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Response of Central Plains Tallgrass Prairies to fire, fertilizer, and atrazine

ROBERT A. MASTERS, KENNETH P. VOGEL, AND ROBERT B. MITCHELL

Authors are range scientist and supervisory research geneticist, USDA-ARS, and research assistant, Department of Agronomy, University of Nebraska, Lincoln 68583.

Abstract

Tallgrass prairies are an important forage resource in the eastern Central Great Plains. The effect of spring burning, fertilization, and atrazine [6-chloro-N-ethyl-N'-(1-methylethyl)-1,3,5-triazine-2,4-diamine] on standing crop of selected herbaceous species and categories of vegetation was determined in 6 tallgrass prairie environments located near Lincoln and Virginia, Neb., from 1987 through 1989 and 1 site near Bloomfield, Neb., in 1987. The grasslands were in good to excellent condition at the time these studies were conducted. Portions of each site were burned in mid-to late spring, atrazine was applied at a rate of 2.2 kg a.i. ha^{-1} in late April to early May, and fertilizer was applied in mid-May. Despite below-normal precipitation at 6 of the 7 sites, burning combined with fertilization improved warm-season grass standing crop by 50 to 127% in 5 of the 7 grassland environments studied. This reflected the positive response of the dominant warm-season grasses, big bluestem (*Andropogon gerardii* Vitman var. *gerardii* Vitman) and indiangrass [*Sorghastrum nutans* (L.) Nash], to burning or fertilization. Atrazine increased warm-season grass standing crop at only the site near Bloomfield. Kentucky bluegrass (*Poa pratensis* L.) and annual bromes (*Bromus* spp.) were more susceptible to atrazine than smooth brome (*Bromus inermis* Leyss.). Forb standing crop was significantly reduced by atrazine alone or by burning followed by atrazine application in 4 of the 7 prairie environments. Burning combined with fertilizer application improved warm-season grass standing crop in good to excellent condition grasslands and obviated the need to use atrazine.

Key Words: herbaceous standing crop, big bluestem (*Andropogon gerardii* Vitman var. *gerardii* Vitman), indiangrass [*Sorghastrum nutans* (L.) Nash], smooth brome (*Bromus inermis* Leyss.), Kentucky bluegrass (*Poa pratensis* L.), warm-season grasses, cool-season grasses, forbs

Tallgrass prairies occur throughout the eastern Central Great Plains of North America and are a valuable resource that can provide high quality warm-season grass forage if properly managed. In this region abundant cool-season forages and crop residues are available for grazing by livestock in the spring, fall, and winter (Waller and Schmidt 1983). However, there is an imbalance in seasonal forage supply because of a lack of warm-season grass forage during the summer. Because of this imbalance, there is a tendency for producers to overstock their warm-season forages, which often leads to deterioration of this resource. Increasing the productivity of the warm-season forages found on existing tallgrass prairies that are in good to excellent condition could improve availability of forage in the summer.

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Methods to improve productivity of tallgrass prairies include spring burning, fertilization, and application of atrazine [6-chloro-N-ethyl-N'-(1-methylethyl)-1,3,5-triazine-2,4-diamine]. Factors that influence the response of tallgrass-dominated plant communities to these treatments include vegetation composition and successional status (Gillen et al. 1987), time of spring burning (Towne and Owensby 1984), and time of fertilizer application (Rehm 1984). Atrazine has been applied to selectively control introduced cool-season grasses Kentucky bluegrass (*Poa pratensis* L.) and smooth brome (*Bromus inermis* Leyss.) and improve productivity of warm-season grasses in degraded tallgrass prairies (Samson and Moser 1982, Waller and Schmidt 1983).

A management strategy that combines atrazine application with fertilization and burning in the spring could improve productivity of warm-season grasses in eastern Central Great Plains tallgrass prairies and alleviate limitations in summer forage supply. The importance of atrazine as a component of a management program must be assessed and other strategies identified because of the suspension of this herbicide from use on rangeland. A series of studies were conducted in tallgrass prairies in good to excellent condition to determine the influence of these treatments on standing crop of the warm- and cool-season grass and forb components of these plant communities and to determine if there is any advantage to including atrazine in a treatment regime with burning and fertilization to improve tallgrass prairie productivity.

