Texas Wintergrass and Buffalograss Response to Seasonal Fires and Clipping

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Abstract

There is increased interest in the use of summer-season fires to limit woody plant encroachment into grasslands, but effects of these fires on grasses are poorly understood. We quantified effects of repeated winter fires, repeated summer fires, and clipping (to simulate grazing) on aboveground total yield, live yield, and percentage of live tissue of C_3 Texas wintergrass (*Nassella leucotricha* [Trin. & Rupr.] Pohl.), and C_4 buffalograss (*Buchloë dactyloides* [Nutt.] Engelm.) in 2 experiments. Monospecific patches of each species were exposed to 1 of 3 fire treatments (no-fire, 2 winter fires in 3 years, or 2 summer fires in 3 years) and 1 of 2 clip treatments (no clip or clip once each spring). Experiment 1 evaluated effects of fire without grazing or clipping on late-growing season (late-season) yields. Late-season total yield of both species recovered from winter and summer fires within 1 or 2 growing seasons post-fire. By 3 years post-fire, Texas wintergrass late-season total yield was 2 times greater in the summer fire treatment than the winter fire or no-fire treatments, and buffalograss late-season total yield was 3 times greater in summer and winter fire treatments than in the no-fire treatment. Experiment 2 evaluated combined effects of fire and clipping the previous spring on spring-season yields. Clipping alone or with fire (summer or winter) reduced Texas wintergrass yields on more sample dates than occurred with buffalograss. By 3 years post-fire, buffalograss spring total yield was greater in all fire and fire + clip treatments than in the clip only or untreated controls. Results suggest: 1) both species were tolerant of summer fire, 2) fire in either season with or without clipping stimulated buffalograss production, and 3) buffalograss was more tolerant than Texas wintergrass to the combined effects of clipping + fire (either season).

Resumen

Hay un creciente interés en el uso del fuego en verano para limitar el avance de las plantas leñosas en los zacatales, pero los efectos de estas quemas en los pastos esta pobremente entendida. En dos experimentos cuantificamos los efectos de quemas repetidas en invierno, quemas repetidas en verano, y corte (simulando el apacentamiento) sobe el rendimiento de biomasa total aérea y el rendimiento y porcentaje de tejido vivo del zacate C_3 "Texas wintergrass" (*Nassella leucotricha* [Trin. & Rupr.] Pohl.) y del C_4 "Buffalograss" (*Buchloë dactyloides* [Nutt.] Engelm.). Parches puros de cada una de estas especies se sometieron a uno de tres tratamientos de fuego (sin fuego, dos fuegos en invierno, o dos fuegos en verano) y a uno de dos tratamientos de corte (sin corte o un corte cada primavera). En el experimento 1 evaluamos los efectos del fuego sin apacentamiento o corte sobre el rendimiento al final de la estación de crecimiento (rendimiento de final de estación). El rendimiento total de final de estación de ambas especies se recuperó de los fuegos de invierno y verano en una o dos estaciones de crecimiento posteriores a las quemas. Para el tercer año posterior a la quema, el rendimiento total de final de estación del "Texas wintergrass" fue dos veces mayor en el tratamiento de quema en verano que en los tratamientos de quemas en invierno o sin quemas, y el rendimiento del "Buffalograss" fue tres veces mayor en los tratamientos de quema en invierno o verano que en el de sin quema. En el experimento 2 evaluamos los efectos combinados del fuego y corte en la primavera previa sobe el rendimiento en primavera. El corte solo o con fuego (en verano o invierno) redujo los rendimientos del "Texas wintergrass" en mas fechas de muestreo que en el "Buffalograss". Al tercer año posterior al fuego, el rendimiento total de primavera del "Buffalograss" fue mayor en todos los tratamientos de fuego y fuego + corte que en el tratamiento de corte solo o en las parcelas control sin tratar. Los resultados sugieren que: 1) ambas especies fueron tolerantes al fuego en verano, 2) el fuego en cualquier estación, con o sin corte, estimuló la producción de "Buffalograss," y 3) el "Buffalograss" fue más tolerante que el "Texas wintergrass" a los efectos combinados de corte + fuego (en cualquier estación).

Key Words: brush management, fire, herbaceous production, prescribed burning, summer fire, woody plant encroachment

INTRODUCTION

Restoration of fire regimes in grasslands encroached by woody plants has been the subject of worldwide interest (Axelrod 1985; Van Auken 2000; Bond et al. 2005; Briggs et al. 2005). In temperate grasslands, prescribed fires are often conducted during the dormant season (winter or early spring) (Wright and Bailey 1982; van Wilgen et al. 1990), but there is increased interest in the application of summer fires in woody-encroached grasslands, because the greater intensity and/or longer duration

This research was funded by USDA–NRICRGP Agricultural Systems Grant No. 94-04256 and the E. Paul and Helen Buck Waggoner Foundation, Vernon, TX.

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Manuscript received 5 July 2006; manuscript accepted 13 December 2006.

of high temperatures of summer fires inflict greater damage to woody plants than caused by winter fires (Trollope 1987; Ansley and Jacoby 1998; Ansley and Taylor 2004). If summer fires are shown to be safe under well-defined fire prescriptions, more information will be needed regarding the responses of nontarget herbaceous species to summer fires alone and in combination with grazing.

Fire is hypothesized to have a negative effect on grass species that are physiologically active at the time of burning (Daubenmire 1968; Howe 1994a; Engle and Bidwell 2001). Thus, later-winter or early spring fires can adversely affect C_3 (cool-season) grasses and favor C_4 (warm-season) grasses, whereas summer fires adversely affect C_4 grasses and favor C_3 grasses (Wright 1974; Trollope 1984, 1987; Bailey 1988; Collins and Wallace 1990; Howe 1995). Accordingly, winter or early spring fires are hypothesized to shift the species composition of mixed C_3/C_4 grass communities towards C_4 dominance, whereas summer or early fall fires are hypothesized to shift the composition of mixed C_3/C_4 grass communities towards C_3 dominance. In the northern and central Great Plains (United States), early spring fires have shifted several C_3/C_4 grass communities towards C_4 dominance (Anderson et al. 1970; Engle and Bultsma 1984; Howe 1994b). However, there is less evidence that summer fires will shift mixed C_3/C_4 communities toward greater C_3 dominance (Steuter 1987; Howe 1995). In a review of the effect of fire season, Engle and Bidwell (2001) conclude that summer fires do not cause long-term changes in species composition.

Other research has proposed that the reason C_4 grasses are more tolerant than C_3 grasses to fire in any season is because they are better adapted, through greater nitrogen use efficiency and N storage properties, to the warm, dry, nitrogen-depleted edaphic conditions caused by frequent fires (Seastedt et al. 1991; Wedin and Tilman 1996; Blair et al. 1998). If this is true, any repeated fire regime, independent of season of burn, should favor C_4 grasses over C_3 grasses.

Although the combined effects of herbivore grazing and fire are increasingly being investigated (Valone and Kelt 1999; Valone 2003; Fuhlendorf and Engle 2004; Archibald et al. 2005), few studies have contrasted effects of seasonal fires (i.e., winter vs. summer fires) and grazing on individual species or ecosystem responses (Knapp et al. 1998).

In the southern Great Plains, summer fires are being considered for suppression of woody species such as honey mesquite (*Prosopis glandulosa* Torr.) (Ansley and Jacoby 1998). Fire return interval in the southern Great Plains grasslands prior to European settlement might have been as frequent as 2–3 years (Frost 1998), and many theorize that such high fire frequencies limited woody encroachment in this region (Axelrod 1985; Van Auken 2000). However, little empirical evidence is available regarding the effects of repeated summer-season fires on herbaceous vegetation in this grassland biome, or the interactions between seasonal fires and grazing (Whisenant et al. 1984; Ford 1999).

