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Late growing-season fire effects in mid-successional tall-grass prairies

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Abstract

Wildfire in the growing season is relatively frequent and interest is increasing in using growing-season fire in management of tallgrass prairie. However, the influence of fire in the growing season on forage production and species composition, especially in mid-successional tallgrass prairie, is largely unknown. Our objective was to compare vegetation composition and production on Loamy Prairie and Very Shallow ecological sites in mid-successional stages in response to late growing-season fire at different frequencies. We applied 4 burning treatments (no burn, or 1, 2, or 3 burns in 5 years) in the late growing season in southern Oklahoma during a series of years of above-average precipitation. The sites were dominated at the beginning of the study by early- and mid-successional species including prairie threeawn (*Aristida oligantha* (Michx)), a species indicating a disturbance history. After the initial burns in 1990, tallgrasses, little bluestem, and perennial grasses were reduced by burning on the Loamy site. Forbs were more productive on burned plots (1,980 kg ha^{-1}) than on plots that were not burned (1,290 kg ha^{-1}) averaged across sites. Total production was not reduced by burning in 1990. Growing-season burns in 2 consecutive years had little influence on species composition or production as compared to a single burn in 2 years. Warm-season perennial grasses other than tallgrasses and little bluestem increased on the Loamy site, but decreased on the Shallow site. Production of cool-season perennial grasses increased to almost 40% of total production on twice-burned plots averaged across sites. Other than the effect on cool-season perennial grasses, 2 burns over a two-year period had little effect beyond the first growing season after the second burn. Twice-burned plots and plots burned 3 times produced more forbs than either plots that were burned once or not burned. Production of perennial grasses was opposite that of forb production. Total production was not reduced on either site regardless of fire frequency. Results indicate managers may expect a short-term reduction in production of forage grasses and an increase in forbs following late growing-season fire in mid-successional tallgrass prairies.

Key words: Burn season, fire ecology, fire frequency, succession, old-field succession, restoration

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Tallgrass prairies provide nutritious forage for livestock and critical habitat for wildlife in the central Great Plains. Prescribed dormant-season fire is an effective management practice for improving habitat for both wild and domestic animals (Launchbaugh and Owensby 1978, Wright and Bailey 1982). Wildfires, however, can occur at almost any season throughout the tallgrass prairie (Bragg 1982), potentially reducing forage production and causing undesirable changes in species composition (Launchbaugh and Owensby 1978). The observation by Komarek (1965) that much of what is known about the ecological effects of fire is based on dormant-season fires remains largely true today. Yet, prescribed fire applied in the growing season in tallgrass prairie is beginning to receive attention in restoration management (Howe 1994a) and brush control (Engle and Stritzke 1991).

The knowledge base on fire effects in tallgrass prairie in the central Great Plains has been gathered largely from studies in late successional prairies and prairies never subjected to cultivation. Knowledge gained from fire research in grasslands that were never cropped may not be entirely relevant to revegetated abandoned fields. Over one-half million ha of land was abandoned by 1930 in Oklahoma alone (Blackwell 1930) and doubtless millions of ha more tallgrass prairie and cross timbers of Kansas and Oklahoma were cultivated and subsequently abandoned after the droughts of the 1930's and 1950's. Many of these lands were allowed to revegetate naturally and continue to remain in mid-successional stages dominated by forbs, annual grasses, and various perennial bunchgrasses including little bluestem (Schizachyrium scoparium (Michx.) Nash) (Booth 1941). Disturbance from heavy grazing and burning may have delayed succession of these old fields (Booth 1941, Risser et al. 1981, p. 439), but the terminal stage of succession may take centuries to obtain (Glenn-Lewin 1980). Except for early studies on reseeding abandoned cropland (e.g., Savage 1939) and research on the successional dynamics of old fields (e.g., Collins and Adams 1983), research on management of naturally revegetated prairies is largely lacking. Thus, our objective was to compare the forage composition and production of mid-successional prairie sites following growing-season fire at different frequencies.

