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Prescribed Fire, Grazing, and Herbaceous Plant Production in Shortgrass Steppe

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Abstract

We examined the independent and combined effects of prescribed fire and livestock grazing on herbaceous plant production in shortgrass steppe of northeastern Colorado in the North American Great Plains. Burning was implemented in March, before the onset of the growing season. During the first postburn growing season, burning had no influence on soil moisture, nor did it affect soil nitrogen (N) availability in spring (April–May), but it significantly enhanced soil N availability in summer (June–July). Burning had no influence on herbaceous plant production in the first postburn growing season but enhanced in vitro dry matter digestibility of blue grama (*Bouteloua gracilis* [Willd. ex Kunth] Lag. ex Griffiths) forage sampled in late May. For the second postburn growing season, we found no difference in herbaceous plant production between sites that were burned and grazed in the previous year versus sites that were burned and protected from grazing in the previous year. Our results provide further evidence that prescribed burns conducted in late winter in dormant vegetation can have neutral or positive consequences for livestock production because of a neutral effect on forage quantity and a short-term enhancement of forage quality. In addition, our results indicate that with conservative stocking rates, deferment of grazing during the first postburn growing season may not be necessary to sustain plant productivity.

Resumen

Examinamos el efecto independiente y combinado del fuego prescrito y el pastoreo de ganado en la producción de herbáceas en los pastizales cortos del noreste de Colorado en las grandes llanuras del Norte América. El fuego se aplicó en marzo, antes del inicio de la época de crecimiento. Durante la primera época de crecimiento después de la aplicación del fuego, no hubo efecto sobre el contenido de humedad del suelo, ni tampoco afectó el contenido de nitrógeno (N) disponible en la primavera (Abril–Mayo), pero tuvo un efecto significativo en el incremento de la disponibilidad del nitrógeno contenido en el suelo durante el verano (Junio–Julio). El fuego no tuvo efecto en la producción de herbáceas en la primera época de crecimiento después de la aplicación del fuego prescrito, pero incrementó la digestibilidad in vitro de la materia seca de navajita (*Bouteloua gracilis* [Willd. ex Kunth] Lag. ex Griffiths) en muestras obtenidas al final del mes de mayo. Para la segunda época de crecimiento, después de la aplicación del fuego, no se encontraron diferencias en la producción de las platas herbáceas entre los lugares que fueron quemados y pastoreados en los años posteriores comparado con los lugares que fueron quemados y protegidos del pastoreo en años previos. Nuestros resultados proporcionan pruebas adicionales de que el fuego pre-escrito aplicado a finales del invierno cuando la vegetación se encuentra en latencia puede tener consecuencias neutrales o positivas para la producción de ganado debido al efecto neutral sobre la calidad de forraje y el incremento de la calidad del forraje a corto plazo. Además nuestros resultados indican que con tasas conservadoras de pastoreo el diferimiento del pastoreo durante la primera época de crecimiento después de la aplicación del fuego podría no ser necesario para sustentar la productividad vegetal.

Key Words: blue grama, *Bouteloua gracilis*, dry matter digestibility, forage quality, grazing management, North American Great Plains, semiarid grassland, soil moisture

INTRODUCTION

Fire and grazing are key drivers of rangeland ecosystem structure and function, but their individual and interactive roles can vary considerably in semiarid versus mesic ecosystems (Oesterheld et al. 1999). Effects of fire and its interaction with grazing have been studied extensively in mesic tallgrass and mixed-grass rangelands of the North American Great Plains (Wright and Bailey 1982; Knapp et al. 1999; Fuhlendorf and Engle 2004; Vermeire et al. 2004; Ansley et al. 2006) and in semiarid sagebrush steppe of the intermountain region (Bates et al. 2009). However, understanding of fire effects in semiarid areas of the western Great Plains is more limited (Ford 1999). In the shortgrass steppe, which occupies the most xeric, southwestern portion of the North American Great Plains (Lauenroth et al. 1999), relatively little is known about the presettlement fire regime or the effects of fire on ecosystem dynamics. Several early studies of wildfires found significant negative effects on forage production for livestock (Hopkins et al. 1948; Launchbaugh 1964; Trlica and Schuster 1969), and fire has been widely suppressed in this region for the past century. Interest in management applications of prescribed fire in shortgrass steppe (McDaniel et al. 1997; Svingen and Giesen

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1999; Augustine et al. 2007) and the comparative role of fire in different grassland ecosystems (Oesterheld et al. 1999) prompted studies of prescribed fire effects in New Mexico (Brockway et al. 2002; Ford and Johnson 2006) and Colorado (Augustine and Milchunas 2009).

