

Semiarid Rangeland Is Resilient to Summer Fire and Postfire Grazing Utilization

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Abstract

Most wildfires occur during summer in the northern hemisphere, the area burned annually is increasing, and fire effects during this season are least understood. Understanding plant response to grazing following summer fire is required to reduce ecological and financial risks associated with wildfire. Forty 0.75-ha plots were assigned to summer fire then 0, 17, 34 or 50% biomass removal by grazing the following growing season, or no fire and no grazing. Root, litter, and aboveground biomass were measured before fire, immediately after grazing, and 1 yr after grazing with the experiment repeated during 2 yr to evaluate weather effects. Fire years were followed by the second driest and fifth wettest springs in 70 yr. Biomass was more responsive to weather than fire and grazing, with a 452% increase from a dry to wet year and 31% reduction from a wet to average spring. Fire reduced litter 53% and had no first-year effect on productivity for any biomass component. Grazing after fire reduced postgrazing grass biomass along the prescribed utilization gradient. Fire and grazing had no effect on total aboveground productivity the year after grazing compared to nonburned, nongrazed sites (1 327 vs. 1 249 ± 65 kg · ha⁻¹). Fire and grazing increased grass productivity 16%, particularly for *Pascopyrum smithii*. The combined disturbances reduced forbs (51%), annual grasses (49%), and litter (46%). Results indicate grazing with up to 50% biomass removal the first growing season after summer fire was not detrimental to productivity of semiarid rangeland plant communities. Livestock exclusion the year after summer fire did not increase productivity or shift species composition compared to grazed sites. Reduction of previous years' standing dead material was the only indication that fire may temporarily reduce forage availability. The consistent responses among dry, wet, and near-average years suggest plant response is species-specific rather than climatically controlled.

Key Words: drought, grassland, herbivory, prescribed burn, productivity, wildfire

INTRODUCTION

Grazing management decisions following wildfire are currently difficult to justify. Federal agencies in the United States commonly require complete removal of livestock for 2 yr following fire to facilitate recovery of plant and soil resources, but rest periods vary from 1 to 3 yr (Bureau of Land Management 2007). These policies can increase costs of wildfire considerably beyond the immediate costs of fire suppression, damaged infrastructure, and immediate loss of forage resources. Agencies lose revenue otherwise gained from grazing leases and have increased costs associated with monitoring. However, these costs are typically minor relative to total agency budgets and provide little incentive to hasten approval for grazing. Livestock producers are faced with the brunt of wildfire impacts, with costs of relocating livestock,

purchasing harvested feeds, leasing pasture, reducing herd size, and obtaining the capital to effect any of those changes. The areal extent of individual wildfires has increased in recent years (Westerling et al. 2006; Rideout-Hanzak et al. 2011), further reducing availability of replacement pasture and amplifying losses to local economies. Degradation of plant and soil resources are primary concerns for all affected parties, but trade-offs between ecological and economic needs cannot be accurately assessed with currently available information. Limited data exist quantifying plant response to fire during the wildfire season, and data are particularly limited regarding grazing effects after fire.

Despite the identified benefits of prescribed fire, wildfires are often perceived to be detrimental to vegetation because they tend to occur during more severe fuel and weather conditions. Worldwide, most fires occur during the dry season (Govender et al. 2006). In the western United States, more than 70% of the wildfires and nearly 90% of the resulting burned area are from fires ignited during the summer months of July and August (Higgins 1984; Westerling et al. 2003). At a global scale, areal extent of summer wildfires has also increased in midlatitudes of the northern hemisphere during recent decades (Riaño et al. 2007). Studies following wildfires are often pseudoreplicated and lack knowledge of prefire conditions, including species composition and productivity. Prescribed fires are seldom conducted during summer because of increased safety and containment concerns. Therefore, data from controlled experiments on fire effects are most lacking for this period.

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Controlled, well-replicated experiments of summer fire effects have been conducted in C₃-dominated rangeland (Vermeire et al. 2011), but have occurred primarily in C₄-dominated grasslands (Ewing and Engle 1988; Howe 1995; Engle et al. 1998; Brockway et al. 2002; Ansley et al. 2006; Ford and Johnson 2006; Castellano and Ansley 2007; Towne and Kemp 2008). Examination following summer wildfire has suggested reduced plant productivity in C₃-dominated, semiarid grassland (Dix 1960; Erichsen-Arychuk et al. 2002), but recent work observed no effects on total above- or belowground production (Vermeire et al. 2011). Research in mesic C₄ grasslands has indicated summer fire promoted C₃ grasses (Steuter 1987; Howe 1995; Engle et al. 1998).

Two divergent themes exist in the management of fire and grazing of rangelands. One suggests that fire and grazing are inseparable processes essential for the maintenance and diversity of rangelands (Fuhlendorf and Engle 2004). The other suggests grazing following fire is damaging to rangeland health and that the two should be separated in time to ensure recovery (Beschta et al. 2004; Letnic 2004; Keeley 2006; Gittins et al. 2011). The split in attitudes can largely be defined geographically in the United States. There has been a purposeful coupling of fire and grazing in mesic rangelands where fires are commonly prescribed and land is primarily in private ownership. Attempts to separate fire and grazing are prominent in semiarid and arid rangelands of the United States where fires are more often wild and land ownership is more evenly split between government and individuals.