Materials and Methods

The experiment was conducted at the Samuel Roberts Noble Foundation, Inc. D. Joyce Coffey Ranch in Love County, Oklahoma, on 2 upland ecological sites (Loamy Prairie and Very Shallow). The Loamy Prairie (Loamy) is a Labette loam with a depth of about 1.2 m; the Very Shallow (Shallow) is a Tarrant loam with hard limestone at a depth of 5 to 25 cm with stones present on the surface (USDA-SCS 1966). Potential vegetation of the Loamy site is dominated by little bluestem, big bluestem (*Andropogon gerardii* Vitman), indiangrass (*Sorghastrum nutans* (L.) Nash), and switchgrass (*Panicum virgatum* (L.)). Potential vegetation of the Shallow site is dominated by hairy grama (*Bouteloua hirsuta* Lag.), tall grama (*B. pectinata* Featherly), Texas grama (*B. rigidiseta* Steud.), and sideoats grama (*B. curtipendula* (Michx.) Torr.). The sites were dominated in 1990 by early- and mid-successional species including prairie threeawn (*Aristida oligantha* (Michx)), a species indicative of a disturbance history of heavy livestock grazing or cropping followed by abandonment (Booth 1941, Rice 1968). We are uncertain about the history of land use on the study area, but because tallgrasses and other late seral species are absent, the Loamy Prairie was likely cultivated. The Very Shallow was not likely cultivated because of shallow, rocky soils. We are also uncertain about the dates of abandonment. Because forage utilization on the area was severe in 1987, we believe the stocking rates before 1987 were excessive. Grazing was excluded from the study sites beginning in 1990 and for the duration of the study.

We used a completely randomized design of 3 replications with 4 treatments (0, 1, 2, or 3 burns) assigned to 10 × 20-m plots located on each of the ecological sites. Replications were located within about 2.5 km of each other. We applied burning treatments in the late growing season from 1990 to 1993 (Table 1). Plots were ignited as headfires with a drip torch at plot boundaries with the long axis oriented parallel with the prevailing wind.

Late summer and early fall in this region can be accompanied by high winds, high air temperature, low relative humidity, and low dead fuel moisture. When these conditions are combined with low live fuel moisture, fire spread is possible. These conditions occurred in 1990 and to a lesser extent in 1991 and 1993 (Table 2). Fuel and weather conditions were unsuitable for fire propagation in 1992. Precipitation was recorded from a weather station in Marietta, Okla., located 9 km east of the study area (Table 3).

Fuel load was estimated by clipping herbaceous vegetation from 5 quadrats (0.5 × 0.5 m) per plot. Fuel moisture, expressed on a dry-weight basis, was determined after samples were oven

Table 1. Dates of burning treatments applied in a study in mid-successional tallgrass prairies in south-central Oklahoma.

Burn frequency	Treatment date: 4 and 5 Sep 1990	3 Oct 1991	1992	9 Aug 1993
0				
3	X	X		X
2	X			X
1	X			

X = Treatment burned in this year.

dried at 70°C for 72 hours. Ambient air temperature and relative humidity were measured with a sling psychrometer. Wind speed 2 m above the soil surface was measured with a totalizing anemometer.

Rate of fire spread (m s^{-1}) was measured with a stopwatch along a 5-m run of the fire marked with metal stakes placed in the center of each burn plot. Headfire behavior could not be measured on 2 Shallow plots in 1991 because inadequate fire spread required the plots be burned with strip headfires. Behavior observation of the headfire was omitted inadvertently on 1 Shallow plot in 1990. Fireline intensity (kW m^{-1}) (Byram 1959) was computed as the product of the fuel load heat of combustion (kJ kg^{-1}) for similar tallgrass prairie fuels (Bidwell and Engle 1991) adjusted for moisture content of the fuel and heat of vaporization, rate of spread, and fuel load. Heat per unit area (kJ kg^{-2}) was calculated as the quotient of fireline intensity and rate of spread (Rothermel and Deeming 1980).

