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Original Research

Changes in Forage Quality and Cattle Performance with Short-Duration Grazing of Mesic Meadows in the Intermountain West ☆

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ABSTRACT

Managers tasked with balancing livestock production and wildlife habitat in mesic meadows face a unique set of challenges. These challenges are compounded in the arid western United States because mesic areas comprise only a small portion of the landscape yet provide vital forage and water resources to livestock and wildlife and are essential to underlying ecosystem integrity and function. Our objectives were to compare the effects of short-duration grazing treatments that varied by season and intensity on the quantity and nutrient quality of pasture forage and average daily gains (ADG) of yearling cattle. We established pastures ($n = 15$ total pastures) in mesic meadows at the University of Idaho Rinker Rock Creek Ranch in south-central Idaho and stocked them with heifers during 2019 and 2020. Heifers grazed six pastures in June (early-season; 16 d) and six pastures in August (late-season; 16 d) at moderate (30−40%) and high (70-80%) relative utilization levels ($n = 3$ pastures per treatment). Three pastures were not grazed by cattle representing controls. Forage was collected and analyzed for nutrient quality at pregrazing, postgrazing, and after a period of regrowth in late September. Contrasted against all other treatments, early-season grazing at a high-intensity produced forages with the highest crude protein ($P <$ 0.001) and lowest neutral-detergent fiber ($P \leq 0.04$) after regrowth. ADGs of yearling heifers were greater ($P \leq 0.01$) during the first year of the trial than the second year. Differences in ADG were not associated with grazing season ($P = 0.08$) or intensity ($P = 0.12$), despite numeric differences. Forage quantity and quality and heifer ADG responses varied between years, likely due to spring and annual precipitation differences. This study demonstrates the effectiveness of early-season grazing at a high intensity for improving forage quality and increasing ADG of livestock grazing mesic meadows.

Introduction

Livestock grazing in mesic or riparian areas creates a unique set of challenges to rangeland managers because of the importance of these habitats to ecological communities and underlying ecosystem integrity and function. In the western United States, these challenges are compounded by a paucity (< 3%) of mesic systems at the landscape scale (Kauffman and Krueger 1984). Unmanaged livestock grazing can degrade rangeland function and associated resources of these ecosystems (Belsky et al. 1999). However, research documenting the adverse effects of livestock grazing often focuses on historic overgrazing, which is not always reflective of modern management (Borman 2005; Davies et al. 2014). Today, a growing body of literature provides evidence for the utility of livestock grazing to sustain or enhance aspects of ecological function when adequately managed (Frost and Launchbaugh 2003; Rosenthal et al. 2012; Oles et al. 2017).

In conjunction with climatic conditions, manipulations of grazing management such as season of use or grazing intensity can facilitate change in ecosystem characteristics including plant community composition or soil exposure (Roath and Krueger 1982; Davis et al., 2014; Souther et al., 2019). When manipulations are applied to grazing management to achieve a desired objective, we refer to this specific application as targeted grazing (Bailey et al.

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2019). Managers may implement targeted grazing to improve habitat quality for wildlife (Krausman et al. 2009), increase plant diversity (Rosenthal et al. 2012), or improve forage quality (Clark et al. 2000; Vavra 2005). Because mesic meadows support vital forage resources for both wildlife and livestock, applying targeted grazing strategies to enhance the quantity and nutritional quality of forages could provide better foraging opportunities and more valuable forage resources later in the year.

Forage production may be stimulated under varying levels of grazing pressure when an adequate opportunity for regrowth is allotted (McNaughton 1979; McNaughton 1983; Donkor et al. 2002). Further, managed grazing can improve the nutritional quality of forages available following regrowth (Vavra 2005; Bailey et al. 2019). For instance, simulated grazing during spring at moderate utilization prompted increases in crude protein, calcium, and phosphorus of bluebunch wheatgrass *(Pseudoroegneria spicata)* in the fall when compared with unclipped plants (Pitt 1986). Further, late-spring grazing by sheep improved crude protein content of bluebunch wheatgrass and Idaho fescue *(Festuca idahoensis)* compared with ungrazed plots (1.0% and 1.3%, respectively) in November on Rocky Mountain elk *(Cervus elaphus nelsoni)* winter range in northeastern Oregon (Clark et al. 2000). In Nevada, livestock grazing between June and July on mesic meadows stimulated regrowth and delayed senescence of palatable forbs, resulting in greater use of grazed pastures than ungrazed pastures by greater sage-grouse (*Centrocercus urophasianus;* Evans 1986). When deliberately applied and executed, manipulations of grazing season and intensity can provide a valuable means for enhancing wildlife habitat and dietary resources; however, such manipulations may not serve as an optimal strategy for livestock production (Holechek et al. 1982).

Grazing livestock performance and production are a product of the relationship among grazing management, forage productivity, and forage quality. Comparisons among grazing management strategies given available pasture and forage resources help determine optimal animal gain and production outcomes (e.g., Heitschmidt et al. 1982; Jung et al. 1985). Further, livestock production and forage quality responses are often evaluated under the context of grazing to determine how to maximize the utility of available forages (e.g., Wenick et al. 2008). Forage quality is positively correlated with crude protein, a measure of nitrogen content, and total digestible nutrients, indicative of energy and forage digestibility (Ball et al. 2001). Alternatively, forage quality is negatively correlated with acid detergent fiber and neutral detergent fiber (NDF), indicators of fiber content and digestibility, which can affect forage intake potential (Ball et al. 2001). In tandem, grazing management and forage responses interact with one another and facilitate livestock performance, thereby determining the effectiveness of the management strategies for livestock production purposes. For example, increases in alfalfa composition of forages under rotational grazing resulted in higher digestibility levels and greater crude protein contents throughout the grazing season compared with continuous grazing, and this change in forage quality resulted in greater weight gains of cattle under rotational management than continuous management (Walton et al. 1981).

Like wildlife, livestock prefer portions of the landscape that yield the resources necessary to support maximum individual performance, otherwise known as optimal habitat (Bailey 2005). In arid landscapes, livestock are attracted to sources of water (Pringle and Landsberg 2004), higher vegetation quality (Zengeya et al. 2012), and less rugged topography (Bailey et al. 1996). Because these are also descriptors of many types of mesic habitats, it is essential to understand how livestock performance, forage quantity, and forage quality respond to various grazing applications and, further, to determine the influence of these responses on resources important to wildlife.