Data supporting postfire grazing recommendations are surprisingly sparse, given the economic impact of wildfires. Early research in northern mixed prairie suggested more than 3 yr may be required for plants to recover from summer fire (Clarke et al. 1943; Dix 1960; Coupland 1973). However, recent research in Great Basin rangeland, which is thought to be more sensitive to grazing than the Great Plains, has indicated dominant perennial grasses typically do not benefit from complete rest from grazing after fire (Bruce et al. 2007; Bates et al. 2009; Roselle et al. 2010). Options to alleviate ecological and economic impacts include grazing burned sites the following growing season, but with deferment until late in the growing season, or with reduced levels of forage utilization. Severe clipping during the early growing season was shown to increase mortality and reduce vigor of three bunchgrass species after fire compared to plants clipped after seed production and nonclipped plants (Jirik and Bunting 1994; Bunting et al. 1998). Thus, deferment of grazing until late summer or autumn is believed to benefit plants by excluding grazing throughout the primary period of plant growth. However, senescent forage is of lower dietary quality, and postfire deferments to the late growing season have been shown to reduce livestock growth considerably compared to early growing season use (Waterman and Vermeire 2011).

Stocking rate, through its effect on forage utilization, is commonly identified as the primary grazing factor controlling plant productivity (Holechek et al. 1995). Despite the importance of stocking rate, few have examined grazing effects at multiple animal densities following disturbance (Wisdom et al. 2006). If grazing is a significant stress for plants following fire, grazing at reduced levels of utilization may mitigate both

the ecological stress of postfire grazing on rangelands and the financial stress of livestock removal.

Our objective was to quantify summer fire and postfire grazing effects by evaluating aboveground and root biomass, litter mass, and soil bulk density response to four levels of utilization (0, 17, 34, and 50% of biomass removed) the first growing season following summer fire in semiarid C₃-dominated grassland and to separate fire and postfire grazing effects by comparisons with nonburned, nongrazed sites. Treatments were assigned in a completely randomized design with measurements taken before fire treatment, immediately after grazing, and 1 yr after grazing. The complete experiment was repeated in consecutive years on adjacent sites to assess weather effects.

Broadly speaking, grasslands evolved with and are well adapted to drought, fire, and grazing (Anderson 2006). Within the northern Great Plains, rangeland productivity has been resilient to summer fire (Vermeire et al. 2011), grazing (Vermeire et al. 2008), and the combined effects of drought and grazing (Heitschmidt et al. 2005). Therefore, we hypothesized (1) that total current-year, dominant perennial grass, and root biomass would be resilient to the combined effects of summer fire and grazing the following growing season. Fire during the dry period of summer quiescence was expected to combust most standing dead vegetation and litter. Grazing was expected to reduce standing crop in proportion to utilization immediately, which should limit standing dead vegetation and litter recruitment the following year. Therefore we hypothesized (2) that subsequent-year standing dead vegetation and litter mass would decrease with fire and increasing postfire grazing utilization. Finally, after observing severe drought in the beginning of the study and with recognition of seasonal precipitation as a primary controlling factor for rangeland productivity in the northern Great Plains (Vermeire et al. 2009), we hypothesized (3) that the magnitude of annual weather effects on biomass would be greater than those of fire and postfire grazing.

STUDY SITE AND METHODS

Study Site

Research was conducted on the Fort Keogh Livestock and Range Research Laboratory located near Miles City, Montana (lat 46°24'N, long 105°56'W; 815 m above sea level [asl]) in a semiarid, northern mixed prairie. The freeze-free period ranges from 110 to 135 d and temperatures range from 38°C during summer to -40°C during winter. Average annual precipitation is 339 mm, with 75% occurring April through September. Precipitation effects on current-year biomass and standing crop are generally greatest during April and May (Heitschmidt and Vermeire 2005; Vermeire et al. 2008).

The study site is a gently rolling upland on Pinehill loam soil (Fine, montmorillonitic Typic Eutroboralfs) with minor inclusions of a Pinehill-Absher complex. Absher soil is a clay loam (fine, smectitic, frigid Leptic Torrertic Natrustalfs). Both soils are deep and well drained. The site was grazed by cattle for decades at a moderate stocking rate of about one animal unit month⁻¹ until May 2003. Current-year biomass ranged from 460 to 1 330 kg·ha⁻¹ during the 10 yr preceding this

research. Vegetation was dominated by perennial C₃ graminoids, with *Hesperostipa comata* (Trin. & Rupr.) Barkworth, *Pascopyrum smithii* (Rydb.) A. Löve, *Carex filifolia* Nutt., and *Poa secunda* J. Presl most abundant, and the perennial C₄ grass *Bouteloua gracilis* (Willd. Ex Kunth) Lag. ex Griffiths. Annual grasses were *Bromus japonicus* Thunb., *B. tectorum* L., and *Vulpia octoflora* (Walter) Rydb. *Artemisia frigida* Willd. was common, with the large shrubs, *Artemisia tridentata* Nutt. ssp. *wyomingensis* Beetle & Young and *Artemisia cana* Pursh, widely spaced. The most common forbs were the annuals *Plantago patagonica* Jacq., *Logfia arvensis* (L.) Holub and *Alyssum alyssoides* L. and the perennials *Sphaeralcea coccinea* (Nutt.) Rydb. and *Phlox hoodii* Richardson.