We measured treatment effects on forage production in July or August of each year by clipping herbage to ground level in three, 0.2 × 0.5-m quadrats per treatment plot and separating current year's growth from litter and mulch. Current year's growth was further separated into little bluestem, tallgrasses (big bluestem, indiangrass, and switchgrass), cool-season perennial grasses (primarily Texas wintergrass (*Stipa leucotricha* Trin. & Rupr.) and scribner panicum (*Dichanthelium oligosanthes* (Schult.) Gould)), other warm-season perennial grasses (primarily *Bouteloua* spp. and *Sporobolus* spp.), annual grasses (primarily prairie threeawn and annual brome (*Bromus* spp.)), and forbs. Quadrat placement during sampling in subsequent harvest years was restricted to avoid areas sampled in previous years.

Table 2. Weather and fuel conditions associated with burning treatments in mid-successional tallgrass prairies in south-central Oklahoma.[a]

Year	Site	Burn frequency	Air temp	Relative humidity	Windspeed	Fuel moisture	Fuel load
			(°C)	(%)	(km h^{-1})	(%)	(kg m^{-1})
1990	Loam	3	36–37	29–40	1–9	22–35	0.61–0.78
		2	33–37	29–45	1–12	28–36	0.67–0.76
		1	33–37	29–42	0–6	31–42	0.64–0.71
	Shallow	3	35–38	39–44	3–9	27–39	0.44–0.64
		2	33–38	29–45	2–7	19–35	0.57–0.64
		1	36–38	29–34	1–12	24–33	0.46–0.64
1991	Loam	3	29–31	45–52	10–14	130–111	0.40–0.43
	Shallow	3	27–31	37–60	7–14	112–144	0.26–0.34
1993	Loam	3	32–37	46–63	8–10	45–69	0.57–0.64
		2	31–37	44–63	8–11	33–59	0.82–0.93
	Shallow	3	34–37	41–46	4–11	27–53	0.49–0.58
		2	33–37	42–50	3–6	33–42	0.53–0.70

[a]Data represent extreme measurements of 3 replications.

Table 3. Precipitation (cm) at Marietta, Oklahoma, 9 km east of study area.

Month	1990	1991	1992	1993	1994	1995	Average (1975–1995)
				(cm)			
Jan.	9.1	6.8	7.9	5.3	2.8	5.8	4.5
Feb.	7.9	2.8	4.9	9.5	7.4	0.7	5.9
March	23.6	9.5	4.6	6.7	7.3	12.2	9.5
April	34.8	5.2	4.1	8.2	14.5	11.4	8.6
May	14.9	10.3	14.5	21.7	17.4	21.4	15.0
June	13.5	17.6	17.4	12.8	4.6	9.8	10.8
July	8.3	2.6	12.4	0.0	17.5	6.7	5.8
Aug.	4.9	6.5	1.8	10.1	2.8	7.7	5.4
Sept.	9.6	21.5	8.4	17.1	16.8		9.8
Oct.	7.4	20.0	0.6	17.2	14.7		10.9
Nov.	12.4	6.3	9.5	37.1	13.5		6.2
Dec.	4.1	19.5	12.8	6.9	7.2		6.3
Total	160.5	128.6	90.0	119.2	126.5		98.1

Table 4. Behavior of fires associated with burning treatments in mid-successional tallgrass prairies in south-central Oklahoma.[a]

Year	Site	Burn frequency	Fireline intensity	Heat per unit area
			(kW m^{-1})	(kJ m^{-2})
1990	Loam	3	2,844 (1,151)	10,535 (808)
		2	2,592 (757)	10,746 (432)
		1	2,793 (1,332)	10,213 (363)
	Shallow	3	2,159 (247)	8,123 (1446)
		2[b]	3,920 (2,484)	9,039 (494)
		1	2,807 (249)	7,365 (339)
1991	Loam	3	266 (50)	5,414 (273)
	Shallow	3[c]	313 (0)	4,471 (0)
1993	Loam	3	894 (243)	8,748 (411)
		2	1,582 (210)	12,855 (400)
	Shallow	3	1,172 (216)	8,110 (336)
		2	1,739 (276)	9,600 (856)

