + (T_{\min i}) + (T_{\min(i+1)})] / 4 \quad (3)$$

Mean daily temperature ranged from 7.8 to -13.0°C with a mean of $-2.3 \pm 0.2^{\circ}\text{C}$ during the winter. During the fall, *MDT* ranged from 16.3 to -9.3°C with a mean of $4.7 \pm 0.3^{\circ}\text{C}$. Mean acclimated temperatures represent the time course of thermal acclimation. The variable L represents the time period in the immediate past used to calculate effect upon present behaviors. The number of prior days used to calculate $T_{\text{acc}i}$ was from 1 to 20:

$$T_{\text{acc}(L)} = \sum_{j=1}^L T_{(i-j)} / L \quad (4)$$

Thus, we were able to quantify *STTS* based on 20 different lengths for acclimation. Short-term thermal stress was defined as the deviation of *MDT* from the hypothetical acclimated temperature $T_{\text{acc}(L)}$:

$$STTS = MDT - T_{\text{acc}(L)} \quad (5)$$

By varying the number of prior days used to calculate $T_{\text{acc}i}$, we can assess varying sensitivity to changing temperature. For example, if behaviors acclimate quickly ($L=1-2$ prior days) then animals demonstrate an ability to rapidly adjust to temperature changes and minimize effects of *STTS*.

The effects of *MDT* and *STTS* on *DGT* and *OMI* were analyzed with Statistical Analysis Systems Institute (SAS; 1988) procedures. Independent variables included in the polynomial stepwise regression were the linear, quadratic and cubic terms for *MDT* and *STTS*, and the *MDT* by *STTS* interaction. Because Beverlin et al. (1989) reported a decline in *DGT* when cows were fitted with total fecal collection bags, presence or absence of a fecal bag was included as an indicator variable in the model. The variation in *DGT* and *OMI* owing to fecal bags was partitioned out in the analysis so as not to confound the parameter estimates of *MDT* and *STTS*.

3. Results and discussion

3.1. Winter Trial

Mean *DGT* (513 ± 2.6 min day⁻¹) was similar to previously reported winter grazing times of parturient cows at the same study site (528 min day⁻¹, Dunn et al., 1988; 510 min day⁻¹, Beverlin et al., 1989). In contrast, Adams et al. (1986) found that 6-year-old cows grazed an average of 446 min day⁻¹ in mid-winter and 432 min day⁻¹ in late fall–early winter. The differences between total grazing time between these winter studies may be due to differences in structural and quantitative forage availability (Leaver, 1985), or the accessibility of naturally occurring shelter.

Daily grazing time decreased as *MDT* decreased ($P < 0.07$), and as *STTS* increased ($P < 0.05$) for acclimation periods calculated from temperature lags of 1, 2 and 20 prior days (Table 1). Adams et al. (1986) also found that *DGT* and *MDT* were inversely related. However, in our study the magnitude of grazing time responses to *MDT* and *STTS* was small, indicating that our free-ranging beef cows maintained consistent grazing behavior within the winter environment. For example, the best fit regression equation (2 day lag, Adj $R^2 = 0.08$) predicted a *DGT* of 517 min day⁻¹ under the warmest conditions (*MDT* of 7.8°C and *STTS* of 12.4°C) and 532 min day⁻¹ under the coldest conditions (*MDT* of -13.0°C

Table 1

Responses of *DGT* to *MDT* and *STTS*, and magnitude of response for acclimation lengths of 1–20 days for winter and fall seasons

Season	Stressor	Acclimation length (days)	Magnitude of response of <i>DGT</i> ^a
Winter	<i>MDT</i>	1–2	1*
		3–19	NS
		20	4*
	<i>STTS</i>	1–2	-1 to -2*
		3–19	NS
		20	-4*
Fall ^b	<i>MDT</i>	1–20	4 to 15*
	<i>MDT</i> ²	1–20	-1.54 to -2.84*
	<i>MDT</i> ³	1–20	0.09 to 0.12*
	<i>STTS</i>	1–20	-4*
	<i>STTS</i> ²	1–7	-0.43 to -0.74*
		8–14	NS
	<i>MDT</i> × <i>STTS</i>	15–20	-0.53 to -1.03*
		1–6	0.39 to 0.99*
		7–14	NS
		15–20	0.94 to 2.63*

^aMin per °C or degree *STTS*.