Vegetation responses were recently compared on burned versus unburned shortgrass steppe over a 6-yr period (Augustine and Milchunas 2009). In most years, prescribed burning did not affect aboveground herbaceous biomass production, enhanced grass nitrogen (N) content early in the growing season, and negatively affected cactus (*Opuntia polyacantha* Haw.) and broom snakeweed (*Gutierrezia sarothrae* [Pursh] Britton & Rusby) abundance. However, several questions remain regarding effects of fire and grazing interactions on aboveground herbaceous biomass production in shortgrass steppe.

First, the influence of fire on soil moisture and N availability may feed back to herbaceous production and contribute to differences in productivity responses in subhumid versus semiarid rangelands (Oesterheld et al. 1999). For example, periodic fire in tallgrass prairie can substantially increase herbaceous production through its effects on the temporal pattern of soil N and light availability (Blair 1997; Johnson and Matchett 2001). Early studies in semiarid grasslands of the western Great Plains suggested that periodic fires would suppress production in dry years and have neutral or positive effects in wet years (Ford 1999), potentially mediated by the effect of litter removal on soil moisture limitations in dry versus wet years. However, the influence of fire on soil nitrogen and moisture availability and how this may in turn influence plant production has not been evaluated in shortgrass steppe.

Second, a trade-off potentially exists between a reduction in forage quantity (if any) on burned areas versus an increase in forage quality. Removal of standing dead biomass by burning enhanced the concentration of N in aboveground biomass of the dominant forage grass, blue grama (*Bouteloua gracilis*), during May–July of the first postburn growing season (Augustine and Milchunas 2009), but livestock may be limited more by their ability to acquire energy rather than protein from forage at this time of year.

Third, experimental studies of fire effects in shortgrass steppe have been conducted either in the absence of grazing (Brockway et al. 2002; Ford and Johnson 2006) or in the presence of grazing (Augustine and Milchunas 2009) but have not evaluated interactions between fire and grazing. Engle and Bidwell (2001) reviewed fire effects in tallgrass prairie and noted that postburn reductions in stocking rate of domestic livestock may facilitate grass recovery depending on local conditions but that understocking for more than one or two years is likely unwarranted. In sagebrush steppe, deferment of livestock grazing on public rangelands for the first several postburn growing seasons is a standard practice to allow for herbaceous vegetation recovery, but recent studies have found that initiation of moderate grazing following completion of the first postburn growth cycle of the dominant grasses does not limit herbaceous recovery (Bruce et al. 2007; Bates et al. 2009).

Here, our objective was to evaluate the potential interactive effects of grazing and fire on herbaceous production, soil moisture, N availability, and forage quality (measured as in vitro dry matter digestibility) in shortgrass steppe. We report on a study in which the randomization of burned and unburned treatments was accomplished by creating burn-exclusion plots within a prescribed burn and grazing was manipulated via exclosures. We predicted that soil moisture and herbaceous production would be negatively affected by the combined effects of fire and grazing, whereas N availability and forage quality would increase.

METHODS

Study Area Description

The study was conducted during 2007–2008 on the eastern unit of the Pawnee National Grassland, which is managed by the US Department of Agriculture (USDA) Forest Service and located approximately 20 km east of Briggsdale in Weld County, Colorado (lat 40°37′3.5″N, long 104°05′47.8″W). The climate is semiarid, with cold, dry winters; most precipitation falls as rain between April and September (Lauenroth and Milchunas 1992). Long-term mean annual precipitation (1951–2005) measured at Briggsdale is 331 mm, and mean growing-season precipitation (April–September) is 265 mm. Annual precipitation was 185, 353, and 302 mm in 2006, 2007, and 2008, respectively, and growing-season precipitation in the same years was 143, 261, and 294 mm. Precipitation during the winter (December–March) preceding the burn was 26 mm (74% of long-term average). Precipitation following the burn was 69 mm during the spring (April–May; 84% of long-term average) and 93 mm during summer (June–July; 85% of long-term average), with most of the summer precipitation occurring during the last week of July.

