Season and Intensity of Burning on Two Grass Species of the Chihuahuan Desert

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Abstract

We investigated effects of three burning seasons under two simulated fuel loads on plant mortality and basal area of small and large blue grama (*Bouteloua gracilis* [H.B.K.] Lag) and broomgrass muhly (*Muhlenbergia rigida* [H.B.K.] Lag) plants in the southern Chihuahuan Desert of Mexico. We simulated prescribed fire with a portable propane burner calibrated to match time and temperature curves reached at 1 700 $kg \cdot ha^{-1}$ and 2 800 $kg \cdot ha^{-1}$ fine fuel loads. Large (initial basal area > 10 cm^2) and small (initial basal area ≤ 10 cm^2) plants were used. For each species, we randomly treated 50 plants in each size class each season at each fuel load; 50 control plants of each species and size received no fire treatment. We estimated basal area change from measurements recorded photographically. Blue grama mortality was affected by season of burning, simulated fuel load, and plant size. Small blue grama plants had higher mortality than large plants. Burning at the high fuel load in winter increased basal area of large blue grama plants; in contrast, basal area was not affected by summer burning, and was reduced by spring burning with high fuel load. Basal area of broomgrass muhly plants was reduced by summer and winter burning and these responses were independent of fuel load and plant size. Our results suggest that winter is the most suitable season for prescription burning to improve southern Chihuahuan Desert grasslands: prescribed fire during this time reduced basal area of broomgrass muhly plants, had the highest mortality on broomgrass muhly, had a positive effect on basal area of small blue grama plants, and had no effect on basal area of large blue grama plants.

Key Words: basal area, blue grama, broomgrass muhly, fire simulation, mortality, plant size

INTRODUCTION

In semiarid rangelands of the southern Chihuahuan Desert in Mexico, desirable grasses such as blue grama (*Bouteloua gracilis* [H.B.K.] Lag) and buffalograss (*Buchloe dactyloides* [Nutt.] J.T. Engelm.) are being replaced by broomgrass muhly (*Muhlenbergia rigida* [H.B.K.] Lag), a grass with poor nutritional quality (Adler and Morales 1999; Yeaton and Flores 2009) and invasive ecological behavior (Delgado-Balbuena et al. 2013) distributed mainly in the Mexican High Plateau and in some localized areas of the Chihuahuan Desert in Arizona, New Mexico, and Texas. There has been relatively little research about effects of season, frequency, and intensity of fire on grasses of the Chihuahuan Desert (Humphrey 1974; Ahlstrand 1982; White and Currie 1983) and almost nothing is known about fire effects on broomgrass muhly.

Reports of fire effects on muhly species generally are scarce. Although Wright (1980) suggested that bush muhly (*Muhlenbergia porteri* Scribn. ex Beal) may be seriously damaged by fire, Aleksoff (1999) indicated that this species responded favorably to fire because of its widely arranged culms. Fryer (2009) found that bush muhly was generally favored by dormant season burns during early spring and winter, and further, that muhly species increase their productivity after fire, a response commonly observed in many other warm season grasses (e.g., Risser et al. 1981; Wright and Bailey 1982). Steuter (1987) found that plains muhly (*Muhlenbergia cuspidata* [Torr. ex Hook.] Rydb.) remained unchanged or increased after spring burning; this response may be attributable to the fact that its growing points are buried and thus insulated by soil (Fryer 2009). Walsh (1995) reported that mountain muhly (*Muhlenbergia montana* [Nutt.] Hitchc.) decreased after burning and required 3 yr to recover in central Arizona.

Potential management practices for mitigating broomgrass muhly invasion in the southern Chihuahuan Desert of Mexico include prescribed burning. The objective of this study was to evaluate the main and interactive effects of season of burning (spring, summer, and winter), plant size (small and large plants), and simulated fuel load (low and high) on mortality and changes in basal area of blue grama and broomgrass muhly in the Chihuahuan Desert. We hypothesized that prescribed fire effects on broomgrass and blue grama mortality would be affected by season of burn (with higher mortality when burned in the summer), plant size (with higher mortality of smaller plants), and fuel load (with higher mortality at higher fuel loads); furthermore, we expected that highest mortality would be observed for small plants burned at the higher fuel load during summer. We used a fully replicated and randomized experiment conducted over 2 yr with 2 800 individually marked plants to address our objectives.

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Table 1. Monthly precipitation (mm) at Vaquerias Experimental Station in Jalisco State, Mexico.

Month	2005	2006	2007	Mean[1]
January	0.0	0.0	18.5	17.0
February	0.5	0.0	33.5	2.5
March	21.4	5.5	0.0	2.0
April	5.0	28.2	10.2	1.5
May	16.2	101.1	37.0	35.0
June	0.0	36.7	117.8	70.0
July	53.0	103.3	184.9	113.7
August	84.9	84.7	17.7	83.0
September	47.8	93.0	83.7	61.0
October	35.4	35.3	44.4	28.0
November	0.0	17.4	6.4	7.0
December	0.0	7.8	0.0	5.0
Total	264.2	513.0	554.1	430.0

[1]20-yr mean.