^bStatistical model included quadratic terms for *MDT* and *STTS*, cubic term for *MDT*, and an interaction of *MDT* and *STTS*.

* $P < 0.10$; NS ($P > 0.10$).

and *STTS* of -16.5°C). The short lag period of 2 days indicated that these cows quickly acclimated to changing ambient temperatures and corresponding cold stress. The response surface for the best fit regression equation is presented in Fig. 1. This response surface is substantially different from that hypothesized by Senft and Rittenhouse (1985), which predicted more pronounced effects of thermal stress. Levine (1985) stated that as an animal is repeatedly exposed to a stressor, subsequent reactions diminish. Our results would suggest that the extreme winter temperatures are not novel to these cattle and their behavioral responses are minimal to cold exposure. Other physiological responsees, including those of the immune system, also show modulation with extended exposure to cold (Kelley, 1985).

Mean *FO* ($0.79 \pm 0.004\%$ BW) was similar to results reported by Beverlin et al. (1989) for beef cows grazing Montana foothill ranges. Organic matter intake as a percentage of BW averaged 1.09 ± 0.005 during this winter trial. This value is similar to *OMI* (0.92% BW) for unsupplemented cows grazing the same area the previous winter (Beverlin et al., 1989). Organic matter intake increased linearly as *MDT* increased ($P < 0.001$), but decreased ($P < 0.05$) slightly as *STTS* increased with a lag of 1–14 days (Table 2). These results appear to agree with predictions that *OMI* decreases with exposure to cold temperatures (Adams et al., 1986) and deviations of current thermal conditions from the animals' acclimated state (Senft and Rittenhouse, 1985). However, the regression equation predicted that the range of *OMI* at the observed extremes of *MDT* (7.8°C , -13.0°C) and *STTS* (12.4°C , -16.5°C) would be 1.11% BW and 1.09% BW, respectively. This minimal response of *OMI* to *MDT* and *STTS* indicates that these gestating range cows maintained relatively constant forage intake under cold temperatures typical of our Montana winters. We assume that these small changes in *OMI* would not be biologically significant to the animals. Beverlin et al. (1989) also observed minimal changes in intake by free-ranging cows to changes in their winter thermal environment.

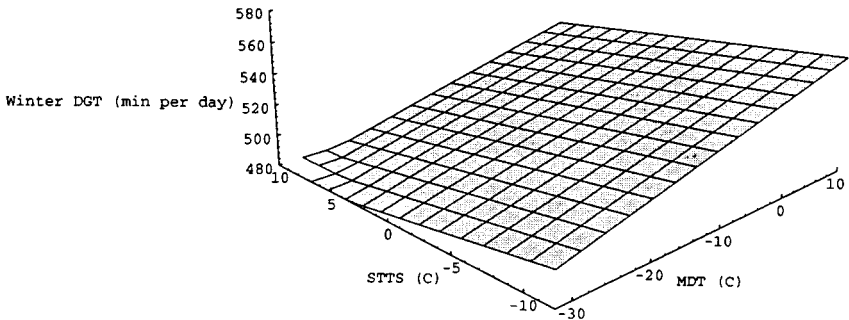


Fig. 1. Daily grazing time (min day^{-1}) of range beef cows during the winter as a function of *MDT* and *STTS*. Illustrated response is the best fit regression equation ($DGT = 525 + 1.26MDT - 1.42STTS$), which is based on a 2 day acclimation period.

Table 2

Responses of daily forage *OMI* to *MDT* and *STTS*, and magnitude of response for acclimation lengths of 1–20 days for winter and fall seasons

Season	Stressor	Acclimation length (days)	Magnitude of response of <i>OMI</i> (%BW) ^a
Winter	MDT	1–4	0.006 to 0.012*
		15–20	NS
	STTS	1–4	–0.003 to –0.008*
		15–20	NS
Fall	MDT	1–20	0.007 to 0.017*
	STTS	1–20	–0.003 to –0.015*
	STTS ²	1	NS
		2–10	0.0003 to 0.0006*
11–20		NS	

^aPercentage of BW per °C or degree STTS.