Here, we measure responses of the C_3 perennial midgrass, Texas wintergrass (*Nassella leucotricha* [Trin. & Rupr.] Pohl.), and the C_4 perennial short-grass, buffalograss (*Buchloë dactyloides* [Nutt.] Engelm.), to seasonal fires and simulated grazing (clipping). Both species are common to the southern Great Plains and are regarded as species that increase under degraded rangeland conditions (McDaniel et al. 1982; Whisenant et al. 1984; Ford 1999). Texas wintergrass production is usually about twice that of buffalograss (Ansley et al. 2004). Our objective was to compare effects of repeated winter fires, repeated summer fires and clipping (to simulate grazing) on aboveground growth (biomass yield) and physiological status (percent live tissue) of each species. We hypothesized that, by 2 years post fire, 1) winter fires will reduce and summer fires will enhance C_3 Texas wintergrass yields, 2) summer fires will reduce and winter fires will enhance C_4 buffalograss yields, and 3) any negative effects of fire will be exacerbated if grasses are annually clipped (to simulate grazing) in addition to being burned. Because first year post-fire yield responses can be highly variable, conclusions regarding hypotheses 1–3 were based on 2- or 3-year post-fire responses. Regarding physiological responses, we also hypothesized that 4) both summer and winter fires will increase percentage of live tissue during the first growing season post-fire in both species, but 5) there should be no differences in percentage of live tissue responses between summer and winter fire treatments.

METHODS

Site Description

Research was conducted on a 160-ha fenced area on a private ranch in north central Texas (lat 33°51′N, long 99°26′W; elevation 381 m). Mean annual rainfall is 665 mm with peak rainfall months in May (119 mm) and September (77 mm) (NOAA 2006). Mean monthly air temperatures range from an average daily maximum of 36°C in July to an average daily minimum of −2.5°C in January. Growing season for C_3 Texas wintergrass can occur year round but is primarily from February through June. Growing season for C_4 buffalograss is from April through September. Pre-burn woody overstory consisted of honey mesquite (3 to 4 m tall trees at 20%–40% canopy cover). Dominant grass species include Texas wintergrass, buffalograss, and C_4 perennial midgrasses meadow dropseed (*Sporobolus compositus* [Poir.] Merr.), and vine mesquite (*Panicum obtusum* H.B.K.). Texas wintergrass and buffalograss occur in extensive, nearly monoculture patches ranging from 5 to 20 m^2. Soils are fine, mixed, thermic Typic Paleustolls of the Tillman series that are 3 to 4 m deep alluvial clay loams underlain by sandstone and shale parent material (Koos et al. 1962). Livestock grazing was excluded since 1989. Prior to the study, the site had not burned for at least 30 years.

Treatments and Data Collection

Thirty-six vegetation patches (18 each of Texas wintergrass and buffalograss) were randomly located on level terrain and similar soil type in interstitial spaces between mesquite trees. Each patch was 10–20 m^2 and had $> 90\%$ canopy cover of either Texas wintergrass or buffalograss. Six patches of each species were left unburned (no-fire), 6 patches were burned in winter in 1993 and 1995 (w93w95), and 6 patches were burned in summer in 1992 and 1994 (s92s94). Winter fires were applied in February or early March and summer fires were applied in September. Fires were applied as headfires using drip torches within bladed fireguards.

Within each patch, 2, 0.6 $\times$ 0.9 m plots were permanently marked. In 1 plot, all herbaceous material (the target species of

Texas wintergrass or buffalograss, plus any other species) was clipped to a 2-cm stubble height once each spring (May) for 5 years (1993–1997). The other plot remained unclipped. Thus, both clipped and unclipped plots occurred within each fire treatment replicate. Once each year, within a week after each spring clipping event, a 0.5 m border area was mowed around each of the clipped plots to reduce the competitive impact of surrounding vegetation.

Using the treatments described, 2 temporally separated experiments were conducted, similar to Ansley et al. (2006). Experiment 1 quantified effects of fire treatments alone on late-growing season (August–September) aboveground yield components: total yield (live + standing dead), live yield, and percent live tissue. Yield components were measured in the unclipped treatment by harvesting all above ground tissue within a 0.25 m^2 quadrat that was located within 5 m of the marked 0.6 $\times$ 0.9 m unclipped plot and resembled the unclipped plot in terms of percent foliar cover of either Texas wintergrass or buffalograss. A different 0.25 m^2 quadrat was harvested each year.

Experiment 2 quantified effects of fire treatments alone, spring clipping alone and the combined effects of fire + clipping on the same 3 yield components, with the exception that these data were collected each spring (May–early June). The same procedure described for Experiment 1 was used to quantify yield components in unclipped treatments. In the clipped treatments, yield components were measured by collecting Texas wintergrass or buffalograss biomass that was clipped within the marked 0.6 $\times$ 0.9 m plot. In the clipping portion of Experiment 2, the first year's sample measured all production after the first burn (in summer 1992 or winter 1993); the clip treatment began in spring 1993, and all subsequent sample years measured standing biomass that had accumulated in 1 year since the previous clip date.

Samples from both experiments were oven dried at 60°C for 48 hr and weighed. A subsample of each sample was used to separate live from dead tissue and estimate live yield and percent live tissue. Total and live yields were expressed as g $\cdot$ m^{-2}. We did not experimentally compare effects of single fires vs. repeated fires of each season within the same post-fire growing season due to a limited number of patches that were of sufficient size to accommodate the clipping treatments.

A few days prior to each fire, standing herbaceous fine fuel was estimated by clipping 5, 0.25-m^2 quadrats located randomly near the marked quadrats in each plot, oven drying at 60°C for 48 hr, then weighing. Air temperature, relative humidity, and wind speed were measured immediately prior to each fire. Peak fire temperature was recorded at 0, 10, and 30-cm above the soil surface and at 1-sec intervals in Texas wintergrass and buffalograss patches that resembled the unclipped 0.6 $\times$ 0.9 m plots in at least 4 of the 6 replicates of each fire within each repeated fire treatment (s92, s94, w93, w95) using glass-insulated type K (Chromel-Alumel) thermocouple wire (20 AWG; 0.8 mm diam.) and a datalogger (Campbell Scientific, Inc., Logan, UT; Ansley et al. 1998). The highest temperature of any of the 3 heights was reported. Herbaceous fine fuel moisture content was measured by obtaining a wet weight of the clipped samples in the field immediately after clipping and comparing this to oven dry weight. Percent moisture was calculated on a wet weight basis ([wet wt $-$ dry wt]/wet wt). Precipitation was recorded at the site.

Statistical Analyses

To evaluate effects of fire treatments alone on late-season yield components (Experiment 1), repeated measures analyses of variance were used with fire treatment (3 levels: no-fire, w93w95, s92s94) and sample date (5 late-season dates; 1993–1997) as main effects (6 replicates per treatment). The replicate within fire treatment error tested fire treatment effects, and the pooled error tested effects of date and fire treatment by date interactions (SAS 2003). Analysis was divided into 2 dates after the first fires in summer 1992 and winter 1993 (1993, 1994), and 3 dates after the second fires in summer 1994 and winter 1995 (1995–1997).

To evaluate effects of fire and clipping on spring yield components (Experiment 2), we used repeated measures analyses of variance that included fire treatment (3 levels), clip treatment (2 levels), and sample date (5 spring dates; 1993–1997) as main effects (6 replicates per treatment). The replicate within fire treatment error tested effects of fire; the clip by replicate within fire treatment error tested effects of clip and fire by clip interactions; and the pooled error tested effects of date, date by fire, date by clip, and date by fire by clip interactions. Analysis was divided into 2 dates after the first fires (1993, 1994) and 3 dates (1995, 1996, and 1997) after the second fires.

