Grazing behavior and production for lactating cows differing in residual feed intake while grazing spring and summer rangeland[1]

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ABSTRACT: The objectives were to determine if previously classified, efficient (LRFI, low-residual-feed intake, $n = 12 \times 2$ yr) vs. inefficient (HRFI, high-residual-feed intake, $n = 12 \times 2$ yr) lactating 2-yr-old Hereford × Angus cows differed in grazing behavior, body weight (BW), body condition score (BCS), and calf weaning weight while grazing rugged rangeland pastures. Cows were fitted with grazing halters containing both an accelerometer and a global positioning system (GPS) data logger during June 14 to July 4, 2016, August 2 to 25, 2016, May 23 to June 12, 2017, and August 5 to 28, 2017. GPS data were recorded at 7-min intervals in 2016 and 4-min intervals in 2017 and accelerometer data recorded at 25 times/s. Grazing time (GT), resting, walking, bite rate (BR), daily travel distance (DTD), elevation, and slope were analyzed with a mixed model that included fixed effects of RFI group, day, and RFI group × day and cow within treatment as the random effect. Cow BW, BCS, and calf weaning weight were analyzed by analysis of variance with treatment as the main effect. There were no differences ($P > 0.10$) due to RFI detected for BW, BCS, or calf weaning weights. During periods of mild heat load (MHL), HRFI cows spent more ($P < 0.05$) time resting during the day at lower elevations ($P < 0.05$) than LRFI cows. During a 6-d period in spring with only 2 h MHL, HRFI cows grazed 1.7 h/d longer than LRFI cows ($P < 0.05$); commencing grazing earlier in the morning and extending the grazing bout later. During the summer with > MHL, LRFI cows grazed more than HRFI cows 18% of the time ($P < 0.10$). The HRFI cows had greater GT than LRFI cows only 3% of the time ($P < 0.10$) during summer. There was no difference ($P > 0.10$) in BR between HRFI and LRFI cattle. The DTD tended ($P < 0.10$) to be greater for LRFI cattle during summer 2017. Over all sample periods, HRFI had greater walking than LRFI 15% of the time and LRFI exceeded HRFI cattle for walking 3% of the time ($P < 0.10$). The greater walking for HRFI was assumed to be associated with more search grazing. Metabolic heat load on hot summer days for HRFI cattle is presumed to have contributed to differences observed in grazing behavior. These results suggest that lactating cows with low-RFI phenotypes appear to be better adapted to grazing rugged rangelands in late summer during periods of MHL.

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INTRODUCTION

A quest to find adapted cows to fit rangeland environments has been a focus of scientists in the western United States for many years. Earlier efforts sought to identify ideal breed compositions to match differing environments (Kress and Nelson, 1988). Today, we continue to pursue the "holy grail" of an ideal, efficient cow to match western environments. As a rancher stated in a recent presentation made at the 2015 Range Beef Cow Symposium (Olsen, 2015), "*The area of production efficiency, and specifically feed efficiency, has plenty of room for improvement in the nation's cow herd*." Beef producer focus groups were conducted throughout Idaho by the Beef Program of Distinction in 2015. A pertinent finding was, "*Recognition that increasing cow size has corresponding feed needs but the amount of available grazing and pasture land is constant. The University of Idaho was encouraged to look at ways that cattle can become more feed efficient*."

Our goal has been to characterize beef cattle that effectively use rangeland and forage-based systems in the West. We also seek to expand understanding of how to enhance the ability of these cows to utilize lower quality and variable forage that often prevails on rangeland. For example, environmental conditions interact with cow biological type in how they use and access rangeland (Sprinkle et al., 2000; VanWagoner et al., 2006; Wyffels et al., 2018).

Higher market value (McDonald et al., 2010) has been associated with bulls with favorable rankings for residual feed intake (RFI), which is expressed as the difference between expected feed intake (based upon body weight [BW] and growth) and actual feed intake (Koch et al., 1963). Although the cattle industry is on a trajectory of producing efficient (low-RFI; LRFI) cattle, little is known about how this trait (measured in a feedlot setting) affects beef cattle efficiency on rangeland. Our earlier research (Sprinkle et al., 2020) demonstrated that nonlactating 2-yr-old LRFI cattle grazing poor quality, late-season rangeland with no protein supplementation lost less BW and body condition score (BCS) than did high-RFI (HRFI) cattle; implying that there is an opportunity to select cows that eat less and also better fit a rangeland environment. However, this research did not examine these divergently ranked cattle on rangeland with the added stress of lactation. We hypothesized that lactating cattle with greater appetite (HRFI cattle) would more aggressively graze rangelands to meet the demands of production; spending more time grazing, as well as accessing more difficult terrain to acquire optimal daily nutrients. Our objective was to determine if grazing behavior (accessing difficult terrain with greater elevation and slope, daily grazing [GT], resting [RT], and walking time [WLK]) differed among lactating 2-yr-old cattle which were divergently ranked for feed efficiency. A secondary objective of this study was to determine if cattle productivity differed between young lactating cows with divergent RFI.

MATERIALS AND METHODS

All procedures were approved by the University of Idaho Animal Care and Use Committee (IACUC # 2015-44). Animal husbandry, management, and handling procedures in the research environment were in accordance with the Ag Guide (2010).

Range Sites

This trial was conducted over spring and summer grazing periods in 2016 and 2017 at the Rinker Rock Creek Ranch located about 18 km southwest of Hailey Idaho (114°23.509′W, 43°23.426′N). The ranch is described more fully at https://www.uidaho.

edu/cnr/rangeland-center/rock-creek but consists of 4,209 ha private land and 4,452 ha of public land, the majority of the public land being administered by the Bureau of Land Management. Upland sagebrush-steppe pastures were grazed from June 14 to July 4 in 2016 in a 909-ha pasture (1,463 to 1,646 m elevation; slopes up to 68% but predominantly 0% to 15%) and from August 2 to August 25 in a 1,345-ha pasture (1,510 to 1,726 m elevation; slopes up to 45% but predominantly 5% to 25%). Cattle grazed upland sagebrush-steppe pastures in 2017 in a 736-ha pasture from May 23 to June 12 (1,609 to 1,723 m elevation; slopes up to 60% but mostly between 5% and 15%) and from August 5 to August 28 in the same late-season pasture used in 2016 with an added 64-ha pasture (1,510 to 1,726 m elevation; slopes up to 40% but mostly between 0% and 15%). After the GT periods for which grazing behavior were recorded, cattle continued to graze in the same late summer grazing pastures described above (64- and 1,345-ha pasture) until a day or two prior to weaning.

Two-yr-old Hereford × Angus haltered cows described later were separated from the rest of the herd for 4 to 5 d in order to facilitate obtaining grazing behavior data used to calibrate halter mounted electronic equipment (Sprinkle et al., 2021). In 2016, this was accomplished by cordoning off a section (16.2 ha for spring; 33.6 ha for summer) of the upland rangeland pastures using temporary electric fence. These cattle were part of a pulse-dose forage intake study in 2016 using alkanes and the smaller pastures made it easier to retrieve repeated fecal samples from the free ranging cattle on these upland pastures. In 2017, preceding and following the use of upland pastures, cattle grazed 25- and 18-ha wet meadow pastures dominated by meadow foxtail (*Alopecurus pratensis* L.), smooth brome (*Bromus inermis*), and sedges (*Carex* spp.), with willows (*Salix* spp.) along the stream corridor. Cattle grazed these pastures for 4 to 8 d while obtaining calibration data. Calibration data collected when cows were grazing these riparian pastures were not included in the grazing behavior data collected on upland pastures. Also, anytime a cow escaped from upland pastures into the riparian pastures, all grazing behavior data were excluded from the upland grazing behavior dataset.

Dominant ecological sites (provisional) for pastures grazed earlier in the grazing season were located within the Elkcreek–Polecreek (25%), Laurentzen–Mulshoe (40%), and Winu–Gaib (13%) soil complexes and included R010AY004ID, R010AY001ID, R010AY008ID, and R010AY021ID. Dominant ecological sites (provisional) for pastures grazed in late summer were within the Moonstone–Earcree soils association (89%) and included R010AY009ID and R010AY008ID. These descriptions are available from the NRCS Web Soil Survey https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm.

The mean annual precipitation (1981 to 2010) near the research sites at the airport in Hailey, Idaho (114°18.171′W, 43°30.448′N, elevation 1,617 m) is 341 mm with 48% falling during April through September. Pastures are dominated by mountain big sagebrush (*Artemisa tridentate* Nutt. ssp. *vaseyana* [Rydb.] Beetle) with subdominant shrub species including antelope bitterbrush (*Purshia tridentata* [Pursh] DC.), and rabbitbrush (*Chrysothamnus* Nutt.). Prominent half-shrubs include sulfur-flower buckwheat (*Eriogonum umbellatum* Torr.). Dominant perennial grasses include Great Basin wildrye (*Leymus cinereus* [Scribn. & Merr.] A. Löve), Columbia needlegrass (*Achnatherum nelsonii* [Scribn.] Barkworth ssp. *nelsonii*), Idaho fescue (*Festuca idahoensis* Elmer), sandberg bluegrass (*Poa secunda* Presl), prairie junegrass (*Koeleria macrantha* [Ledeb.] Schult.), bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] A. Löve ssp. *spicata*), and bottlebrush squirreltail (*Elymus elymoides* [Raf.] Swezey ssp. *elymoides*). The dominant annual grass is cheatgrass (*Bromus tectorum*). The dominant forbs are arrowleaf balsamroot (*Balsamorhiza sagittata* [Pursh] Nutt.) and lupine (*Lupinus* L. spp).

Forage Production and Nutritive Value

In 2016, forage production was estimated at the beginning of each grazing period by hand clipping 20 randomized 0.16 m^2 quadrats in an area representative of the experimental pastures. Forage production in 2017 was estimated by clipping 10 randomized 0.16 m^2 quadrats at the end of August and in mid-September at each of two different strategically placed key forage monitoring areas located within each pasture. Forage utilization data were obtained at the end of the growing season and after grazing using the U.S. Forest Service Utilization Gauge (USDA Forest Service, 1980). Forage production in 2017 was adjusted upwards for forage utilization by dividing the unadjusted forage production by $(1 - \text{forage utilization percentage}/100)$. All perennial and annual graminoids rooted within the quadrat frame within the sampled areas were clipped to ground level and dried for 48 to 71 h at 65 °C. Palatable half shrubs and edible forbs were clipped separately and analyzed as browse. The majority of browse consisted of sulfur-flower buckwheat and only the current year's plant leaders were clipped for this plant. Sagebrush canopy was not sampled for production.

A time window of forage nutritive value was estimated over the 2 yr of the study by analyzing the clipped forage obtained in late spring, mid-summer, and late summer. Crude protein (Padmore, 1990a, 1990b; Gavlak et al., 1996; Miller et al., 1997) was determined on replicate samples (n = 5 clipped plots/replicate) of clipped forage by a commercial laboratory (Ward Laboratories, Inc., Kearney, NB). Forage digestibility of the clipped forage samples at the same laboratory was estimated in vitro from acid detergent fiber using the Ankom 200/220 Fiber Analyzer (Ankom Co., Macedon, NY) and following the procedures of Mertens (1992). Forage mineral concentrations for Ca, P, Mg, K, Na, Fe, Zn, Cu, Mn, Mo, S, and Co were analyzed at the same laboratory using inductively coupled atomic plasma analysis (Campbell and Plank, 1991; Kovar, 2003). Poor replication of Co analysis samples among forage replicates resulted in these samples being excluded from the study. Samples were analyzed for Se at the South Dakota Agricultural Laboratories (Brookings, SD) using fluorometric procedures (Olson et al., 1975; Koh and Benson, 1983; Palmer and Thiex, 1997; AOAC, 2016).