[a]Values represent means (±1 SE) of 3 replications except where noted.
[b]n=2
[c]n=1

Analysis of variance applied to the 1991, 1992, and 1993 clipping data was conducted by year, with each year having a unique set of treatments. Main effects were burn treatment and site. Burn treatments for the 1991 clipping data were pooled because only 1 burn treatment had been applied in 1990 to all the burn plots. Thus, analysis of the 1991 clipping data tested for a difference between 2 treatments (i.e., burned or not burned). The 1 and 2 burn-frequency treatments were pooled for the 1992 and 1993 clipping data, which resulted in a test of 3 burn treatments (i.e., not burned, burned once, and burned twice). The 1994 and 1995 data were analyzed as a split-plot in time with years of measurement serving as sub plots and site (Loamy or Shallow) and burn treatment (0, 1, 2, or 3 burns) serving as main plots. Means for burn treatments and interactions were separated by a Fishers protected LSD at $P < 0.10$.

Results and Discussion

Fuel load was heavy in each of the burns (Table 2). Above average precipitation late in the 1991 growing season (Table 3) resulted in high fuel moisture, which delayed burning in the 1991 growing season compared to other years. Burning conditions resulted in high intensity fires in 1990 and 1993 and lower intensity fires in 1991 (Table 4). Monthly and vegetation-year precipitation (November to August) were above average each year of the study period (Table 3).

Effects of One Burn

Production of several vegetation components the growing season after the 1990 burns was affected by burning (Table 5). The most significant response to the 1990 burns was on the Loamy site where production of tallgrasses, little bluestem, and perennial grasses was reduced by burning. Production of no vegetation component was reduced by burning on the Shallow site. Forbs produced more on burn plots (1,980 kg ha^{-1}) than on plots not burned (1,290 kg ha^{-1}) averaged over sites. Growing-season fires in late successional tallgrass prairies resulted in similar increases in forbs, but grazing history (i.e., moderate grazing or no grazing) influenced the response (Ewing and Engle 1988, Engle et al. 1993). Production of forbs was negatively correlated with production of grasses in late successional tallgrass prairies in the Kansas Flint Hills (Briggs and Knapp 1995), and the earlier the burn in the dormant-season in the Kansas Flint Hills, the greater the increase in early and mid-successional species including forbs (Towne and Owensby 1984). Matrix tallgrass prairie species (i.e., the tallgrasses and little bluestem) contributed minor amounts to community production in this study. Mid-successional species including Texas wintergrass and warm-season midgrasses appear competitive with forbs after fire disturbance in this grassland.

Because of their growth habit and competitive ability, tallgrasses are more tolerant of fire than are little bluestem and other bunchgrasses (Svejcar and Christiansen 1986, Collins 1987, Ewing and Engle 1988, Mitchell et al. 1996). Indeed, tallgrasses as a group are resistant even to fires within their active growth period (Adams et al. 1982, Ewing and Engle 1988, Engle et al. 1993). Indiangrass, the first tallgrass species to invade abandoned cropland, was the primary tallgrass occupying the Loamy site in our study, and may explain the reduction of tallgrasses following fire in our study. Indiangrass, which overwinters tillers produced on biennial rhizomes (McKendrick et al. 1975), may be less resistant than either switchgrass or big bluestem to burning in the late growing season.