For both sets of analyses, within-sample date post-hoc analyses were performed if significant date by treatment interactions were found. Means were separated using Fisher's protected LSD ($P < 0.05$ unless otherwise noted). Percentage data were arcsine transformed. Nonnormal data were $\log_{10}$ transformed prior to analysis. Otherwise all data met the statistical assumptions of repeated measures ANOVA. All means shown are nontransformed values.

RESULTS

Fire Behavior and Effect on Mesquite

Air temperature was lower and wind speeds were greater during winter fires than summer fires (Table 1). Grass fine fuel amount was greater in Texas wintergrass than in buffalograss patches, with greatest differences in the summer 1992 fires. Grass moisture content was similar between species except in the winter 1995 fires, when it was greater in Texas wintergrass.

Peak fire temperature mostly occurred at 10-cm height and was slightly greater in summer fires than in winter fires during the first fires (s92 vs. w93) and much greater in summer than winter in the second fires (s94 vs. w95) in both species' patches (Table 1). Peak fire temperatures were lower in the winter 1995 fires (range, 461°C to 490°C) than in all other fires (range, 608°C to 672°C) in both species. Averaged over all fires, peak fire temperature was slightly greater in Texas wintergrass (621°C) than in buffalograss (584°C) patches, but this difference was not significant ($P < 0.05$).

All fires were considered of moderate to high intensity with flame heights exceeding 2 m in most plots. The repeated fire treatments reduced mesquite canopy cover by 92% and 98% in winter and summer fires, respectively (Ansley and Jacoby 1998).

Precipitation

Annual precipitation was above the 30-year average in early 1992 and the middle part of 1995 and below average during a critical portion of the growing season (March–June) in 1994

Table 1. Air temperature (AT), relative humidity (RH), wind speed (Wind), and grass fine fuel amount, grass tissue moisture content (Moisture), and peak temperatures (Peak Temperature) during the fires in unclipped patches of Texas wintergrass (Nale) and buffalograss (Buda) (SE in parentheses). Weather conditions were the same for each species within each fire treatment.

Fire Treatment	AT (°C)	RH (%)	Wind ($m \cdot s^{-1}$)	Species	Fuel ($g \cdot m^{-2}$)	Moisture (%)	Peak Temperature (°C)
s92	33.5 (1.0)	27.0 (3.8)	2.1 (0.4)	*Nale*	276 (19)	21.4 (0.3)	671 (33)
				Buda	153 (30)	21.5 (4.6)	635 (34)
w93	20.0 (1.2)	38.3 (9.5)	5.0 (1.3)	*Nale*	269 (31)	19.0 (1.5)	649 (45)
				Buda	170 (20)	15.4 (1.2)	608 (85)
s94	32.2 (1.1)	45.3 (3.3)	3.2 (0.5)	*Nale*	179 (20)	11.1 (1.1)	672 (27)
				Buda	140 (11)	9.8 (1.8)	630 (26)
w95	25.4 (2.1)	26.3 (2.9)	4.2 (1.5)	*Nale*	130 (25)	32.5 (2.3)	490 (97)
				Buda	112 (22)	17.0 (0.7)	461 (43)

and 1996 (Fig. 1). The first growing season post-fire after the summer 1992 and winter 1993 fires (i.e., March–September 1993) had near normal precipitation, whereas the first growing season after the second set of fires in summer 1994 and winter 1995 (i.e., March–September 1995) had above normal precipitation.

Experiment 1—Fire Only Effects

Most late-season response variables of Texas wintergrass and buffalograss had significant fire treatment by date interactions (Table 2). There were a few variables, in particular with Texas wintergrass, where only the main effects of fire treatment or date were significant.

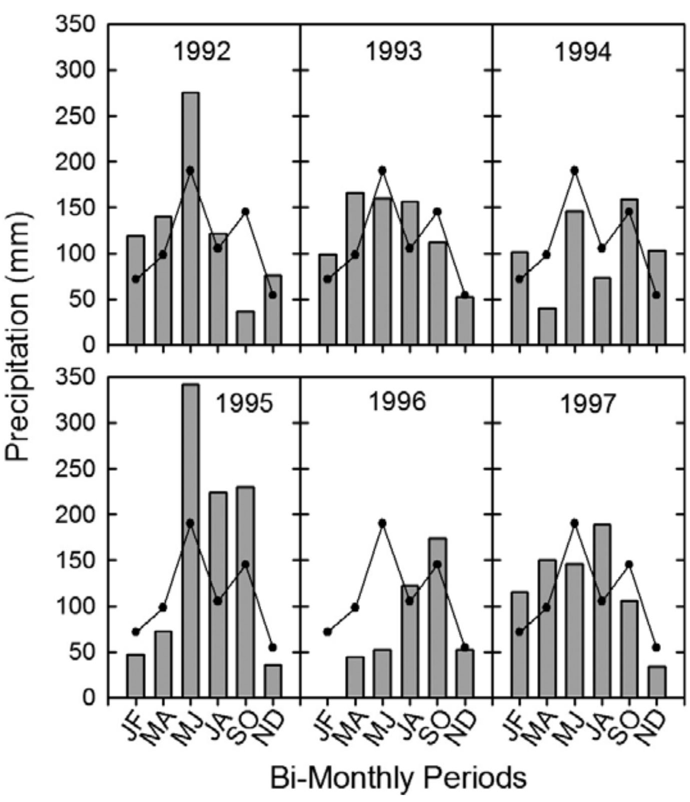

Figure 1. Bimonthly precipitation (bars) from 1992 to 1997 compared to 30-year bimonthly average (line) (NOAA 2006).

Texas wintergrass total yield was greatest in the no-fire treatment and lowest in the summer fire treatment the first growing season after the first fires in summer 1992 (s92) or winter 1993 (w93) (Fig. 2A). This difference was not found the second year post-fire. After the second fires in summer 1994 (s94) or winter 1995 (w95), Texas wintergrass total yield was similar among all 3 treatments the first and second years post-fire, but showed a trend of being 2 times greater in the summer fire than the winter fire or no-fire treatments at 3 years post-fire (Fig. 2B). However, lack of a significant fire by date interaction prevented within-date post-hoc analysis.

Texas wintergrass late-season live yield was lower in both summer and winter fire treatments than the no-fire treatment 1 growing season after the first fires, and continued to be lower in the winter fire treatment than the no-fire at 2 years post-fire (Fig. 2C). Following the second fires (s94, w95), there was no difference in live yield among fire treatments during the 3 years post-fire (Fig. 2D).

Texas wintergrass late-season percentage of live tissue was similar among all treatments until 2 years after the first fires and 3 years after the second fires when it showed a trend of being greater in the no-fire treatment, but a lack of a fire by date interaction prevented within date analyses (Figs. 2E and 2F).

Buffalograss late-season total yield was lower in both fire treatments than the no-fire treatment the first year after the first fires (s92, w93), but, unlike Texas wintergrass, total yield in both fire treatments exceeded the no-fire by 2 years post-fire (Fig. 3A). Similar to Texas wintergrass, total yield was similar between the no-fire and fire treatments the first year after the second fires (Fig. 3B). By 3 years after the second fires, total yield in both the winter and summer fire treatments was more than double the no-fire treatment.

Buffalograss late-season live yield was lower in both fire treatments than the no-fire the first year after the first fires (Fig. 3C), but these differences disappeared by 2 years post-fire. Live yield was similar among treatments after the second fires until 3 years post-fire when it was greater in the summer fire treatment than the no fire (Fig. 3D). Texas wintergrass exhibited the same trend but differences were not significant (Fig. 2D).