METHODS

The study was conducted on semiarid rangeland at the Vaquerias Experimental Station in the Los Llanos de Ojuelos subprovince of Mexico in the southern Chihuahuan Desert. Our study pasture had a history of 8 yr with no livestock grazing. Elevation at the site is 2 130 m above sea level, and soils are dominated by loams and sandy loams with a caliche layer at 50 cm. Topography is mainly flat with gentle slopes from 0% to 5%. Climate consists of warm summers and cool dry winters with average temperatures fluctuating from 16°C to 18°C; the average daily minimum and maximum temperatures are 4.5°C in January and 25°C in July (CETENAL 1970). Average annual precipitation is 430 mm, occurring mainly in summer. During this study we had 38% below, and 19% and 28% above average precipitation in 2005, 2006, and 2007, respectively (Table 1).

Vegetation in the study area is dominated by shortgrass species. Primary grasses are blue grama, wolftail (*Lycurus phleoides* H.B.K. Kunth), threeawn (*Aristida* spp. L.), needlegrass (*Microchloa kunthii* Desv.), and broomgrass muhly. There are also large populations of broomweed (*Haplopappus venetus vernonioides* cultivar *Isocoma* Kunth), brickellbush (*Brickellia spinulosa* A. Gray), pricklypear (*Opuntia streptacantha* Lemaire), and huisache (*Acacia farnesiana* [L.] Willd).

The experimental design was a completely randomized design with a factorial combination of three factors (plant size, season of burning, and fuel load) for each species. We defined two plant size classes based on initial basal area measurements: large and small plants had basal areas > 10 cm^2 and ≤ 10 cm^2, respectively. For each season of burning we randomly selected 50 plants of each size class for each simulated fuel load treatment for each species. Fuel load treatments were randomly assigned to plants. Because the study was conducted in native rangeland and plants were randomly selected, we placed no restrictions on distance between plants used in the experiment except that burn barrel placement did not overlap two target plants; ca. 90% of the target plants, however, were separated by 5 m to 10 m.

We simulated prescribed fire using a portable propane burner designed by Britton and Wright (1979) and calibrated using a series of combinations of gas pressure and time to obtain specific time temperature curves reached with 1 700 kg · ha^{-1} and 2 800 kg · ha^{-1} of fine fuel, as found in a typical prescribed burn (Wright et al. 1976). In the calibration process we generated the following prediction equation for temperature (°C): temperature$=-30.613+157.9x_1+5.7196x_2$, ($\hat{R}^2=0.881$), where x_1=gas pressure (kg · cm^{-2}), and x_2=time (seconds). Temperatures of 143.4°C and 184.8°C for fuel loads of 1 700 kg · ha^{-1} and 2 800 kg · ha^{-1} were reached by burning with pressures of 10 psi for 11 s and 18 s for low and high fuel loads, respectively (Britton and Wright 1979). Plants were burned in spring (April), summer (June), and winter (December) of 2005 and 2006. Burned plants were marked with a painted nail and numbered tag for follow-up plant mortality and basal area evaluations. We also evaluated 50 nonburned control plants of each species and size class.

In autumn 2007, one growing season after fire treatments, we evaluated each plant for mortality, assuming plants with no live tillers to be dead. We assessed changes in basal area of living plants that were burned in 2006 by measuring total soil surface area covered by grass crown using photographic techniques (Owens et al. 1985; Britton et al. 1990; Roshier et al. 1997; Bennett et al. 2000; May et al. 2008). We took an overhead photo of each plant from a height of 1.5 m with a digital camera (Polaroid Foveon) immediately after burning (initial area) and again at the end of the following growing season (final area) to estimate percentage of change. To estimate basal area, we delineated the perimeter of each plant by wrapping it once with a steel chain (0.5 cm wide, 3 m long); we then placed a 70×50 cm grid over the plant crown (using the graduated sides [cm] as reference) and took a photo. Raw format was used because this separates the colors in the photo into layers rather than mixing them as is normally done in digital cameras. We analyzed photographs with Adobe Photoshop software: basal areas outlined by the chain were filled with a dull color, estimating the number of pixels. We converted this to area using a factor of 2 126 pixels · cm^{-2}.

For each year, we analyzed data as a completely randomized design with a $2\times3\times2$ factorial arrangement of plant size, season, and fuel load. We used the Fisher's Protected LSD test to compare treatment means. We assessed normality assumptions with the Shapiro-Wilk (Shapiro and Wilk 1965) test and homogeneity of variance assumptions with Levene's (1960) test. Mortality data are binomial in nature; use of a generalized linear model, however, was not possible with these data because of quasi-complete separation (i.e., mortality responses largely separated treatments into their levels; Webb et al. 2004). Therefore, we analyzed mortality data with a general linear model (SAS 2010) and adjusted for heterogeneous variances following Brown and Forsythe (1974) to test our hypotheses listed above.