Animal Measurements and Grazing Behavior

The 2-yr-old lactating cows used in this study were previously phenotyped for RFI as a cohort of 160 yearling heifers as described by Hall et al. (2015) and classified as either average, efficient (LRFI), or inefficient (HRFI). Yearling heifers were fed a roughage diet during the 49-d RFI trial (preceded by a 10-d warm-up period) consisting of 80% alfalfa hay, 10% wheat middlings, and 10% liquid supplement as a total mixed ration. The heifer RFI scores were categorized by their standard deviation according to the contemporary mean. Heifers classified as efficient had RFI ≤0.5 standard deviations below the mean and those classified as inefficient had RFI ≥0.5 standard deviations above the mean. One exception to this threshold value was an efficient cow chosen in 2017 with a score of −0.40; chosen to maintain equal experimental numbers for each treatment. Due to our desire to compare young cows who varied greatly in feed efficiency, only 2-yr-old efficient and inefficient cows chosen as herd replacements for this rangeland herd were used for grazing behavior determinations (n = 24 for each year). The average RFI of efficient and inefficient cows were −0.91 ± 0.068 and 0.84 ± 0.068 in 2016, and −0.75 ± 0.123 and 0.80 ± 0.064 in 2017, respectively.

Approximately mid-May of both 2016 and 2017, 160 Hereford × Angus mixed-age cattle were transported 372 km from the University of Idaho Nancy M. Cummings Research, Extension and Education Center (NMCREEC) at Carmen, Idaho (113°52.697′W, 45°17.322′N) to the Rinker Rock Creek Ranch. From within the main cowherd, a subset of divergently ranked (12 efficient; 12 inefficient), lactating 2-yr-old cows were fitted with customized grazing halters containing both a 3-axis accelerometer (USB Logger Model XB, Gulf Coast Data Concepts, LLC, Waveland, MS) and a global positioning system (GPS) logger (iGotU GT-120, Mobile Action Technology, New Taipei City, Taiwan; Knight et al., 2018). Both the accelerometer and the GPS logger had a rechargeable Li-ion 3.7 V, 5200 mAh battery (Tenergy Li-ion 18650, Freemont, CA) soldered to the equipment to extend data logging to 30 d (Sprinkle et al., 2021). The two sample periods within each year were timed to gather grazing behavior data during mid- (d 133 to 153 for 2016; d 107 to 127 for 2017) and late lactation (d 181 to 205 for 2016 and 2017).

The entire cowherd had free choice access to a mineral mix (Simplot Western Stockmen's, Caldwell, ID) distributed two to three times a week to ensure an average consumption of 113 g/d for each cow. The composition of the mineral supplement on a dry matter basis was 3.0% crude protein, 26% salt, 12.5% Ca, 6.3% P, 5.2% Mg, 0.16% K, 0.25% S, 13.4 ppm Fe, 2.2 ppm Mn, 2,089 ppm Zn, 2,089 ppm Cu, 129 ppm I, and 38.7 ppm Se, with 417.5 ppm organic Zn and 209.1 ppm organic Cu. Mineral was distributed at predetermined salting sites within the pastures following pasture rotations and movements within pastures. No other supplementation was provided to cows grazing these upland pastures.

Milk production on all 2-yr-old haltered cows was estimated at NMCREEC in March 2016 using weigh-suckle-weigh procedures (Williams et al., 1979) at peak lactation (following a 13.5 h calf separation period; 55 d postpartum for efficient cows and 53 d for inefficient cows) and at Rinker Rock Creek Ranch during late lactation (following a 12 h calf separation period; 182 d postpartum for efficient and 180 d for inefficient cows). Milk production data were not collected in 2017.

Cow BW and BCS (1 to 9, 9 = fattest; Richards et al., 1986) were obtained for all 2-yr-old cows at approximately d 60 (2016) or d 90 (2017) of lactation, d 180 of lactation, and at calf weaning (approximately 222 d of lactation) during both years of the study. Calf weaning weights were adjusted to a 205-d standardized weaning weight according to BIF guidelines (BIF, 2010).

Daily GT, RT (including standing, lying down, and rumination), and WLK were estimated every 5 s using the 3-axis accelerometer (Sprinkle et al., 2021). The accelerometer monitored head movement for 25 data points every s (25 Hz) and these observations were averaged to every 5 s. Data were compiled using Python coding (https://www.python.org/).

Observed daily activity for each cow was obtained by one to three observers over multiple time periods over 3 d at the beginning of each sampling period following the procedures suggested by Ganskopp and Bohnert (2009). Scan sampling for daily activity (grazing, resting, and walking) was done for all grazing cohorts that were in visual range at 5-min intervals. Each sampling cohort was visually observed for a minimum of 20 min before moving to another cohort group, with all haltered cows being evaluated within the group (Sprinkle et al., 2021). Observational sampling occurred during peak grazing periods in early morning and late afternoon as well as during mid-day when cows typically rest. Reliable walking data were collected as cows were trailed to and from the working corrals. The collection of observational data was necessary to obtain a "data signature" to match raw accelerometer output to daily grazing activity.

It was necessary to obtain a "data signature" for each cow since the final equations used to separate daily activity differed for each cow (Sprinkle et al., 2021). The procedures and equations used to convert raw accelerometer *g* values for the x, y, and z axes to final estimates of grazing, walking, and resting are fully described by Sprinkle et al. (2021). These prediction equations were evaluated for each cow using both error scores and plotted probability plots obtained from quadratic discriminant analysis (SAS v. 9.4, SAS Inst., Inc., Cary, NC). These predictor equations used to separate daily activity were compiled in the Python coding for each cow and summarized every 5 s by d for each 2-h time period beginning at midnight.

Focal sampling for bite rate (BR, bites/min) was conducted on single animals (Sprinkle et al., 2000) during either the AM or PM observation time periods for approximately 10 to 15 min by 1 to 3 observers. Cows watched rotated among observers on alternate days or with duplicate observations on the same day to help alleviate variation among observers. At least 4 replicate samples per observation period were acquired whenever possible. Beginning and ending times for each replicate were recorded in the field on a tablet computer using a spreadsheet with an integrated timestamp. Sometimes (3%) cattle commenced resting, walking to water, or ruminating in the midst of an observed grazing bout, so it was not always possible to obtain multiple sample replicates of 4 or greater during the grazing observation period. Bite rate frequency data were averaged over each observation period. Any BR average with less than 3 reps was deleted.

One of three observers in the spring of 2017 recorded some BR data which used a discrete time period instead of active grazing bouts, resulting in some unreasonable values (e.g., 3 bites/min over 4 min 39 s). Therefore, all BR data were excluded for this observer. Another observer (one of two) in the summer of 2017 failed to record repeated reps for one sample day, recording data over the top of other data and only collecting a maximum of 2 reps/cow. All data for that observer for that day were excluded.

The GPS loggers recorded locations at 7-min intervals in 2016 and at 4-min intervals in 2017 and daily travel distance (DTD) along the travel path was calculated. The fix interval in 2017 was reconfigured for data acquisition every 3.5 min instead of every 5 min because it became apparent from 2016 retrieved data that the timing for satellite transmission needed to be reduced to accommodate missed satellite pings when cattle were in deep canyons. Additionally, the daily averages for elevation, maximum elevation, average slope, maximum slope, and the amount of time spent on slopes greater than 15% were calculated. The methodology for processing GPS data are well established (Turner et al., 2000; Bailey et al., 2018), but further details follow. Raw GPS data files were downloaded into file folder entitled *C:\GT_DATA_LOG* instead of using the manufacturer's software platform in order to preserve detailed satellite information and estimated horizontal positioning errors for GPS satellite fixes. These raw data files were then imported into an Excel (version Microsoft Office 365 Pro Plus) spreadsheet and processed further using guidelines available from an instruction manual by Knight and Bailey (https://app.box.com/s/ayzk1e2zskinotjyjypv1u4whluc7roa).

Formulas were placed within the Excel spreadsheet to calculate the time difference between waypoints and the rate of travel for all waypoints exceeding 84 m/min travel time (Chapinal et al., 2009) were excluded. Additionally, all waypoints exceeding 300 m Estimated Horizontal Positional Error were excluded. Also, points with altitudes <1,300 or >2,000 m from the GPS data loggers at this location were indicative of failed satellite fixes and were also excluded. Waypoints were converted from latitude and longitude format to the Universal Transverse Mercator coordinate system so as to more accurately estimate travel distances. An online website for doing this conversion is provided in the Knight and Bailey manual described previously. Once the data cleaning in Excel was complete, data were further processed in ArcMap (vs. 10.2.2, ESRI Inc., Redlands, CA). Those GPS positions appearing outside of the mapped fenceline were treated as outliers and deleted. Data were then compared from day to day, and those points sharply diverging from the general path were deleted. Most of these waypoints were due to the GPS logger dropping a satellite when recording a location. From within ArcMap, a digital elevation model map layer was imported for the experimental pastures from the United States Geological Service (https://viewer.nationalmap.gov/basic/) following the directions of Knight and Bailey. With this spatial layer, both elevation and slope characteristics for each waypoint were generated. The fully processed data were exported from ArcMap into Excel and the time spent on slopes greater than 15% was determined with an if, then conditional equation. Finally, a Pivot Table was utilized within Excel to identify maximum, minimum, and average slopes and elevation, DTD, time spent on slopes >15%, elevational gain, and total GPS waypoint count for each cow on a daily basis. Data were then compiled into a master dataset for statistical analysis.

Since DTD was inflated by bounces in GPS fixes when an animal was stationary, we adjusted each cow's DTD by the estimated error accompanying stationary GPS fixes. The GPS collars were tested at 5-min intervals for 24 h at a location that was identified with a real-time kinematic GPS location (±3 cm, Karl and Sprinkle, 2019). The average travel distance obtained for each stationary GPS waypoint was 9.27 m (Karl and Sprinkle, 2019). Each cow's DTD was adjusted by multiplying this error by the number of fixes for resting. This was done by dividing the total minutes of daily RT by the average GPS fix interval (4.10 min in 2017; 6.93 min in 2016) and multiplying the number of waypoints by the stationary error as shown in equation (1).

$$\left(\left(\left(\left(\text{Resting time } \frac{\text{min}}{\text{d}}\right) \div 4.10\,\text{min/fix}\right) - 15 \text{ expected deleted outlier waypoints}\right) \times 9.27\,\text{m/fix}\right) \div 1{,}000\,\frac{\text{m}}{\text{km}} = \text{km DTD}\,\frac{\text{deleted}}{\text{d}} \tag{1}$$

For example, 630-min RT would result in 1.29 km being deleted from the DTD for a cow being considered in 2017.

Information on using accelerometers for determining grazing behavior and in processing data are fully described in Sprinkle et al. (2021). Additional resources are available at the shared website folder (https://app.box.com/s/ayzk1e2zskinotjyjypv1u-4whluc7roa) containing example data, programming code, spreadsheets hands on training exercises, and an instruction manual.

Table 1 provides information on the sampling frequency for cows in this trial for GPS and accelerometer data for all sample periods. In the spring of 2016, there was an average of 19 d accelerometer and GPS data for inefficient cows and 21 d for efficient cows. In the summer of 2016, there was an average of 18 d for inefficient and 20 d for efficient cattle for all grazing behavior data. In the spring of 2017, inefficient cattle had an average of 12 d GPS and 17 d accelerometer data, while efficient cattle averaged 11 d GPS and 17 d accelerometer data. In the summer of 2017, inefficient cattle averaged 21 d GPS and 20 d accelerometer data and efficient cows averaged 20 d GPS and 19 d accelerometer data. Over all sample periods in both yr, 11 d GPS data were excluded among some cows for poor satellite reception. All of these deletions occurred in the spring of 2016 while cattle had access to deeper canyons. Only 4 d of 1,647 total accelerometer days were excluded for faulty data recording (0.24%). For these faulty recorded data, it is likely that the halter mounted accelerometer was bumped, temporarily displacing the fixed placement of the accelerometer and resulting in unreasonable daily activity values (Sprinkle et al., 2021).

The overall error for observed GT, RT, and WLK for observed grazing behavior data (239,400 lines data points; 332.6 h cattle observed data) fitted against prediction equations averaged 18.57% for RT, 23.07% for GT, and 48.05% for WLK. Since the error for WLK was highest (Sprinkle et al., 2021), data separation for calculated grazing behavior on the full accelerometer dataset for each cow followed this sequence order: 1) RT, 2) GT, and 3) WLK.

Table 1. Sampling frequency for grazing behavior for lactating 2-yr-old cows on Idaho rangeland

Item	Total d, GPS[1]	*n*	Total d, accelerometer[1]	*n*	Total d escaped pasture[2]
June 14 to July 4, 2016[a]					
Efficient cows[3]	225	11	227	11	0
Inefficient cows[3]	193	10	205	11	0
August 2 to August 25, 2016[b]					
Efficient cows[3]	245	12	241	12	34
Inefficient cows[3]	221	12	221	12	52
May 23 to June 12, 2017[c]					
Efficient cows[3]	135	12	183	11	35
Inefficient cows[3]	132	11	167	10	23
August 5 to August 28, 2017[d]					
Efficient cows[3]	221	11	188	10	0
Inefficient cows[3]	207	10	215	11	0

[1]GPS = global positioning system; days listed are for all cows over all days.