The objective of this experiment was to evaluate how manipulations of season and intensity of short-duration grazing influence the quantity and quality of forages and average daily gain (ADG) of crossbred yearling heifers in mesic meadows. We hypothesized that forage quantity would decrease as a function of increasing grazing pressure. Further, we hypothesized that forage quality would be a function of grazing season and intensity because these differences in grazing management would facilitate variation in the phenological stages and regrowth progression of forages (Clark et al. 2000). Therefore, we predicted that heifers would have access to higher-quality forages during early-season grazing than during late-season grazing. Also, we expected that optimal forage quality in the fall would be most pronounced in pastures grazed during the early season at greater intensities. Lastly, we hypothesized that ADG of yearling heifers would not vary significantly among treatments due to the limited amount of time available to individuals to select the most palatable vegetation. We predicted that ADG would be slightly greater in early-season treatments than late-season treatments due to differences in the quality of available forage during these seasons (Waldie et al. 1983; Ball et al. 2001) and that heifers grazing at moderate intensities would have greater gains than heifers at high intensities. To help account for variation in forage responses to grazing management, we accounted for patterns of precipitation and seasonal changes in soil moisture.

Methods

Location

The Rinker Rock Creek Ranch is a research station managed by the University of Idaho and located approximately 15 km southwest of Bellevue, Idaho, in Blaine County. Elevation on the ranch ranges from 1,475 to 1,860?. Historically, precipitation (1981–2010) ranged from 30.5 to 40.6 cm, and temperatures (1981–2010) ranged from −10.5°C in December to 31.1°C in July and August (PRISM Group and Oregon State University 2020). To determine the effects of variation in short-duration grazing treatments, we established experimental grazing pastures in mesic meadows on the southern end of Rinker Rock Creek Ranch (43°20′57.51“N, 114°22′49.31”W).

The mesic meadows used in this experiment were historically planted for hay production and livestock grazing. During our grazing trial, forage grass communities were dominated by non-native meadow foxtail *(Alopecurus pratensis)*. Less abundant grasses included smooth brome *(Bromus inermis)* and Kentucky bluegrass *(Poa pratensis)*. Common dandelion *(Taraxacum officinale)*, yellow salsify *(Tragopogon dubius)*, clover (*Trifolium* spp.), and willowherb (*Epilobium* spp.) were the most abundant forbs throughout the meadow. Willows (*Salix* spp.) dominated the riparian corridor along Rock Creek, but Woods' rose *(Rosa woodsii)* and mountain big sagebrush *(Artemisia tridentata)* were also present at low densities (< 2% cover of entire meadow).

Experimental design

We used a completely random design to evaluate the effects of short-duration (16-d) grazing on responses of forage quantity, quality, and livestock gains. Short-duration grazing took place from May to August. Grazing treatments occurred in the same short-duration pastures ($n = 15$), approximately 1.7 ha each, during 2019 and 2020. Year was incorporated into the design of all analyses. Treatments were designed as a 2×3 factorial reflecting levels of season (early or late) and grazing intensity (control, moderate, high). To evaluate differences in responses during regrowth sampling periods, treatments were designed as a 2×2 factorial plus

Table 1
Average relative use ± standard deviation (%)[1] of common grasses collected post grazing (< 7 d) in pastures ($n = 3$ pastures per treatment) associated with early-season (early June) and late-season (early-August) grazing treatments at moderate (30–40%) and high (70–80%) grazing intensities in 2019 and 2020 at the Rinker Rock Creek Ranch in south-central Idaho.[2]

	Early		Late	
Yr	Moderate	High	Moderate	High
2019	36.02 ± 4.32	70.10 ± 5.53	38.10 ± 3.50	77.22 ± 2.81
2020	38.53 ± 2.14	79.97 ± 2.58	39.25 ± 2.40	78.33 ± 1.53

[1] Relative use was determined using a modified utilization gauge and growth curves developed for common meadow grasses.
[2] Pastures were grazed for 16 d in 2019 and 2020.

control because controls were common for both the early- and late-season observations. Two seasonal grazing treatments were created by stocking yearling heifers into six pastures early ($n = 148$; average beginning body weight (BW); hereafter, BW = 359 ± 2.86 kg; June 4–20, 2019; June 2–18, 2020) and six pastures late ($n = 113$; average beginning BW = 396 ± 3.57 kg; July 30–August 15, 2019; July 28–August 13, 2020) during the grazing season. At the onset of early-season grazing, forage grasses were transitioning from boot to flowering stages. Alternatively, forage grasses had developed seed and were in seed shatter stages during late-season grazing. During both early- and late-grazing seasons, yearling heifers were stratified by BW and randomly stocked into three pastures to achieve moderate grazing utilization (30–40% relative utilization; $\bar{x} = 6$ heifers per pasture in 2019, average beginning BW = 391 ± 4.24 kg; $\bar{x} = 5$ heifers per pasture in 2020, average beginning BW = 352 ± 5.05 kg) or three pastures to achieve high grazing utilization (70–80% relative utilization; $\bar{x} = 18$ heifers per pasture in 2019, average beginning BW = 394 ± 3.89 kg; $\bar{x} = 14$ heifers per pasture in 2020, average beginning BW = 353 ± 3.54 kg). We restocked the same heifers used in early-season treatments for the late-season treatments. We reassigned individual heifers to the same grazing intensity pastures during both early and late seasons. Three pastures provided controls without cattle grazing ($n = 3$ pastures per treatment; $n = 15$ total pastures). We calculated stocking rates to achieve the desired grazing utilization level using dry weight plant biomass production (g) extrapolated to the pasture scale (Ellison et al. in press). In each pasture, we monitored relative use of yearly forage production during and after trials using a modified utilization gauge with curves developed for the most common grasses across the meadow (Aldon and Francis 1984; Table 1). We developed height-weight relationship curves by measuring heights and corresponding weights (g) of forage grasses ($n = 50$ per species) within pastures before grazing. We used grass height measurements of grazed and ungrazed plants collected along vegetation transects to determine relative use (%) of livestock after grazing (USDA and USDOI 1996).