RESULTS

Blue Grama—Mortality

For plants burned in 2005 (a relatively dry year), plant size, fuel load, and season of burn acted independently of each other

Table 2. Mortality (mean % [SE]; $n=50$) of large and small blue grama plants burned in spring, summer, or winter of 2005 with high and low fuel load simulations in the southern Chihuahuan Desert of Mexico.

	High fuel load		Low fuel load		
Treatment	Large	Small	Large	Small	Mean
Control[1]	0 (0)	0 (0)	0 (0)	0 (0)	0
Spring	22 (5.9)	72 (6.4)	0 (0)	(7.1)	37.5 a[2]
Summer	2 (2.0)	56 (7.1)	0 (0)	38 (6.9)	24.4 b
Winter	12 (4.6)	72 (6.4)	4 (2.8)	48 (7.1)	34.0 a

[1]We used the same control plants ($n=50$) in each size for both fuel load simulation treatments.
[2]Treatment means followed by the same lowercase letter are not significantly different ($P > 0.05$).

Table 3. Mortality (mean % [SE]; $n=50$) of large and small blue grama plants burned in spring, summer, or winter of 2006 with high and low fuel load simulations in the southern Chihuahuan Desert of Mexico.

	High fuel load				Low fuel load			
Treatment	Large		Small		Large		Small	
Control[1]	0 (0)		0 (0)		0 (0)		0 (0)	
Spring	0 (0)	a[2]A[3]z[4]	64 (6.86)	bAy	2 (2.0)	aAz	46 (7.12)	bBx
Summer	2 (2.0)	aAz	16 (5.24)	bAz	2 (2.0)	aAz	28 (6.41)	bBy
Winter	2 (2.0)	aAz	8 (3.88)	aAz	2 (2.0)	aAz	6 (3.39)	aAz

[1]We used the same control plants ($n=50$) in each size for both fuel load simulation treatments.
[2]Plant size means within a season of burn and fuel load followed by the same lowercase letters (a,b) are not significantly different ($P > 0.05$).
[3]Fuel load means within season of burn and plant size followed by the same uppercase letters (A,B) are not significantly different ($P > 0.05$).
[4]Season of burn means within a fuel load and plant size followed by the same lowercase letters (x,y,z) are not significantly different ($P > 0.05$).

($F_{1;445.6}=1.61$, $P=0.20$) in their effects on mortality (Table 2). Small blue grama plants had higher ($F_{1;445.6}=260.4$, $P < 0.01$) mortality (48.9% ± 2 SE) than large plants (5.7% ± 1.9 SE) and mortality was higher ($F_{1;445.6}=27.0$, $P < 0.01$) with high fuel loads (39.3% ± 2 SE) than low fuel loads (24.3% ± 2.4 SE). Mortality was lower ($F_{1;445.6}=7.99$, $P < 0.01$) for plants burned in the summer (24.4% ± 2.5 SE) but similar ($F_{1;445.6}=0.12$, $P=0.32$) for plants burned in spring (37.5% ± 2.5 SE) and in winter (34% ± 2.5 SE). Our study area experienced a relatively wet year in 2006 and under these conditions, season of burn, plant size, and fuel load interacted ($F_{2;423.7}=4.23$, $P=0.02$; Table 3) in their effects on blue grama mortality. Small plants had higher ($F_{1;423.7}=6.45$, $P=0.02$) mortality than large plants at both fuel loads when they were burned in spring or summer; however, when plants were burned in winter, mortality was not affected ($F_{1;423.7}=1.18$, $P=0.28$) by plant size at either fuel load. Fuel load did not affect ($F_{1;423.7}=0.13$, $P > 0.72$) mortality of large plants in any season of burning, and did not affect ($F_{1;423.7}=0.13$, $P=0.72$) mortality of small plants burned in winter. However, mortality was higher ($F_{1;423.7}=10.7$, $P < 0.01$) for small plants burned in spring at the high fuel load than at the lower fuel load, and also higher ($F_{1;423.7}=4.74$, $P=0.03$) for small plants burned in summer at the low fuel load than at the high fuel loads. Season of burning did not affect mortality of large plants burned at high fuel loads ($F_{2;423.7}=0.09$, $P=0.92$) or at low fuel loads ($F_{2;423.7}=0$, $P=1$). Mortality of small plants, however, was affected by season of burning under high ($F_{2;423.7}=60.3$, $P < 0.01$) and low ($F_{2;423.7}=26.4$, $P < 0.01$) fuel loads: in general, mortality was higher for plants burned in spring than in winter (Table 3).