Materials and Methods

Three studies were conducted during a 3 year period from 1987 through 1989 in 7 environments to determine the response of tallgrass-dominated plant communities to burning, fertilization, and atrazine application in the spring. Plant community response to treatments was assessed and livestock were excluded from the study sites the year of treatment.

Study 1

In 1987, sites were established on grasslands located 15 km northwest of Lincoln, Neb., (Nine-Mile Prairie) and 10 km southwest of Bloomfield, Neb. The soil at the site near Lincoln was a Sharpsburg silty clay loam (Typic Arguidoll) and near Bloomfield was a Dickinson loamy sand (Typic Hapludoll). The Lincoln site was a tallgrass prairie that had not been grazed and had been burned at 2 to 3 year intervals since 1968. The Bloomfield site supported a grassland community that had been grazed annually since revegetation with tall- and mid-grasses in the 1950's.

One-half of an area (148 × 54-m) was burned at the Lincoln and Bloomfield sites on 18 April and 23 April 1987, respectively. Three plots (74 × 18-m) were delineated within the burned and unburned areas at each site. In May 1987, one-half of each plot was fertilized with 110 kg N ha^{-1}. In addition, 22 kg P ha^{-1} was applied at the Bloomfield site because the soil was phosphorus deficient. Atra-

Table 1. Botanical composition of tallgrass prairies near Bloomfield, Lincoln, and Virginia, Nebraska.[1]

	1987		1988			1989	
	Bloomfield	Lincoln	Lincoln	Virginia-G	Virginia-H	Lincoln	Virginia
	%						
Big bluestem	0	68	78	19	11	60	42
Indiangrass	40	13	2	28	29	16	14
Prairie/Tall dropseed	0	0	0	41	12	1	11
Other warm-season grasses	48	12	7	2	36	4	6
Smooth brome	7	0	0	0	4	0	7
Kentucky bluegrass	NH[2]	NH	9	1	1	1	9
Scribner's/Wilcox's panicum	3	1	0	4	3	1	6
Other cool-season grasses	0	1	0	0	0	1	0
Sedge	1	3	0	2	2	5	4
Forbs	1	2	4	3	2	10	1

[1]Expressed as a percent of total herbaceous standing crop.
[2]Not harvested separately (NH).

zine was applied at 2.2 kg active ingredient (a.i.) ha^{-1} to half of each fertilized and unfertilized plot within the burned and unburned areas. In early August 1987, vegetation within two 0.5-m^2 quadrats placed within each subplot was clipped to a 2-cm stubble height, separated by species, oven-dried, and weighed.

Study 2

In 1988 sites were established on tallgrass prairies near Lincoln (Nine-Mile Prairie) and Virginia (Dalbey-Halleck Farm), Neb. The soil at the site near Lincoln was a Sharpsburg silty clay loam and that near Virginia was a Pawnee clay loam (Aquic Argiudoll). The Lincoln site had a similar history to the tallgrass prairie in Study 1. Two sites located 5 km south of Virginia on a tallgrass prairie were used in this study. For a period of 25 years before initiation of this study, 1 site (Virginia-G) had been moderately grazed for 50 to 60 days during the summer and the other site (Virgina-H) had been hayed in late July or early August. The Virginia-G site was sprayed with atrazine at 4.4 kg a.i. ha^{-1} in 1986 and with 1.1 or 2.2 kg a.i. ha^{-1} of 2,4-D [(2,4-dichloro-phenoxy)acetic acid] each year from 1982 to 1987. Both sites were burned in mid-April 1986 and 1987.

Eight plots (10 × 20-m) were established at each site in April 1988. Four of these plots were burned on 6 May 1988. After burning four, 5 × 10-m subplots were delineated within each main plot. On 12 May 1988 randomly selected subplots were fertilized at a rate of 110-22 kg N-P ha^{-1} and atrazine was applied at a rate of 2.2 kg a.i. ha^{-1} to 1 fertilized and 1 unfertilized subplot within each plot. In August 1988, vegetation within 2, 0.25 m^2 quadrats randomly placed within each subplot was clipped to a 2-cm stubble height, separated by species, oven-dried, and weighed.