Methods

Forty 0.75-ha plots (75 × 100 m) were selected and randomly assigned five fire-grazing treatments with four replications within each of two fire treatment years. Treatments were no fire and no grazing, and summer fire followed by one of four levels of forage utilization on a biomass basis (0, 17, 34, or 50%). The experiment was repeated by selecting contiguous blocks of 20 plots located adjacent to one another to receive fire treatment in either 2003 (Experiment 1) or 2004 (Experiment 2) and grazing treatment in 2004 or 2005, respectively.

Fires were applied to individual plots 29 August 2003 and 24 and 25 August 2004 with the use of a ring fire technique and 3-m fuel breaks to mineral soil around the perimeters. Fuel loads were 1504 kg · ha⁻¹ during 2003 and fires burned with ambient temperature of 19.4 to 21.1°C, 42 to 50% relative humidity, and 5.6–14.8 km · h⁻¹ winds. During 2004, fuel loads of 1569 kg · ha⁻¹ were burned with ambient temperature of 22.8–26.7°C, 22–34% relative humidity, and 8.0–30.6 km · h⁻¹ winds. Fire coverage was complete for all vegetated portions of each plot.

Grazing treatments were applied late June through early July of the first growing season after fire (2004 and 2005). Plots receiving grazing treatments were stocked during late June and early July with 3, 6, or 9 sheep *Ovis aries* in 2004 and 6, 12, or 18 sheep in 2005 to achieve desired utilization levels of 17, 34, and 50%, respectively, by mid-July. Sheep were Columbia, Rambouillet, and Targee ewes (53 ± 6 kg). Forage utilization was estimated visually and by clipping inside and outside of four randomly placed cages (1 × 2 m) in each of the grazed plots to determine when to terminate grazing. Final stocking rates for 17, 34, and 50% utilization treatments were 4.3, 8.4, and 12.2 animal unit days · ha⁻¹ (1 AUD = 9.08 kg dry-matter forage) during 2004 and 25.4, 51.0, and 77.7 AUD · ha⁻¹ during 2005. The Livestock and Range Research Laboratory Institutional Animal Care and Use Committee considered use of sheep in this study as a standard management practice requiring no official approval for handling and experimental procedures.

Plots were sampled mid-July before fire treatments, immediately following grazing, and 1 yr following grazing. Species composition was estimated using the dry-weight-rank method (Gillen and Smith 1986) with 20 systematically located 0.25-m² circular quadrats per plot. Dry-weight-rank groups were *P. smithii*, *H. comata*, *C. filifolia*, other C₃ perennial grasses, C₄ perennial grasses, annual grasses, forbs, and shrubs. *Hesper-*

ostipa comata was included with other cool-season grasses in 2003 and estimated separately thereafter. Species classified as other C₃ perennial grasses were *P. secunda*, *Koeleria macrantha* (Ledeb.) Schult., *Nassella viridula* (Trin.) Barkworth, *Pseudoroegneria spicata* (Pursh) A. Löve, *Elymus elymoides* (Raf.) Swezey, and *Agropyron cristatum* (L.) Gaertn. *Poa secunda* was most abundant of the other C₃ perennial grasses. C₄ perennial grasses were predominantly *B. gracilis*, but also included *Bouteloua dactyloides* (Nutt.) J.T. Columbus, *Sporobolus cryptandrus* (Torr.) A. Gray, and *Aristida purpurea* Nutt.

After dry-weight ranks were determined, standing crop of graminoids, forbs, and *A. frigida* were estimated by clipping each group to ground level. Litter was collected from quadrats after standing vegetation was clipped. Samples were oven dried to a constant weight at 60°C and weighed to the nearest 0.01 g. Standing-crop subsamples were separated into current and past years' growth and reweighed to determine current-year biomass as an estimate of productivity. Dry-weight ranks were weighted by quadrat biomass to compute biomass estimates by component.

Twenty soil cores (4.2 cm diameter × 30 cm deep) were systematically sampled in each plot to determine bulk density and root mass. Cores were individually bagged in the field then dried to a constant weight in the laboratory and weighed to estimate bulk density. Root samples were removed from each core with the use of a hydropneumatic root washer and rinsed clean of remaining soil. Roots were then dried to a constant weight at 60°C and weighed to the nearest 0.01 g. Roots were heated in a 550°C muffle furnace for 5 h to determine root mass on an organic-matter basis, subtracting ash weight.

Biomass data for each aboveground component, litter, and root organic matter and soil bulk density were analyzed with the use of SAS MIXED analysis of covariance with repeated measures to determine effects of summer fire and postfire grazing utilization. Models included the main effects of experiment, fire-grazing treatment, time since fire, and their interactions. The random effect was plot, and pretreatment data were used as the covariate when significant. Pretreatment grass standing crop was not sorted into current and past years' growth, and *H. comata* and other C₃ perennial grasses were not estimated separately for pretreatment measurements in 2003. Therefore, pretreatment data could not be used as a covariate for analyses of current-year grass, other C₃ perennial grasses, or *H. comata* biomass. Time since fire treatment (1 yr after fire at grazing cessation, or 2 yr after fire = 1 yr after grazing) was the repeated measure. Aboveground biomass components for grazed sites 1 yr after fire were used to represent grazing utilization by component. Planned contrasts were conducted on second-year postfire data across experiments to assess whether grazing (across utilization levels) after fire affected individual herbage, litter, or root components and soil bulk density relative to nongrazed sites that were not burned or burned during summer. Actual utilization was assessed by plotting observed residual biomass at cessation of grazing on predicted residual biomass, based on the product of biomass on burned, nongrazed sites and 1 minus the prescribed percent utilization expressed as a decimal.