Buffalograss late-season percentage of live tissue was greater in the no-fire treatment than the summer or winter fire treatments at 2 years after the first fires (Fig. 3E) and 3 years after the second fires (Fig. 3F).

Table 2. Significant ($P < 0.05$) main and interaction effects on Texas wintergrass and buffalograss late-season yield components (Experiment 1) after the first (s92, w93) and second fire (s94, w95) treatments. Independent variables were fire treatment (F) and date (D).

Species	Interval	Yield component	Interaction
Texas wintergrass	Post-first fires	Total yield	F × D
	(2 dates)	Live yield	F × D
		Percent live	F, D
Texas wintergrass	Post-second fires	Total yield	F, D
	(3 dates)	Live yield	D
		Percent live	F, D
Buffalograss	Post-first fires	Total yield	F × D
	(2 dates)	Live yield	F × D
		Percent live	D
Buffalograss	Post-second fires	Total yield	F × D
	(3 dates)	Live yield	F × D
		Percent live	F × D

Experiment 2—Fire and Clipping Effects

There were significant fire treatment by date, clip treatment by date, or fire by clip by date interactions for all Texas wintergrass and buffalograss spring-season response variables in the fire and clipping study (Experiment 2) (Table 3). In all cases there was either a significant fire by date or fire by clip by date interaction.

Texas wintergrass spring-season total yield in unclipped plots was much lower in both fire treatments than in the no-fire treatment the first spring after the s92 and w93 fires, but this difference was gone by 1994, the second spring post-fire (Fig. 4A). A similar trend occurred after the second fires (s94, w95), except that total yield in the winter fire treatment did not increase to levels equal to the no-fire or summer fire treatments until 1997, 3 years post-fire (Fig. 4B). Within the clipped treatment, differences in total yield between fire treatments followed trends similar to the no clip treatment (Figs. 4C and 4D).

Buffalograss spring-season total yield in the unclipped plots was lower in both fire treatments than in the no-fire treatment the first spring after the s92 and w93 fires, but yield in the summer fire treatment exceeded the no-fire by 2 years post-fire, in 1994 (Fig. 4E). After the second fires, spring total yield was greater in the summer fire treatment than the no-fire at 2 years post-fire, in 1996, and was greater in both fire treatments than the no-fire at 3 years post-fire, in 1997 (Fig. 4F). Within the clipped treatment, differences in total yield between fire treatments followed trends similar to the no clip treatment (Figs. 4G and 4H).

Clipping significantly reduced spring total yield in Texas wintergrass more frequently (i.e., on more sample dates) than it did in buffalograss. Of the 15 possible combinations of fire treatment (3) and post-fire dates (5), clipping reduced Texas wintergrass total yield 9 times, and buffalograss total yield 5 times (Table 4). The average magnitude of this reduction was similar between species (approx. 50%). Significant reductions in total yield by clipping occurred on more dates in the summer fire treatment than the winter fire or no-fire in both species.

There were 3 dates for each species when clipping + fire reduced total yield to a greater degree than the effect of clipping alone ("n.a." in Table 4). In addition, there was one instance at 3 years after the second summer fire (in 1997) when the positive effect of summer fire on Texas wintergrass total yield was removed by clipping. This did not occur in buffalograss.

Texas wintergrass spring live yields were similar among fire treatments on most dates with the exception that during the first spring after the s92 and w93 fires, live yield was lower in the summer fire treatment than in the no-fire or winter fire treatments (Fig. 5A). Clipping prolonged this difference between the summer fire and the no-fire for an additional year, and also reduced live yields in the winter fire

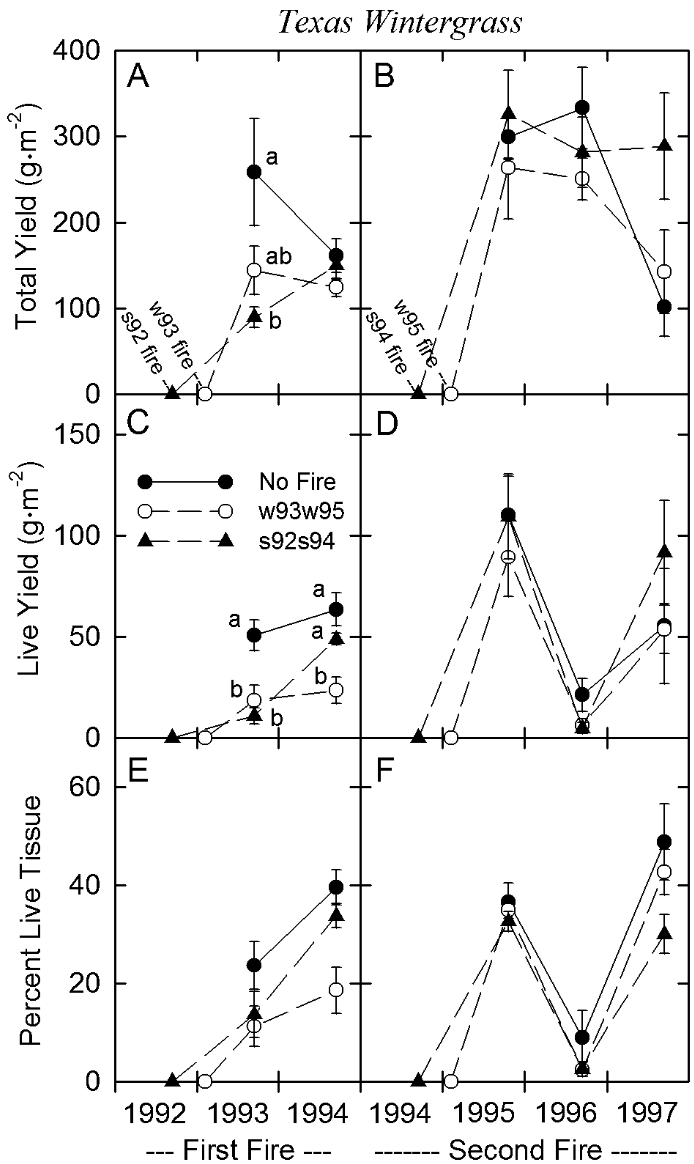

Figure 2. Texas wintergrass late-season yield components within unclipped treatments exposed to fire treatments in summer 1992 (s92) or winter 1993 (w93) (**A, C, E**), and again in summer 1994 (s94) or winter 1995 (w95) (**B, D, F**) (Experiment 1). Vertical lines are ± 1 standard error (SE). Different letters within a sample date indicate significant differences among treatments; LSD ($P < 0.05$). In this and remaining figures, a zero value indicates the time immediately *after* each fire when herbaceous standing crop was zero. Fire season and year indicated in top panel apply to each zero point.