Experimental Design

We studied a 259-ha site where the USDA Forest Service conducted a prescribed burn on 17 March 2007. The site was relatively flat (0–3% slope) with well-drained loam and fine sandy loam soils. Vegetation is dominated by the perennial, grazing-tolerant shortgrasses blue grama and buffalograss (*Buchloe dactyloides* [Nutt.] J. T. Columbus; Milchunas et al. 1989; Lauenroth and Milchunas 1992). Before burning, we established 10 randomly selected 30×30 m plots, with five of these randomly selected to be protected from burning and five with no protection from the burn. On the day of burn implementation, the five plots receiving the "no-burn" treatment were protected by crews that established a wet line approximately 1 m outside the plot and then initiated back burns around the plot at the same time that head fires were being lit with drip torches for the full 259-ha area. The burn was conducted with ambient temperatures of 20–22°C, relative humidity of 22–25%, and average wind speeds of 0.9–3.1 $m \cdot s^{-1}$ (gusting to 6.3 $m \cdot s^{-1}$). During the 10 yr preceding the burn, the study area was grazed annually by cattle during June–October at an average stocking rate of 0.3 animal unit $months \cdot ha^{-1}$, which corresponds to a light stocking rate for shortgrass steppe rangeland. After the burn, the area was grazed at the same stocking rate during 1 June–15 October 2007.

A 4×4 m exclosure constructed with welded wire livestock panels (which excluded both cattle and pronghorn antelope, *Antilocapra americana*) was established in each plot before grazing in 2007. Exclosures were removed in November 2007 to avoid effects of snow drifting over the winter and were reestablished in the same locations on each plot in April 2008. These 10 exclosures therefore provided sites that were 1) burned in 2007 and ungrazed in 2007 and 2008 or 2) unburned and ungrazed in 2007 and 2008. We also established a second 4×4 m exclosure in a previously grazed location within each 30×30 m plot in April 2008. These additional 10 exclosures provided sites that were 1) burned and grazed in 2007 and ungrazed in 2008 and 2) unburned and grazed in 2007 and ungrazed in 2008.

Measurements

In 2007, we harvested aboveground, herbaceous biomass in 15 0.1-m^2 (0.2×0.5 m) quadrats within each of the five burned and unburned plots on 30–31 May (before cattle grazing). We also harvested aboveground, current-year biomass of herbaceous plants in 10 0.1-m^2 quadrats within each exclosure on 30–31 July. These harvests provide an estimate of the effect of burning on herbaceous production during the first postburn growing season but do not account for the effect of grazing during that time. For all biomass harvests, aboveground biomass of cactus was removed from quadrats before clipping and is not included in herbaceous biomass values. In addition, we separated harvested biomass into current-year production versus previous years' growth. In 2008, we harvested aboveground, herbaceous biomass in 10 0.1-m^2 quadrats within each of the 20 exclosures on 5–8 August. These values provide an estimate of peak herbaceous biomass for the grazing × burning treatments applied in 2007.

During the 2007 growing season, we examined burn effects on soil moisture and soil N availability. Soil moisture was measured at approximately two week intervals during April–July. In shortgrass rangeland, 55–65% of total root biomass is found in the upper 10 cm of the soil profile (Lauenroth and Milchunas 1992), and this soil layer displays the greatest amount of temporal variation (Leetham and Milchunas 1985). If fire affects soil moisture by removing litter and standing dead plant material and thereby enhancing evaporation at the soil surface, these effects are most likely to be detected in the upper soil layer. Therefore, on each of the eight sampling dates, we measured volumetric soil moisture content using a time-domain reflectrometry (TDR) probe (FieldScout TDR 300; Spectrum Technologies, Plainfield, IL) inserted vertically at 0–10-cm depth at 20 locations along a transect bisecting each 30×30 m plot. We also collected soil cores (0–10-cm depth) paired with TDR measurements of soil moisture at 20 locations on two dates in June and confirmed that volumetric soil moisture measured by the TDR probe was closely correlated with gravimetric soil moisture from soil cores (gravimetric soil moisture [%] $= 0.541 \times$ volumetric soil moisture [%] $- 1.342$; $F_{1,18} = 222.2$, $P < 0.0001$; $r^2 = 0.93$). We measured soil inorganic N (NH_4^+ and NO_3^-) availability using in situ ion-exchange membranes (Plant Root Simulator[PRS]^{TM}-probes; Western Ag Innovations Inc, Saskatoon, Canada) inserted into the soil in the presence of plant roots at a depth of 2–8 cm. We used eight cation and eight anion probes per 30×30 m plot and two incubation periods (28 March–29 May and 29 May–28 July 2007; 62 and 59 d, respectively). Probes were cleaned with deionized water immediately after being removed from the soil before analysis. Probes were eluted with 17.5 mL of 0.5 M HCl for 1 h, and inorganic N (NH_4^+-N and NO_3^--N) was determined colorimetrically (Hangs et al. 2004).