Blue Grama—Basal Area

Fuel load, plant size, and season of burning interacted ($F_{2;211.1}=5.0$, $P < 0.01$) in their effects on basal area change of blue grama. For small plants, neither fuel load nor season of burning, nor their interaction ($P=0.23$) affected basal area change. Different patterns were observed for large plants: control plants and plants burned with high fuel load in summer experienced no change in basal area (Fig. 1). Basal area of large blue grama plants increased 37.4% ($t_{161.6}=3.18$, $P=0.002$) when burned in winter but decreased 29.2% ($t_{161.6}=-2.51$, $P=0.01$) when burned in spring. When large plants were burned with low fuel load, basal area was not affected when burning took place during summer or winter but increased 34.9% when plants were burned in spring.

Broomgrass Muhly—Mortality

In 2005, season of burning and plant size interacted ($F_{2;97.1}=6.03$, $P < 0.01$) in their effects on broomgrass muhly: there was no mortality of large plants regardless of season of burning, and although mortality was low among small plants, more plants died in winter (4% ± 2.8 SE and 6% ± 3.4 SE at low and high fuel loads, respectively) than in spring (0%) or summer (0%). In 2006,

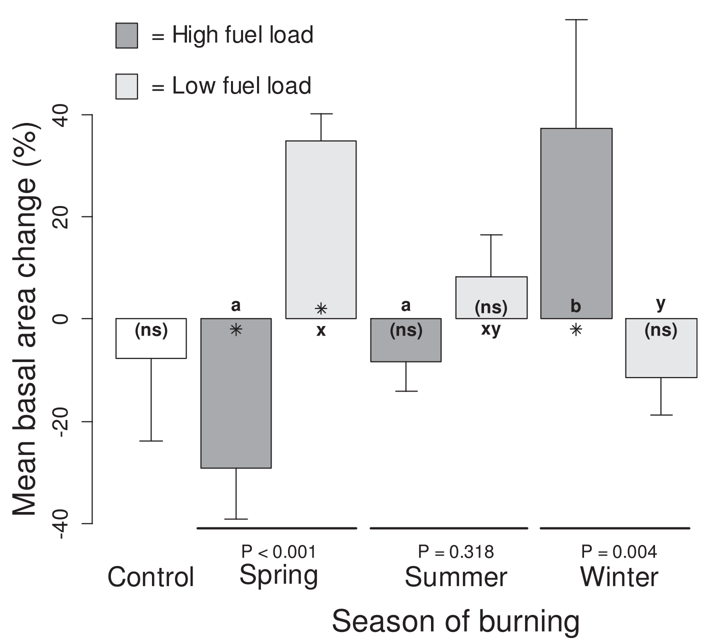

Figure 1. Mean (SE) basal area change (%) of large blue grama plants burned in 2006. Seasonal means within high fuel load followed by the same lowercase letters (a, b), or means within low fuel load followed by the same lowercase letters (x, y), are not significantly different ($P > 0.05$, Fisher's Protected LSD test). P values correspond to comparisons of low and high fuel loads within a season of burning. Bars with an embedded ''ns'' are not significantly different from zero; bars with an asterisk are significantly different from zero ($P < 0.05$).

mortality was not affected by season of burn ($F_{2;467.3}=1.37$, $P=0.25$), plant size ($F_{1;467.3}=2.78$, $P=0.10$), fuel load ($F_{1;467.3}=0$, $P=1$), or any of their interactions ($P=0.14$).

Broomgrass Muhly—Basal Area

Basal area was not affected by plant size, fuel load or any interactions among experimental factors ($P>0.1423$) but only by season of burning ($F_{2;299.2}=28.71$, $P<0.01$). Basal area of control plants increased 18.6% whereas basal area of spring-burned plants did not change; basal area of summer-burned plants decreased 14.4%; and basal area of winter-burned plants decreased even more (–47.8%).

DISCUSSION

Pyke et al. (2010) proposed a conceptual framework for predicting vegetation response to fire that explicitly highlighted the importance of a reductionist approach in understanding fire's effects at the level of the individual plant ("first-order" effects). Fully recognizing that "plant community development after fire results from an intricate set of environmental processes that depend on complex timing of biotic and abiotic factors to form plant trajectories during years following fire" (Pyke et al. 2010:275; also see Steuter and McPherson 1995), these authors cogently argued that "first-order fire effects can set the stage of subsequent post-fire succession and as such are important to consider when predicting plant community response to fire" (Pyke et al. 2010:275). We concur with this viewpoint: an important first step in understanding fire effects, particularly in a management context where the overall goal is manipulation of individual species, is an understanding of how "target plants" respond to fire. Our study was specifically designed to document fire effects on broomgrass muhly, an undesirable native grass with invasive characteristics, and on blue grama, a common but desirable associated species in our study area. This is a research strategy that has yielded practical, data-based management guidelines for a number of target species (for a general review, see Wright and Bailey [1982]; for more recent specific examples, see Vermeire and Roth [2011]; Strong et al. [2013a, b]; Russell et al. [2013]). When information at the individual plant level is available, then interpretations of fire effects can be expanded to include community-level responses in 1) the strict multivariate sense (e.g., Taylor et al. 2012, Wester et al. 2014) or 2) as a "collective response" in the sense of Wester et al. (2014; e.g., Rideout-Hanzak et al. 2011; Vermeire et al. 2011; Taylor et al. 2012).