[2]GPS data were excluded when cows escaped from upland pasture to upland pasture in the spring of 2017. Both accelerometer and GPS data were excluded when cows escaped from upland pastures to riparian meadows in the summer of 2016. Cows did not escape pastures during the spring of 2016 or the summer of 2017. However, in the summer of 2017, cows were slowly gathered in random clusters from upland pastures to the riparian meadows by the ranch crew starting on August 19 and extending to August 29. All behavior data following removal from upland pastures were excluded. Also, anytime GPS logger stopped, all accelerometer data in the summer of 2017 were excluded as well since it was not possible to know if the cow was still in the upland pasture. The average days data were excluded in the summer of 2017 for pasture removal was 4.7 d for Efficient and 1.5 d for Inefficient cows.

[3]Efficient cows were ranked as LRFI and Inefficient cows were ranked as HRFI yearling heifers.

[a]Two GPS loggers were lost and 1 logger failed; 2 accelerometers failed; 1 GPS shut down early on d 15; 2 accelerometers shut down early on d 15 and 21. Six cows had 1 d of data excluded when moved out of pasture for a single experiment station field day. There were 11 d of GPS data over all cows excluded due to poor satellite reception. One d of accelerometer data for 1 cow was excluded due to improper recording.

[b]Two GPS loggers shut down on d 8 and 15; 1 accelerometer shut down on d 23. Accelerometer days were excluded on days when no GPS data were recorded since it was not possible to know if cows stayed in upland pasture instead of breaking into riparian meadows. Two d of accelerometer data were excluded from two different cows due to improper recording.

[c]Two halters were lost in the field and recovered later with partial data recovery; 3 accelerometers failed; 1 GPS logger failed. Power saving option was not enabled on GPS loggers so none of the loggers recorded the full 21 d; averaged 12 d for Inefficient cattle and 11 d for Efficient cattle. Four accelerometers shut down prior to the end of the sampling period on d 6, 7, 10, and 19. One d of accelerometer data for 1 cow was excluded due to improper recording.

[d]One halter was lost in the field and recovered later with partial data recovery; 1 accelerometer was lost and not recovered; 2 accelerometers failed; 3 GPS loggers failed. One accelerometer shut down on d 18.

Thus, a large portion of errors observed for WLK were avoided using this procedure.

Statistical Analyses

Daily GT, RT, WLK, DTD, average and maximum elevation, average and maximum slope, and percentage of time on slopes greater than 15% were analyzed with a mixed effects model for repeated measures (v. 9.4, SAS Inst., Inc., Cary, NC) by sample period with the fixed effects of RFI group, day, and the interaction between RFI group × day. Cow within RFI group was included as a random repeated subject. The GPS data from May 2017 only contained the fixed effects of RFI group and RFI group × day due to several missing daily values for cows that were excluded when they broke out of the pasture. Bite rate data were analyzed by mixed model with fixed effects of RFI group, day, observer, and observer × RFI group; the exception being BR data for August 2017, which excluded day due to overparameterization of the model. Cow within RFI group was included as a random repeated subject. The denominator degrees of freedom for all grazing behavior *F*-statistics were approximated using the Satterthwaite method. For all these models, a simplified compound symmetry covariance structure was used to model the relationships between repeated observations. Cow BW, BCS milk production, and adjusted calf weaning weight were analyzed by a general linear least squares model with RFI group as a fixed main effect. Milk production also included the fixed effect of calf sex for March 2016 peak milk production. Least squares treatment means for all statistical models were separated using the pairwise contrasts (PDIFF, v. 9.4, SAS Inst., Inc., Cary, NC). Statistical differences in least square means were evaluated using the pdmix800.sas macro as originally described by Saxton (1998).

Table 2. Climate data for research trial on Idaho rangeland[1]

Sample period	Average daily maximum temperature, °C	Average daily minimum temperature, °C	Precipitation, mm	Total h THI[a] ≥72
June 14 to July 4, 2016	25.9	9.4	1	59
August 2 to August 25, 2016	27.8	10.6	0	57
May 23 to June 12, 2017	21.3	6.8	31	22
August 5 to August 28, 2017	27.5	11.4	5	31
Historic averages (May)	19.1	3.7	58	
Historic averages (June)	23.6	6.8	41	
Historic averages (July)	28.5	8.7	16	
Historic averages (August)	29.9	9.2	7	

[1]Temperature data are from the Friedman Memorial Airport weather station in Hailey, Idaho, 18 km northeast of experimental pastures. Due to missing data, rainfall data are from the Bellevue weather station in Bellevue, Idaho, 14 km northeast of experimental pastures. Long term averages listed are from historic data at the Friedman Memorial Airport (1981 to 2010).

[a]THI = temperature humidity index. MHL is experienced by livestock when the THI exceeds 72. Severe heat load is experienced when THI reaches 79. No days were encountered with THI ≥79.

RESULTS AND DISCUSSION

Climatic Data

Climatic data for this trial are summarized in Table 2. These data were collected at the Hailey Airport (1,618 m) and Bellevue weather stations (1,587 m) which were higher elevation than the lowest elevation areas of Rinker Rock Creek Ranch. Therefore, cattle may have experienced some higher daily temperatures than those reported at the weather stations during some time periods. Table 2 also presents the hours within each sample period when cattle experienced mild heat load (MHL). *Bos taurus* cattle have been shown to exhibit MHL when the temperature and humidity index (THI) exceeds 72 (Du Preez et al., 1990; Armstrong, 1994) and to exhibit severe heat load when the THI reaches 79 (Hahn and Mader, 1997). Precipitation received at the Bellevue weather station (14 km northeast of experimental pasture; 114°15.462′W, 43°28.014′N) from April through September was 115 mm in 2016 and 120 mm in 2017. The actual rainfall received during the 2016 sampling periods was minimal (only 1 mm) and cattle experienced more hours in MHL (Table 2) in 2016 than they did in 2017.

Forage Production and Nutritive Value

Forage production and nutritive value data are summarized in Table 3. As mentioned previously, forage nutritive value and production were determined upon cattle entry into experimental pastures during 2016. To assist in building a historical database of forage quality at different times of the year at the recently acquired Rinker Rock Creek Ranch, forage quality in 2017 was obtained following grazing in late August and mid-September. Forage production was obtained at the same time and the forage production adjusted for forage removal by grazing is reported in Table 3. Forage nutritive value declined as the season of year advanced past late spring, as is common with cool-season grass dominated rangeland (Ganskopp and Bohnert, 2001). However, adequate forage supply (Table 3) probably assisted these 2-yr-old cows in selecting a higher quality diet than what was determined in the clipped forage (Sprinkle et al., 2000).

This ranch was somewhat understocked at the time of this study, as is demonstrated by the forage utilization data in each pasture. The average end of grazing season utilization ± the 90% confidence interval was 23.7 ± 2.72% for the 2016 spring pasture; 23.1 ± 3.94% and 35.1 ± 5.02% for two locations in the 2016 summer pasture; 24.3 ± 3.67% and 22.0 ± 3.42% for two locations in the spring 2017 pasture; and 28.9 ± 4.12% and 10.8 ± 2.28% at two locations in the summer 2017 pasture. The lower stocking rate probably accommodated an ability for cattle to practice selective grazing, and as cattle production data will demonstrate later, the loss of body condition for these 2-yr-old cows from turn out to weaning was minimal.

Grazing Behavior

Overall grazing behavior When GT, RT, and WLK means were compared for all grazing periods (Table 4), averaged over all days of each sample period, there were no differences ($P > 0.10$) observed. Similarly, there were no differences in DTD or in the elevational and slope gradient cows accessed ($P > 0.05$) with data averaged over all days

Table 3. Forage production and quality for experimental pastures

Pasture	Sample	Year	Forage production, kg/ha ± 90% CI	TDN[1], %	CP[1], %	Ca, %	P, %	K, %	Mg, %	S, %	Na, %	Zn, ppm	Fe, ppm	Mn, ppm	Cu, ppm	Mo, ppm	Se, ppm
Spring	Grass	2016	321 ± 86	57.1	8.8	0.58	0.23	1.46	0.11	0.12	0.04	18.4	141	38	4.7	3.6	0.027
Spring	Browse	2016	235 ± 96	65.7	10.3	0.80	0.21	1.69	0.20	0.12	0.05	22.8	181	33	3.2	1.2	0.041
Summer	Grass	2016	435 ± 185	54.3	5.1	0.66	0.15	1.20	0.14	0.09	0.03	22.7	119	59	2.6	4.5	ND[a]
Summer	Browse	2016	115 ± 27	56.5	9.1	1.25	0.36	1.29	0.28	0.16	0.03	30.9	160	41	3.0	1.8	0.021
Spring[2]	Grass	2017	1,040 ± 493	47.6	3.3	0.37	0.09	0.83	0.08	0.06	0.04	12.7	273	35	2.2	3.6	0.023
Spring[2]	Grass	2017	590 ± 283	46.3	3.8	0.37	0.10	0.86	0.09	0.06	0.04	18.1	194	37	3.1	2.2	0.025
Summer[2]	Grass	2017	1,643 ± 1,060	47.6	3.7	0.44	0.14	1.38	0.09	0.07	0.04	23.6	91	92	2.7	3.7	0.042
Summer[2]	Grass	2017	3,274 ± 1,900	45.3	3.7	0.40	0.11	1.25	0.10	0.07	0.05	15.3	105	48	1.8	2.2	0.023
Lactating cow NASEM requirement[3]				56.0	9.6	0.19	0.13	0.70	0.20	0.15	0.10	30	50	40	10	—	0.10

[1]TDN = total digestible nutrients, based upon in vitro acid detergent fiber digestibility; CP = crude protein. Forage quality for 2016 was determined on forage samples obtained at the time of cattle entry into pasture.

[2]Samples in 2017 were from two different sampling sites for each of the spring and summer pastures. No browse was encountered in 10 randomized plots at each key area. Forage quality for 2017 was determined on forage obtained August 31 for summer grazed pasture and on September 16 for spring grazed pasture.

[3]Based upon Nutrient Requirements of Beef Cattle, National Research Council, (NASEM, 2016). Calcium and phosphorus requirements are dependent upon cow size, physiological state, and milk production. Estimate shown is for a 470 kg cow at mid-lactation with 8 kg /d peak milk production.

[a]ND = nondetectable, less than 0.02 ppm.

of the sampling period, though there was a tendency ($P < 0.10$) for efficient cattle to travel further and climb higher than inefficient cattle in the summer of 2017. The day × RFI group interaction was significant ($P < 0.05$) or tended to be significant ($P < 0.10$) in each sample period for either daily activity (resting, grazing, and walking) or GPS generated data (daily travel and grazing locations), or both (Tables 4 and 7 to 10). These interactions appeared to be highly associated with daily heat load, which shall be discussed later.

Forage harvesting BR When BR was summarized over all observers (Table 4), no differences between efficient and inefficient cattle were detected. Differences between observers ($P < 0.05$) were detected. Observers with less experience typically recorded lower rates (bites/min) for BR. Within the same observers, no differences were detected between efficient and inefficient cattle except for one observer who recorded a greater ($P < 0.020$) BR for inefficient cattle in August 2016 (45.8 ± 2.91 for inefficient vs. 37.1 ± 2.85 bites/min for efficient). Other research we have conducted found no differences in BR between efficient and inefficient 2-yr-old nonsupplemented, pregnant cattle on late-season rangeland (Sprinkle et al., 2020); and no differences in BR between a mix of protein supplemented and nonsupplemented 2-yr-old efficient and inefficient pregnant cattle on late-season rangeland (Sprinkle et al., 2019). This later study did find that the BR for supplemented 2-yr-old cattle was greater ($P < 0.05$) than that of nonsupplemented cattle for 1 yr of the trial. It appeared that cattle facing greater nutritional demand altered their harvest efficiency (Krysl and Hess, 1993), spending more time searching for a quality diet and engaging in less "intense" grazing (Barton et al., 1992).