Residuals were subjected to the Shapiro-Wilk test for normality (Shapiro and Wilk 1965); log-transformed response

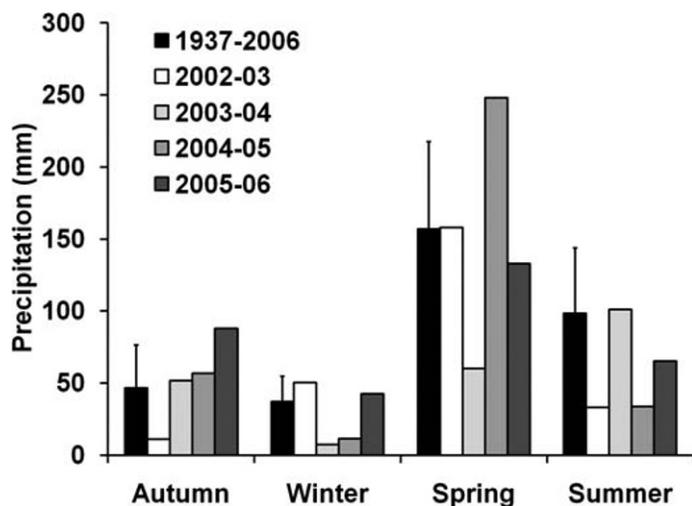


Figure 1. Autumn (October–December), winter (January–March), spring (April–June), and summer (July–September), precipitation for pretreatment year, each year of study, and 70-yr mean seasonal precipitation (± 1 SD).

variables were analyzed when the normality hypothesis was rejected. Transformed data are presented as backtransformed means with standard errors of the means. Levene's test was used to assess the assumption of homogeneous variances in the main plot analysis. Significance of tests was declared at $\alpha = 0.05$ and interactions were followed by tests of simple effects. Tests generating P values between 0.05 and 0.10 are reported and discussed as trends.

RESULTS

Weather and Time-Since-Fire Effects

Experiment 1 was preceded by near-average spring precipitation, but the summer when plots were burned was the third driest and sixth hottest in 70 yr (Fig. 1). The next year, when grazing treatments were applied, winter and spring were the driest and second driest during the same period. Spring was the fifth wettest the year after grazing. Experiment 2 was burned during the year of severe spring drought and grazed following the wet spring. Spring precipitation was slightly less than average the year after grazing for Experiment 2.

Artemisia frigida was more abundant for Experiment 2 than Experiment 1 (36 vs. 18 ± 4 $\text{kg} \cdot \text{ha}^{-1}$). Biomass varied by the interacting effects of experiment and time since fire for most components regardless of fire-grazing treatment (Table 1). In Experiment 1, annual grass biomass was uniformly light and litter was similar both years. Otherwise, biomass of other components increased sharply from the initial drought year to the wet conditions of the second growing season after fire. Grass biomass increased nearly sevenfold between periods. In contrast, fewer differences were observed between the wet and near-average spring conditions of the first and second years postfire for Experiment 2. Root mass during the dry first year of Experiment 1 was only 78% of that during other periods, which were all similar. Greater biomass from wet spring conditions resulted in litter mass being about 87% greater the

Table 1. Biomass ($\text{kg} \cdot \text{ha}^{-1}$) of grass, grass components, litter, and root (30 cm) organic matter by time since fire and spring precipitation characterization (dry, average, or wet) 1 and 2 yr postfire, averaged across fire-grazing treatments with standard errors and P values for the weather \times time-since-fire interaction.

Component	Time since fire	Experiment spring conditions		Stderr	P value
		Dry, wet	Wet, avg.		
Grass	1 yr	194 d ¹	1095 b	37	< 0.0001
	2 yr	1343 a	980 c		
<i>Pascopyrum smithii</i>	1 yr	86 c	368 a	28	< 0.0001
	2 yr	424 a	289 b		
<i>Hesperostipa comata</i>	1 yr	16 c	273 ab	25	< 0.0001
	2 yr	333 a	229 b		
<i>Carex filifolia</i>	1 yr	60 b	100 b	16	< 0.0001
	2 yr	238 a	93 b		
C ₄ grass	1 yr	35 c	100 b	15	< 0.0001
	2 yr	231 a	64 bc		
Other C ₃ grass	1 yr	30 c	156 a	18	< 0.0001
	2 yr	130 ab	100 b		
Annual grass	1 yr	4 c	62 b	16	0.0135
	2 yr	29 bc	169 a		
Litter	1 yr	267 b	290 b	25	0.0002
	2 yr	336 b	557 a		
Root organic matter	1 yr	6 686 b	8 802 a	309	0.0003
	2 yr	8 589 a	8 316 a		

¹Means within components are similar when followed by a common letter ($P > 0.05$).

next year (second year after fire in Experiment 2) than at any other time. Annual brome biomass was greatest during the second year postfire in Experiment 2, promoted by the additional litter and greater than average precipitation the previous autumn. Soil bulk density was 1.30 ± 0.01 $\text{g} \cdot \text{cm}^{-3}$ the second year after fire in Experiment 1 and greater than the 1.25 ± 0.01 $\text{g} \cdot \text{cm}^{-3}$ observed for any other time in either experiment.