Study 3

In 1989 study sites were established on tallgrass prairies near Lincoln (Nine-Mile Prairie) and Virginia (Dalbey-Halleck Farm), Neb. The soil at the site near Lincoln was a Shelby clay loam (Typic Argiudoll) and that near Virginia was a Pawnee clay loam. Management of the Lincoln and Virginia sites was similar to that in Study 1 and Virginia-G in Study 2, respectively, except that the site near Lincoln was burned by a wildfire on 10 March 1988.

Eight plots (10 × 20-m) were delineated at each site in April 1989. Four plots were burned on 19 April and 20 April 1989 at Virginia and Lincoln, respectively. After burning, four, 5 × 10-m subplots were delineated within each main plot. On 26 April 1989 atrazine was applied at a rate of 2.2 kg a.i. ha^{-1} to 2 randomly selected subplots within each main plot. In mid-May fertilizer at a rate of 67–22 kg N-P ha^{-1} was applied within each burn treatment main

Table 2. Mean standing crop and F-test probabilities of warm-season grasses harvested in the summer after applications of fire, fertilizer, and atrazine in the spring to grassland sites near Bloomfield, Lincoln, and Virginia, Nebraska.

		1987		1988			1989	
Treatment[1]		Bloomfield	Lincoln	Lincoln	Virginia-G	Virginia-H	Lincoln	Virginia
		kg ha^{-1}						
BFA		7792	10138	4342	9555	4216	5051	3030
BF		4829	9342	5698	8830	3649	5178	2568
BA		4331	5415	3083	5400	2618	3700	2678
B		2088	5097	3568	5810	2290	3670	2271
FA		5313	7050	4730	6322	2487	3964	3353
F		1339	5976	3362	5433	2924	3993	3669
A		3284	4820	3726	4774	1953	3818	2009
O		2266	4703	3222	4376	2314	2969	1714
Source of variation	df	F-test probabilities						
Burn(B)	1	ND[2]	ND	0.24	0.01	<0.01	0.15	0.89
Fertilizer(F)	1	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Atrazine(A)	1	<0.01	0.08	0.98	0.38	0.90	0.49	0.38
B × F	1	<0.01	<0.01	0.16	0.02	0.02	0.11	0.01
B × A	1	0.92	0.95	0.03	0.59	0.03	0.38	0.35
F × A	1	0.10	0.25	0.99	0.37	0.82	0.32	0.56
B × F × A	1	0.29	0.69	0.27	0.72	0.67	0.49	0.49

[1]Treatments are burned in spring (B), fertilized (F), atrazine applied at 2.2 kg a.i./ha (A), and no treatment (O). Fertilizer rates: 110–22 kg N-P/ha applied at Bloomfield in 1987 and Lincoln and Virginia in 1988, 110 kg N/ha applied at Lincoln in 1987, and 67–22 kg N-P/ha^{-1} applied at Lincoln and Virginia in 1989.
[2]Main effect of burning could not be determined because the whole plots were non-replicated.

plot to 1 subplot that had been treated with atrazine and 1 that had not. In late July 1989, vegetation within two 0.25-m^2 quadrats randomly placed within each subplot was clipped to a 2-cm stubble height, separated by species, oven dried, and weighed.

Botanical Composition

The sites used in these studies were in good to excellent condition as indicated by botanical composition (Table 1). The grassland near Bloomfield was dominated by indiangrass [*Sorghastrum nutans* (L.) Nash] and little bluestem [*Schizachyrium scoparium* (Michx.) Nash], with each comprising 40% of the warm-season grasses, while big bluestem (*Andropogon gerardii* Vitman var. *gerardii* Vitman) was uncommon. At the sites near Lincoln, big bluestem constituted 60% or more of the herbage with indiangrass as the next most common species except on the site treated in 1988. Indiangrass, tall dropseed [*Sporobolus asper* (Michx.) Kunth], prairie dropseed [*Sporobolus heterolepis* (Gray) Gray], and big bluestem were the most common grasses at the tallgrass prairie sites near Virginia. The cool-season grass component of the 7 grassland environments evaluated in these studies ranged from 1 to 10% except at the site near Virginia in 1989 which contained 22% cool-season grasses. The most common cool-season grasses were smooth brome, Kentucky bluegrass, Scribner's panicum [*Dicanthelium oligosanthes* (Schult.) Gould var. *scribnerianum* Nash], and Wilcox's panicum [*Dicanthelium oligosanthes* (Schult.) Gould var. *wilcoxianum* (Vasey) Gould and Clark].