It is widely known that a plant's response to fire is influenced by the combined effects of general environmental conditions (e.g., "wet year" and "dry year" effects both prior to and following burning), seasonal effects (usually related to phenology but also confounded with weather conditions), fuel load and fire intensity, and factors related to plant size and fuel arrangement (Wright and Bailey 1982; Steuter and McPherson 1995; McPherson 1997). From an ecological perspective, however, it is important to incorporate species-specific responses into these generalities and to identify the conditions under which these factors either act independently of each other, or interact with each other, in their effects on plant response.

Year-to-Year and Seasonal Effects

Weather patterns, especially with respect to amount and distribution of rainfall, can have a dramatic effect on a plant's response to fire. Many studies of fire effects on warm-season grasses have documented responses to "wet" and "dry" years and to dormant-season and growing-season fires (e.g., Wright and Bailey [1982] and references therein). The common emphasis on "dormant" vs. "growing-season" burns has a long history in applied range management and is based on the idea that summer fires may be more damaging to plants because defoliation occurs when plants are actively growing (Steuter and McPherson 1995) and may have depleted carbohydrate reserves following spring green-up, with meristems already elevated, and perhaps under water stress because of reduced soil water content (Risser et al. 1981; Steuter and McPherson 1995), and because increased solar radiation can desiccate plants and inhibit regrowth, particularly during dry years (Copeland et al. 2002); also see McPherson (1995:135), who concluded that "The effects of early-summer fires are more obvious and longer-lasting than the effects of fires in other seasons." More recently, however, Taylor et al. (2012) showed that summer fire during periods of below-average precipitation can reduce or eliminate woody species with few long-term effects on perennial warm season grasses. Preliminary results on effects of summer fire on invasive exotic grasses in south Texas indicate exotics experience higher mortality than natives (A. Toomey and S. Rideout-Hanzak, unpublished data, 2014). It is clear that season of burning is a topic of research interest that is yielding new insights in fire ecology and prescribed burning.

In our study blue grama plants were more adversely affected by fire in all burn seasons during the dry year (2005) than the wet year (2006). Similar results are common in the literature (e.g., Wright 1974, 1980; White and Currie 1983; Lauenroth et al. 1994; Brockway et al. 2002; Ford and Johnson 2006). Our experiment, however, evaluated spring burns as well as summer and winter burns, enabling us to address one of the characteristics of an individual plant that can affect its response to fire: a plant greening up in spring may be more succulent than more mature summer growth or dormant winter forage, and this can affect its response to fire because water is a better conductor of heat than air (Pyke et al. 2010). Fire behavior also differs between seasons of burn (Ewing and Engle 1988), even when fuel loads are similar, because of differences in fuel moisture and weather (e.g., Strong et al. 2013a). We showed that the effects of spring, summer, or winter burning were often species-specific and usually depended on fuel load. Season of burning had little or no effect on broomgrass mortality regardless of year. Different patterns were detected for blue grama. In 2006 we found a strong seasonal effect to our treatments that was manifested in a three-way interaction between plant size, fuel load, and season. For example, small plants had higher mortality than large plants at both fuel loads when burned in summer or spring; when plants were burned in winter, however, mortality was not affected by plant size at either fuel load. Under the drier conditions of 2005, these effects, although significant, acted independently of each other. Additionally, our blue grama results differ from numerous reports (Trlica and Cook 1971; Wright 1974; White and Currie 1983; Schacht and

Stubbendieck 1985; Anderson 2003) that show beneficial effects of spring burning on this species (as well as many other warm season grasses).

Plant Size Effects

Although a plant's size is an important factor that affects its response to fire (Pyke et al. 2010), field-based fire studies of herbaceous plants that specifically incorporate plant size effects are uncommon (e.g., Wright and Klemmedson 1965; Silva et al. 1990; Kaye et al. 2001). Small plants are often more susceptible to fire (Steuter and McPherson 1995) because of their less-developed root system, fewer phytomers, and overall lower resource levels (Grace and Platt 1995). Also, small perennial grass plants have less developed tussock, and it is more likely that meristematic tissue of small grasses is more easily reached and damaged by heat (Silva and Castro 1989; Steuter and McPherson 1995). We specifically addressed plant size in our experiment. During our relatively dry year (2005), small blue grama plants showed higher mortality than large plants, and this response was independent of fuel load or season of burning. Broomgrass responded differently under these dry conditions: we observed no mortality of large plants at all, and only low mortality of small plants if they were burned in the winter. Under the generally wetter conditions of 2006, however, our experimental factors interacted in their effects on blue grama mortality: small blue grama plants had higher mortality than larger blue grama plants when burned in spring or summer but similar mortality to large plants when burned in the winter. In stark contrast, broomgrass mortality was unaffected by plant size during the wetter year. Clearly, the size-specific responses of broomgrass muhly to fire warrant study.