Early dormant-season burns leave soil exposed before the onset of the following growing season, thereby increasing runoff and evaporative losses and decreasing total herbage production (Anderson 1965, McMurphy and Anderson 1965, Towne and Owensby 1984, Mitchell et al. 1996). Svejcar (1990) found that soil moisture did not limit production on burned plots in a wet year. Thus, above-average precipitation may explain why burning did not reduce total production in 1991 (3,330 and 3,270 kg ha^{-1} on the unburned and burned plots, respectively, averaged across sites). In 2 studies of late growing-season fires in late successional tallgrass prairie in northern Oklahoma, total production was not reduced the year following burning (Ewing and Engle 1988) or total production was reduced less than 600 kg ha^{-1} the year following burning (Engle et al. 1993). It is possible that burning interacts with other management inputs, such as grazing management or time since last burn, to determine availability and use of resources other than soil water (Seastedt et al. 1991, Briggs and Knapp 1995).

Table 5. Production (kg ha^{-1}) of herbage components July 30, 1991 following a single growing-season burn in 1990 in mid-successional tallgrass prairies in south central Oklahoma[a].

Site	Burn treatment[b]	TG[c]	LB	CSP	OPG	AG	Forbs	PG	Total
		(kg/ha)							
Loamy Prairie	No burn	420	100	970	900	170	1,440	2,390	4,000
	Burned	0	0	660	450	60	1,960	1,110	3,130
OSL									
Burn[d]		0.08	0.04					0.01	
Very Shallow	No burn	0	0	530	860	140	1,130	1,390	2,670
	Burned	10	0	440	630	130	2,010	1,080	3,210
OSL									
Burn		0.59	—					0.43	
OSL[e]									
Burn		0.08	0.03	0.29	0.28	0.26	0.07	0.01	0.72
Site × Burn		0.06	0.03	0.56	0.72	0.43	0.62	0.10	0.13

[a]Interaction means presented for clarity of interpretation.
[b]n=3 for not burned and n=9 for burned.
[c]TG is tallgrasses; LB is little bluestem; CSP is cool-season perennial grasses (primarily scribner panicum and Texas wintergrass); OPG is other warm-season perennial grasses; AG is annual grasses (primarily prairie threeawn and annual brome); PG is sum of perennial grasses; Total is total production of current year's growth.
[d]Observed significance level within a site for the burn effect when the interaction (Site × Burn) effect is signficant ($P < 0.10$).
[e]OSL=observed significance level ($P < 0.10$) over burn treatments and sites.

Our data and data from other studies (Ewing and Engle 1988, Engle et al. 1993) indicate burning in the late growing season in the tallgrass prairie has little apparent influence on total community production in years of normal or above-normal precipitation in either mid- or late successional tallgrass prairies. Dormant-season burning removes excessive litter accumulation and can increase herbage production (Hulbert 1969, Knapp and Seastedt 1986, Hulbert 1988). Litter amounts were 3,680 and 3,160 kg ha^{-1} on unburned Loamy and Shallow sites, respectively by 1991. Variation in litter on unburned sites is related to previous year's precipitation, and appears to reach stability earlier on sites with shallow soils than on sites with deep soils (Abrams et al. 1986). Burning may have reduced total production, especially on the Shallow site, had this study been conducted within a dry period or following another management scenario that resulted in reduced litter accumulation.

Effects of Multiple Burns

Two burns in 2 years appeared to have little influence on amount or composition of forage production as compared to a single burn. Little bluestem had begun to grow vigorously in widely scattered bunches on plots that were not burned. Hence,

Table 6. Production (kg ha^{-1}) of herbage components August 18, 1992 following growing-season burns in mid-successional tallgrass prairies in south central Oklahoma[a].

Site	Burn frequency	TG[b]	LB	CSP	OPG	AG	Forbs	PG	Total
		(kg/ha)							
Loamy Prairie	No burn[c]	0	4,160	930	600	100	1,400	5,690	7,190
	One[d]	0	10	480	1,490	230	1,640	1,980	3,860
	Two[c]	0	30	1,200	680	30	1,440	1,910	3,390
OSL					0.07				
Burn[e]									
$LSD_{0.10}$					890				
Very Shallow	No burn	0	0	640	1,660	340	980	2,300	3,620
	One	0	10	660	690	660	980	1,360	3,000
	Two	0	0	520	410	790	1,470	800	930
OSL					0.02				
Burn[d]									
$LSD_{0.10}$					730				
OSL[f]									
Burn		—	0.21	0.39	0.11	0.61	0.82	0.10	0.11
Site × Burn		—	0.21	0.19	0.01	0.62	0.66	0.47	0.28