Experiment Design and Data Analyses

Study 1 was designed as a randomized complete block arranged as a split-split plot. Burning treatments constituted the whole plots, but were not replicated. Fertilizer and atrazine treatments were the subplots and sub-subplots, respectively, and were replicated 3 times within the burned and unburned whole plots. Because whole plots were nonreplicated, an error term could not be generated to test the main effect of burning. Despite the restriction in placement of burn treatments, appropriate error terms could be developed to test fertilizer and atrazine main effects and interactions with each other and burning (Anderson and McLean 1974). Testing the interactions that include burning are appropriate if the differences observed in plant response resulted from burning and not other factors unique to the burned or unburned whole plots. Given the similarity in botanical composition, soil characteristics, and management history between the whole plots at each site, we were confident that interactions with burning could be tested. Data from burned and unburned whole plots at each site were pooled after the error variances were determined to be equal. Equality of error variances was determined using a F-test where $P \leq 0.05$ (Steel and Torrie 1980). Studies 2 and 3 were designed as randomized complete blocks arranged as split plots with 4 replications per treatment combination. Burning treatments were the whole plots and fertilizer and atrazine treatments were randomly assigned subplots within the replicated whole plots. Hierarchial analysis of variance was used in each study to determine the influence of main effects (except main effect of burning 1987) and interactions on

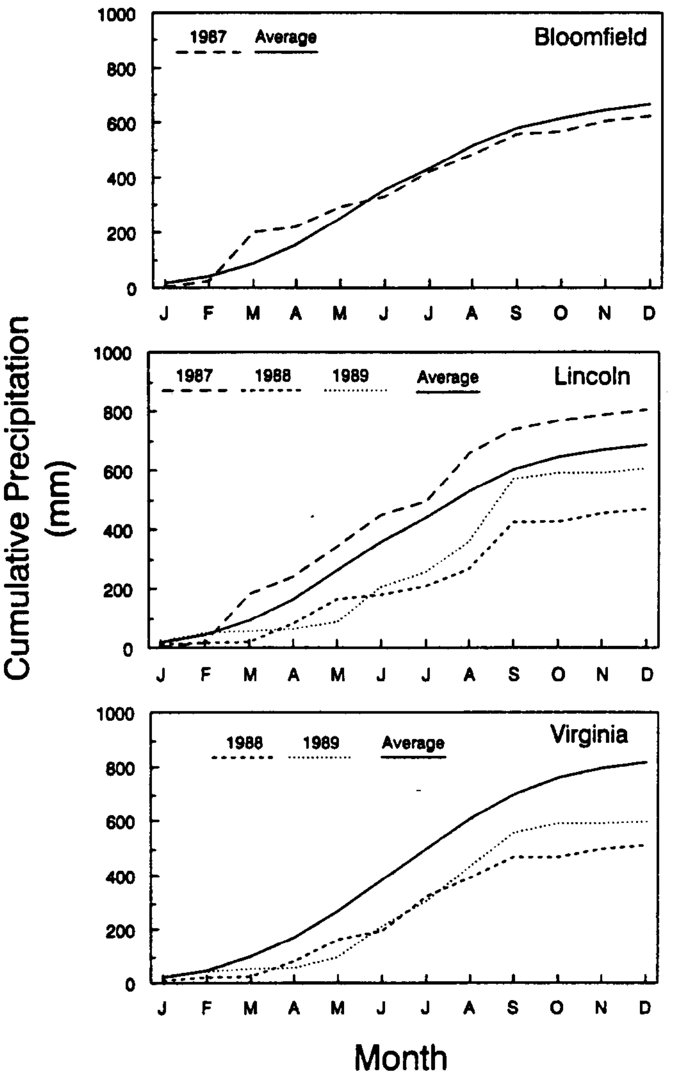

Fig. 1. Cumulative precipitation at 3 locations in eastern Nebraska during the time that these studies were conducted.