Livestock

The University of Idaho Institutional Animal Care and Use Committee (IACUC) approved all procedures conducted as part of this study (IACUC 2019-8; IACUC 2020-08). In 2019, we stocked crossbred (Hereford × Angus) yearling heifers ($n = 75$; average beginning BW = 377.4 ± 5.3 kg) from the University of Idaho Nancy M. Cummings Research, Extension, and Education Center in short-duration grazing pastures. In 2020, we stocked crossbred (Hereford × Angus) yearling heifers ($n = 73$; 341 ± 4.4 kg initial BW) supplied by Prescott Cattle for use in the experiment. During both years of investigation, we weighed heifers using a portable livestock scale and scale-head (3′ × 8′ Livestock Scale, Central City Scales Inc., Central City, NE; Scale Indicator–Tru-Test XR 5000, Datamars, Mineral Wells, TX). Heifers were weighed 2 consecutive days before and after grazing trials. We calculated final pregrazing and postgrazing weights as the average between weights collected during consecutive weigh days. Once pretrial BWs were collected, heifers were stratified by BW and randomly assigned to pastures ensuring that average pregrazing BW was similar across pastures.

Forage biomass and nutrient analysis

Vegetation transects ($n = 4$ per pasture) stratified by dominant vegetation cover type were established in short-duration grazing pastures. Along transects, we collected vegetation biomass three times: before (> 7 d) and after (< 7 d) livestock grazing and following a period of regrowth (late September) at four locations per pasture. In ungrazed control pastures, we collected biomass before (< 7 d) and after (< 7 d) grazing during early- and late-season periods and again in late September. We collected biomass in plots measuring 1 m^2 paired with vegetation transects. We clipped biomass in plots to ground level at the 10-, 20-, 30-, 40-, or 50-m marks of transects coinciding with pre-early season, postearly season, prelate season, postlate season, and regrowth sampling periods, respectively. We changed locations of biomass plots between sampling periods to avoid potential effects from previous clipping. When collecting biomass, we only clipped and collected the current year's growth to prevent skewing the current year's production results with the previous year's residual biomass. Once clipped, we sorted vegetative biomass by functional group (grass and grasslike plants and forbs) into paper bags for weight, percent dry matter (DM), and nutrient analyses.

We determined the wet weight of biomass samples by weighing biomass bags to the nearest gram using a digital scale (VALOR 7000 Bench Scale, OHAUS Corporation, Parsippany, NJ). We then oven-dried samples in a forced-air oven at 65.6°C for 48 h and then reweighed samples following drying to obtain dry weight (g) measurements. To determine relative forage DM of each sample, we divided dry weight measurements by wet weight measurements and multiplied values by 100. Once we obtained DM values, we ground individual forage samples once through a 2-mm screen and then through a 1-mm screen using a forage cutting mill (Retsch, Verder Scientific Inc., Newtown, PA). Samples were bagged and shipped to Ward Laboratories, Inc. in Kearney, Nebraska, to determine crude protein (%; CP), total digestible nutrients (%; TDN), acid detergent fiber (%; ADF), and NDF (%; NDF) on a DM basis (Ward Laboratories Inc. 2021).

Soil moisture

We collected soil moisture (m3 m-3) information beginning the first week of grazing trials during both years of the study for use as an explanatory covariate when comparing differences in herbaceous biomass, CP, TDN, ADF, and NDF. We placed soil moisture sensors (5TM and EC-20 probes, Decagon, Pullman, WA; Teros 10 soil moisture sensors, METER Group, Pullman, WA) and data loggers (EM-50 and EM-5 loggers, Decagon, Pullman, WA) that recorded soil moisture every 24 h at a single location in each pasture to collect coarse temporal information (2019: June 4–October 3; 2020: June 1–September 23). Measurements were averaged by week to provide soil moisture measurements throughout grazing trials in both 2019 and 2020.

Statistical analysis

We used linear mixed-effects models (LMMs) from the package lme4 in R for all analyses (Bates et al. 2015; R Core Team 2020). We adjusted error degrees of freedom within models using Satterthwaite method. We assessed diagnostic plots of residuals versus fitted values and quantile-quantile plots to ensure models satisfied the assumptions of homogeneity of variance and normality. We deemed explanatory variables and differences between them statistically significant at $P \le 0.05$. When we observed a statistically significant effect, we evaluated differences among levels of explanatory variables relevant to our underlying hypotheses using the package emmeans in R (Lenth 2021). We applied a Bonferroni adjustment when evaluating multiple comparisons to limit type II error. Estimates are reported as least-squared means ± 1 standard error derived from the LMMs.

Forage biomass and nutrient analysis

To determine how varying season and intensity of short-duration grazing treatments influenced quantity and quality of forages, we applied LMMs to the response values of forage DM, herbaceous biomass (kg ha^{-1} DM; hereafter, forage biomass), CP, TDN, ADF, and NDF aggregated by mean to the pasture level during pregrazing, postgrazing, and regrowth sampling periods. We evaluated the main effects of year, season of grazing, and grazing intensity, including the three-way interaction among these variables and all possible two-way interactions on forage nutrient responses during sampling periods. These models assessed the fixed effects of year, season of grazing, grazing intensity, the three-way interaction among all main effects, and all possible two-way interactions through single and multiple degree of freedom contrasts. We included pasture as a random effect in all models to account for intrinsic variation among pastures.

Average daily gains of livestock

Models to evaluate how ADGs of livestock responded to short-duration grazing treatments included the fixed main effects of year, season of grazing, intensity of grazing, and the three-way and all possible two-way interactions. Grazing season and intensity were established as a 2×2 factorial to represent early- and late-season applications at both moderate and high intensities of grazing. We included pasture as a random effect in all models to account for intrinsic differences associated with each pasture. Finally, we evaluated the effect of pregrazing BW measured as the initial weight of each individual recorded before stocking as a potential covariate. Estimates of ADG are reported as kg d^{-1} plus or minus standard error.

Results

Precipitation

Spring and annual precipitation varied between years. In 2019, annual precipitation (77.3 cm) was above average, but in 2020 it was average (35.81 cm) in Camas County, Idaho, at 1,750-m elevation and approximately 37 km northwest from our study area (Fig. 1; USDA and NRCS 2021).