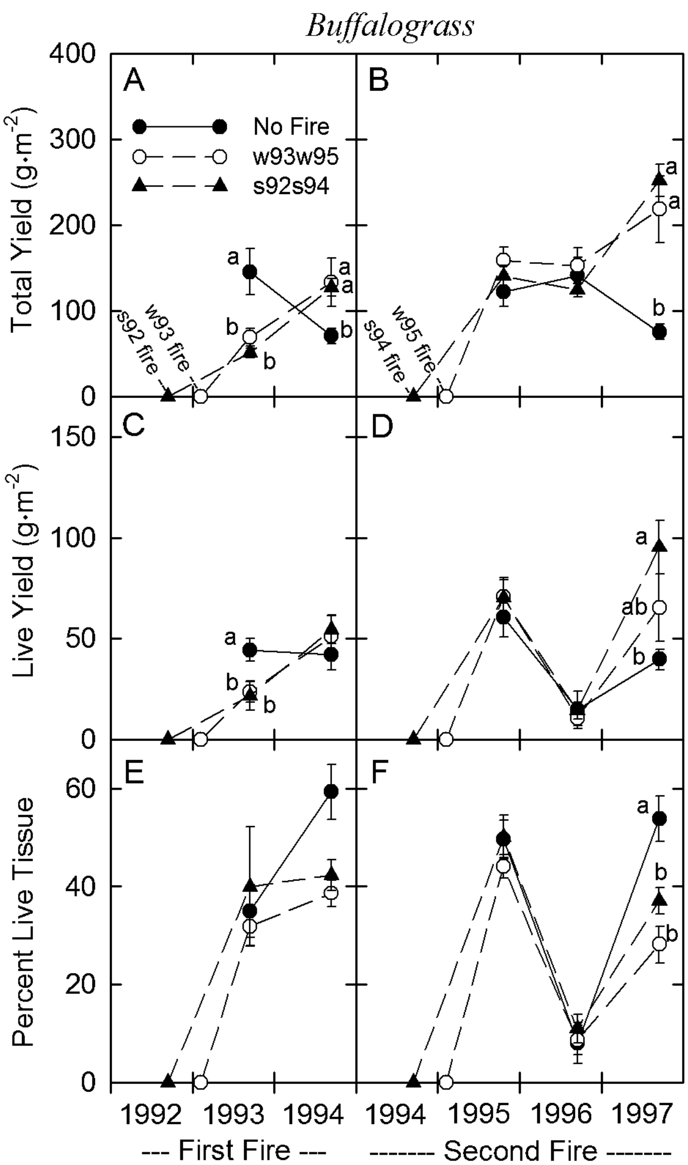

Figure 3. Buffalograss late-season yield components within unclipped treatments exposed to fire treatments in summer 1992 (s92) or winter 1993 (w93) (**A, C, E**), and again in summer 1994 (s94) or winter 1995 (w95) (**B, D, F**) (Experiment 1). Details same as Figure 2.

treatment (Fig. 5C). These trends were not apparent after the second fires (Figs. 5B and 5D).

Buffalograss spring-season live yields followed a different trend than Texas wintergrass in unclipped treatments; there was greater live yield in the summer fire treatment than the no-fire at 2 years after the first fires, in 1994 (Fig. 5E), and 2 and 3 years after the second fires, in 1996 and 1997 (Fig. 5F). In the clipped buffalograss treatments, trends between fire treatments were mostly similar to the unclipped treatments (Figs. 5G and 5H).

Similar to total yields, clipping significantly reduced spring live yield in Texas wintergrass more frequently (7 times) than it did in buffalograss (3 times), of the 15 possible combinations of fire treatment and post-fire date (Table 5). However, the average magnitude of the reduction was slightly greater in buffalograss. A greater number of significant reductions by

Table 3. Significant ($P < 0.05$) interaction effects on Texas wintergrass and buffalograss spring-season yield components (Experiment 2) after the first (s92, w93) and second fire (s94, w95) treatments. Independent variables were fire treatment (F), clip treatment (C) and date (D).

Species	Interval	Yield component	Interaction
Texas wintergrass	Post-first fires	Total yield	F × D
	(2 dates)	Live yield	F × C × D
		Percent live	F × C × D
Texas wintergrass	Post-second fires	Total yield	F × D
	(3 dates)	Live yield	F × D, C × D
		Percent live	F × D
Buffalograss	Post-first fires	Total yield	F × C × D
	(2 dates)	Live yield	F × D, C × D
		Percent live	F × D, C × D
Buffalograss	Post-second fires	Total yield	F × D, C × D
	(3 dates)	Live yield	F × D, C × D
		Percent live	F × D

clipping occurred in the summer fire than the winter fire or no-fire treatments for both species.

The number of dates that clipping + fire reduced live yield to a greater degree than the effect of clipping alone was limited to 2 dates for Texas wintergrass and 1 date for buffalograss (Table 5). Similar to total yield, there was one instance at 3 years after the second summer fire (in 1997) when the positive effect of summer fire on Texas wintergrass live yield was removed by clipping.

Texas wintergrass spring percentage of live tissue in unclipped plots was greater in the fire treatments than the no-fire treatment the first spring after both the first and second fires, but this difference disappeared by the second spring post-fire (Figs. 6A and B). A similar trend occurred among fire treatments in the clipped plots, except that percent live tissue was lower in the summer fire treatment than the other treatments 2 years after the second fires, in 1996 (Fig. 6D).

Buffalograss spring percentage of live tissue remained greater in the fire treatments than the no-fire treatment for 2 years after the first fires in both unclipped and clipped plots (Figs. 6E and 6G), but this trend was not as clear after the second fires as live tissue in all treatments increased sharply the first year post fire, in 1995 (Figs. 6F and 6H).

Within each fire treatment and year, clipping significantly increased percentage of live tissue on a few occasions, and more frequently in Texas wintergrass (4 times) than in buffalograss (2 times) (data not shown). Clipping never reduced percentage of live tissue.

DISCUSSION

Experiment 1—Fire Only Effects

Texas wintergrass total yield was enhanced by summer fire by 3 years post-fire, but was not reduced by winter fire for more than 1 growing season post-fire. Thus, the results support part of Hypothesis 1 that summer fires will enhance Texas wintergrass total yield, but do not support the other part of Hypothesis 1