Possible search grazing by inefficient cattle During the spring of 2016, there were 3 d during which inefficient cattle had greater ($P < 0.05$) WLK than did efficient cattle. Throughout all sample periods (Tables 7 to 10), inefficient cattle had 11 d when they had greater ($P < 0.05$) or tended to have greater ($P < 0.05$) WLK than efficient cattle; the converse being true for only two instances. The greater WLK for inefficient cattle did not result in greater DTD for any of these days. Rather, the greater WLK for inefficient cattle is more likely associated with daily grazing bouts, suggesting greater "search" grazing for inefficient cattle. Our earlier research (Sprinkle et al., 2019) reported a similar finding for inefficient vs. efficient cattle grazing low quality, late-season rangelands. We have hypothesized that inefficient grazing cattle with greater nutritional demands express this by searching for a better-quality diet, thus reducing RT and increasing WLK. Research conducted by Gregorini et al. (2015) support this assumption wherein they found that grazing LRFI lactating Holstein cows walked less and more slowly, masticated less, and took more bites per feeding station than did lactating HRFI Holstein cows.

Daily GT, RT, and WLK budget The daily time budget for the time spent grazing, resting, or walking differed among all sample periods for the efficient vs. inefficient cattle in this study (Tables 5 and 6). Inefficient cattle commenced grazing earlier (P < 0.05) in the morning than did efficient cattle during the spring of both 2016 and 2017. Conversely, efficient cattle started grazing earlier (P < 0.05) in the morning during the summer of 2017. Efficient cattle in 2017 also grazed more (P < 0.05) during the early evening hours of spring (1800 to 1959) and late evening hours (2200 to 2359) of summer. In the summer of 2016, inefficient cattle rested more (P < 0.05) during the heat of the day (1400 to 1559), most likely due to increased metabolic heat load accompanying the presumed larger gastrointestinal tract for cattle with greater appetite (Sprinkle et al., 2000; Fitzsimons et al., 2014).

Lactation causes an increase in gastrointestinal tract size (Forbes, 1986), and organic matter intake lags behind peak milk production, peaking at mid-lactation (Rosiere et al., 1980; Hunter and Siebert, 1986; Coleman et al., 2014). Thus, it was expected that GT (a proxy for forage intake) would be aggressively expressed during the spring sample periods, especially by inefficient cattle with supposedly greater appetite. The inefficient cattle in this study manifested this tendency by exhibiting increased grazing during the early morning hours (Tables 5 and 6) of mid-lactation.

Grazing behavior responses to heat stress Tables 7 to 10 characterize the day to day differences in grazing behavior for each sample period. Since these differences in grazing behavior appear to be closely linked to the THI, daily climate data and the hours of each day that cattle experienced a THI ≥72 are shown as well.

The spring 2016 sample period (Table 7) was characterized by 59 total h (Table 2) when the THI was ≥72. During this time period, efficient cattle had greater (P < 0.05) or tended to have greater (P < 0.10) GT on 3 d than did inefficient cattle. Efficient cattle also accessed (P < 0.05) or tended to access (P < 0.10) steeper slopes or greater elevation than did inefficient cattle on 4 d. There were 2 d (July 2, July 4) in which inefficient cattle accessed

Table 4. Grazing behavior for lactating 2-yr-old cows on Idaho rangeland

Item	Efficient cows[1]	n	Inefficient cows[1]	n	RFI group	RFI group × day
					P-value	P-value
June 14 to July 4, 2016						
DTD[2], km/d	5.8 ± 0.21	11	5.5 ± 0.21	10	0.415	0.014
Average slope, %	10.0 ± 0.56	11	10.5 ± 0.59	10	0.575	0.006
Maximum slope, %	36.2 ± 4.27	11	29.8 ± 4.48	10	0.314	0.622
Percentage of time on slopes >15%	16.5 ± 1.51	11	15.3 ± 1.59	10	0.591	0.197
Average elevation for day, m	1,521 ± 2.8	11	1,518 ± 3.0	10	0.394	0.659
Maximum elevation for day, m	1,547 ± 2.7	11	1,545 ± 2.9	10	0.544	0.307
Grazing, h/d	10.7 ± 0.24	11	10.3 ± 0.26	11	0.483	0.305
Resting, h/d	10.3 ± 0.38	11	10.3 ± 0.42	11	0.994	0.165
Walking, h/d	2.7 ± 0.30	11	3.3 ± 0.33	11	0.202	0.164
BR, bites/min	36.7 ± 1.21	12	36.3 ± 1.27	12	0.819	—
August 2 to August 25, 2016						
DTD[2], km/d	7.1 ± 0.20	12	7.2 ± 0.21	12	0.647	0.461
Average slope, %	10.8 ± 0.35	12	10.9 ± 0.36	12	0.859	0.624

Table 4. Continued

Item	Efficient cows[1]	*n*	Inefficient cows[1]	*n*	RFI group	RFI group × day
					P-value	*P*-value
Maximum slope, %	28.7 ± 0.75	12	28.2 ± 0.78	12	0.726	0.568
Percentage of time on slopes >15%	20.5 ± 1.89	12	21.5 ± 1.94	12	0.746	0.300
Average elevation for day, m	1,549 ± 2.9	12	1,542 ± 2.9	12	0.128	0.048
Maximum elevation for day, m	1,595 ± 3.2	12	1,594 ± 3.3	12	0.713	0.394
Grazing, h/d	10.2 ± 0.21	12	10.2 ± 0.22	12	0.855	0.102
Resting, h/d	11.4 ± 0.17	12	11.1 ± 0.18	12	0.363	0.478
Walking, h/d	2.4 ± 0.18	12	2.7 ± 0.18	12	0.296	0.382
BR, bites/min	38.0 ± 2.25	12	43.2 ± 2.18	12	0.114	—
May 23 to June 12, 2017						
DTD[2], km/d	4.9 ± 0.38	12	5.1 ± 0.43	11	0.713	<0.0001
Average slope, %	7.5 ± 0.20	12	7.2 ± 0.22	11	0.231	<0.0001
Maximum slope, %	27.2 ± 1.53	12	27.0 ± 1.64	11	0.948	<0.0001
Percentage of time on slopes >15%	7.0 ± 0.94	12	6.0 ± 1.02	11	0.480	<0.0001
Average elevation for day, m	1,655 ± 2.3	12	1,658 ± 2.1	11	0.459	<0.0001
Maximum elevation for day, m	1,685 ± 2.6	12	1,688 ± 2.5	11	0.527	<0.0001
Grazing, h/d	10.3 ± 0.25	11	10.8 ± 0.26	10	0.173	0.089
Resting, h/d	10.9 ± 0.30	11	10.7 ± 0.32	10	0.727	0.574
Walking, h/d	2.9 ± 0.20	11	2.5 ± 0.21	10	0.195	0.967
BR, bites/min	52.6 ± 2.39	12	49.2 ± 2.62	12	0.242	—
August 5 to August 28, 2017						
DTD[2], km/d	5.9 ± 0.19	11	5.4 ± 0.18	10	0.078	0.984
Average slope, %	6.7 ± 0.27	11	6.1 ± 0.26	10	0.161	0.578
Maximum slope, %	21.7 ± 0.83	11	20.5 ± 0.87	10	0.279	0.677
Percentage of time on slopes >15%	4.3 ± 0.59	11	3.2 ± 0.61	10	0.382	0.519
Average elevation for day, m	1,590 ± 2.1	11	1,586 ± 2.2	10	0.124	0.955
Maximum elevation for day, m	1,612 ± 2.8	11	1,606 ± 2.9	10	0.097	0.988
Grazing, h/d	11.6 ± 0.43	10	10.7 ± 0.43	11	0.168	0.276
Resting, h/d	10.5 ± 0.36	10	10.7 ± 0.33	11	0.717	0.090
Walking, h/d	2.2 ± 0.24	10	2.8 ± 0.22	11	0.143	0.356
BR, bites/min	43.5 ± 2.23	12	45.9 ± 2.07	12	0.452	—

[1]Efficient cows were ranked as LRFI and Inefficient cows were ranked as HRFI as yearling heifers.

[2]DTD = daily travel distance.

Table 5. Daily activity by time of day for lactating 2-yr-old cows in 2016

		Spring (June 14 to July 4)		Summer (August 2 to 25)	
Grazing period, h	Daily activity, min	Efficient[1]	Inefficient[1]	Efficient[1]	Inefficient[1]
0000 to 0159	Grazing	27 ± 4.6[a]	25 ± 5.1[a]	27 ± 2.5[a]	31 ± 2.6[a]
0000 to 0159	Resting	91 ± 4.8[a]	93 ± 5.3[a]	85 ± 2.3[a]	79 ± 2.4[a]
0000 to 0159	Walking	2 ± 0.4[a]	2 ± 0.4[a]	8 ± 1.7[a]	10 ± 1.7[a]
0200 to 0359	Grazing	27 ± 3.9[a]	23 ± 4.3[a]	21 ± 2.5[a]	20 ± 2.6[a]
0200 to 0359	Resting	92 ± 3.9[a]	94 ± 4.3[a]	91 ± 2.5[a]	92 ± 2.6[a]
0200 to 0359	Walking	2 ± 0.4[a]	2 ± 0.5[a]	8 ± 1.9[a]	8 ± 2.0[a]
0400 to 0559	Grazing	**32 ± 3.7[a]**	**46 ± 4.1[b]**	17 ± 2.5[a]	16 ± 2.6[a]
0400 to 0559	Resting	**84 ± 4.2[b]**	**63 ± 4.7[a]**	99 ± 3.5[a]	95 ± 3.5[a]
0400 to 0559	Walking	**5 ± 1.1[a]**	**10 ± 1.2[b]**	7 ± 1.6[a]	7 ± 1.7[a]
0600 to 0759	Grazing	82 ± 3.3[a]	78 ± 3.6[a]	81 ± 2.6[a]	83 ± 2.6[a]
0600 to 0759	Resting	19 ± 2.0[a]	14 ± 2.0[a]	24 ± 1.6[a]	21 ± 1.7[a]
0600 to 0759	Walking	21 ± 2.6[a]	29 ± 2.9[a]	14 ± 2.1[a]	16 ± 2.2[a]
0800 to 0959	Grazing	54 ± 2.7[a]	49 ± 3.0[a]	72 ± 2.5[a]	70 ± 2.6[a]
0800 to 0959	Resting	53 ± 2.3[a]	55 ± 2.5[a]	32 ± 2.3[a]	33 ± 2.4[a]
0800 to 0959	Walking	15 ± 1.5[a]	17 ± 1.7[a]	16 ± 1.2[a]	17 ± 1.2[a]
1000 to 1159	Grazing	58 ± 2.0[a]	57 ± 2.0[a]	45 ± 2.6[a]	44 ± 2.7[a]
1000 to 1159	Resting	45 ± 3.7[a]	44 ± 4.1[a]	60 ± 2.7[a]	59 ± 2.8[a]
1000 to 1159	Walking	16 ± 1.7[a]	19 ± 1.9[a]	15 ± 1.7[a]	19 ± 1.8[a]
1200 to 1359	Grazing	57 ± 1.4[a]	53 ± 1.5[a]	50 ± 2.4[a]	50 ± 2.5[a]
1200 to 1359	Resting	48 ± 2.4[a]	50 ± 2.5[a]	57 ± 3.2[a]	54 ± 3.4[a]
1200 to 1359	Walking	15 ± 1.3[a]	17 ± 1.3[a]	14 ± 1.6[a]	16 ± 1.7[a]
1400 to 1559	Grazing	56 ± 2.3[a]	52 ± 2.3[a]	53 ± 2.9[a]	46 ± 3.0[a]
1400 to 1559	Resting	51 ± 2.5[a]	54 ± 2.6[a]	**51 ± 2.9[a]**	**64 ± 2.7[b]**
1400 to 1559	Walking	15 ± 1.6[a]	14 ± 1.7[a]	12 ± 1.3[a]	13 ± 1.4[a]
1600 to 1759	Grazing	55 ± 2.5[a]	55 ± 2.6[a]	51 ± 2.6[a]	47 ± 2.7[a]
1600 to 1759	Resting	52 ± 3.4[a]	49 ± 3.5[a]	58 ± 2.4[a]	61 ± 2.5[a]
1600 to 1759	Walking	14 ± 1.4[a]	16 ± 1.5[a]	12 ± 1.4[a]	12 ± 1.4[a]
1800 to 1959	Grazing	72 ± 2.5[a]	70 ± 2.8[a]	84 ± 1.6[a]	83 ± 1.7[a]
1800 to 1959	Resting	28 ± 1.9[a]	24 ± 2.0[a]	20 ± 1.4[a]	18 ± 1.5[a]
1800 to 1959	Walking	21 ± 2.8[a]	30 ± 3.1[a]	15 ± 2.1[a]	22 ± 2.1[a]
2000 to 2159	Grazing	82 ± 3.2[a]	75 ± 3.6[a]	87 ± 3.1[a]	86 ± 3.2[a]
2000 to 2159	Resting	15 ± 1.6[a]	13 ± 1.7[a]	18 ± 2.1[a]	15 ± 2.2[a]
2000 to 2159	Walking	25 ± 3.0[a]	32 ± 3.4[a]	16 ± 2.0[a]	18 ± 2.0[a]
2200 to 2359	Grazing	45 ± 4.8[a]	39 ± 5.3[a]	27 ± 2.9[a]	32 ± 3.0[a]
2200 to 2359	Resting	67 ± 4.9[a]	73 ± 5.5[a]	82 ± 3.3[a]	80 ± 3.3[a]
2200 to 2359	Walking	7 ± 0.9[a]	8 ± 1.0[a]	8 ± 1.7[a]	11 ± 1.7[a]

[1]Efficient cows were ranked as LRFI and Inefficient cows were ranked as HRFI as yearling heifers. In the spring of 2016, there were n = 11 cows for both efficient and inefficient cows. In the summer of 2016, there were n = 12 cows for both efficient and inefficient cows.