Dry matter

There was a year-by-season interaction ($P < 0.001$) before grazing, an intensity ($P = 0.01$) and year-by-season interaction ($P = 0.04$) after grazing, and a season-by-intensity interaction following regrowth ($P = 0.04$) on forage DM. In all cases with year interactions, forage DM was lower in 2019 than 2020 while the patterns of DM over treatments were consistent. Before grazing, forage DM was lower in early-season ($P = 0.004$) and late-season ($P < 0.001$) grazing during 2019 (Early: 24.80% ± 2.27%, Late: 41.40% ± 2.27%) than 2020 (Early: 36.70% ± 2.27%, Late: 72.00% ± 2.27%; Fig. 2a). As expected, DM was also lower before early-season grazing than late-season grazing in 2019 ($P = 0.001$) and 2020 ($P < 0.001$; see Fig. 2a). Forage DM was greater ($P = 0.01$) after grazing occurred in high-intensity pastures (64.90% ± 2.58%) than in controls (49.80% ± 2.94%), but no differences in DM were observed between high and moderate intensities (57.60% ± 2.58%; $P = 0.20$) or between moderate intensity and controls ($P = 0.22$; see Fig. 2a). After grazing, DM was similar ($P = 0.28$) between 2019 (36.90% ± 2.75%) and 2020 (43.80% ± 2.75%) in the early season; however, DM in the late season was lower ($P < 0.001$) during 2019 (65.30% ± 2.75%) than 2020 (83.70% ± 2.75%; see Fig. 2a). Again, DM was lower following early-season than late-season grazing in 2019 ($P < 0.001$) and 2020 ($P < 0.001$; see Fig. 2a). Finally, after regrowth, DM in early-season high-intensity grazing (69.40% ± 3.56%) was numerically lower ($P = 0.06$) than in late-season high-intensity grazing (86.90% ± 3.56%), but comparisons between all season and intensity combinations indicated there were no differences in regrowth DM (see Fig. 2a).

Forage biomass

Biomass (kg ha^{-1} DM) depended on year-by-season ($P < 0.001$) and year-by-intensity ($P = 0.03$) interactions before grazing and the interaction between year and intensity ($P = 0.05$) after grazing, and they varied by year ($P < 0.001$) following regrowth. In all cases, year interactions describe greater estimates of forage biomass in 2019 than 2020 across treatments. Biomass estimates were greater before grazing in 2019 (Early: 1 701 ± 244, Late: 3 917 ± 244) than 2020 (Early: 1 157 ± 244, Late: 1 870 ± 244) during both early-season ($P = 0.03$) and late-season ($P < 0.001$; see Fig. 2b). Similarly, biomass estimates from before grazing decreased from 2019 to 2020 across control (2019: 3 147 ± 396, 2020: 1 677 ± 396; $P < 0.001$), moderate-intensity (2019: 2 405 ± 299, 2020: 1 608 ± 299; $P = 0.02$), and high-intensity (2019: 2 875 ± 299, 2020: 1 255 ± 299; $P < 0.001$) as the effects of grazing accumulated across two seasons (see Fig. 2b). Biomass estimates following grazing were greater during 2019 and 2020 in control (2019: 4 240 ± 431, 2020: 1 512 ± 431; $P < 0.001$) and moderate (2019: 2 394 ± 373, 2020: 725 ± 373; $P = 0.01$) intensities (see Fig. 2b). Estimates of biomass following grazing under high intensities were similar ($P = 0.22$) between years (2019: 1 529 ± 373, 2020: 455 ± 373; see Fig. 2b). In 2019, biomass was similar ($P = 1.00$) under high and moderate intensities after grazing but, as expected, greatest in ungrazed controls at that time ($P = 0.002$, $P = 0.05$, respectively). In 2020, biomass estimates following grazing were similar between high and moderate intensities ($P = 1.00$), but these estimates were also considered similar to ungrazed controls ($P = 0.74$, $P = 1.00$, respectively; see Fig. 2b). After regrowth, biomass estimates were again greater ($P < 0.001$) in 2019 (2 486 ± 195) than 2020 (712 ± 195; see Fig. 2b). Regrowth estimates of forage biomass were similar between control (2,285 ± 386) and moderate intensities (1 719 ± 273; $P = 0.78$), control and high intensities (1,136 ± 273; $P = 0.11$), and moderate and high intensities ($P = 0.48$) when averaged across years. During pregrazing ($P = 0.21$), postgrazing ($P = 0.94$), and regrowth ($P = 0.19$) sampling periods, we found no evidence to support inclusion of initial soil moisture as a potential covariate on forage biomass.

Crude protein

There was a year-by-season ($P = 0.03$) interaction before grazing, main effects of year ($P = 0.002$) and season ($P < 0.001$) after grazing, and a main effect of year ($P = 0.002$) and interaction between season and intensity ($P \le 0.01$) after regrowth on forage CP. Before grazing, CP was greater during the early season (2019: 11.86% ± 0.35%, 2020: 12.96% ± 0.35%) than late season (2019: 6.33% ± 0.35%, 2020: 6.32% ± 0.35%) in 2019 ($P < 0.001$) and 2020 ($P < 0.001$; Fig. 3a). Crude protein increased ($P = 0.03$) before early-season grazing from 2019 to 2020, whereas CP percentages were similar ($P = 1.00$) before late-season grazing between years (see Fig. 3a). After grazing, CP increased ($P < 0.002$) from 2019 (6.16% ± 0.24%) to 2020 (7.34% ± 0.24%) when averaged across

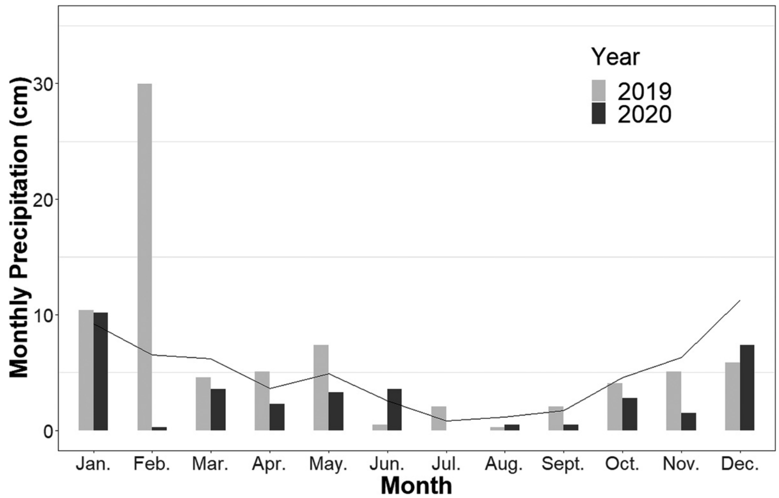

Figure 1. Monthly precipitation during 2019 and 2020. Average precipitation over the past 30 yr is displayed as a line. Data were collected from the US Department of Agriculture and Natural Resources Conservation Service Solider R. S. Idaho SNOTEL Site in Camas County, Idaho.