* $P < 0.10$; NS ($P > 0.10$).

3.2. Fall Trial

Mean *DGT* (482 ± 3.7 min day⁻¹) was lower than our winter grazing times and those measured in previous winter studies at the same site (Dunn et al., 1988; Beverlin et al., 1989). Available forage quantity would be higher during the fall than the winter, and grazing times would be expected to be lower. Mean *DGT* declined nonlinearly as daily temperature declined (cubic, $P < 0.001$, Table 1) indicating that cows generally grazed considerably less at colder temperatures. This response differs with the linear responses of grazing times to minimum daily temperature during early winter reported by others (Malechek and Smith, 1976; Adams et al., 1986). Using acclimated temperatures calculated for a lag of 1–7 and 15–19 days, *DGT* decreased nonlinearly as *STTS* increased (cubic, $P < 0.05$, Table 1). For acclimated temperatures from 8 to 14 days, *DGT* decreased linearly as *STTS* increased ($P < 0.001$).

Senft and Rittenhouse (1985) hypothesized that under free-ranging conditions the foraging behavior of cattle is independent of temperatures within their thermoneutral zone. Our results indicated that during the fall there is a narrow range of temperatures within which free-ranging cattle graze independently of ambient temperature, but respond to *STTS*. Only at intermediate temperatures (2–8°C) were cows insensitive to changes in ambient temperature. Outside of this narrow range, *DGT* changed as a result of increased or decreased *MDT*.

The response of *DGT* of our free-ranging beef cows to *STTS* during the fall was not entirely independent of *MDT*. The model for the 5 day acclimation lag explained the most variation in the data (Adj $R^2 = 0.30$), and thus best describes the response of *DGT* to *MDT* and *STTS* during the fall (Fig. 2). From the ob-

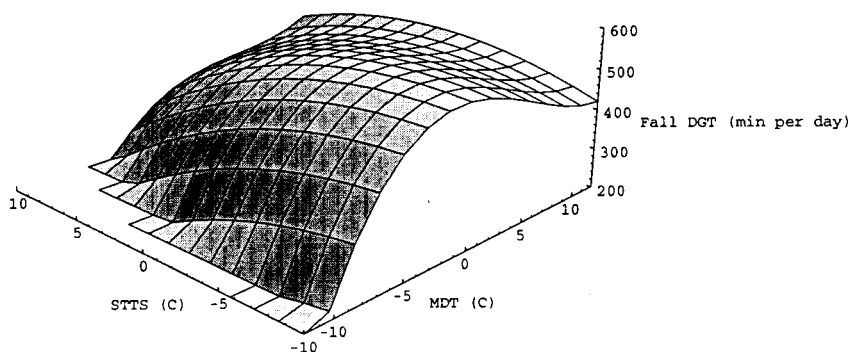


Fig. 2. Daily grazing time (min day^{-1}) of range beef cows during the fall as a function of *MDT* and *STTS*. Illustrated response is the best fit regression equation ($DGT = 512 + 6.63MDT - 2.07MDT^2 + 0.12MDT^3 - 10.09STTS - 0.74STTS^2 + 0.93MDT * STTS$), which is based on a 5 day acclimation period.

served extremes in *MDT* (16.3, -9.3) and *STTS* (12.1, -16.0), the model predicted that *DGT* should range from 288 to 544 min day^{-1} . Exposure to declining and fluctuating temperatures during the fall may have been relatively novel compared with the consistently cold temperatures during winter. Stressor effects are more pronounced in response to novel or unfamiliar environments (Levine, 1985). In addition, it is likely that these cattle were less insulated in the fall than in the winter. Hair coats were probably less thick and still shedding during the fall. Total thermal insulation is only 60% the capacity measured following cold adaptation (Christopherson and Young, 1986). The response surface of *DGT* to thermal conditions in the fall indicated that these cattle were not yet fully adapted to cold exposure.

Mean *FO* in the fall ($0.72 \pm 0.004\%$ BW) was slightly less than mean *FO* observed in winter, presumably because of the higher *IVOMD* of diets selected during the fall ($33.73 \pm 0.68\%$) compared with those selected in winter ($27.86 \pm 0.42\%$). Mean *OMI* was $1.09 \pm 0.006\%$ BW throughout the trial and was similar to *OMI* determined from the winter trial. Organic matter intake increased as *MDT* increased, but decreased as *STTS* increased for acclimation lengths of 1–20 days (Table 2). The decrease in *OMI* was not linear ($P < 0.10$) in response to *STTS* for lag periods of 2–10 days.