[a,b]Means within row, by sampling period, with differing superscripts differ ($P < 0.05$). To aid in data discovery, significant differences are shown in bold. Trends ($P < 0.10$) existed in spring for 0600 to 0759 resting and walking; 1200 to 1359 grazing; and 1800 to 1959 walking. Trends ($P < 0.10$) existed in summer for 0000 to 0159 resting and 1800 to 1959 walking.

greater ($P < 0.05$) or tended ($P < 0.10$) to access greater elevational gradients and/or steeper slopes than did efficient cattle. Efficient cattle also tended ($P < 0.10$) to rest more on July 2 than did inefficient cattle. July 2 was a hotter day but had light winds prevailing from 1400 to dusk with some wind gusts (up to 34 km/h) in mid- to late afternoon. July 4 was a mild day with no instances of THI exceeding 72.

The summer 2016 grazing period (Table 8) had 57 h (Table 2) when the THI was ≥72 and there were 8 of 10 d from August 13 to August 22 with periods when cows where in MHL. Grazing behavior differed ($P < 0.05$) between efficient and inefficient cattle when hotter and cooler days were compared. For example, inefficient cattle grazed 1.5 h longer ($P < 0.05$) than efficient cattle on a mild day (August 9; 0 h THI ≥72) but efficient cattle tended to graze longer (1.1 h; $P < 0.10$) than inefficient cattle on a hot day (August 19; 4 h THI ≥72). Furthermore, efficient cattle climbed higher ($P < 0.05$) in the pasture on 4 of the 8-d consecutive time period referred to earlier. Inefficient cattle favored the lower elevation areas of the pasture close to water and shade as temperatures increased

Table 6. Daily activity by time of day for lactating 2-yr-old cows in 2017

		Spring (May 23 to June 12)		Summer (August 5 to 28)	
Grazing period, h	Daily activity, min	Efficient[1]	Inefficient[1]	Efficient[1]	Inefficient[1]
0000 to 0159	Grazing	16 ± 4.3[a]	28 ± 4.5[a]	34 ± 5.9[a]	27 ± 5.7[a]
0000 to 0159	Resting	95 ± 4.0[a]	90 ± 4.2[a]	84 ± 4.9[a]	85 ± 4.6[a]
0000 to 0159	Walking	9 ± 2.4[a]	3 ± 2.5[a]	6 ± 2.6[a]	8 ± 2.5[a]
0200 to 0359	Grazing	**13 ± 3.8[a]**	**29 ± 3.9[b]**	41 ± 6.7[a]	33 ± 6.6[a]
0200 to 0359	Resting	99 ± 3.4[a]	90 ± 3.5[a]	77 ± 5.2[a]	79 ± 5.0[a]
0200 to 0359	Walking	8 ± 2.6[a]	2 ± 2.7[a]	6 ± 2.7[a]	9 ± 2.5[a]
0400 to 0559	Grazing	32 ± 3.9[a]	41 ± 4.1[a]	**37 ± 6.1[a]**	**18 ± 6.1[b]**
0400 to 0559	Resting	79 ± 4.1[a]	73 ± 4.3[a]	83 ± 4.9[a]	95 ± 4.8[a]
0400 to 0559	Walking	10 ± 1.7[a]	6 ± 1.8[a]	4 ± 3.5[a]	6 ± 3.2[a]
0600 to 0759	Grazing	77 ± 3.3[a]	80 ± 3.2[a]	69 ± 4.5[a]	73 ± 4.2[a]
0600 to 0759	Resting	23 ± 3.4[a]	21 ± 3.3[a]	35 ± 4.4[a]	29 ± 4.1[a]
0600 to 0759	Walking	18 ± 1.6[a]	20 ± 1.7[a]	16 ± 2.3[a]	19 ± 2.2[a]
0800 to 0959	Grazing	56 ± 3.3[a]	53 ± 3.2[a]	77 ± 5.1[a]	83 ± 4.8[a]
0800 to 0959	Resting	55 ± 1.8[a]	57 ± 1.8[a]	27 ± 4.2[a]	18 ± 4.0[a]
0800 to 0959	Walking	14 ± 1.6[a]	11 ± 1.6[a]	17 ± 2.4[a]	18 ± 2.3[a]
1000 to 1159	Grazing	59 ± 1.8[a]	60 ± 1.8[a]	58 ± 4.1[a]	49 ± 3.8[a]
1000 to 1159	Resting	44 ± 1.4[a]	44 ± 1.4[a]	50 ± 4.1[a]	59 ± 3.8[a]
1000 to 1159	Walking	16 ± 1.7[a]	16 ± 1.6[a]	9 ± 2.0[a]	12 ± 1.9[a]
1200 to 1359	Grazing	65 ± 2.5[a]	65 ± 2.6[a]	72 ± 3.7[a]	72 ± 3.5[a]
1200 to 1359	Resting	37 ± 2.6[a]	37 ± 2.7[a]	32 ± 2.9[a]	32 ± 2.7[a]
1200 to 1359	Walking	18 ± 1.6[a]	18 ± 1.7[a]	15 ± 1.7[a]	17 ± 1.6[a]
1400 to 1559	Grazing	59 ± 2.7[a]	57 ± 2.6[a]	59 ± 3.0[a]	60 ± 2.8[a]
1400 to 1559	Resting	50 ± 4.1[a]	53 ± 4.0[a]	47 ± 3.3[a]	47 ± 3.0[a]
1400 to 1559	Walking	12 ± 2.0[a]	13 ± 2.0[a]	14 ± 1.4[a]	13 ± 1.3[a]
1600 to 1759	Grazing	60 ± 2.4[a]	60 ± 2.5[a]	60 ± 3.0[a]	58 ± 2.8[a]
1600 to 1759	Resting	45 ± 2.8[a]	46 ± 2.9[a]	46 ± 2.8[a]	47 ± 2.5[a]
1600 to 1759	Walking	14 ± 2.1[a]	13 ± 2.0[a]	14 ± 1.0[a]	15 ± 1.0[a]
1800 to 1959	Grazing	**82 ± 1.9[a]**	**76 ± 1.9[b]**	85 ± 4.3[a]	84 ± 4.1[a]
1800 to 1959	Resting	22 ± 2.3[a]	24 ± 2.2[a]	18 ± 2.8[a]	15 ± 2.6[a]
1800 to 1959	Walking	17 ± 1.6[a]	20 ± 1.7[a]	18 ± 2.9[a]	21 ± 2.7[a]
2000 to 2159	Grazing	75 ± 3.7[a]	74 ± 3.6[a]	70 ± 2.5[a]	68 ± 2.3[a]
2000 to 2159	Resting	26 ± 3.5[a]	24 ± 3.5[a]	35 ± 3.1[a]	33 ± 2.9[a]
2000 to 2159	Walking	19 ± 1.9[a]	22 ± 2.0[a]	16 ± 1.7[a]	19 ± 1.6[a]
2200 to 2359	Grazing	17 ± 4.7[a]	30 ± 4.9[a]	**47 ± 8.0[a]**	**22 ± 8.1[b]**
2200 to 2359	Resting	92 ± 4.4[a]	87 ± 4.6[a]	70 ± 6.2[a]	87 ± 6.3[a]
2200 to 2359	Walking	**11 ± 2.5[a]**	**3 ± 2.7[b]**	7 ± 3.7[a]	7 ± 3.5[a]

[1]Efficient cows were ranked as LRFI and Inefficient cows were ranked as HRFI as yearling heifers. In the spring of 2017, there were $n = 11$ cows efficient and $n = 10$ inefficient cows. In the summer of 2017, there were $n = 10$ cows efficient and $n = 11$ inefficient cows.

[a,b]Means within row, by sampling period, with differing superscripts differ ($P < 0.05$). To aid in data discovery, significant differences are shown in bold. Trends ($P < 0.10$) existed in spring for 0000 to 0159 grazing and walking; 0200 to 0359 resting and walking; and 2200 to 2359 grazing. Trends ($P < 0.10$) existed in summer for 0800 to 0959 resting and 2200 to 2359 resting.

in the summer of 2016. Two days following the 8-d time period with increased heat load, a mild day was encountered (August 24) which resulted in inefficient cattle using ($P < 0.05$) stepper slopes than did efficient cattle.

Cattle grazed the spring 2017 pasture (Table 9) in mid-lactation and temperatures were milder (only 22 h total with MHL; Table 2). During a 6-d time period in which there was only 2 h with THI ≥72, inefficient cattle grazed 1.7 h longer ($P < 0.05$) than did efficient cattle. During the spring 2017 sampling period, there were about equal days for either efficient vs. inefficient cattle with respect to increased ($P < 0.10$) use of steeper slopes or areas of the pasture with greater elevation. Efficient cows spent a greater ($P < 0.05$) amount of time on steeper slopes than did inefficient cows on May 29 (8.5 ± 2.10% vs. 2.2 ± 2.21%) and tended ($P < 0.10$) to spend more time on steeper slopes on May 31 (16.0 ± 2.50% vs. 10.1 ± 2.21%). However, inefficient cows had a greater average elevation ($P < 0.05$) than inefficient cows on May 31 (1,663 ± 3.9 vs. 1,644 ± 4.6 m). It is

Table 7. Differences in daily grazing behavior for lactating 2-yr-old cows on Idaho rangeland during spring 2016