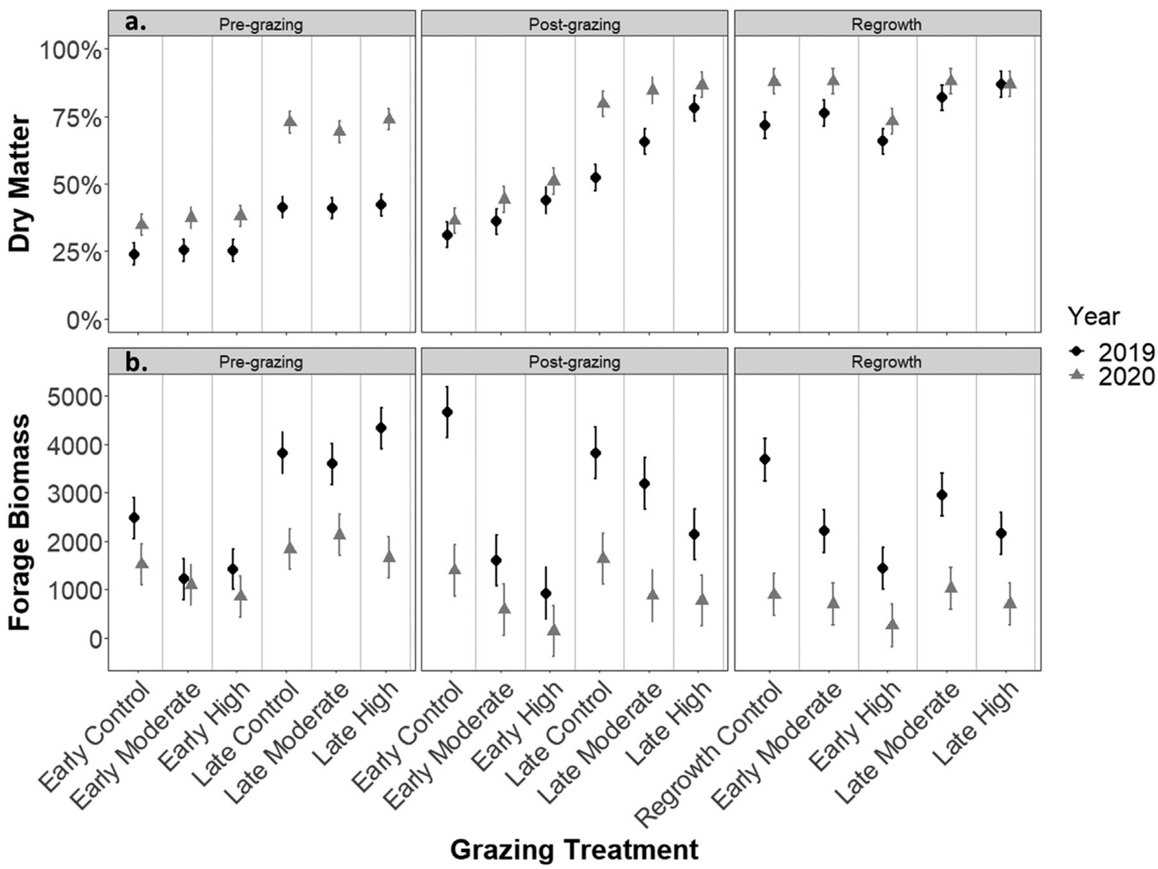

Figure 2. Least-squares means ± standard error of a, forage dry matter (%) and b, forage biomass (kg ha^{-1}) dry basis collected (< 7 d) during pregrazing and postgrazing sampling periods associated with early-season (early June) and late-season (early August) grazing and during the regrowth sampling period (late September) in 2019 and 2020 at the Rinker Rock Creek Ranch in south-central Idaho. Grazing treatments are described by season (early or late) and intensity (control, moderate, or high; n = 3 pastures per treatment).

all short-duration grazing treatments (see Fig. 3a). Again, CP was greater (P < 0.001) following early-season (8.71% ± 0.24%) than late-season (4.79% ± 0.24%) grazing (see Fig. 3a). CP was less responsive to grazing intensity (P = 0.08) than grazing season during postgrazing sampling; however, we did observe numerical declines in CP with increasing grazing intensity. Lastly, regrowth CP was greater (P = 0.002) in 2020 (5.47% ± 0.14%) than 2019 (4.57% ± 0.14%) across treatments and controls (see Fig. 3a). Across years, CP during the regrowth period was greatest in early-season high-intensity treatments (7.19% ± 0.26%) when compared with early-season moderate-intensity (4.79% ± 0.26%; P < 0.001), late-season moderate-intensity (4.71% ± 0.26%; P < 0.001), late-season high-intensity (4.12% ± 0.26%; P < 0.001), and control (4.28% ± 0.26%; P < 0.001) treatments (see Fig. 3a). Aside from early-season high-intensity, CP was similar (P > 0.05) across all other treatments during the regrowth period. CP was not adjusted for variation in initial soil moisture during pregrazing (P = 0.55), postgrazing (P = 0.06), or regrowth (P = 0.28) sampling periods.