[a]Interaction means presented for clarity of interpretation.
[b]TG is tallgrasses; LB is little bluestem; CSP is cool-season perennial grasses (primarily scribner panicum and Texas wintergrass); OPG is other warm-season perennial grasses; AG is annual grasses (primarily prairie threeawn and annual brome); PG is sum of perennial grasses; Total is total production of current year's growth.
[c]n=3
[d]n=6
[e]Observed significance level within a site for the burn effect when the interaction (Site × Burn) effect is signficant ($P < 0.10$).
[f]OSL=observed significance level over burn treatments and sites.

variation in little bluestem, and therefore total production, was high on the Loamy site (Table 6). Production of other perennial grasses (OPG) increased on the Loamy site following 1 burn but not 2 burns. The OPG species decreased on the Shallow site following 1 and 2 burns. The OPG species on the Loamy site were primarily warm-season mid-grasses including species of dropseed (*Sporobolus* spp.) and grama (*Bouteloua* spp.). Species that accounted for the decrease in OPG species on the Shallow site included several species of grama, which are bunchgrasses. The bunchgrass growth form is especially sensitive to fire when accumulated herbage within the bunch causes meristematic tissue damage (Wright 1971).

Cool-season species respond variably to late growing-season fire in late-seral tallgrass prairie (Ewing and Engle 1988, Engle et al. 1993). Because the active growth period of cool-season species begins about the time of late growing-season fire, cool-season species should be favored by late growing-season fire (Hover and Bragg 1981, Howe 1994b). It was not until 1993, after 2 fires that we were able to detect a difference in production of cool-season perennial (CSP) grasses averaged across sites (Table 7). Averaged across sites, CSP grass production was 520, 720, and 1,290 kg ha^{-1} on the no burn, once burned, and twice burned plots, respectively (LSD = 470). Production of CSP grasses in 1993 on the twice-burned plots was more than double that of the no burn treatment plots and represented 70% of the perennial grass production and almost 40% of total production. The effect of burning was not carried over into following years or subsequent burning did not influence production of CSP (Table 8). This may have been a result of the timing of fires within the late growing season, or of precipitation favorable to CSP grasses relative to warm-season species.

Other than the effect on cool-season perennial (CSP) grasses, 2 burns over a two-year period had little effect beyond the first growing season following the burn. We were unable to detect any other differences in production or composition among the burn treatments on either site (Table 7). The influence of late-growing season fires in late seral tallgrass prairie was similarly minimal in other studies (Engle et al. 1992, Engle et al. 1993). This leads us to conclude that conventional wisdom of prolonged reduction in forage production and prolonged changes in species composition following wildfire (Launchbaugh and Owensby 1978) is not applicable to mid-successional tallgrass prairie in southern Oklahoma, at least in periods of above-average precipitation. Prairies contain a population reservoir of ruderal species that occupy open soils following growing-season burns (Abrams 1988, Ewing and Engle 1988), but the copious presence of ruderals is short lived after late growing-season fire. This suggests that the primary influence on this site is the disturbance history from tillage and grazing rather than burning.

More forbs were produced in 1994 on the plots burned 3 times (averaged across sites) than on the unburned and once-burned plots, but the plots burned twice also produced more forbs (1,360, 940, 2,250, and 2,150 kg ha^{-1} for the unburned, once burned, twice burned, and 3 times burned treatments, respectively, LSD=570) (Table 8). Production in 1994 of perennial grasses, averaged across sites, was opposite that of forb production (1,760, 2,180, 870, and 680 kg ha^{-1} for the unburned, once burned, twice burned, and 3 times burned treatments, respectively, LSD=370).