We assessed fire effects on forage quality coincident with the time when cattle began grazing the site in 2007 by collecting aboveground biomass from patches dominated by blue grama on 25 May 2007. Handplucked samples were collected along five replicate transects within each 30×30 m plot, oven-dried, ground to pass a 1-mm screen, and analyzed for in vitro dry matter digestibility following the procedures of Tilley and Terry (1963) as modified by White et al. (1981).

Statistical Analyses

We analyzed burn effects on aboveground herbaceous biomass production, soil moisture, and soil N availability in 2007 using repeated-measures analysis of variance within a completely randomized experimental design that treated burning and time as fixed effects (Proc GLM, SAS System for Windows, v9.2). We analyzed interactive effects of burning and grazing on herbaceous production in 2008 with a general linear mixed model that accounted for the experimental design's split-plot structure (burn treatment analyzed at the whole-plot level and grazing treatment at the split-plot level) implemented using the Proc GLM in SAS.

RESULTS

Soil moisture fluctuated substantially over the course of the 2007 growing season ($F_{7,56} = 111.5$, $P < 0.01$), but prescribed burning had no detectable effect on soil moisture at any time (time × burn interaction: $F_{7,56} = 0.74$, $P = 0.64$; burn main effect $F_{1,8} = 0.68$, $P = 0.43$; Fig. 1). For soil inorganic N availability as measured by the PRS^{TM} resin probes, we detected a significant interaction between the burn treatment and time of measurement (time × burn interaction: $F_{1,8} = 3.36$, $P = 0.10$; Fig. 2). Analysis of the main effects of burning on soil N revealed no effect in April–May ($F_{1,8} = 0.24$, $P = 0.64$) but a large, significant increase in soil N availability on burned compared to unburned plots in June–July ($F_{1,8} = 5.84$, $P = 0.04$; Fig. 2).

Burning had no detectable effect on aboveground herbaceous biomass measured either in late May or late July in 2007 (time × burn interaction: $F_{1,8} = 0.16$, $P = 0.70$; burn main effect: $F_{1,8} = 1.0$, $P = 0.35$; Fig. 3). Current-year herbaceous biomass measured in late May was greater than biomass in late July ($F_{1,8} = 13.3$, $P < 0.01$), reflecting the dry conditions that occurred during the summer of 2007 (Fig. 1). Burning reduced standing dead biomass from the previous year by 86% compared to unburned plots in late May, but the magnitude of this difference declined substantially for the late July harvest (time × burn interaction: $F_{1,8} = 8.73$, $P = 0.02$; burn main effect: $F_{1,8} = 28.13$, $P < 0.01$). Standing dead biomass declined on both burned and unburned plots between late May and late July ($F_{1,8} = 10.74$, $P = 0.01$) and made up only a minor portion (4–9%) of total aboveground herbaceous biomass by late July (Fig. 3). Burning enhanced in vitro dry matter digestibility of hand-plucked blue grama samples by 11% in late May (mean ± 1

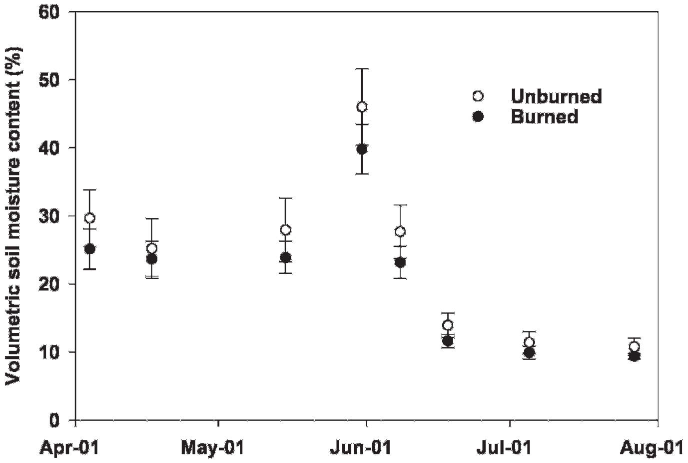

Figure 1. Soil moisture content (mean ± 1 SE) in burned and unburned treatments on the Pawnee National Grassland, Colorado, during April–July 2007.