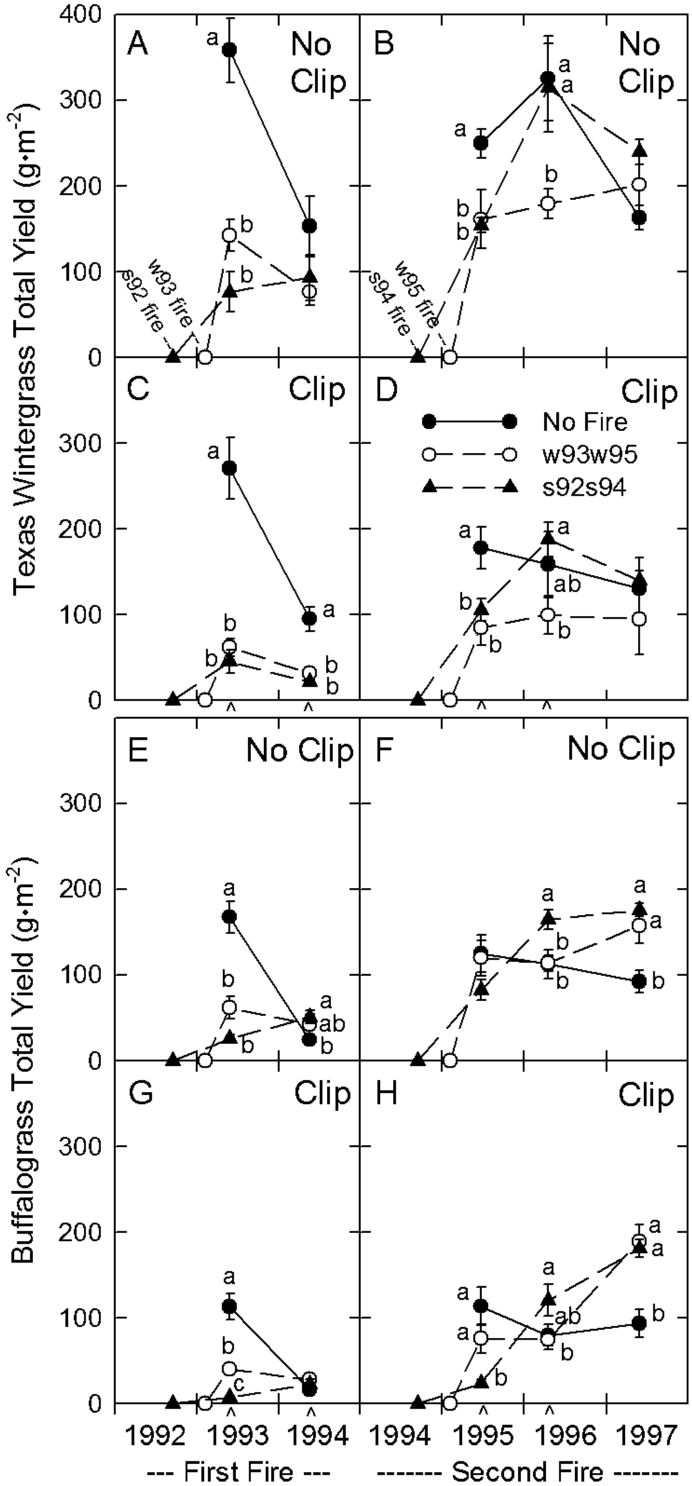

Figure 4. Texas wintergrass (**A–D**) and buffalograss (**E–H**) total yields during spring sample dates in unclipped (**A, B, E, F**) and clipped (**C, D, G, H**) treatments exposed to fire treatments in summer 1992 (s92) or winter 1993 (w93), and again in summer 1994 (s94) or winter 1995 (w95) (Experiment 2). Clip treatments are indicated with a '⋀' on the X axis. Different letters within each sample date indicate significant differences between treatments; LSD ($P < 0.05$). Vertical lines are ± 1 SE.

Table 4. Fire treatments and year when significant ($P < 0.05$) differences in spring-season total yield occurred between clipped vs. unclipped Texas wintergrass (Nale) and buffalograss (Buda). Means are followed by SE in parentheses (values from Fig. 4). Asterisk indicates times when clip + fire significantly reduced yield but clip alone did not. n.a. = negatively additive; r.p. = removed positive response to fire.

Species	Fire treatment	Year	Years post-fire	Total yield (no-clip) g · m^{-2}	Total yield (clip) g · m^{-2}	% Reduction %	Clip + Fire effect
Nale	no-fire	1995		249.6 (16.9)	177.9 (24.7)	28.7	
	no-fire	1996		325.4 (49.1)	158.6 (38.8)	51.2	
	w93w95	1993*	1	142.1 (18.8)	62.1 (10.4)	56.3	n.a.
	w93w95	1994*	2	76.4 (15.5)	31.5 (4.6)	58.8	n.a.
	w93w95	1996	2	179.2 (17.0)	99.6 (22.5)	44.4	
	s92s94	1994*	2	93.1 (26.4)	21.4 (2.7)	77.0	n.a.
	s92s94	1995	1	153.9 (8.9)	105.5 (12.8)	31.4	
	s92s94	1996	2	314.4 (52.0)	187.6 (20.1)	40.3	
	s92s94	1997*	3	239.7 (14.8)	139.9 (11.8)	41.6	r.p.
Avg.				197.1	109.3	47.7	
Buda	no-fire	1993		167.4 (18.3)	113.1 (13.8)	32.4	
	w93w95	1996*	2	113.8 (9.4)	74.7 (11.1)	34.3	n.a.
	s92s94	1993	1	25.5 (4.9)	7.6 (1.9)	70.2	
	s92s94	1994*	2	51.2 (7.3)	23.1 (5.6)	54.9	n.a.
	s92s94	1995*	1	82.5 (12.1)	23.9 (4.7)	71.0	n.a.
Avg.				88.1	48.5	52.6	

that winter fires will reduce Texas wintergrass yields. Thus, we reject Hypothesis 1.

Few studies have quantified Texas wintergrass response to seasonal fires. In a study that contrasted seasonal fires, Whisenant et al. (1984) found that both a winter and a late-summer fire reduced Texas wintergrass standing crop the first growing season post-fire, but, by 2 years post-fire, there was no difference in standing crop between summer fire, winter fire, and no fire treatments. Owens et al. (2002) found a slight decrease in Texas wintergrass density (No. plants · m^{-2}) in July 1994 after winter or summer fires in 1991, 1992, and 1993 in south Texas, but it was not determined whether this was a significant difference. Engle et al. (1998) found that a late-summer fire decreased C_3 grass (primarily Texas wintergrass) production for up to 3 years post-fire on a loamy site in Oklahoma. However, on a very shallow site, Texas wintergrass response was similar to our study: production decreased the first year post-fire, but increased over the no fire treatment by 3 years post-fire. Results from these 2 studies and ours, support Trollope's (1984) assumption that summer fires benefit C_3 grasses, but do not support the general assumption by Wright (1974) and others that winter fires harm this species.

Buffalograss late-season total and live yields were not negatively affected by summer fire more than 1 growing season post-fire; by 3 years post-fire, both summer and winter fires increased total yield, and summer fire increased live yield. Thus, we reject the first part of Hypothesis 2 that summer fires will reduce buffalograss yields. However, the results support the second part of Hypothesis 2 that winter fires will enhance buffalograss yields.