Table 3. Mean standing crop of warm-season grasses harvested in the summer, following applications of fire, fertilizer, and atrazine in the spring to tallgrass prairies near Bloomfield, Lincoln, and Virginia, Nebraska[1].

Spring burning	Fertilizer[2]	1987 Bloomfield	1987 Lincoln	1988 Lincoln	1988 Virginia-G	1988 Virginia-H	1989 Lincoln	1989 Virginia
		kg ha^{-1}						
None	None	2775	4761	3474	4595	2133	3394	1861
None	Fertilize	3326	6513	4046	5877	2705	3978	3511
Burn	None	3210	5246	3325	5605	2454	3685	2474
Burn	Fertilize	6311	9741	5020	9192	3932	5115	2799
LSD (0.05)		934	1303	NS[3]	1325	535	NS	694

[1]Standing crop averaged across atrazine treatments.
[2]Fertilizer rates: 110–22 kg N-P/ha^{-1} applied at Bloomfield in 1987 and Lincoln and Virginia in 1988, 110 kg N/ha^{-1} applied at Lincoln in 1987, and 67–22 kg N-P/ha^{-1} applied at Lincoln and Virginia in 1989.
[3]Not significant at $P \leq 0.05$ level of probability.

Table 4. Mean standing crop of warm-season (Warm) and cool-season (Cool) grasses harvested in the summer following applications of fire, fertilizer, and atrazine in the spring to tallgrass prairies near Bloomfield, Lincoln, and Virginia, Nebraska.

		1987[1]		1988[2]			
		Bloomfield		Lincoln		Virginia-H	
Spring burning	Atrazine	Warm	Cool	Warm	Cool	Warm	Cool
	kg a.i. ha^{-1}	kg ha^{-1}					
None	0	2631	279	3292	457	2619	395
None	2.2	5180	110	4228	28	2220	311
Burn	0	—	—	4633	123	2970	277
Burn	2.2	—	—	3712	177	3417	137
	LSD (0.05)	1134	142	1136	266	535	NS[3]

[1]Standing crop averaged over burning and fertilizer treatments.
[2]Standing crop averaged over fertilizer treatments.
[3]Not significant.

standing crop of selected herbaceous species and categories of vegetation. Treatment means were compared using Fisher's-protected least significant difference (Steel and Torrie 1980).

Results and Discussion

Precipitation was below normal at 6 of 7 sites during the studies (Fig. 1). Precipitation amounts in 1987 were 18% above the long-term average at Lincoln and 6% below average at Bloomfield. Precipitation at Lincoln in 1988 and 1989 was 31 and 9% below normal, respectively. Amount of precipitation at Virginia was 38 and 27% below normal in 1988 and 1989, respectively. The precipitation deficit at Lincoln and Virginia in 1988 and 1989 became more pronounced as the growing season progressed.

Fertilization increased ($P<0.01$) warm-season grass standing crop in all prairie environments evaluated (Table 2). Burning combined with fertilization increased standing crop of warm-season grasses by 50 to 127% in 5 of the 7 tallgrass prairie environments as compared to standing crop from unburned and unfertilized areas (Tables 2 and 3). Warm-season grass standing crop on burned and fertilized areas was greater than on burned or fertilized areas at both sites in 1987 and near Virginia in 1988 (Table 3). Moreover, there was a trend for a similar response at the Lincoln sites in 1988 and 1989. The observed increases in standing crop were in part due to the positive effect of burning or fertilization on big bluestem and indiangrass. Big bluestem and indiangrass standing crop were increased ($P\leq0.05$) by burning in 4 environments and by fertilization in 3 environments. These findings are consistent with studies conducted in a tallgrass prairie in Oklahoma (Graves and McMurphy 1969) and in the Kansas Flint Hills (Owensby and Smith 1979) where burning and fertilization increased warm-season grass yields. Knapp and Seastedt (1986) indicated that burning benefits tallgrass prairie by removing plant biomass accumulations that can be quite large and, if allowed to remain, can stifle plant productivity. Removing this biomass enhances the light environment of the emerging plant shoots and warms the soil earlier in the spring, which increases organic matter decomposition and improves nutrient availability (Knapp 1984, Seastedt 1988). Nitrogen addition increases warm-season grass yield by overcoming any limitation in the availability of this nutrient. Seastedt (1988) determined that burned tallgrass prairies are nitrogen-limited environments because much of this nutrient is immobilized by plant roots on frequently burned sites.