SE = 69.9 ± 0.2% on burned plots and 62.9 ± 0.7% on unburned plots; $t_2 = 9.16$, df = 8, $P < 0.01$).

In 2008, we found no evidence that grazing during the first postburn growing season interacted with burning to influence herbaceous production (burn × grazing interaction: $F_{1,8} = 0.15$, $P = 0.71$) and no evidence that burning affected aboveground herbaceous production during the second year after the burn ($F_{1,8} = 1.24$, $P = 0.30$; Fig. 4).

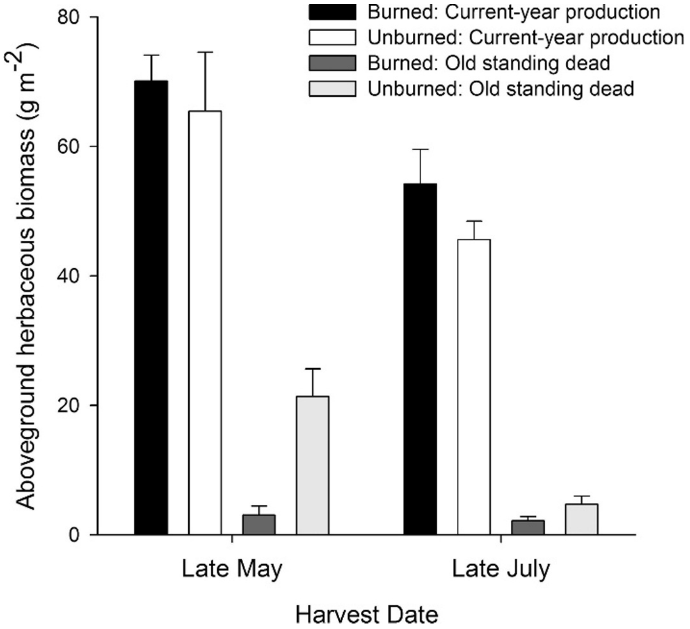

Figure 3. Aboveground herbaceous biomass (current-year production) and aboveground standing dead biomass remaining from the previous growing seasons (old standing dead) on burned versus unburned treatments as of 31 May and 31 July 2007, on the Pawnee National Grassland, Colorado.

DISCUSSION

The high degree of interannual variation in precipitation in semiarid regions of the North American Great Plains has strongly influenced perceptions of the role of fire and led to the hypothesis that fire effects will be positive in years with above-average precipitation (Wright 1974) and negative in below-average years (Launchbaugh 1964; Dwyer and Pieper 1967). This hypothesis is based on the idea that litter removal can negatively affect soil moisture through increased evaporative loss and that the magnitude of this effect increases during dry years (Augustine and Milchunas 2009). In sagebrush steppe rangelands with coarse-textured soils, studies have also shown that fires can increase water loss to runoff due to both ground

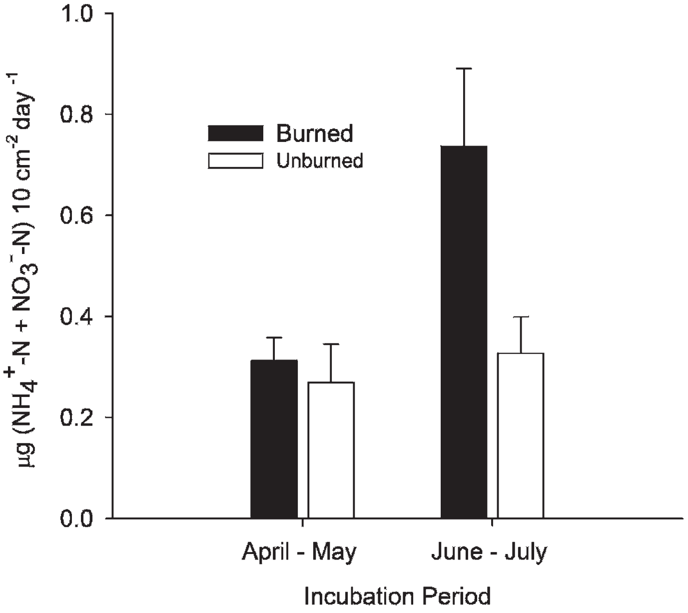

Figure 2. Soil inorganic nitrogen availability (mean ± 1 SE) in burned and unburned treatments on the Pawnee National Grassland, Colorado, during April–July 2007.