Item	Efficient cows[1]	*n*	Inefficient cows[1]	*n*	*P*-value
June 14, 2016 (19.4 °C maximum temperature; 0 h THI[a] ≥72; mostly sunny)					
Grazing, h/d	10.6 ± 0.47	10	8.9 ± 0.46	11	0.030
Resting, h/d	10.0 ± 0.57	10	11.2 ± 0.58	11	0.133
Walking, h/d	3.1 ± 0.36	10	3.7 ± 0.38	11	0.259
June 22, 2016 (28.3 °C maximum temperature; 1 h THI[a] ≥72; clear)					
Grazing, h/d	11.6 ± 0.45	11	10.4 ± 0.48	10	0.091
Resting, h/d	9.6 ± 0.56	11	10.4 ± 0.60	10	0.315
Walking, h/d	2.4 ± 0.35	11	3.1 ± 0.38	10	0.232
June 23, 2016 (27.2 °C maximum temperature; 0 h THI[a] ≥72; clear)					
Maximum elevation, m	1,547 ± 6.5	11	1,528 ± 6.9	10	0.049
June 24, 2016 (20.6 °C maximum temperature; 0 h THI[a] ≥72; clear)					
Grazing, h/d	12.4 ± 0.45	11	10.8 ± 0.48	10	0.032
Resting, h/d	8.4 ± 0.56	11	9.7 ± 0.60	10	0.123
Walking, h/d	2.8 ± 0.35	11	3.4 ± 0.38	10	0.269
June 26, 2016 (27.2 °C maximum temperature; 0 h THI[a] ≥72; clear)					
Percent of time on slopes >15%	22.1 ± 4.03	7	10.2 ± 3.81	8	0.033
June 30, 2016 (29.4 °C maximum temperature; 5 h THI[a] ≥72; cloudy, thunderstorms, light rain)					
Grazing, h/d	10.8 ± 0.45	11	9.7 ± 0.50	9	0.147
Resting, h/d	10.2 ± 0.56	11	10.5 ± 0.62	9	0.672
Walking, h/d	2.7 ± 0.35	11	3.7 ± 0.39	9	0.096
July 1, 2016 (29.4 °C maximum temperature; 6 h THI[a] ≥72; partly to mostly cloudy afternoon)					
Grazing, h/d	9.9 ± 0.45	11	9.7 ± 0.50	9	0.746
Resting, h/d	10.9 ± 0.56	11	9.9 ± 0.62	9	0.238
Walking, h/d	2.9 ± 0.35	11	4.3 ± 0.39	9	0.013
Average elevation, m	1,529 ± 5.4	11	1,515 ± 5.9	11	0.076
DTD[2], km/d	8.9 ± 0.48	10	6.1 ± 0.53	8	0.0001
July 2, 2016 (31.1 °C maximum temperature; 6 h THI[a] ≥72; mostly fair)					
Grazing, h/d	9.9 ± 0.45	11	10.2 ± 0.50	9	0.683
Resting, h/d	10.8 ± 0.56	11	9.4 ± 0.62	9	0.086
Walking, h/d	2.9 ± 0.35	11	4.3 ± 0.39	9	0.016
Average slope, %	10.0 ± 1.10	11	14.1 ± 1.16	10	0.011
Percent of time on slopes >15%	16.7 ± 3.30	11	25.9 ± 3.46	10	0.056
July 3, 2016 (29.4 °C maximum temperature; 7 h THI[a] ≥72; clear)					
Average elevation, m	1,538 ± 5.4	11	1,523 ± 5.6	10	0.058
DTD[2], km/d	7.1 ± 0.48	10	4.9 ± 0.50	9	0.002
July 4, 2016 (26.1 °C maximum temperature; 0 h THI[a] ≥72; partly cloudy)					
Maximum elevation, m	1,541 ± 6.5	11	1,566 ± 7.2	9	0.008
Average slope, %	10.0 ± 1.10	11	16.1 ± 1.21	9	0.0002
Percent of time on slopes >15%	15.3 ± 3.30	11	26.3 ± 3.62	9	0.025

[1]Efficient cows were ranked as LRFI and Inefficient cows wereranked as HRFI as yearling heifers.

[2]DTD = daily travel distance.

[a]THI = temperature humidity index. MHL is experienced by livestock when the THI exceeds 72. Severe heat load is experienced when THI reaches 79. No days were encountered with THI ≥79.

supposed that these cows were further uphill in the sloping pasture, but on milder slopes.

The late lactation, summer 2017 grazing period (Table 10) was characterized by 31 h when the THI was ≥72 (Table 2). Inefficient cattle failed to express the increased GT like they did in the spring sampling period. Efficient cattle grazed longer ($P < 0.05$) or tended to graze longer ($P < 0.10$) on 5 of the 20 d of data collection. Efficient cattle also climbed higher or used steep slopes than did inefficient cattle ($P < 0.05$) on two additional days.

Through all sampling periods (Tables 7 to 10), the DTD differed on four individual days, being greater ($P < 0.05$) for inefficient cattle in one instance and for efficient cattle in three instances. As been mentioned previously, the mean DTD for

Table 8. Differences in daily grazing behavior for lactating 2-yr-old cows on Idaho rangeland during summer 2016

Item	Efficient cows[1]	*n*	Inefficient cows[1]	*n*	*P*-value
August 9, 2016 (23.3 °C maximum temperature; 0 h THI[a] ≥72; clear)					
Grazing, h/d	9.0 ± 0.44	12	10.5 ± 0.44	12	0.017
Resting, h/d	11.7 ± 0.41	12	10.5 ± 0.41	12	0.035
Walking, h/d	3.4 ± 0.32	12	3.1 ± 0.32	12	0.566
August 10, 2016 (24.4 °C maximum temperature; 0 h THI[a] ≥72; mostly sunny)					
DTD[2], km/d	8.0 ± 0.48	12	9.5 ± 0.48	12	0.031
August 13, 2016 (29.4 °C maximum temperature; 6 h THI[a] ≥72; mostly sunny, mostly cloudy after 1600 h)					
Grazing, h/d	10.8 ± 0.44	12	10.6 ± 0.45	11	0.760
Resting, h/d	11.3 ± 0.41	12	10.4 ± 0.42	11	0.135
Walking, h/d	1.9 ± 0.32	12	2.9 ± 0.33	11	0.024
August 14, 2016 (30.6 °C maximum temperature; 4 h THI[a] ≥72; mostly sunny, partly cloudy to cloudy after 1200 h)					
Grazing, h/d	10.7 ± 0.45	11	10.1 ± 0.49	9	0.364
Resting, h/d	11.3 ± 0.42	11	10.8 ± 0.46	9	0.476
Walking, h/d	2.0 ± 0.33	11	3.1 ± 0.36	9	0.038
August 17, 2016 (31.1 °C maximum temperature; 7 h THI[a] ≥72; thunderstorms, no measurable precipitation)					
Average elevation, m	1,585 ± 5.9	9	1,560 ± 6.0	9	0.008
August 18, 2016 (29.4 °C maximum temperature; 4 h THI[a] ≥72; mostly sunny)					
Average elevation, m	1,584 ± 5.9	9	1,559 ± 6.0	9	0.008
August 19, 2016 (26.1 °C maximum temperature; 4 h THI[a] ≥72; mostly sunny, partly cloudy after 1400 h)					
Grazing, h/d	10.4 ± 0.45	11	9.3 ± 0.49	9	0.099
Resting, h/d	11.3 ± 0.42	11	11.7 ± 0.46	9	0.526
Walking, h/d	2.2 ± 0.33	11	2.9 ± 0.36	9	0.157
August 21, 2016 (30.6 °C maximum temperature; 7 h THI[a] ≥72; clear)					
Grazing, h/d	10.3 ± 0.49	9	7.7 ± 0.82	3	0.006
Resting, h/d	11.7 ± 0.46	9	13.6 ± 0.78	3	0.038
Walking, h/d	2.0 ± 0.36	9	2.7 ± 0.59	3	0.290
Average elevation, m	1,574 ± 5.9	9	1,543 ± 8.9	3	0.007
August 22, 2016 (28.3 °C maximum temperature; 1 h THI[a] ≥72; clear)					
Average elevation, m	1,564 ± 5.6	11	1,544 ± 6.0	9	0.025
Maximum elevation, m	1,601 ± 6.3	11	1,580 ± 6.9	9	0.027
August 24, 2016 (23.3 °C maximum temperature; 0 h THI[a] ≥72; clear, partly cloudy after 1300 h)					
Grazing, h/d	9.5 ± 0.47	11	10.1 ± 0.49	9	0.353
Resting, h/d	11.4 ± 0.44	11	11.6 ± 0.46	9	0.740
Walking, h/d	3.1 ± 0.35	11	2.2 ± 0.36	9	0.093
Average slope, %	12.1 ± 0.67	11	14.4 ± 0.72	9	0.027
Percent of time on slopes >15%	20.1 ± 3.73	11	38.4 ± 4.05	9	0.002

[1]Efficient cows were ranked as LRFI and Inefficient cows were ranked as HRFI as yearling heifers.

[2]DTD = daily travel distance.

[a]THI = temperature humidity index. MHL is experienced by livestock when the THI exceeds 72. Severe heat load is experienced when THI reaches 79. No days were encountered with THI ≥79.

efficient cattle during the summer of 2017 tended ($P < 0.10$) to be greater than for inefficient cattle.

Effects of metabolic heat load Presumably, inefficient cows would be expected to have greater appetite than efficient cows and should increase daily GT when conditions are favorable, which happened in the spring of 2017. Yet, greater appetites are accompanied by larger gastrointestinal tracts (Sprinkle et al., 2000), increasing metabolic heat load and reducing heat tolerance. This research tied larger gastrointestinal tracts to greater rectal body temperatures but additional research should be done with LRFI vs. HRFI cattle to further explore the relationship of core body temperature to the size of the digestive tract. Inefficient cattle in August of 2016 and 2017 could have experienced greater heat fatigue than efficient cattle, thus reducing opportunities to increase GT following an extended time with elevated temperatures.

Although different cattle were fitted with grazing halters in 2016 and 2017, it is interesting to compare patterns of grazing during the milder, earlier spring weather of 2017 to the hotter weather of the summer of 2016. Figures

Table 9. Differences in daily grazing behavior for lactating 2-yr-old cows on Idaho rangeland during spring 2017

Item	Efficient cows[1]	*n*	Inefficient cows[1]	*n*	*P*-value
May 28, 2017 (22.2 °C maximum temperature; 0 h THI[a] ≥72; mostly sunny)					
Grazing, h/d	10.5 ± 0.46	10	11.1 ± 0.54	7	0.376
Resting, h/d	10.5 ± 0.54	10	10.9 ± 0.64	7	0.657
Walking, h/d	3.1 ± 0.30	10	2.1 ± 0.34	7	0.028
May 29, 2017 (23.3 °C maximum temperature; 0 h THI[a] ≥72; mostly sunny)					
Percent of time on slopes >15%	8.5 ± 2.10	10	2.2 ± 2.21	9	0.041
Average slope, %	7.8 ± 0.47	10	6.2 ± 0.49	9	0.019
May 31, 2017 (26.1 °C maximum temperature; 0 h THI[a] ≥72; mostly sunny)					
Grazing, h/d	9.8 ± 0.48	9	11.4 ± 0.54	7	0.025
Resting, h/d	11.3 ± 0.57	9	10.1 ± 0.64	7	0.189
Walking, h/d	3.0 ± 0.31	9	2.4 ± 0.34	7	0.162
Percent of time on slopes >15%	16.0 ± 2.50	7	10.1 ± 2.21	9	0.078
Average elevation, m	1,647 ± 4.6	7	1,663 ± 3.9	9	0.014
Maximum elevation, m	1,673 ± 5.5	7	1,688 ± 4.7	9	0.043
June 1, 2017 (22.2 °C maximum temperature; 0 h THI[a] ≥72; light rain, not measurable)					
Grazing, h/d	10.2 ± 0.50	8	12.0 ± 0.51	8	0.012
Resting, h/d	11.0 ± 0.60	8	9.9 ± 0.60	8	0.188
Walking, h/d	2.9 ± 0.32	8	2.2 ± 0.32	8	0.120
Maximum slope, %	17.6 ± 3.57	7	25.8 ± 3.19	9	0.087
June 2, 2017 (22.2 °C maximum temperature; 0 h THI[a] ≥72; clear)					
Grazing, h/d	9.6 ± 0.50	8	11.6 ± 0.51	8	0.007
Resting, h/d	11.7 ± 0.60	8	10.1 ± 0.60	8	0.070
Walking, h/d	2.7 ± 0.32	8	2.3 ± 0.32	8	0.334
June 3, 2017 (24.4 °C maximum temperature; 0 h THI[a] ≥72; mostly sunny)					
Grazing, h/d	9.7 ± 0.50	8	11.2 ± 0.51	8	0.033
Resting, h/d	11.2 ± 0.60	8	10.1 ± 0.60	8	0.199
Walking, h/d	3.2 ± 0.32	8	2.7 ± 0.32	8	0.301
June 4, 2017 (27.2 °C maximum temperature; 2 h THI[a] ≥72; mostly sunny)					
Grazing, h/d	10.1 ± 0.50	8	11.6 ± 0.51	8	0.043
Resting, h/d	11.1 ± 0.60	8	9.8 ± 0.60	8	0.125
Walking, h/d	2.9 ± 0.32	8	2.7 ± 0.32	8	0.693
June 6, 2017 (27.2 °C maximum temperature; 1 h THI[a] ≥72; clear)					
Maximum slope, %	45.1 ± 3.84	6	34.3 ± 3.58	7	0.041
June 7, 2017 (29.4 °C maximum temperature; 7 h THI[a] ≥72; mostly sunny)					
Maximum elevation, m	1,670 ± 6.4	5	1,702 ± 9.6	2	0.008

[1]Efficient cows were ranked as LRFI and Inefficient cows were ranked as HRFI as yearling heifers.