Weather \times Time-Since-Fire \times Fire-Grazing Interactions

Total current-year biomass varied by the interacting effects of experiment, time since fire, and fire-grazing treatment as did forb biomass and old standing dead mass (Fig. 2). In Experiment 1, total biomass was light and showed no fire or grazing effects 1 yr postfire. The second year after fire total biomass increased sharply, with similar values for nonburned and burned plots that were not grazed. Total biomass of burned plots that were grazed was similar to nongrazed burned plots, but plots grazed to 34% utilization had more total biomass than nonburned plots. In Experiment 2, total biomass was similar between burned and nonburned plots that were not grazed both years. Grazing reduced total biomass after summer fire along the prescribed utilization gradient (Fig. 3). However, no differences were observed among any treatments the year after grazing.

No differences in old standing dead material were expected or observed among grazing treatments in burned plots 1 yr postfire, because nearly all had combusted during fires (Fig. 2).

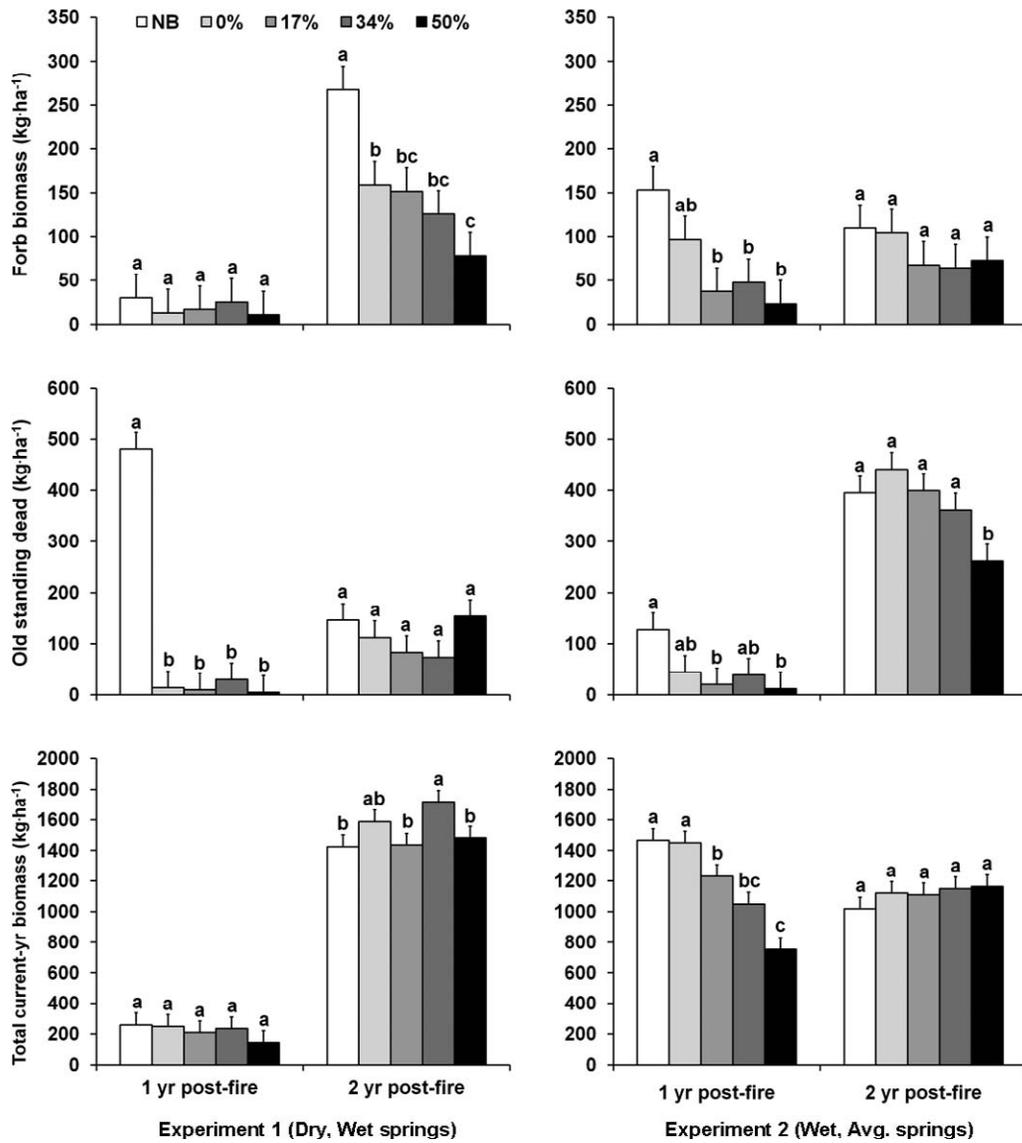


Figure 2. Forb, old standing dead, and total current-year biomass by experiment, fire-grazing treatment, and time since fire with standard errors for the experiment \times fire-grazing-treatment \times time-since-fire interaction. Treatments are nonburned and nongrazed (NB), summer-burned and nongrazed (0%), and summer-burned and grazed the first year after fire to achieve 17, 34, or 50% utilization and nongrazed the second year after fire. Fire-grazing treatment means within experiment and time since fire with a common letter above bars are similar ($P > 0.05$).

Nonburned plots had considerably more standing dead mass than all of the burned plots 1 yr after fire in Experiment 1. Only burned plots grazed at 17 or 50% utilization had less standing dead than nonburned plots 1 yr after fire in Experiment 2. Standing dead mass was similar among all treatments 2 yr after fire, with the exception that there was less on plots grazed at 50% utilization during Experiment 2.