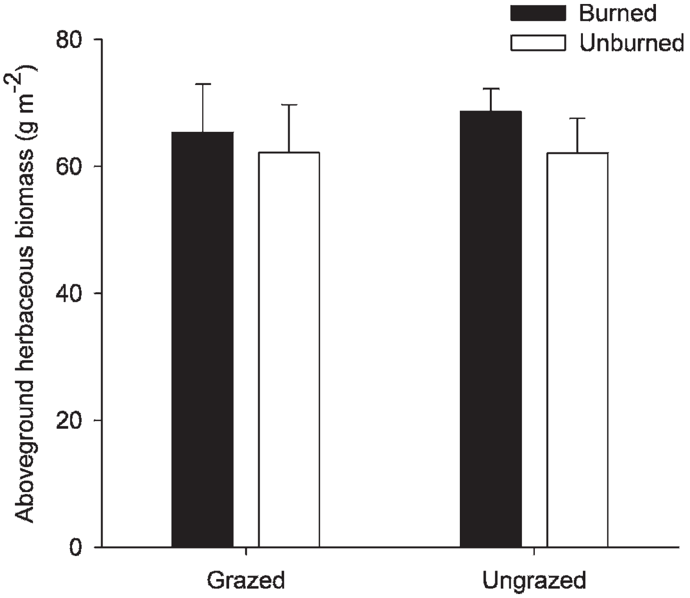

Figure 4. Effects of burning and grazing on current-year production of aboveground herbaceous biomass production during 2008 on the Pawnee National Grassland, Colorado.

cover removal and increased water repellency due to changes in hydrophobic organic compounds at the soil surface (Pierson et al. 2008). In contrast, we found that prescribed fire in shortgrass steppe did not negatively affect aboveground herbaceous production or soil moisture during the first postburn growing season despite below-average precipitation during the winter preceding the burn and the growing season following the burn. Another study addressing spring burns and soil moisture in blue grama–dominated rangeland of Montana also reported no effect of prescribed fire on soil moisture but found a positive burn effect on forage production (White and Currie 1983). The low topographic relief and fine-textured soils of many rangelands of the western Great Plains may minimize fire effects on runoff as compared with sagebrush steppe (Pierson et al. 2008). The lack of a burn effect on soil moisture in our study suggests that additional factors, such as the timing and intensity of burns or the way that burns affect other soil resources, may underlie variation among studies (Brockway et al. 2002; Augustine and Milchunas 2009; Scheintaub et al. 2009) in how burning affects plant production in semiarid rangelands.

Hypotheses concerning positive fire effects on herbaceous plant production in other rangelands have focused on the collective influence of litter removal on light, water, and N limitations to subsequent plant growth in tallgrass prairie (Blair 1997) and the combination of changes in shrub–grass competition and inorganic N availability in sagebrush steppe (Davies et al. 2007). Light limitation is unlikely to affect plant growth within the sparse canopy of the shortgrass steppe (Burke et al. 1998), but fire effects on soil N availability have not been examined. We hypothesized that burning would enhance N availability early in the growing season due to litter removal. In contrast, we found that burning did not affect N availability in spring (April–May) but did result in a surprisingly large enhancement of N availability in summer (June–July) during a period of plant senescence. Although June–July was primarily a dry period, we note that a thunderstorm occurred in late July (after the last soil moisture measurement but before removal of resin probes), which likely allowed for diffusion of inorganic N to the probes in spite of dry conditions during most of the incubation period. Fire-induced enhancement of soil N during the first postburn growing season has also been documented in sagebrush steppe (Davies et al. 2007) and montane shrublands and grasslands (Hobbs and Schimel 1984) and in the latter case was attributed to increased soil temperature. Our finding of increased N availability in summer but not during the 2-mo spring incubation that immediately followed the burn could potentially be related to seasonally dependent soil temperature and microbial responses to burning. Other additional or alternative mechanisms include indirect burn effects on belowground processes, such as plant inputs to the soil and rates of plant N uptake. Our findings suggest that further attention to fire effects on belowground processes in shortgrass steppe is warranted.