Fuel Load Effects

Roberts et al. (1988) found no effects of fire intensity on weeping lovegrass (*Eragrostis curvula* [Shrader] Ness) or tobosagrass (*Hilaria mutica* [Buckl.] Bent). Similarly, Ansley et al. (2008) reported no difference in tobosagrass yield and recovery rates between high- and low-intensity winter fires. Our results suggest that effects of fuel load on plant response are not so easily summarized. Whereas neither broomgrass mortality nor basal area change were affected by fuel load under any conditions, blue grama's responses to fuel load depended on a number of factors. For example, during the relatively dry conditions of 2005, blue grama experienced higher mortality under high fuel load simulations, and this effect was consistent across plant size as well as season of burning. Under relatively wetter conditions, however, fuel load effects interacted with both season of burn and plant size in their effects on blue grama mortality. Fuel load also affected basal area changes of blue grama, but these effects depended on plant size.

IMPLICATIONS

Fire can be used successfully to depress one plant species and enhance another, and selective grazing of coarse, nonpalatable plants can be increased significantly after burning (Heirman and Wright 1973). Use of fire in the southern Chihuahuan Desert to control undesirable grasses such as broomgrass muhly is a suitable and economical option with low risk of damage to desirable grass species such as blue grama. Considering the high resistance of broomgrass muhly to fire (as reflected by our basal area and mortality data), prescribed burning used in a combination with prescribed grazing can be used as a management tool for removing broomgrass muhly old growth, and increasing the forage quality, palatability, and livestock utilization, thereby reducing its competitive advantage over more palatable key species when left unburned (McAtee et al. 1979).

However, prescriptions must be considered carefully as some seasons and weather conditions could result in damage to blue grama. Our results show that, under the weather conditions of the Mexican High Plateau, large blue grama plants can survive fire in relatively dry and wet years, whereas small plants are severely damaged by spring and summer burns under dry conditions, but are more resistant to burning in these seasons when precipitation patterns are favorable. Our results can help determine appropriate timing of prescribed burning, considering highly variable precipitation patterns in the southern Chihuahuan Desert. Relative to basal area responses, both summer and winter burns can be used to improve southern Chihuahuan Desert grasslands because they negatively affected basal area of broomgrass muhly plants regardless of size, had a positive effect on basal area of small blue grama plants, and had no effect on basal area of large blue grama plants. Relative to plant mortality, winter is the most suitable season for prescription burning. Based on these results, therefore, we recommend winter burning for control of broomgrass muhly: when burned in winter, subsequent reductions in broomgrass basal area during the following growing season can benefit this grassland community because reduced competitive ability of broomgrass muhly may favor more desirable species such as blue grama and buffalograss. Our results support the recommendations of Brockway et al. (2002) to use dormant season burning in shortgrass ecosystems of New Mexico to improve species quality and productivity.

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LITERATURE CITED

Adler, P. B., and J. M. Morales. 1999. Influence of environmental factors and sheep grazing on an Andean grassland. *Journal of Range Management* 52:471–480.

Ahlstrand, G. M. 1982. Response of Chihuahuan Desert mountain shrub vegetation to burning. *Journal of Range Management* 35:62–65.

Aleksoff, K. C. 1999. *Muhlenbergia porteri*. Fire effects information system. US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available at: http://www.fs.fed.us/database/feis/. Accessed 5 October 2014.

Anderson, M. D. 2003. *Bouteloua gracilis*. Fire effects information system. US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available at: http://www.fs.fed.us/database/feis/. Accessed 5 October 2014.

Ansley, R. J., W. E. Pinchak, and D. L. Jones. 2008. Mesquite, tobosagrass and common broomweed responses to fire season and intensity. *Rangeland Ecology & Management* 61:588–597.

Bennett, L. T., T. S. Judd, and M. A. Adams. 2000. Close range vertical photography for measuring cover changes in perennial grasslands. *Journal of Range Management* 53:634–641.

Britton, C. M., and H. A. Wright. 1979. A portable burner for evaluating effects of fire on plants. *Journal of Range Management* 32:475–476.

Britton, C. M., G. R. McPherson, and F. A. Sneva. 1990. Effects of burning and clipping on five bunchgrasses in eastern Oregon. *Great Basin Naturalist* 50:115–120.