The model which explained the most variation in *OMI* ($\text{Adj } R^2 = 0.21$) included *MDT* and *STTS* over a 13 day lag period. This regression equation predicted that the observed extremes in *MDT* (16.33, -9.27°C) and *STTS* (12.13, -15.97°C) would increase mean *OMI* (1.09% BW) by 0.06% BW or decrease it by 0.05% BW. These small responses are probably not biologically significant. Thus, free-ranging beef cows maintained relatively consistent forage intake during the initial stages of exposure to fluctuating and cold temperatures characteristic of the fall despite changes in *DGT*. To maintain consistent intake with declines in *DGT*, the animal would have to increase bite rate, bite size or both. We

did not quantify these variables, thus we cannot attribute which variable(s) compensated for declining *DGT* with lower *MDT*.

The consistent intake of range forage by free-roaming beef cows during the winter trial indicated that exposure to thermal stressors during mid-winter was not novel to the animals. Physiological acclimation, by increasing resting metabolism and shifting their thermoneutral zone to cooler temperatures, has been reported for beef cows exposed to naturally occurring cold winter conditions (Young, 1975). The thermal regimes experienced by acclimated animals within familiar winter environments may simply be within their thermoneutral zones.

Ingram and Dauncey (1985) suggested that obtaining food is of highest priority under free-ranging conditions, taking precedence over thermoregulatory behavior except under the most severe climatic conditions. From our fall trial, the small changes in *OMI* in relation to *STTS* do not support Beverlin et al.'s (1989) hypothesis that forage intake of free-ranging cows may change more rapidly to thermal stressors during the fall transitional periods than during prolonged cold exposure associated with winter.

Beverlin et al. (1989) also suggested that maintaining consistent forage intake during winter may represent a minimizing of collective behaviors and thereby daily energy expenditures within familiar environments. Apparently, this also applies to the fall transitional periods when animals are acclimating to declining ambient temperatures. As Dunn et al. (1988) suggested, previous grazing experiences in an environment may mitigate certain behavioral responses to thermal stressors during familiar and transitional periods. The cows used in this study were 6 (winter trial) and 7 years old (fall trial), having lived at the research site since they were 2 year olds. Thus, they were familiar with the site and had been exposed to similar thermal stressors in previous years.

Many reviews on forage intake have concluded that free-roaming ruminants increase intake in response to cold exposure (Baile and Forbes, 1974; Weston, 1982; Arnold, 1984). This increase is generally a result of homeothermy challenges from *STTS* and physiological adaptations arising from thermal acclimation (Young, 1987). Cattle have shown a 30–40% elevation in resting metabolic rate once acclimated to cold temperatures (Young, 1975; Christopherson, 1985), but this response is linked to increased hormone activities independent of level of feeding (Christopherson, 1985). The potential for increased appetite drive exists for cattle grazing winter rangelands, and increased intakes may result if forage quality components and digestive physiological responses within cold environments are not first-limiting. In related studies at our site, unsupplemented cows have ruminal ammonia concentrations of ≤ 2 mg dl⁻¹, well below a suggested minimum of 5 mg dl⁻¹ (Lodman et al., 1990). Daily forage intake has increased in response to supplemental feeding, but the response has been small (Miner and Petersen, 1989). It is likely that on foothill rangelands used for winter grazing in these northern latitudes that forage attributes, both qualitative and quantitative restrict intake responses to cold temperatures.

The best-fit equations for *DGT* in winter and fall were based on *L* values of 2 days and 5 days, respectively (Figs. 1 and 2). The shorter acclimation length for

winter indicated an ability to minimize effects of thermal stress within a consistently cold environment. For unsupplemented cattle grazing winter foothill rangelands at northern latitudes, the thermal environment is a minor factor influencing grazing behaviors. Other environmental conditions, especially qualitative and quantitative aspects of the available forage, are probably more influential upon both total grazing time per day and daily forage intake.

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