A comparison of studies where burning reduced the productivity of shortgrass rangelands to the conditions in our studies on the Pawnee National Grassland suggests that vegetation is least affected by fire in sites when burns occur in dormant vegetation with relatively low fuel loads. Comparisons of fuel loads across studies are limited by variation in the measurements of current-year production versus previous-year standing dead and litter, but previous studies reporting negative fire effects in shortgrass were at sites with annual herbaceous production of 100–350 $g \cdot m^{-2}$ (Launchbaugh 1964; Trlica and Schuster 1969; Brockway et al. 2002) with no plant consumption by livestock. In addition, negative effects on herbaceous production have been reported for burns conducted when a portion of the plants are photosynthetically active (Dix 1960; Brockway et al. 2002; Ford and Johnson 2006; Scheintaub et al. 2009). In contrast, studies have found neutral or positive effects on sites dominated by blue grama where annual herbaceous production is 40–145 $g \cdot m^{-2}$, and the burn is conducted before the onset of plant growth (this study; White and Currie 1983; Augustine and Milchunas 2009; Scheintaub et al. 2009).

Relative to other rangelands worldwide, the shortgrass steppe is one of the most resistant to grazing and fire in terms of plant community composition and productivity (Milchunas and Lauenroth 1993; Milchunas et al. 2008). This resistance to aboveground disturbances may be attributed in large part to traits of the dominant shortgrasses: blue grama and buffalograss. Blue grama is the most abundant species in the shortgrass steppe and is characterized by consistently high allocation of resources belowground throughout the growing season (Menke and Trlica 1981; Milchunas et al. 2008). Buffalograss has a prostrate growth form that reduces losses to grazing and also exhibits high regrowth potential. For example, a recent study found that the combination of burning and simulated grazing (clipping) had no effect on aboveground productivity of buffalograss compared to burned and unclipped treatments (Castellano and Ansley 2007). The combination of plant species resistant to aboveground disturbances and the conservative stocking rates used in our study may explain the finding that grazing of recently burned shortgrass steppe did not negatively affect aboveground herbaceous production.

MANAGEMENT IMPLICATIONS

Three key questions concerning potential effects of prescribed burns on livestock production are 1) effects on forage quantity, 2) effects on forage quality, and 3) whether burned sites need to remain ungrazed for a recovery period following burning. Our results indicate that late winter burns conducted in previously grazed shortgrass steppe do not suppress forage production. In addition, removal of standing dead by burning significantly enhanced the digestibility of blue grama in late May, when cattle typically begin summer grazing on shortgrass steppe. Whether this will influence cattle gains depends on many factors, including stocking rate, plant growth rates, and the degree to which current forage production (vs. consumption of old standing dead) is sufficient to meet the daily forage demand of stocked animals. However, we note that by the end of July, standing dead from the previous year contributes minimally to total available forage, and hence loss to burning is likely to affect herbage intake by cattle only in dry years (i.e., with low spring and early summer forage production) and only early in the grazing season (May–July). Where burning affects $< 50\%$ of a pasture and cattle have free access among burned and unburned areas (patch-burn grazing sensu Fuhlendorf and Engle 2004), enhanced forage quality on the burned portion could allow for increased daily forage intake rates by cattle in wet years, while old standing dead retained on the unburned portions could provide insurance against the possibility of low forage production in dry years.

Variation in burn conditions, plant community composition, and local weather conditions precludes the development of broadly applicable rules of thumb for postfire management (Engle and Bidwell 2001). However, recent studies suggest that a variety of rangelands in western North America may be resilient to the combined effects of fire followed by properly applied grazing management, including tallgrass prairie (Fuhlendorf and Engle 2004) and sagebrush steppe (Bruce et al. 2007; Bates et al. 2009). In this study, we found that deferment of grazing during the first postburn growing season had no effect on forage production in shortgrass steppe compared to sites grazed at a conservative stocking rate during the first postburn growing season. While these findings cannot be extrapolated beyond the conditions of the experiment, they indicate a need for further evaluation of livestock grazing at a variety of stocking rates during the first postburn growing season in shortgrass steppe.

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