[a]THI = temperature humidity index. MHL is experienced by livestock when the THI exceeds 72. Severe heat load is experienced when THI reaches 79. No days were encountered with THI ≥79.

1 to 3 demonstrate the apparent relationship between metabolic heat load and its relationship to grazing behavior for these divergently ranked cattle. Figure 1 shows the average daily heat load for the 6-d time span (2 h with THI ≥72) during the spring of 2017 to a 6-d time span (35 h with THI ≥72) in the summer of 2016. Comparing these contrasting time periods, it is apparent that cattle in the summer of 2016 were subjected to a 4- to 6-h period each day when they would be considered to be in MHL while cattle for the 6-d time span in the spring of 2017 experienced no heat load issues. Accordingly, daily cattle behavior for GT was altered substantially during these two diverse time periods. During the spring of 2017 (Fig. 2), inefficient cattle commenced grazing earlier in the morning and continued grazing later during the morning grazing bout ($P < 0.05$) than did efficient cattle. There were no differences ($P > 0.133$) in GT between these RFI groups during any other periods of the day. As temperatures increased and cattle experienced MHL during the summer of 2016, inefficient cattle spent more time resting ($P < 0.05$) during the heat of the day (Fig. 3). Early morning GT did not differ ($P > 0.766$) between efficient and inefficient cattle but efficient

Table 10. Differences in daily grazing behavior for lactating 2-yr-old cows on Idaho rangeland during summer 2017

Item	Efficient cows[1]	*n*	Inefficient cows[1]	*n*	*P*-value
August 5, 2017 (30.6 °C maximum temperature; 5 h THI[a] ≥72; clear)					
Grazing, h/d	12.1 ± 0.53	10	11.4 ± 0.52	11	0.383
Resting, h/d	10.6 ± 0.48	10	10.2 ± 0.45	11	0.613
Walking, h/d	1.7 ± 0.31	10	2.6 ± 0.29	11	0.046
August 7, 2017 (26.1 °C maximum temperature; 0 h THI[a] ≥72; partly cloudy)					
Grazing, h/d	12.5 ± 0.53	10	10.7 ± 0.52	11	0.029
Resting, h/d	9.8 ± 0.48	10	10.7 ± 0.45	11	0.265
Walking, h/d	2.1 ± 0.31	10	2.8 ± 0.29	11	0.103
August 8, 2017 (26.1 °C maximum temperature; 0 h THI[a] ≥72; thunderstorms, no measurable precipitation)					
Grazing, h/d	12.2 ± 0.53	10	10.8 ± 0.52	11	0.079
Resting, h/d	10.0 ± 0.48	10	10.7 ± 0.45	11	0.400
Walking, h/d	2.1 ± 0.31	10	2.7 ± 0.29	11	0.165
August 9, 2017 (24.4 °C maximum temperature; 0 h THI[a] ≥72; mostly sunny)					
Grazing, h/d	12.4 ± 0.53	10	10.7 ± 0.52	11	0.031
Resting, h/d	9.7 ± 0.48	10	10.7 ± 0.45	11	0.229
Walking, h/d	2.2 ± 0.31	10	2.8 ± 0.29	11	0.163
August 14, 2017 (21.1 °C maximum temperature; 0 h THI[a] ≥72; some precipitation 0215 to 0255 h)					
Grazing, h/d	11.8 ± 0.53	10	9.7 ± 0.53	10	0.009
Resting, h/d	9.9 ± 0.48	10	11.8 ± 0.47	10	0.049
Walking, h/d	2.7 ± 0.31	10	2.8 ± 0.30	10	0.818
August 15, 2017 (25.6 °C maximum temperature; 0 h THI[a] ≥72; mostly sunny)					
Grazing, h/d	12.2 ± 0.53	10	10.8 ± 0.53	10	0.079
Resting, h/d	9.5 ± 0.48	10	10.3 ± 0.47	10	0.299
Walking, h/d	2.6 ± 0.31	10	3.1 ± 0.30	10	0.308
August 16, 2017 (27.2 °C maximum temperature; 7 h THI[a] ≥72; mostly sunny)					
Percent of time on slopes >15%	17.2 ± 1.82	11	6.2 ± 2.00	9	0.0002
Average elevation, m	1,606 ± 5.3	11	1,591 ± 5.8	9	0.047
Average slope, %	8.1 ± 0.51	11	5.6 ± 0.54	9	0.001
August 21, 2017 (26.1 °C maximum temperature; 7 h THI[a] ≥72; clear)					
Maximum slope, %	26.5 ± 2.99	7	17.6 ± 2.82	8	0.033
August 25, 2017 (29.4 °C maximum temperature; 3 h THI[a] ≥72; mostly sunny)					
Grazing, h/d	11.3 ± 0.67	4	10.8 ± 0.59	6	0.551
Resting, h/d	11.5 ± 0.65	4	10.8 ± 0.55	6	0.425
Walking, h/d	1.5 ± 0.40	4	2.6 ± 0.34	6	0.041
August 26, 2017 (30.6 °C maximum temperature; 7 h THI[a] ≥72; clear)					
Grazing, h/d	11.4 ± 0.67	4	10.8 ± 0.59	6	0.523
Resting, h/d	11.3 ± 0.65	4	10.6 ± 0.55	6	0.468
Walking, h/d	1.7 ± 0.40	4	2.8 ± 0.34	6	0.046
August 27, 2017 (30.6 °C maximum temperature; 6 h THI[a] ≥72; clear)					
Grazing, h/d	11.6 ± 0.67	4	10.7 ± 0.62	5	0.321
Resting, h/d	11.2 ± 0.65	4	10.9 ± 0.58	5	0.687
Walking, h/d	1.5 ± 0.40	4	2.6 ± 0.36	5	0.039
DTD, km/d	7.0 ± 0.59	4	5.0 ± 0.53	5	0.017
August 28, 2017 (31.1 °C maximum temperature; 8 h THI[a] ≥72; mostly sunny)					
Grazing, h/d	11.7 ± 0.67	4	10.9 ± 0.62	5	0.430
Resting, h/d	11.1 ± 0.65	4	10.3 ± 0.58	5	0.400
Walking, h/d	1.6 ± 0.40	4	3.0 ± 0.36	5	0.015

[1]Efficient cows were ranked as LRFI and Inefficient cows were ranked as HRFI as yearling heifers.

[a]THI = temperature humidity index. MHL is experienced by livestock when the THI exceeds 72. Severe heat load is experienced when THI reaches 79. No days were encountered with THI ≥79.

cattle did graze longer ($P < 0.05$) during the 2000 to 2200 time period. Inefficient cattle positioned themselves at lower areas of the pasture, closer to shade and water when experiencing greater heat load during the summer of 2016 (Fig. 4). Figure 4 shows GPS locations for all the hot days in

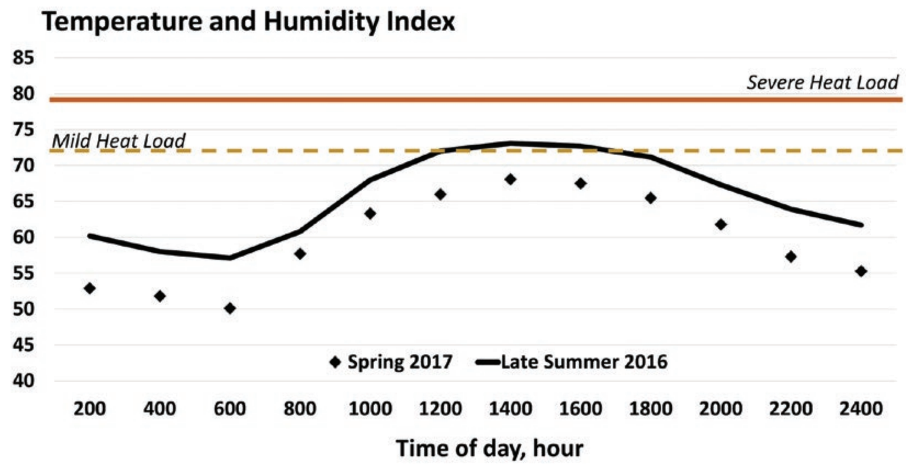

Figure 1. Average THI over 6 d for spring 2017 and summer 2016. MHL is experienced by livestock when the THI exceeds 72 and severe heat load is experienced when the THI reaches 79. During the 6-d period in 2017, there were a total of 2 h of THI ≥72. During the 6-d period in 2016, there were a total of 35 h of THI ≥72. Grazing behavior for the efficient vs. inefficient cattle in this trial had marked differences when the THI was above or below the threshold for MHL for extended time periods during the day (see Figs. 2 and 3 and Tables 8 and 9).

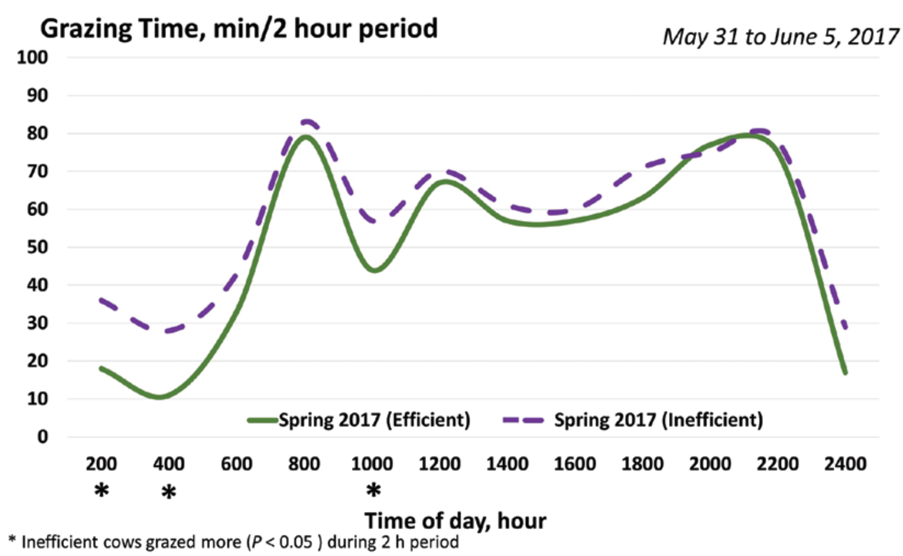

Figure 2. Daily time budget for grazing activity for lactating (118 d) Efficient (n = 8) vs. Inefficient (n = 8) 2-yr-old cows on Idaho rangeland in the spring of 2017. Efficient cattle were ranked as LRFI and Inefficient cattle were ranked as HRFI as yearling heifers. This 6-d time period was characterized by only having 2 h with THI being ≥72 (MHL). For 5 of the 6 days, total daily GT for Inefficient cattle exceeded that of Efficient cattle by 1.7 h ($P < 0.05$; see Table 9). Inefficient cattle started grazing earlier and continued the morning grazing bout later in the morning ($P < 0.05$) than did Efficient cattle.

August 2016 (THI ≥72) for two cows representative of the majority of both efficient and inefficient cattle. The GPS data confirm the changing patterns of grazing behavior as these divergently ranked 2-yr-old cattle were challenged by metabolic heat load.

In this semiarid environment with less humidity, the THI never exceeded the threshold necessary to move into a severe heat load (THI ≥79). Nevertheless, the days that cows experienced MHL (72 ≤ THI < 79) with limited cloud cover or wind caused changes in behavior between the efficient vs. inefficient cows.

Cow efficiency and rangeland adaptability Cows that have the genetics for improved feed efficiency exhibited behavior to better access terrain and distribute more evenly on rangeland in the summer time. On public land ranches with endangered fish or riparian area concerns, this adds further value to these efficiently ranked cows. Recent research (Bailey et al., 2015; Pierce, 2019) suggests that genetic markers may exist to classify cows that better fit rugged rangeland environments and that there may be a relationship between RFI classification and terrain use by beef cattle. Our research supports the conclusions reached by those scientists.