The negative influence of repeated burning on perennial grasses persisted over more years (2,640, 2,270, 1,300, and 1,700 kg ha^{-1} for the unburned, once burned, twice burned, and 3 times burned treatments, respectively, LSD=650, averaged across sites in 1995), than the positive influence on forbs, which was not detected in 1995 (Table 8). Again, total production was not influenced in either the year after the third burn event (i.e., 1994), nor did the effect persist into the second growing season (i.e., 1995) after the third burn (Table 8). Variation in other herbage components was high in both years after the third burn event, and we could not detect any differences in production among burn treatments. Forage production on these sites is dominated by bunchgrasses in the vegetation category other perennial grasses (OPG), which appears to be sensitive to repeated burning (1,390, 1,170, 580, and 630 kg ha^{-1} for the unburned, once burned, twice burned, and 3 times burned treatments, respectively, averaged across sites and years 1994 and 1995, LSD=520). Annual grasses, primarily prairie threeawn and several species of cool-season grasses, which also increased under repeated burning (90, 90, 320, and 860 kg ha^{-1} for unburned, once burned, twice burned, and 3 times burned treatments, respectively, averaged across sites and years 1994 and 1995, LSD=480), are a relatively minor component of the vegetation that appear to require multiple disturbance events to increase.

Table 7. Production (kg ha^{-1}) of herbage components August 13, 1993 following growing-season burns in mid-successional tallgrass prairies in south central Oklahoma[a].

Site	Burn frequency	TG[b]	LB	CSP	OPG	AG	Forbs	PG	Total
		(kg/ha)							
Loamy Prairie	No burn[c]	0	1,110	740	820	100	1,470	2,680	4,240
	One[d]	0	0	490	1,430	130	1,830	1,930	3,890
	Two[c]	0	20	1,320	990	200	770	2,330	3,300
Very Shallow	No burn	0	0	390	900	290	1,010	1,290	2,590
	One	0	20	620	1,140	210	760	1,780	2,740
	Two	10	0	730	1,040	320	670	1,790	2,780
OSL[e]									
Burn		0.21	0.21	0.09	0.40	0.46	0.14	0.88	0.82
Site × Burn		0.21	0.20	0.22	0.80	0.75	0.23	0.36	0.67

[a]Interaction means presented for clarity of interpretation.
[b]TG is tallgrasses; LB is little bluestem; CSP is cool-season perennial grasses (primarily scribner panicum and Texas wintergrass); OPG is other warm-season perennial grasses; AG is annual grasses (primarily prairie threeawn and annual brome); PG is sum of perennial grasses; Total is total production of current year's growth.
[c]n=3
[d]n=6
[e]OSL=observed significance level ($P < 0.10$) over burn treatments and sites.

Table 8. Production (kg ha^{-1}) of herbage components August 16, 1994 and August 14, 1995 following growing-season burn in mid-successional tallgrass prairies in south central Oklahoma[a].

Year	Site	Burn frequency[b]	TG[c]	LB	CSP	OPG	AG	Forbs	PG	Total
			(kg/ha)							
1994	Loamy Prairie	No burn	0	620	370	460	180	1,620	1,460	3,260
		One	0	300	490	1,190	60	1,340	1,980	3,380
		Two	0	40	220	270	330	2,210	530	3,060
		Three	0	180	320	260	1,290	1,880	760	3,930
	Very Shallow	No burn	0	130	180	1,740	40	1,100	2,060	3,200
		One	0	140	570	1,670	220	530	2,380	3,130
		Two	0	0	680	540	130	2,290	1,220	3,640
		Three	0	0	550	50	1,410	2,420	600	4,430
	OSL (1994)									
	Burn							0.03	0.01	
	Site × Burn								0.51	
1994		Burn								
Year	Site	frequency[b]	TG[e]	LB	CSP	OPG	AG	Forbs	PG	Total
1995	Loamy Prairie	No burn	0	1,170	390	2,110	70	1 090	3,670	4,820
		One	80	0	500	1,360	60	2,030	1,930	4,020
		Two	0	0	210	1,260	520	2,410	1,470	4,400
		Three	0	20	500	1,500	590	1,020	2,020	3,630
	Very Shallow	No burn	0	0	370	1,240	80	1,300	1,610	2,990
		One	0	610	370	1,630	20	730	2,610	3,370
		Two	0	0	870	270	280	720	1,130	2,130
		Three	0	0	680	710	130	1,260	1,390	2,780
	OSL (1995)									
	Burn							0.81	0.09	
	Site × Burn								0.12	
	OSL[d]									
	Burn		0.42	0.53	0.25	0.02	0.06	0.17	0.01	0.66
	Site × Burn		0.42	0.53	0.02	0.46	0.96	0.21	0.27	0.60
	Year × Site		0.33	0.73	0.86	0.02	0.67	0.26	0.02	0.01
	Site × Burn		0.42	0.77	0.66	0.51	0.20	0.09	0.34	0.11
	Year × Site × Burn		0.42	0.13	0.73	0.39	0.93	0.21	0.09	0.37