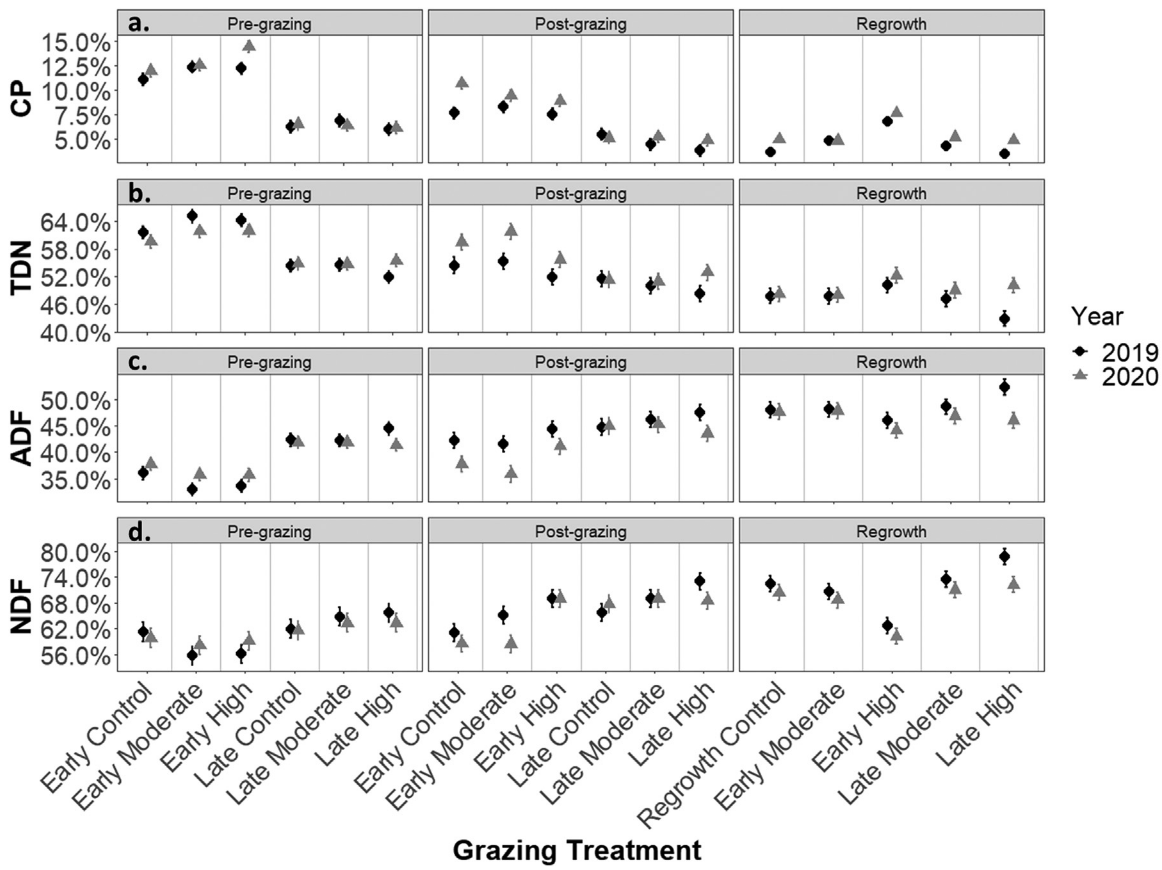

Figure 3. Least-squares means ± standard error of a, crude protein (CP), b, total digestible nutrients (TDN), c, acid detergent fiber (ADF), and d, neutral detergent fiber (NDF) on a dry basis collected (< 7 d) during pregrazing and postgrazing sampling periods associated with early-season (early June) and late-season (early August) grazing and during the regrowth sampling period (late September) in 2019 and 2020 at the Rinker Rock Creek Ranch in south-central Idaho. Grazing treatments are described by season (early or late) and intensity (control, moderate, or high; n = 3 pastures per treatment).

Total digestible nutrients

There was a year-by-season ($P = 0.02$) interaction before grazing, year ($P = 0.002$) and season ($P < 0.001$) main effects after grazing, and year ($P = 0.03$) effect following regrowth on forage TDN. Before grazing, forage TDN was greater in the early season than late season in 2019 (Early: 63.60% ± 0.77%, Late: 53.60% ± 0.77%; $P < 0.001$) and 2020 (Early: 61.10% ± 0.77%, Late: 55.00% ± 0.77%; $P < 0.001$; see Fig. 3b). After grazing, TDN was lower ($P = 0.002$) across all short-duration grazing treatments in 2019 (51.90% ± 0.70%) than 2020 (55.30% ± 0.70%; see Fig. 3b). Measurements of TDN were greater ($P < 0.001$) following early-season (56.40% ± 0.70%) than late-season (50.80% ± 0.70%) grazing when averaged over years and grazing intensities (see Fig. 3b). Regrowth TDN increased ($P = 0.03$) between 2019 (47.10% ± 0.74%) and 2020 (49.50% ± 0.74%) across all treatments and controls (see Fig. 3b). Forage TDN was numerically greater ($P = 0.07$) in early-season treatments (49.50% ± 0.83%) than late-season treatments (47.30% ± 0.83%) after regrowth; however, there were no statistical differences between grazing seasons. Initial soil moisture was not included as a covariate in TDN models during pregrazing ($P = 0.26$), postgrazing ($P = 0.22$), or regrowth ($P = 0.31$) sampling periods.

Acid detergent fiber

There was a year-by-season ($P = 0.02$) interaction before grazing, main effects of year ($P = 0.002$) and season ($P < 0.001$) after grazing, and a main effect of year ($P = 0.03$) following regrowth on forage ADF. Before grazing, ADF did not change from 2019 to 2020 under early-season (2019: 34.20% ± 0.68%, 2020: 36.40% ± 0.68%; $P = 0.12$) or late-season (2019: 43.00% ± 0.68%, 2020: 41.70% ± 0.68%; $P = 0.76$) grazing (see Fig. 3c). As expected, ADF values were lower before early-season grazing than late-season grazing in 2019 ($P < 0.001$) and 2020 ($P < 0.001$; see Fig. 3c). After grazing, ADF was greater ($P = 0.002$) in 2019 (44.40% ± 0.61%) than 2020 (41.40% ± 0.61%) when averaged across all treatments and controls (see Fig. 3c). Further, ADF was higher ($P < 0.001$) following late-season (45.40% ± 0.61%) than early-season (40.50% ± 0.61%) grazing (see Fig. 3c). Regrowth ADF measurements decreased ($P = 0.03$) from 2019 (48.60% ± 0.65%) to 2020 (46.50% ± 0.65%) across all treatments and controls (see Fig. 3c). In contrast to differences detected before and after grazing, regrowth ADF was similar ($P = 0.07$) between early-season (46.50% ± 0.73%) and late-season grazing (48.50% ± 0.73%; see Fig. 3c). Regrowth ADF was similar among all levels of grazing intensity ($P = 0.48$). Again, it was not necessary to include initial soil moisture as a potential covariate for forage ADF during pregrazing ($P = 0.26$), postgrazing ($P = 0.22$), or regrowth ($P = 0.31$) sampling periods.