As with total biomass, forb biomass was light and similar across treatments 1 yr postfire in Experiment 1 (Fig. 2). Forbs were much less abundant on burned than nonburned plots 2 yr after fire, and plots that had received 50% utilization the previous year had less forb biomass than nongrazed burned plots. Burned plots grazed at 17 or 34% utilization had intermediate forb biomass values between those not grazed and those grazed to 50%. In Experiment 2, grazing reduced forb biomass below that of nonburned plots 1 yr after fire and forb

biomass on burned nongrazed plots did not differ from nonburned or grazed plots. Contrary to the apparent continuing effects of fire and grazing in Experiment 1, there were no differences in forb biomass among treatments 2 yr postfire in Experiment 2.

Fire-Grazing Effects

C_4 perennial grasses decreased gradually with increasing utilization across experiments and times since fire (Fig. 4), indicating some grazing effects persisted after sites were released from grazing. C_4 grasses were the only biomass component for which this was the case. Burned sites that were not grazed sites did not differ from nonburned sites that were not grazed. Grazing to 17 and 34% utilization reduced C_4 grasses relative to nonburned sites, but biomass for these treatments was intermediate and similar to burned sites that

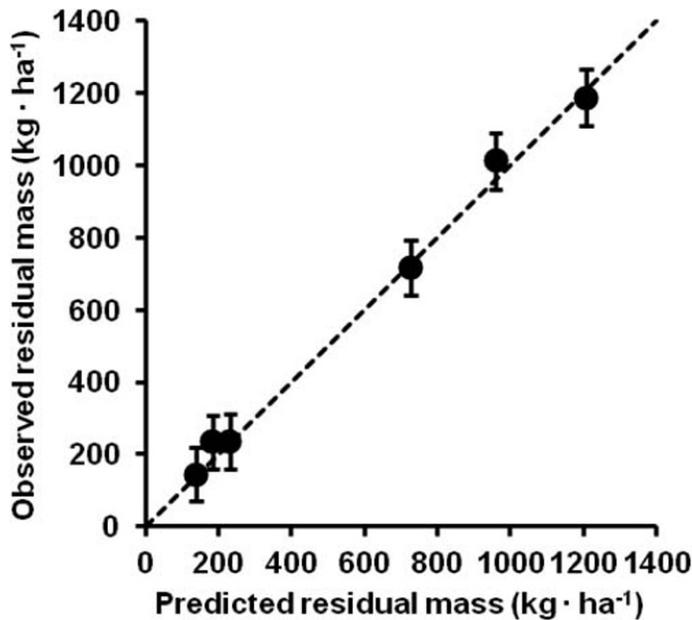


Figure 3. Mean observed residual total biomass and standard errors by experiment and utilization treatment vs. predicted residual total biomass based on nongrazed, summer-burned sites and 1:1 dashed line.

were not grazed and those that were grazed to 50% utilization. *C*₄ grass biomass on burned sites grazed to 50% utilization was 46% of that on nongrazed burned sites and 40% of that on nonburned sites.

Fire-grazing treatment and time since fire interacted in their effects on most biomass components or showed tendencies ($0.05 < P < 0.10$) to that effect (Table 2). Grass, *P. smithii*, and *C. filifolia* biomass generally decreased with increasing utilization 1 yr after fire, when the sites were grazed. Other components were similar across utilization treatments 1 yr after fire. Relative to nongrazed treatments, fire reduced litter mass about 60%. Other components were similar between burned and nonburned sites that were not grazed 1 yr after fire.

Postfire grazing effects did not carry over to the second year after fire for most components (Table 2). Grazing at 50% utilization reduced litter mass compared to nongrazed sites, and sites grazed to 17% utilization and reduced *H. comata* about 32% compared to nongrazed sites. Differences among utilization treatments for burned sites were also observed for *A. frigida* and grass biomass. However, the patterns were less clear. *A. frigida* biomass was greater for sites previously grazed to 50% than 17% utilization, but neither differed from the nongrazed sites. Similarly, sites previously grazed to 34% utilization had greater grass biomass than those grazed at 17%, but neither differed from the more extreme nongrazed or 50% utilization treatments. Comparing burned and nonburned sites that were not grazed, fire increased grass and *P. smithii* biomass and reduced annual grass and litter mass. Neither root organic matter nor biomass of other *C*₃ grasses differed among fire or postfire grazing treatments during the study.

Contrasts comparing postfire grazing across utilization levels to nongrazed sites 1 yr after grazing revealed some differences between grazed sites and nonburned sites, but no differences between grazed and nongrazed sites that were burned (Table 3). Forb, annual grass, and litter mass on grazed sites were each

about half of what was observed on nonburned sites. Grass biomass as a whole, and *P. smithii* biomass in particular, were greater on burned then grazed than nonburned sites. All other components had similar biomass between grazed and nonburned treatments, including *C*₄ grasses, for which a fire-grazing treatment effect was observed when including both times since fire in models. Soil bulk density on grazed sites was also similar to that on burned and nonburned sites that were not grazed.

DISCUSSION

The hypothesis that standing dead vegetation and litter mass decrease with fire and increasing post-fire grazing utilization was partially supported by the data. Standing dead vegetation was reduced by fire during the first year of Experiment 1. Fire had little or no effect on standing dead material afterward because the drought limited production and subsequent standing dead material and fire did not alter total production during the dry, near-average, or wet year. Fifty percent utilization during a wet spring reduced the next year's standing dead vegetation, but to a lesser extent than may be expected. Grazing selectivity may explain why 50% use resulted in 59% as much standing dead the next year compared to nongrazed sites. Animal selection for forage with greater dietary quality suggests remaining stubble would be of lesser average quality and less readily degradable, allowing a greater percentage to persist.