Brockway, D. G., R. G. Gatewood, and R. B. Paris. 2002. Restoring fire as an ecological process in shortgrass prairie ecosystems: initial effects of prescribed burning during the dormant and growing seasons. *Journal of Environmental Management* 65:135–152.

Brown, M. B., and A. B. Forsythe. 1974. The ANOVA and multiple comparisons for data with heterogeneous variances. *Biometrics* 30:719–724.

Comision de estudios del Territorio Nacional (CETENAL). 1970. Carta de climas 14Q-III Qro. México, D.F., Mexico: Instituto de Geografía, Universidad Nacional Autónoma de México.

Copeland, T. E., W. Sluis, and H. F. Howe. 2002. Fire season and dominance in an Illinois tallgrass prairie restoration. *Restoration Ecology* 10:315–323.

Delgado-Balbuena, J., J. T. Arredondo, H. W. Loescher, E. Huber-Sannwald, G. Chavez-Aguilar, M. Luna-Luna, and R. Barretero-Hernandez. 2013. Differences in plant cover and species composition of semiarid grassland communities of central Mexico and its effects on net ecosystem exchange. *Biogeosciences* 10:4673–4690.

Ewing, A. L., and D. M. Engle. 1988. Effects of late summer fire on tallgrass prairie microclimate and community composition. *American Midland Naturalist* 120:212–223.

Ford, P. L., and G. V. Johnson. 2006. Effect of dormant vs. growing season fire in shortgrass steppe: biological soil crust and perennial grass responses. *Journal of Arid Environments* 67:1–14.

Fryer, J. L. 2009. *Muhlenbergia cuspidatae*. Fire effects information system. US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available at: http://www.fs.fed.us/database/feis/. Accessed 5 October 2014.

Grace, S. L., and W. J. Platt. 1995. Effects of adult tree density and fire on the demography of pregrass stage juvenile longleaf pine (*Pinus palustris* Mill.). *Journal of Ecology* 83:75–86.

Heirman, A. L., and H. A. Wright. 1973. Fire in medium fuels of west Texas. *Journal of Range Management* 26:331–335.

Humphrey, R. R. 1974. Fire in the deserts and desert grassland of North America. *In*: T. T. Kozlowski and C. E. Ahlgren [eds.]. Fire and ecosystems. New York, NY, USA: Academic Press. p. 366–399.

Kaye, T. N., K. L. Pendergrass, K. Finley, and J. B. Kauffman. 2001. The effect of fire on the population viability of an endangered prairie plant. *Ecological Applications* 11:1366–1380.

Lauenroth, W. K., O. E. Sala, D. P. Coffin, and T. B. Kirchner. 1994. The importance of soil water in the recruitment of *Bouteloua gracilis* in the shortgrass steppe. *Ecological Applications* 4:741–749.

Levene, H. 1960. Robust tests for equality of variances. *In:* I. Olkin, S. G. Ghurye, W. Hoeffding, W. G. Madow, and H. B. Mann [eds.]. Contributions to probability and statistics: essays in honor of Harold Hotelling. Stanford, CA, USA: Stanford University Press. p. 278–292.

May, B. C., D. B. Wester, C. M. Britton, and T. Bryson. 2008. Macro- and microhabitat characteristics of Kuenzler's hedgehog cactus, *Echinocereus fendleri* var *kuenzleri*. *Haseltonia* 14:170–175.

McAtee, J. W., C. J. Scifres, and D. L. Drawe. 1979. Digestible energy and protein content of gulf cordgrass following burning or shredding. *Journal of Range Management* 32:376–378.

McPherson, G. R. 1995. The role of fire in the desert grasslands. *In:* M. P. McClaran and T. R. Van Devender [eds.]. The desert grassland. Tucson, AZ, USA: University of Arizona Press. p. 130–151.

McPherson, G. R. 1997. Ecology and management of North American savannas. Tucson, AZ, USA: University of Arizona Press. 208 p.

Owens, M. K., H. G. Gardiner, and B. E. Norton. 1985. A photographic technique for repeated mapping of rangelands plant populations in permanent plots. *Journal of Range Management* 38:231–232.

Pyke, D. A., M. L. Brooks, and C. D'Antonio. 2010. Fire as a restoration tool: a decision framework for predicting the control or enhancement of plants using fire. *Restoration Ecology* 18:274–284.

Rideout-Hanzak, S., D. B. Wester, C. M. Britton, and H. Whitlaw. 2011. Biomass not linked to perennial grass mortality following severe wildfire in the southern High Plains. *Rangeland Ecology & Management* 64:47–55.

Risser, P. G., E. C. Birney, H. D. Blocker, S. W. May, W. J. Parton, and J. A. Wiens. 1981. The true prairie ecosystem. US/IBP Synth. Series No. 16. Stroudsburg, PA, USA: Hutchinson Ross Publishing Co. 557 p.

Roberts, F. H., C. M. Britton, D. B. Wester, and R. G. Clark. 1988. Fire effects on tobosagrass and weeping lovegrass. *Journal of Range Management* 41:407–409.