Neutral detergent fiber

NDF varied by season ($P < 0.001$) before grazing, season ($P < 0.001$) and intensity ($P = 0.004$) after grazing, and year ($P = 0.01$) and the interaction between season and intensity ($P < 0.001$) after regrowth. NDF before ($P < 0.001$) and after ($P < 0.001$) grazing was lower in the early season (pregrazing: 58.30% ± 0.96%, postgrazing: 63.50% ± 0.84%) compared with late season (pregrazing: 63.40% ± 0.96%, postgrazing: 68.80% ± 0.84%; see Fig. 3d). Increases in

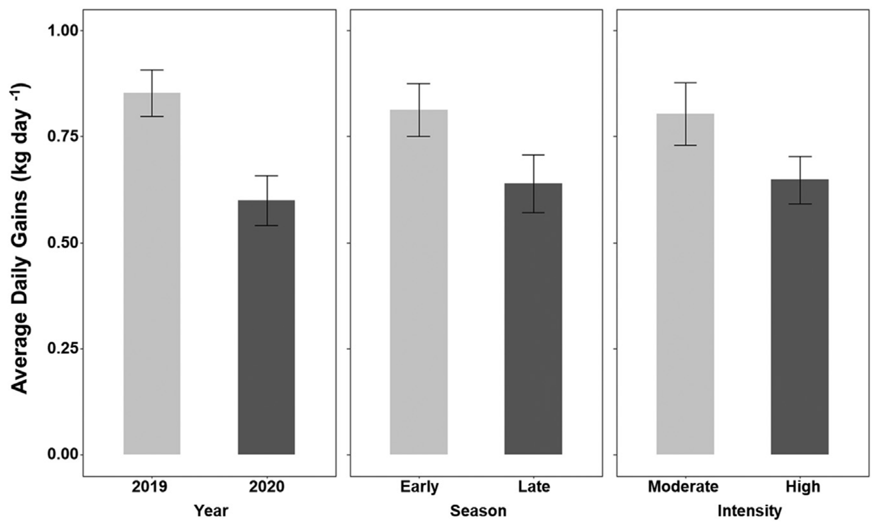

Figure 4. Least-squares means ± standard error of average daily gains (kg d^{-1}) per individual yearling heifer (Angus × Hereford crossbred) by year, season (Early: early June; Late: early August), and intensity (Moderate: 30–40% relative use; High: 70–80% relative use) of short-duration grazing treatments in 2019 and 2020 at the Rinker Rock Creek Ranch in south-central Idaho.

grazing intensity resulted in numerically higher NDF estimates after grazing (see Fig. 3d). NDF after grazing was greater under high-intensity grazing (69.90% ± 1.03%) than moderate-intensity (65.40% ± 1.03%; $P = 0.02$) or ungrazed controls (63.20% ± 1.10%; $P = 0.005$; see Fig. 3d). During the regrowth sampling period, NDF was lower ($P = 0.01$) in 2020 (68.50% ± 0.82%) than 2019 (71.60% ± 0.82%) across all treatments (see Fig. 3d). Further, NDF was lower under early-season high-intensity grazing (61.40% ± 1.52%) than early-season moderate-intensity (69.60% ± 1.52%; $P = 0.04$), late-season moderate-intensity (72.30% ± 1.52%; $P = 0.01$), late-season high-intensity (75.40% ± 1.52%; $P < 0.001$), and ungrazed controls (71.30% ± 1.08%; $P = 0.01$; see Fig. 3d). Differences in forage NDF were not adjusted for initial soil moisture during pregrazing ($P = 0.54$), postgrazing ($P = 0.15$), or regrowth ($P = 0.98$) sampling periods.

Average daily gains of livestock

Average daily gains (ADG; kg d^{-1}) of livestock were greater ($P \leq 0.01$) in 2019 (0.85 ± 0.05) than 2020 (0.60 ± 0.06) across all short-duration grazing treatments (Fig. 4). Further, the ADG of yearling heifers were numerically greater ($P = 0.08$) in the early season (0.81 ± 0.06) compared with the late season (0.64 ± 0.07; see Fig. 4). Yearling heifers achieved numerically greater ($P = 0.12$) gains under moderate intensities (0.80 ± 0.07) compared with high intensities (0.65 ± 0.06; see Fig. 4). Pregrazing BW did not explain ($P = 0.84$) any of the observed variation in ADG of heifers.

Discussion

Mesic systems provide abundant forage and water resources shared by wildlife and livestock (Krausman et al. 2009; Swanson et al. 2015). In our study, we observed that forage DM and forage biomass varied in response to grazing season and intensity; however, overall DM was lower and biomass greater in 2019 than 2020, likely due to greater precipitation in 2019. In a defoliation experiment of smooth brome and Kentucky bluegrass, increased defoliation intensity decreased shoot DM compared with nondefoliated plants (Donkor et al. 2002). Similarly, we observed lower regrowth DM with high-intensity grazing during the early season. Increases in grazing intensity during the late season were likely unable to replicate these patterns because defoliation occurred after meadow foxtail had entered a state of semidormancy in which growth was halted or minimal in response to low moisture conditions (Schoth 1945). Forage production is positively associated with increases in spring, early summer, and annual precipitation (Smoliak 1956; Lauenroth and Sala 1992; Derner et al. 2008b). With adequate precipitation, grazed sites can produce greater total forage biomass than ungrazed sites (Patton et al. 2007). When averaged across years, regrowth biomass in late September was similar across ungrazed, moderate-intensity, and high-intensity grazing treatments, despite numeric decreases with increasing grazing intensity. When allowed adequate rest periods following grazing, meadow foxtail (Wenick et al. 2008) and other rhizomatous grasses (Broadbent et al. 2019) can recover and produce additional biomass. This recovery could explain why biomass estimates increased between postgrazing and regrowth sampling periods under moderate- and high-intensity grazing.