Burned sites had less litter mass 1 and 2 yr after fire than nonburned sites and litter mass decreased with increasing utilization 2 yr after fire. Reduced litter and canopy cover have been shown to generally reduce soil water content (Willms et al. 1993) and examination of summer fire effects supported these findings (Vermeire et al. 2011). Although fire and grazing

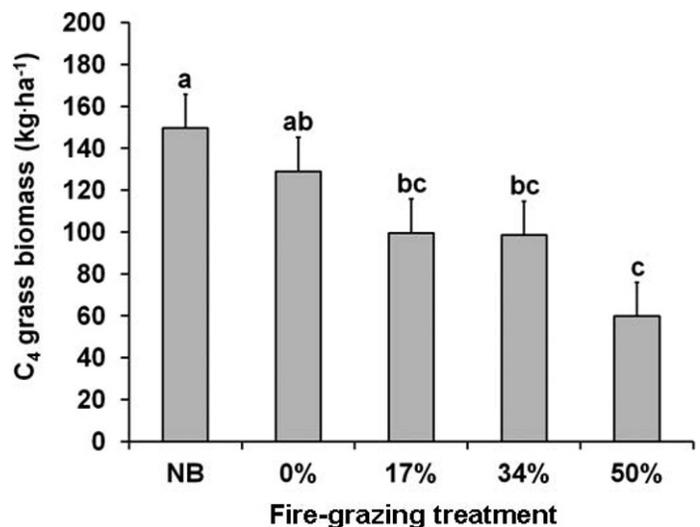


Figure 4. Fire-grazing treatment effects on *C*₄ perennial grasses across experiments and times since fire. Treatments are nonburned and nongrazed (NB), summer-burned and nongrazed (0%), and summer-burned and grazed the first year after fire to achieve 17, 34, or 50% utilization and nongrazed the second year after fire. Means with a common letter above bars are similar ($P > 0.05$).

Table 2. Biomass ($\text{kg} \cdot \text{ha}^{-1}$) of *Artemisia frigida*, grass, grass components, litter, and root (30 cm) organic matter by time since fire and fire-grazing treatment averaged across experiments with standard errors and *P* values for the fire-grazing-treatment \times time-since-fire interaction. Treatments are nonburned and nongrazed (NB), summer-burned and nongrazed (0%), and summer-burned and grazed the first year after fire to achieve 17, 34, or 50% utilization and nongrazed the second year after fire.

Component	Time since fire	Fire-grazing treatment					Stderr	<i>P</i> value
		Nonburned	0%	17%	34%	50%		
<i>Artemisia frigida</i>	1 yr	36 a ¹	14 ab	8 b	8 b	6 b	8	0.0608
	2 yr	35 ab	37 ab	30 b	38 ab	54 a		
Grass	1 yr	725 ab	791 a	686 ab	599 b	421 c	58	0.0002
	2 yr	989 c	1 196 ab	1 134 bc	1 302 a	1 187 ab		
<i>Pascopyrum smithii</i>	1 yr	180 ab	278 a	252 ab	269 ab	156 b	43	0.0413
	2 yr	159 b	383 a	380 a	473 a	388 a		
<i>Hesperostipa comata</i>	1 yr	262 a	161 ab	148 b	78 b	74 b	39	0.0176
	2 yr	247 ab	346 a	253 ab	325 ab	236 b		
<i>Carex filifolia</i>	1 yr	105 a	102 a	117 a	65 ab	11 b	25	0.0988
	2 yr	140 b	151 ab	213 a	145 ab	177 ab		
Other C ₃ grass	1 yr	62	100	106	93	104	29	0.7951
	2 yr	76	149	88	111	148		
Annual grass	1 yr	23 a	39 a	30 a	41 a	33 a	25	0.0523
	2 yr	178 a	46 b	81 b	78 b	110 ab		
Litter	1 yr	484 a	193 b	242 b	193 b	281 b	39	0.0564
	2 yr	694 a	426 b	432 b	383 bc	298 c		
Root organic matter	1 yr	8 140	7 342	7 295	7 582	8 363	488	0.5584
	2 yr	7 946	7 905	8 285	9 012	9 114		

¹Fire-grazing treatment means within component and time since fire are similar when followed by a common letter ($P > 0.05$).

reduced litter mass compared to nongrazed sites, it is not clear whether or to what extent postfire grazing affects litter mass relative to nonburned sites that are grazed. Litter differences between burned and nonburned sites that are grazed would be expected to diminish with decreasing productivity and increasing utilization.

Neutral or positive responses 1 yr after grazing strongly supported the hypothesis that total current-year and dominant perennial grass biomass are resilient to the combined effects of summer fire and grazing. The only exception was that 50% utilization reduced *H. comata* biomass the year after grazing compared to burned sites that were not grazed, but had no

Table 3. Mean biomass ($\text{kg} \cdot \text{ha}^{-1}$) of aboveground herbage components, old standing dead, litter, and root (30 cm) organic matter and soil bulk density ($\text{g} \cdot \text{cm}^{-3}$) the first year following grazing and second year after fire with standard errors and *P* values for planned contrasts between nonburned and nongrazed sites vs. summer-burned and grazed sites and summer-burned and nongrazed sites vs. summer-burned and grazed sites.