[a]Interaction means presented for clarity of interpretation.
[b]n=3
[c]TG is tallgrasses; LB is little bluestem; CSP is cool-season perennial grasses (primarily scribner panicum and Texas wintergrass); OPG is other warm-season perennial grasses; AG is annual grasses (primarily prairie threeawn and annual brome); PG is sum of perennial grasses; Total is total production of current year's growth.
[d]OSL=observed significance level for analysis of variance as a split-plot in time.
[e]Observed significance level within a year for site and burn effects when an interaction with the year effect is signficant ($P < 0.10$).

Succession on these sites in the absence of burning or grazing remained in the bunchgrass stage on both sites throughout the study, with little change in little bluestem or tallgrasses, the dominants and key forage species of late seral tallgrass prairie. Burning in the growing season induced regression by increasing forb species and decreasing perennial grasses even on these disturbed sites, but recovery from a single burn was complete by the second growing season after burning (Table 7). More frequent burns reduced perennial grass production for at least 2 seasons (Table 8). Still, the disturbance influence of these fires appears less than conventional wisdom would suggest. Multivariate analysis of species cover data for these treatments substantiated this, indicating that time since the study began, year (i.e., precipitation), and site were more important factors influencing community dynamics than burning treatment (Crockett et al. 1997).

Management Implications

Managers may expect a short-term reduction in production of forage grasses and an increase in forbs following late growing-season fires in mid-successional tallgrass prairies. Herbicides such as 2,4-D [(2,4-dichloro-phenoxy)acetic acid], will reduce the competition of forbs in late successional prairies (Engle et al. 1993), but the benefits have not been tested in prairies similar to those in the present study. Managers should be cautioned that warm-season bunchgrasses that dominate earlier seres may not respond as favorably to competitive release from forbs as the tallgrasses that dominate later seres.

With repeated late growing-season burning, managers might increase the composition to cool-season perennial (CSP) grasses, which might be of value as winter livestock forage. Managers with an interest in certain wildlife species, including bobwhite quail (*Colinus virginianus*), could use late growing-season burning to improve habitat by opening the soil surface and stimulating forbs. Our results indicate the increased forb production from a single late growing-season burn will likely be realized only the following year. Repeated burning, when practical, may prolong the benefits.

Late-growing season burning can be used to enhance biodiversity in late successional tallgrass prairies by increasing the contribution of forbs, which dominate the floristic diversity of these prairies (Briggs and Knapp 1995). Growing-season fires can be used also to retard woody species invasion (Engle and Stritzke 1991), suppress warm-season grasses, and increase species diversity in tallgrass prairies (Glenn-Lewin et al. 1990, Howe 1994b). We cannot recommend late growing-season fires as a single means of inducing succession over a short time period to dominance by tallgrasses and other perennial grasses in mid-successional tallgrass prairies similar to those in this study. Inducing succession of disturbed tallgrass prairies to later successional stages over a short time period through late growing-season burning appears unlikely, even in a series of years of above-average precipitation as experienced in this study.

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