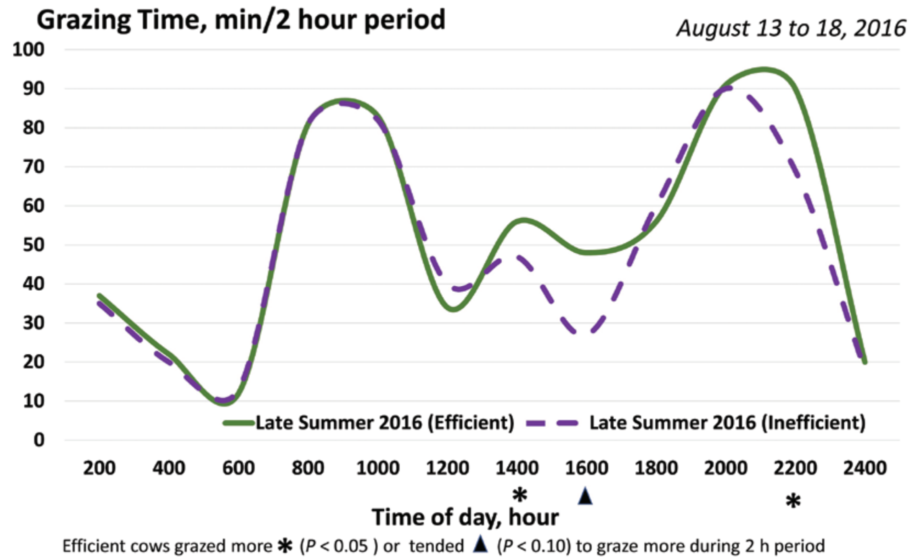

Figure 3. Daily time budget for grazing activity for lactating (196 d) Efficient (n = 10) vs. Inefficient (n = 9) 2-yr-old cows on Idaho rangeland in the summer of 2016. Efficient cattle were ranked as LRFI and Inefficient cattle were ranked as HRFI as yearling heifers. This 6-d time period was characterized by having 35 h with THI being ≥72 (MHL). Inefficient cattle spent less time ($P < 0.05$; $P < 0.10$) grazing than did Efficient cattle for a 4-h time period during the heat of the day.

A matter of concern is whether efficient cows are able to maintain similar BW and BCS and calf weaning weights when grazing rangeland. Lower RFI (more efficient) is associated with increased leanness, at least in the feedlot (Richardson et al., 1998; Herd and Bishop, 2000; Herd et al., 2003; Kerley, 2010). A review article by Randel and Welsh (2013) reported that "*Selection for low residual feed intake results in selection of leaner heifers that reach puberty at older ages. These leaner heifers calve later in their first and subsequent calving seasons*." Herd et al. (2003) stated that selection for lower RFI might affect reproductive performance of the progeny (i.e., increased leanness may fail to provide the necessary body stores to maintain reproductive efficiency in situations with limited feed availability). Conversely, Kerley (2010) stated that the effect on reproduction with negative-RFI cattle (greater efficiency) would be minimal.

The magnitude of having leaner heifers come into the cow herd should not be a problem with more productive grazing environments, but it could be a problem with harsh environments with low feed availability. Some of this negative effect would be ameliorated by lesser maintenance requirements, especially as the heifer matures. It is important to evaluate cows differing in feed efficiency in a rangeland environment for both productivity and adaptability (grazing behavior, harvesting efficiency, and terrain use).

Conflicting reports for adaptability to a grazing environment by efficient vs. inefficient cattle are present in reported research. In a study by Basarab et al. (2011) on improved pasture in Alberta, Canada, with *B. taurus* heifers, negative-RFI heifers had lower pregnancy (77%; $P = 0.09$) and calving (73%; $P = 0.05$) rates than did positive-RFI cattle (86% pregnancy; 84% calving). Another study conducted by Basarab et al. (2007) over 10 production cycles revealed that cows that produced low-RFI progeny had 2 to 3 mm more backfat than dams that produced high-RFI progeny. A subset of these mature cows were tested after weaning on a diet of barley silage, barley straw, and protein supplement, and low-RFI cows consumed less feed than high-RFI cows.

A principal reason for our doing this research was to determine if efficient cattle, faced with the added stress of lactation, could function competitively to their inefficient herdmates with respect to grazing behavior and production. Our earlier research (Sprinkle et al., 2020) indicated that efficient 2-yr-old nonlactating cows appeared to better handle the stresses of grazing poor quality, late-season forage in a rangeland environment, losing less BCS and BW. Realizing the challenges that lactation places on cows grazing rangeland and acknowledging the lower BCS that other research has identified for young LRFI cows, we documented the effects of RFI status on BCS, BW, milk production, and calf weaning weights in this rangeland research.

Table 11 illustrates the production results obtained for this small dataset of 48 2-yr-old cows on Idaho rangeland in 2016 and 2017. Efficient cattle performed similarly ($P > 0.408$) to inefficient cattle in this rangeland setting in all respects for milk production, calf weaning weights, BCS, and

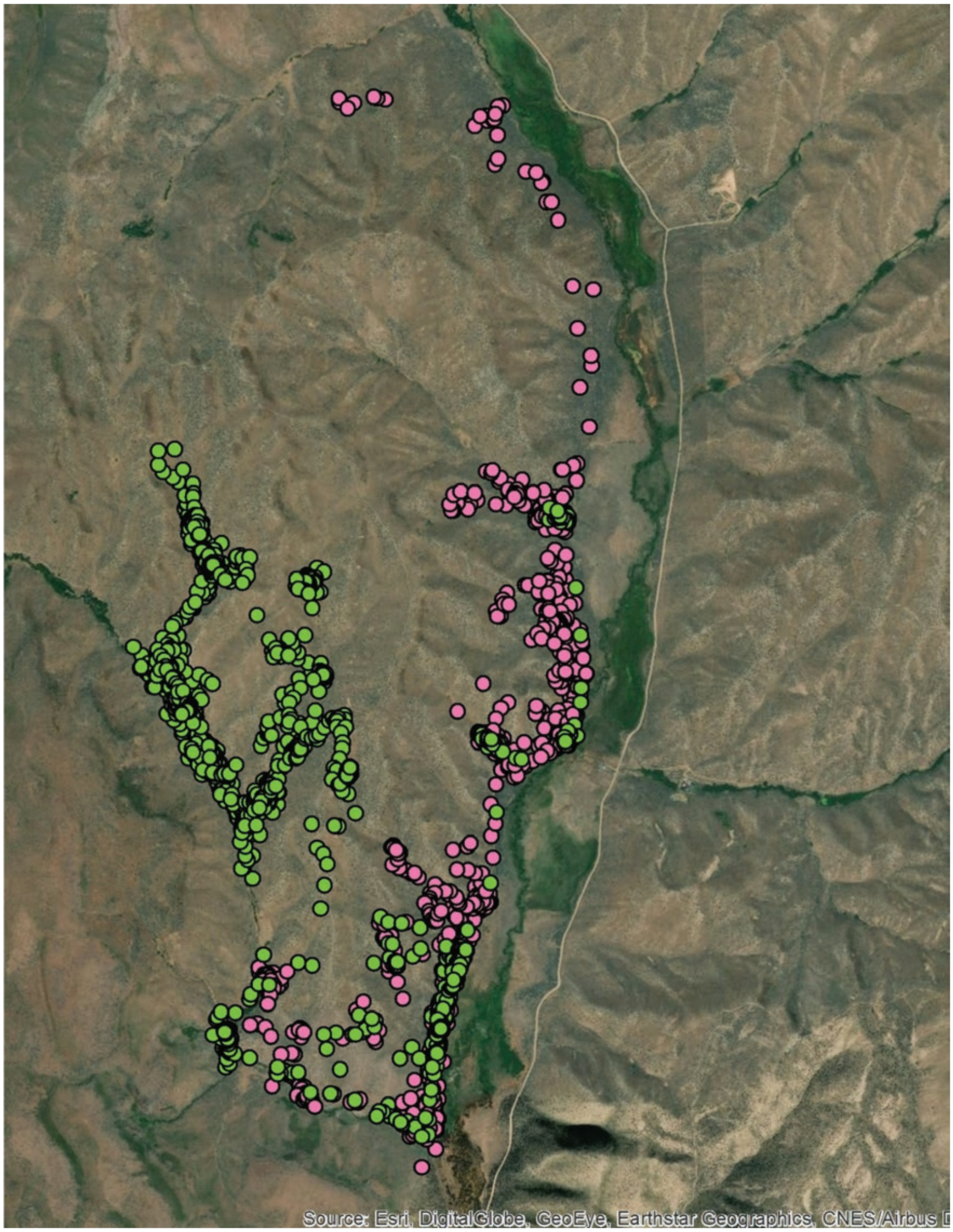

Figure 4. Efficient vs. Inefficient cow grazing locations during all hot days (days with the THI ≥72; n = 10 for Efficient; n = 9 for Inefficient) in August 2016. Efficient cattle were ranked as LRFI and Inefficient cattle were ranked as HRFI as yearling heifers. Efficient cow is shown in green and Inefficient cow is shown in pink. Pink dots are at lower elevations. For this time period, 70% of the Efficient cattle (7 of 10 collars used for GPS map) utilized higher elevations ($P < 0.05$; Table 8) while 56% of Inefficient cattle (five of nine collars used for GPS map) favored lower elevations ($P < 0.05$; Table 8). These two cows are representative of the aforementioned groups.

BW. Early indications imply that efficient, lactating 2-yr-old cattle suffered no negative productivity effects while grazing Idaho rangelands when compared with inefficient cattle with greater appetite. We will continue to gather production data over a period of years and will be evaluating fertility, longevity, and profitability of divergently ranked cattle for feed efficiency in both an irrigated and rangeland environment.

The preponderance of our results from both GPS and accelerometer data indicate that cattle ranked as efficient via RFI also function competitively in rangeland environments. We have rejected our original hypothesis that these young 2-yr-old efficient cattle may face a disadvantage when the added stress of lactation is experienced in an extensive rangeland environment. Rather, it appears that when cattle experience MHL during the summer, efficient (LRFI) cattle climb higher in rugged terrain pastures and spend less time resting during the heat of the day. This finding is one of several important considerations when contemplating what

Table 11. Cow and calf production data for lactating 2-yr-old cows on rangeland

Item	Efficient cows[1]	*n*	Inefficient cows[1]	*n*	*P*-value
2016					
March 25 milk production, kg/d[2]	7.9 ± 0.42	11	8.1 ± 0.42	11	0.767
March 30 cow BW, kg	463 ± 10.1	12	472 ± 10.1	12	0.516
March 30 cow BCS	4.9 ± 0.16	12	5.0 ± 0.16	12	0.719
August 1 cow BW, kg	458 ± 9.8	12	462 ± 9.8	12	0.770
August 1 cow BCS	5.4 ± 0.19	12	5.5 ± 0.19	12	0.764
August 1 milk production, kg/d[2]	5.3 ± 0.64	11	4.9 ± 0.80	7	0.731
September 12 cow BW, kg	470 ± 9.7	12	474 ± 9.7	12	0.757
September 12 cow BCS	4.9 ± 0.21	12	4.7 ± 0.21	12	0.408
September 12 adjusted weaning wt, kg[3]	259 ± 6.2	12	257 ± 6.2	12	0.778
2017					
May 2 cow BW, kg	466 ± 11.5	12	475 ± 11.5	12	0.618
May 2 cow BCS	5.5 ± 0.15	12	5.5 ± 0.15	12	1.000
July 28 cow BW, kg	448 ± 10.1	12	449 ± 10.1	12	0.973
July 28 cow BCS	4.4 ± 0.21	12	4.3 ± 0.21	12	0.781
September 13 cow BW, kg	458 ± 10.3	11	464 ± 10.8	10	0.709
September 13 cow BCS	4.6 ± 0.17	11	4.8 ± 0.18	10	0.518
September 13 adjusted weaning wt, kg[3]	264 ± 5.8	12	258 ± 5.8	12	0.428

[1]Efficient cows were ranked as LRFI and Inefficient cows were ranked as HRFI as yearling heifers.

[2]Estimated by weigh-suckle-weigh following a 13.5 h separation period for March 25 with a 55 d postpartum interval for Efficient cows and 53 d interval for Inefficient cows; August 1 had 12 h separation interval with 182 d postpartum interval for Efficient cows and 180 d interval for Inefficient cows.

[3]Calf weights adjusted to 205 d.

type of cattle should be used when grazing rugged, riparian pastures with endangered species concerns. Our research suggests that this would be particularly true for grazing operations located in rugged terrain closer to the equator than Idaho.

Conflict of interest statement. None declared.

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