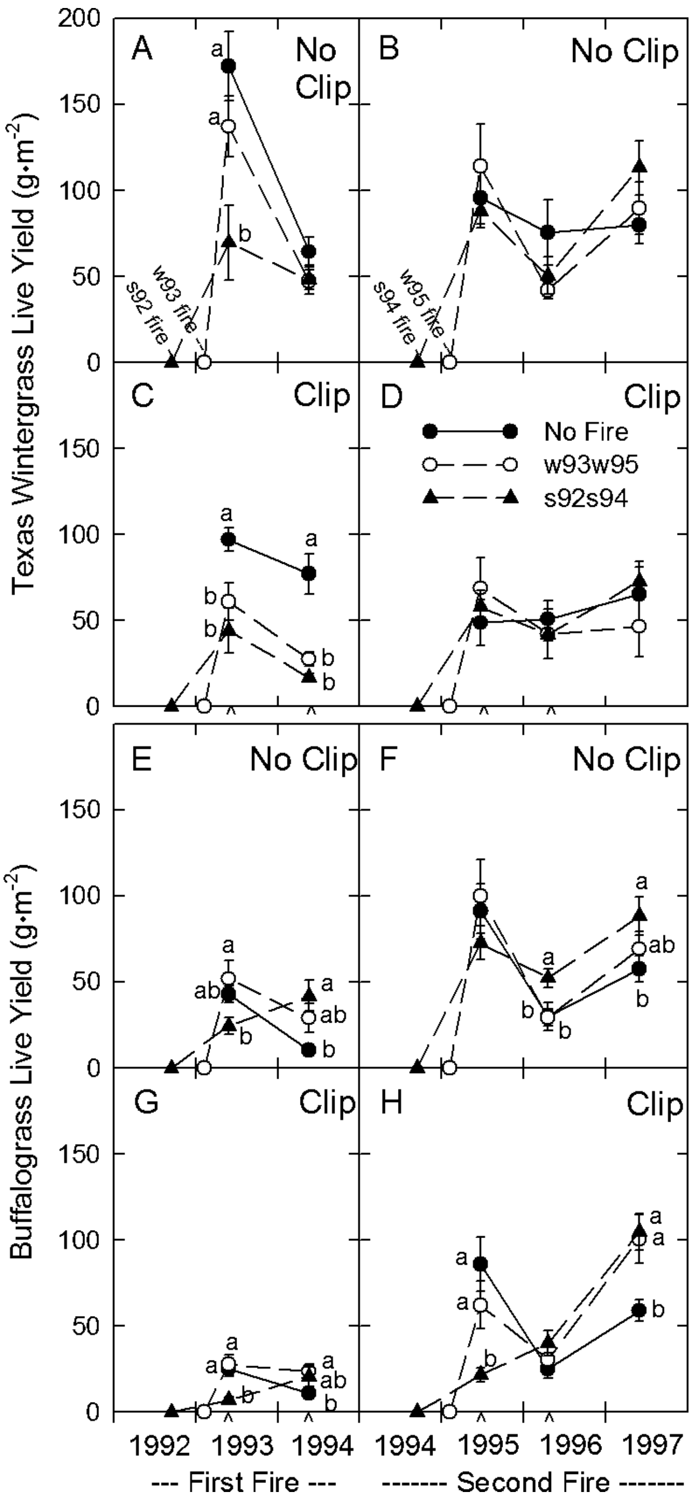

Figure 5. Texas wintergrass (**A–D**) and buffalograss (**E–H**) live yields during spring sample dates in unclipped (**A, B, E, F**) and clipped (**C, D, G, H**) treatments exposed to fire treatments in summer 1992 (s92) or winter 1993 (w93), and again in summer 1994 (s94) or winter 1995 (w95) (Experiment 2). Details same as Figure 4.

Few studies have compared buffalograss response to summer and winter fires within the same experiment (Owens et al. 2002). With respect to responses to winter fires, Launchbaugh (1964) found in a mixed community of buffalograss and blue grama (*Bouteloua gracilis* [H.B.K.] Lag. ex Griffiths) that yields were reduced by a winter fire for 1 year post-fire on 1 site, and for 2 years post-fire on a second site, but yields were equal to the no fire on both sites by the third year. Similarly, Wright (1974) found that late-winter fires slightly lowered buffalograss yield at 1 and 2 years post-fire, but there was no difference in yield between burned and unburned treatments by the third year. Anderson et al. (1970) found that 16 consecutive years of early spring (March) burning in Kansas Flint Hills reduced buffalograss basal cover by half. In contrast, Whisenant and Uresk (1990) found that spring fires (April) in South Dakota slightly increased buffalograss standing crop by 2 and 3 years post-fire. However, it should be noted that buffalograss yield values reported in this study ranged from 2–10 g · m^{-2} in contrast to the 80–260 g · m^{-2} range in our study. We also note that studies by Anderson et al. (1970) and Whisenent and Uresk (1990) were done in mixed communities and the fire effects on individual species might have been either amplified or reduced by competitive interactions with other species. Owens et al. (2002) found a decrease in buffalograss density (No. plants · m^{-2}) in July 1994 after summer fires in 1991 and 1993, but it was not determined whether this was a significant difference.

Table 5. Fire treatments and year when significant ($P < 0.05$) differences in spring-season live yield occurred between clipped vs. unclipped Texas wintergrass (Nale) and buffalograss (Buda). Means are followed by SE in parentheses (values from Fig. 5). Asterisk indicates times when clip + fire significantly reduced yield but clip alone did not. n.a. = negatively additive; r.p. = removed positive response to fire.

Species	Fire treatment	Year	Years post-fire	Total yield (no-clip) g · m^{-2}	Total yield (clip) g · m^{-2}	% Reduction %	Clip + Fire effect
Nale	no-fire	1993		172.3 (20.1)	97.0 (6.2)	43.7	
	no-fire	1995		95.7 (17.5)	48.7 (13.3)	49.1	
	w93w95	1993	1	137.0 (17.7)	61.1 (10.7)	55.4	
	w93w95	1994*	2	47.3 (7.8)	27.5 (4.0)	41.9	n.a.
	s92s94	1994*	2	47.9 (5.8)	16.9 (2.2)	64.7	n.a.
	s92s94	1995	1	87.9 (7.7)	58.0 (9.3)	34.0	
	s92s94	1997*	3	113.2 (15.7)	72.9 (8.4)	35.6	r.p.
Avg.				100.2	54.6	46.3	
Buda	no-fire	1993		42.9 (4.8)	24.9 (3.6)	41.9	
	s92s94	1993	1	24.2 (4.8)	6.9 (2.0)	71.5	
	s92s94	1995*	1	72.6 (9.8)	21.5 (4.1)	70.3	n.a.
Avg.				46.6	17.8	61.2	

In a review article, Ford (1999) found only 2 studies that quantified buffalograss response to summer fires and, of these, either there was no treatment replication or measurements were made only one year after fire. Buffalograss percent composition by weight was similar between burned and unburned treatments 1 year after a summer fire in south Texas, but no data were collected after the first year (Box et al. 1967). Burning in either summer or winter had little effect on standing crop of common curleymesquite (*Hilaria berlangeri* [Steud.] Nash), a species similar to buffalograss, during 4 post-fire years in south Texas (Mayeux and Hamilton 1988).

Buffalograss late-season total yield recovery after summer fire in the current study was more rapid than was found with the C_4 midgrass, sideoats grama (*Bouteloua curtipendula* [Michx.] Torr.), exposed to the same fire treatments on a nearby site (Ansley et al. 2006). However, by 3 years post-fire, both buffalograss and sideoats grama had greater total yield in the summer fire treatment than the no-fire treatment, although buffalograss yield was 3 times greater, and sideoats grama yield was 2 times greater in the summer fire than the no-fire treatment.

Experiment 2—Fire and Clipping Effects

Effects of clipping were evaluated with spring-season growth data only. Total and live weight values represented year-long accumulated totals since the previous spring clipping treatment, and interpretation must be made within this context. The additional stress of clipping created a differential response of these C_3 and C_4 grass species to seasonal burning. Spring clipping in the no-fire, summer fire, and winter fire treatments reduced C_3 Texas wintergrass total and live yields more frequently than occurred in C_4 buffalograss (Tables 4 and 5); clipping never significantly increased total or live yields in either species. The number of times clipping exacerbated the negative effects of fire on total or live yields in either species was infrequent and did not occur by 3 years post-fire. Therefore, with respect to both species, we reject Hypothesis 3 that any negative effects of fire (based on 2- or 3-year post-fire responses) will be exacerbated if grasses are annually clipped in addition to being burned.

The 1997 results at 3 years after the second fires provide the best comparison of long-term responses to fire and clipping treatments (Figs. 4 and 5). In this year, buffalograss total and live yields were enhanced by fire treatments within clipped and unclipped patches, but clipping did not affect total and live yields over what the fire treatments did alone (Figs. 4F, 4H, 5F, and 5H). In contrast, clipping decreased Texas wintergrass total and live yields within the summer fire treatment (Tables 4 and 5). However, this decrease by clipping represented the removal of a positive effect of summer fire on Texas wintergrass yields and, as such, cannot be interpreted as exacerbating any negative effect of fire. Still, it demonstrates that Texas wintergrass was slightly less tolerant of the combined effects of fire and clipping than was buffalograss.

The recovery of buffalograss spring-season total yield from summer fire was more rapid than what was found with sideoats grama exposed to similar fire and clipping treatments (Ansley et al. 2006). Unlike buffalograss, clipping severely reduced sideoats grama total yield in all fire treatments, including the no-fire treatment. However, similar to buffalograss, sideoats grama total and live yield within clipped patches was greater in the summer fire than the no-fire treatment by 3 years post-fire.

Percentage of Live Tissue

The results support Hypothesis 4 that both summer and winter fires will temporarily increase percentage of live tissue during the first 1 or 2 growing seasons post-fire in both species, but this was only apparent in the spring and not the late-season samples. The results also support Hypothesis 5, that there would be no difference in percentage of live tissue between summer and winter fire treatments.