Biomass component	Treatment ¹			Contrasts of nonburned and nongrazed vs. burned and grazed sites		Contrasts of burned and nongrazed vs. burned and grazed sites	
	Nonburned nongrazed	Burned nongrazed	Burned grazed	Stderr	<i>P</i> value	Stderr	<i>P</i> value
<i>A. frigida</i>	35	37	41	12	0.6003	12	0.7371
Forb	189	132	93	28	0.0017	28	0.1780
Grass	1 026	1 203	1 193	78	0.0408	78	0.9041
<i>P. smithii</i>	159	383	414	55	< 0.0001	54	0.5713
<i>C. filifolia</i>	140	152	178	31	0.2260	31	0.4123
<i>H. comata</i>	247	346	271	49	0.6175	49	0.1366
C ₃ grass	76	149	116	43	0.3665	43	0.4411
C ₄ grass	193	135	136	33	0.1004	33	0.9552
Annual grass	<u>178</u>	<u>46</u>	<u>90</u>	40	0.0338	40	0.2749
Total	1 249	1 371	1 327	65	0.2386	65	0.5060
Standing dead	270	277	222	33	0.1544	33	0.1087
Litter	693	425	372	56	< 0.0001	56	0.3547
Root OM	7 952	7 898	8 804	595	0.1634	595	0.1392
Soil bulk density	1.28	1.26	1.27	0.01	0.7528	0.01	0.4536

¹Underlined numerals indicate everything above is a component of the total below.

effect relative to nonburned sites that were not grazed. Based on biomass differences between grazed and nongrazed burned sites at the end of grazing periods (Table 2), sheep selected graminoids, specifically *P. smithii*, *C. filifolia*, and *B. gracilis*. The species selected were similar to those previously reported for sheep on nonburned rangeland in the region (Alexander et al. 1983) and match those selected by cattle on similar sites (Samuel and Howard 1982). Therefore, the grazing effects observed and the lack of effects should be applicable to both species of livestock.

The utilization levels tested are all considered nondetrimental for nonburned rangeland. Therefore, productivity should only have been reduced if fire made the plants more sensitive to defoliation. Such was clearly not the case. Engle and Bidwell (2001) suggested changes in species composition and productivity following fire and grazing were likely the results of increased utilization. Grazing animals are attracted to recently burned sites (Vermeire et al. 2004), so burned patches within an incompletely burned pasture can receive considerably greater utilization than intended if stocking rates are set assuming even, pasture-wide use.

Although fire did not reduce productivity, the loss of standing dead vegetation nevertheless could reduce forage availability and increase use of current-year biomass if stocking rates are not adjusted. During drought, nonburned pastures had nearly three times the available forage (current+standing dead) as burned pastures because considerable standing dead vegetation persisted to the following year and new production was limited. Nonburned pastures only had 6% more available forage than burned pastures when growing conditions were good and standing dead vegetation was limited by the previous year's drought. Total forage availability was 8 to 11% greater on burned than nonburned sites 2 yr after fire. The degree to which stocking rates may need to be adjusted would vary with the amount of standing dead vegetation typically carried over between years and conditions affecting current-year production. Successful managers adjust stocking rates based on forage availability regardless of fire. The key difference that fire may cause is an immediate short-term reduction in standing dead vegetation.

The current experiments were not designed to determine how the intra-annual timing of grazing affected plant response, so these data cannot address the significance of early growing-season grazing deferment. Others observed severe postfire defoliation before flowering was detrimental to bunchgrasses (Jirik and Bunting 1994). Our grazing treatments were applied during late June and early July, the period for which 90% of the annual plant production has already typically occurred (Vermeire et al. 2009), flowering is incomplete, and foliage is mostly photosynthetically active. Although the likelihood of nondetrimental grazing earlier during the growing season is unknown, results indicated deferment until after flowering and senescence was not necessary to maintain plant productivity.

Interannual weather-induced shifts in biomass were greater than those from fire, grazing, or the interaction of fire and grazing. Given the extreme dry and wet springs during the study period, the magnitude of weather effects is not surprising. However, the assessment of postfire grazing effects during these extreme and near-average conditions for plant

growth expands the scope of inference to a wide range of postfire environments. We propose that plant response to postfire grazing is species-specific rather than weather- or climate-specific, and that postfire grazing utilization effects mirror grazing effects without fire.

IMPLICATIONS

Results indicate resilience of aboveground and belowground plant biomass to summer fire and postfire grazing at 17 to 50% utilization during the growing season after fire. No evidence was detected to suggest complete rest from grazing was required to conserve plant productivity following fire. However, temporary fire-induced reductions in standing dead vegetation may reduce total forage availability, necessitating a reduction in initial stocking rates so as not to exceed desired levels of utilization. Earlier work established that summer fire did not affect total productivity relative to nonburned sites in the northern Great Plains (Vermeire et al. 2011). The current data further indicate grazing during late June and early July with up to 50% biomass removal after summer fire had no additional effect on biomass components compared to nongrazed, summer-burned sites. Effects were limited for even the most contrasting comparison of sites grazed after fire and sites neither burned nor grazed. The increase in perennial grass biomass and reductions in forb, annual grass, and litter mass on sites that were burned and grazed were driven primarily by fire effects, and both forbs and annual grasses were predominantly nonnative species. Consistent responses among dry, wet, and near-average years suggest results are robust to a large range of postfire weather conditions.

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