Early-season grazing facilitated increases in forage CP and numerical increases in regrowth TDN in conjunction with reciprocal declines in ADF and NDF after 1 yr of grazing treatments. As forages mature, leaf-to-stem ratios decline corresponding to decreases in CP and increases in fiber contents (Ball et al. 2001; Arzani et al. 2004). Throughout most stages of grass development, leaves have higher CP and lower ADF than stems (Baron et al. 2000). Therefore, early-season grazing can halt the maturation of forages in earlier phenological stages when leaf-to-stem ratios are high, prolonging forage nutritional quality during regrowth compared with ungrazed plants. Similarly, bluebunch wheatgrass clipped during early phenological stages, such as the boot, emergence, flowering, or seed formation stages, exhibits greater CP and lower ADF compared with unclipped plants (Pitt 1986). In our study, early-season grazing took place when dominant forage grasses were transitioning from boot to flowering stages. In contrast, grasses had developed seed and were in seed shatter stages at the onset of late-season grazing. Differences in phenological stage at the time of defoliation likely explain differences in forage quality between grazing seasons. Additionally, when defoliation occurs during later phenological stages, improvements in forage quality compromise the vigor and reproductive potential of the plant (McLean and Wikeem 1985; Pitt 1986). Further, higher-intensity grazing can also suppress plant development and prolong time spent in vegetative stages depending on the phenological stage of forages during defoliation (Clark et al. 2000; Pavlů et al. 2006). In fact, high levels of defoliation can result in plant regrowth from axillary buds (Mueller and Richards 1986; Yuan et al. 2020). Under this scenario, plant development is delayed, resulting in senescence at an earlier phenological stage (Clark et al. 2000), thereby increasing forage quality. Because forage nutritional responses depend on phenological stage and grazing intensity, regrowth CP was highest and NDF lowest under early-season high-intensity grazing compared with all other treatments.

ADGs of crossbred yearling heifers varied by year, but differences between grazing seasons and intensities were not statistically significant, supporting our hypothesis that short-duration treatments would not allow adequate time for differential gains. Differences in ADG between 2019 and 2020 likely result from variation in biomass available before grazing, which we attribute to differences in spring and annual precipitation and grazing treatments between years. Grazing season gains of yearling beef cattle have shown strong hyperbolic increases with abundant spring precipitation during a long-term experiment in Wyoming (Derner et al. 2008a). Although ADG was similar between early and late seasons, interpreting the cause of numeric differences in gain is important from a production standpoint, especially when considering the same individuals were used for grazing during both seasons, suggesting that variation in forages and not differences in livestock contributed to these observations. Further, because leaves have higher CP and lower ADF throughout most stages of grass development (Baron et al. 2000), forage maturation corresponds with decreases in CP and increases in fiber contents (Ball et al. 2001; Arzani et al. 2004). Therefore, early-season grazing allowed heifers access to higher-quality forages with greater leaf-to-stem ratios than late-season grazing. This pattern aligns with forages on riparian areas in northeastern Oregon, which had lower DM, greater CP, and lower ADF and NDF during early-summer grazing periods than late-summer periods (Parsons et al. 2003). In our study, during a single 16-d trial, the average individual heifer gained approximately 2.72 kg more during the early season than late season. Further, ADGs were numerically greater under moderate than high intensities. When evaluating performance across 32 combined grazing days from June to August, this translates to a 4.80-kg advantage per yearling heifer under moderate- compared with high-intensity grazing. However, this difference comes with the caveat that higher-intensity grazing supported more individuals than moderate-intensity grazing. When extrapolated to total production across 32 grazing days during early and late seasons, this difference in stocking equated to a 140.54 kg ha^{-1} and 85.91 kg ha^{-1} advantage in 2019 and 2020, respectively, under high-intensity grazing. Therefore, improvements in individual performance under moderate-intensity grazing did not overcome total production from high-intensity grazing. This finding is consistent with other long-term studies that have documented improvements in ADG with decreases in grazing intensity in the mixed-grass prairie of Wyoming (Manley et al. 1997; Derner et al. 2008a). Slightly greater gains under moderate-intensity grazing were likely a function of decreased competition for high-quality forages among heifers.

Because forage quantity and quality are responsive to grazing management (Pavlů et al. 2005; Wenick et al. 2008), grazing strategies that optimize these characteristics of forage can be implemented to improve habitat for livestock and wildlife. In mesic meadow communities dominated by non-native forage grasses, short-duration grazing during the early season at a high intensity improved regrowth qualities of forages in mesic meadow pastures over the short term, despite lower total precipitation from 2019 to 2020. However, statistically similar biomass estimates in 2019 and 2020 across grazing intensities do not reflect the numerically low estimates of regrowth biomass under high-intensity grazing, which is important given the shared dependence of wildlife on forage in mesic systems. Forage responses to precipitation are well documented (Lauenroth and Sala 1992; Derner et al. 2008a), and this study provides further support for the importance of factoring environmental conditions into grazing management plans. The ADG of yearling heifers did not vary depending on season or intensity of short-duration grazing. Due to the tendency of grazing to elicit site-specific responses in mesic systems (Oles et al. 2017), the most effective grazing treatment in this study may not produce similar outcomes in other locations if initial pasture conditions are not comparable. Grazing management should be tailored to meet local environmental conditions, management objectives, and needs of both wildlife and livestock.

Implications

In mesic meadow communities dominated by non-native forage grasses, nutritional quality of forages can be enhanced through variation in the season and intensity of short-duration grazing. Early summer (early June) grazing at high intensities can delay the phenological progression of forages, subsequently enhancing forage quality into the fall (late September) and possibly the following year. If grazing occurs late in the summer (early August), forage quality is unlikely to respond because grasses such as meadow foxtail have already matured and entered a state of dormancy. Increasing grazing intensity can result in lower forage biomass; however, this is highly contingent on environmental factors such as early growing season and annual precipitation. Differences in the average daily gains of livestock between treatments will be small yet may be of economic importance in livestock production. However, because the nutritional quality of forages decreases with increasing plant maturity, grazing early in the summer will provide livestock with access to higher-quality forage than grazing later in the summer. Further, increases in grazing intensity will result in slightly lower individual gains but greater total livestock production per hectare.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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