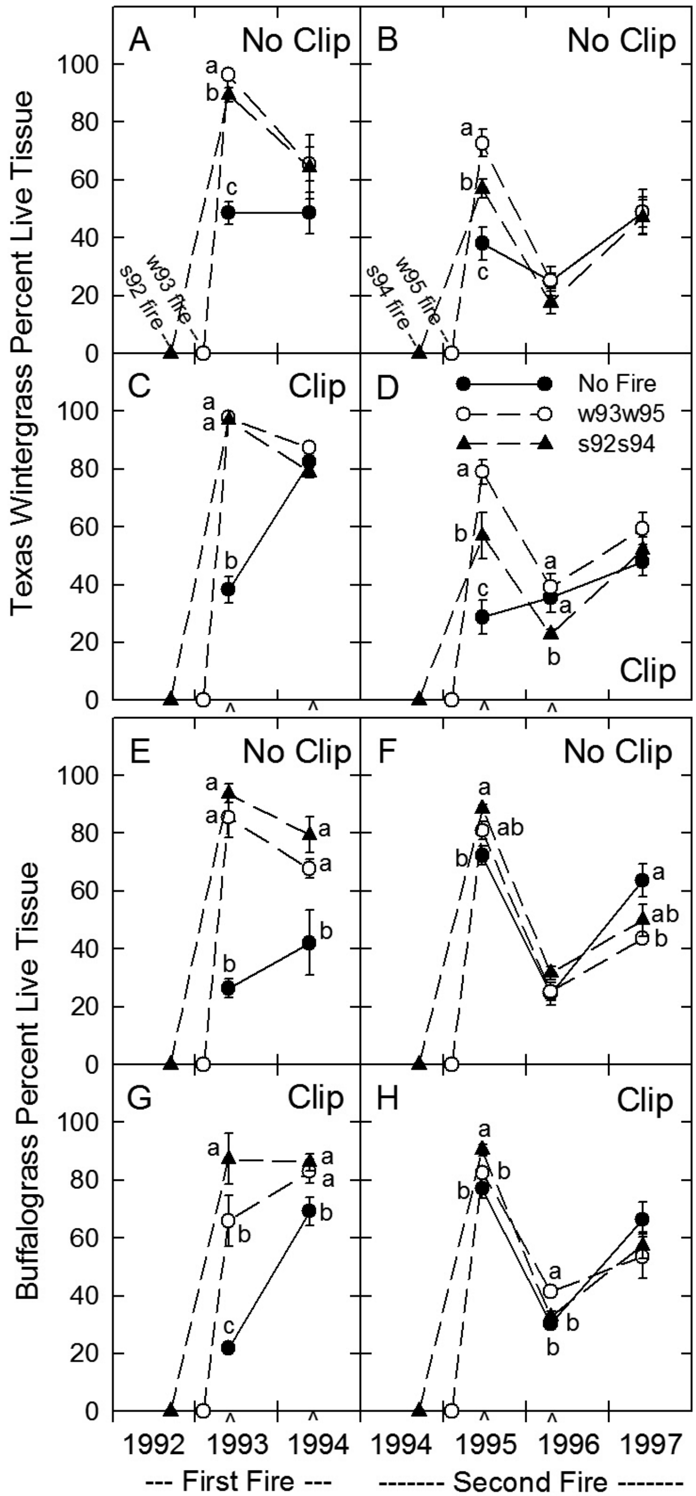

Figure 6. Texas wintergrass (**A–D**) and buffalograss (**E–H**) percentage live tissue during spring sample dates in unclipped (**A, B, E, F**) and clipped (**C, D, G, H**) treatments exposed to fire treatments in summer 1992 (s92) or winter 1993 (w93), and again in summer 1994 (s94) or winter 1995 (w95) (Experiment 2). Details same as Figure 4.

The summer fire treatment might have slowed the rate of decomposition of standing dead tissue from post-fire grass growth. At 3 years after the second fire, in 1997, late-season total yields of both species were nearly 3 times greater in the summer fire than the no-fire treatment (Figs. 2B and 3B), yet percentage of live tissue was lower in the summer fire than the no-fire in both species (Figs. 2F and 3F). As a result, standing dead tissue was over 4 times greater in the summer fire treatment than the no-fire (46 vs. 197 $g \cdot m^{-2}$ in Texas wintergrass; 36 vs. 157 $g \cdot m^{-2}$ in buffalograss) at 3 years post-fire. A slower rate of standing dead decomposition in the summer fire treatment might have been due to a higher tissue C:N ratio that could have resulted from a fire-mediated soil nitrogen deficiency. Several studies have found a higher C:N ratio in roots and rhizomes of frequently burned grasses (Ojima et al. 1994; Blair et al. 1998; Johnson and Matchett 2001; Fynn et al. 2003).

Effects of Precipitation

Differences in precipitation caused contrasting first year post-fire responses after the first and second fires in each seasonal fire treatment. Differences in total and live yields, as well as percentage of live tissue, were much greater between the no-fire and fire treatments after the first set of fires than after the second fires in both species. Above-normal rain in the 1995 growing season, the first year after the second fires, might have allowed Texas wintergrass and buffalograss total and live yields to recover more rapidly from the summer 1994 or winter 1995 fires than from the first fires in summer 1992 and winter 1993. These results indicate that first year responses to fire can be highly variable and point to the importance of longer post-fire evaluation periods (Mayeux and Hamilton 1988).

Effect of Mesquite Canopy Reduction By Fire

Removal of the competitive effects of the mesquite overstory by fire must be considered in the interpretation of results from this study. Theoretically, mesquite removal would favor the growth of C_4 grasses that are shaded by mesquite during their peak growth periods. In contrast, C_3 Texas wintergrass growth is not necessarily enhanced by mesquite removal (Ansley et al. 2004). Thus, the better performance of buffalograss over Texas wintergrass in response to the combined effects of fire and clipping might be in part because the fire-mediated reduction of mesquite canopies was more beneficial to buffalograss. Removal of mesquite canopies by winter or summer fires did not cause any significant increases in Texas wintergrass total or live yields, in clipped, or in unclipped plots, with the exception that late-season total yield of unclipped Texas wintergrass showed a trend of being greater in the summer fire treatment than the no-fire in fall 1997, 3 years post-fire (Fig. 2B).

MANAGEMENT IMPLICATIONS

Results suggest that different management strategies might be required for these 2 species if fire and grazing are part of the management strategy. Buffalograss appeared to be very tolerant of frequent burning and clipping, even if fires were in summer. Without fire, buffalograss growth was stable, but below maximum. In contrast, Texas wintergrass was more sensitive to the combined effects of fire and clipping. By 3 years post-fire, Texas wintergrass yields were slightly enhanced by summer fire, but the advantage gained by summer fire was eliminated if summer fire was combined with clipping. In contrast, buffalograss production increased with any treatment that included fire: winter fire alone, summer fire alone, winter fire + clipping, and summer fire + clipping. Results imply that combinations of grazing and fire could ultimately favor buffalograss, and possibly other C_4 grasses, over Texas wintergrass. However, we must emphasize that responses in this study were measured within monocultures and might not reflect post-fire competitive responses of individual species within mixed communities (Mayeux and Hamilton 1988; Owens et al. 2002). This study isolated the effects of seasonal fire and/or clipping from the potentially confounding effects of interspecies competition.

ACKNOWLEDGMENTS

The W. T. Waggoner Estate provided land area for the research. We thank Dr. Pete Jacoby, Betty Kramp, David Jones, Gerral Schulz, Tim Tunnell, and Duane Lucia who assisted with treatment implementation and data collection.

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