Roshier, D., S. Lee, and F. Boreland. 1997. A digital technique for recording of plant population data in permanent plots. *Journal of Range Management* 50:106–109.

Russell, M. L., L. T. Vermeire, N. A. Dufek, and D. J. Strong. 2013. Fire, defoliation and competing species alter *Aristida purpurea* biomass, till, and axillary bud production. *Rangeland Ecology & Management* 66:290–296.

SAS [computer program]. 2010. Version 9.3. Cary, NC, USA: SAS Institute, Inc.

Schacht, W., and J. Stubbendieck. 1985. Prescribed burning in the loess hills mixed prairie of southern Nebraska. *Journal of Range Management* 38:47–51.

Shapiro, S. S., and M. B. Wilk. 1965. An analysis of variance test for normality (complete samples). *Biometrika* 52:591–611.

Silva, J. F., and F. Castro. 1989. Fire, growth and survivorship in a Neotropical savanna grass *Andropogon semiberbis* in Venezuela. *Journal of Tropical Ecology* 5:387–400.

Silva, J. F., J. Raventos, and H. Caswell. 1990. Fire and fire exclusion effects on the growth and survival of two savanna grasses. *Acta Oecologica* 11:783–800.

Steuter, A. A. 1987. C_3/C_4 production shift on seasonal burns in the Northern mixed prairie. *Journal of Range Management* 40:27–31.

Steuter, A. A., and G. R. McPherson. 1995. Fire as a physical stress. *In:* D. J. Bedunah and R. E. Sosebee [eds.]. Wildland plants: physiological ecology and developmental morphology. Denver, CO, USA: Society for Range Management. p. 550–579.

Strong, D. J., A. C. Ganguli, and L. T. Vermeire. 2013a. Fire effects on basal area, tiller production, and mortality of the C_4 bunchgrass, purple threeawn. *Fire Ecology* 9:89–99.

Strong, D. J., L. T. Vermeire, and A. C. Ganguli. 2013b. Fire and nitrogen effects on purple threeawn (*Aristida purpurea*) abundance in northern mixed-grass prairie old fields. *Rangeland Ecology & Management* 66:553–560.

Taylor, C. A., D. Twidwell, N. E. Garza, C. Rosser, J. K. Hoffman, and T. D. Brooks. 2012. Long-term effects of fire, livestock herbivory removal, and weather variability in Texas semiarid savanna. *Rangeland Ecology & Management* 65:21–30.

Trlica, M. J., Jr., and C. W. Cook. 1971. Defoliation effects on carbohydrate reserves of desert species. *Journal of Range Management* 24:418–425.

Vermeire, L. T., J. L. Crowder, and D. B. Wester. 2011. Plant community and soil environment response to summer fire in the Northern Great Plains. *Rangeland Ecology & Management* 64:37–46.

Vermeire, L. T., and A. D. Roth. 2011. Plains prickly pear response to fire: effects of fuel load, heat, fire weather, and donor site soil. *Rangeland Ecology & Management* 64:404–413.

Walsh, R. A. 1995. *Muhlenbergia montana*. Fire effects information system. US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available at: http://www.fs.fed.us/database/feis/. Accessed 5 October 2014.

Webb, M. C., J. R. Wilson, and J. Chong. 2004. An analysis of quasi-complete binary data with logistic models: applications to alcohol abuse data. *Journal of Data Science* 2:276–285.

Wester, D. B., S. Rideout-Hanzak, C. M. Britton, and H. Whitlaw. 2014. Plant community response to the East Amarillo Complex wildfires in the southern High Plains, USA. *Community Ecology* 15:222–234.

White, R. S., and P. O. Currie. 1983. Prescribed burning in the northern Great Plains: yield and cover responses of 3 forage species in the mixed grass prairie. *Journal of Range Management* 36:179–183.

Wright, H. A. 1974. Effect of fire on southern mixed prairie grasses. *Journal of Range Management* 27:417–419.

Wright, H. A. 1980. The role and use of fire in the semidesert grass–shrub type. Ogden, UT, USA: US Department of Agriculture, Forest Service. INT-85. 24 p.

Wright, H. A., and A. W. Bailey. 1982. Fire ecology: United States and southern Canada. New York, NY, USA: Wiley. 501 p.

Wright, H. A., S. C. Bunting, and L. F. Neuenschwander. 1976. Effect of fire on honey mesquite. *Journal of Range Management* 29:467–471.

Wright, H. A., and J. O. Klemmedson. 1965. Effect of fire on bunchgrasses of the sagebrush–grass region in southern Idaho. *Ecology* 46:680–688.

Yeaton, R. I., and J. L. Flores Flores. 2009. Community structure of a southern Chihuahuan Desert grassland under different grazing pressures. *South African Journal of Botany* 75:510–517.