The site at Virginia 1989 was the only site where warm-season grass standing crop was greater on the fertilized areas than on the burned and fertilized areas (Table 3). This resulted from the significant ($P<0.03$) contribution made by prairie and tall dropseed to the total warm-season grass standing crop on unburned and fertilized areas. The standing crop of the dropseeds was 1,308 kg ha^{-1} on unburned and fertilized areas as compared to 617 kg ha^{-1} produced on burned and fertilized areas. Difference in warm-season grass standing crop between the burned and unburned areas that were fertilized may also result from burning-induced removal of the protective mulch layer and below-average precipitation during 1988 and 1989 (Fig. 1). The combined effect of these 2 factors could have depleted the soil water available for plant growth on burned areas more rapidly than on unburned areas.

Warm-season standing crop was significantly affected ($P\leq0.05$) by the main effect of atrazine only at the Bloomfield site (Tables 2 and 4). The positive response of warm-season grasses to atrazine occurred in conjunction with suppression of the cool-season grass component of the plant community. This suppression may have contributed to improve warm-season grass standing crop by reducing competitiveness of the cool-season grasses. Waller and Schmidt (1983) determined that atrazine applied in the spring increased yield of warm-season grasses in an eastern Nebraska tallgrass prairie by suppressing smooth brome and Kentucky bluegrass. Growth enhancement caused by atrazine may also account for the 97% increase in warm-season grass standing crop where the herbicide was applied at the Bloomfield site. Sublethal doses of *s*-triazines have been found to stimulate growth of perennial grasses (Reis 1976) and improve blue grama [*Bouteloua gracilis* (H.B.K.) lag ex Steud.] drought tolerance (Hyder et al. 1976).

The warm-season grass component of the remaining 6 tallgrass prairie environments was largely unresponsive to atrazine application. The interaction of burning by atrazine influenced standing crop of warm-season grasses at the Lincoln and Virginia-H sites in 1988 (Tables 2 and 4). Warm-season grass standing crop from areas that were treated with atrazine was no different from that on burned areas. The lack of response of the Virginia site in 1989 to atrazine was unexpected since cool-season grasses comprised 22% of the plant community (Table 1). The lack of response may be due to the relatively high amount of smooth brome, Scribner's panicum, and Wilcox's panicum, which are less susceptible to atrazine than Kentucky bluegrass. The absolute dominance of warm-season grasses and minor occurrence (<10%) of cool-season grasses at the sites near Lincoln and Virginia in 1988 negated the positive effect of atrazine-induced cool-season grass suppression on warm-season grass standing crop.

Cool-season grasses were not a dominant component of the tallgrass prairies studied (Table 1). This reflected the date of plant harvest, which occurred well past the time of cool-season grass peak production and the good to excellent condition of the grasslands. Despite the small amount of standing crop, response of the cool-season grasses to the various treatments could be assessed. Kentucky bluegrass and annual bromes (*Bromus* spp.) appeared to be more susceptible to atrazine than smooth brome. Atrazine reduced ($P\leq0.05$) the standing crop of Kentucky bluegrass in 4 of the 5 environments sampled in 1988 and 1989. Annual bromes were

Table 5. Mean standing crop of forbs harvested in summer following applications of fire, fertilizer, and atrazine in the spring to grassland sites near Bloomfield, Lincoln, and Virginia, Nebraska.

		1987		1988	1989
Spring burning	Atrazine	Bloom-field[1]	Lincoln[2]	Virginia-H[1]	Lincoln[2]
	kg a.i. ha^{-1}	- - - - - - - - -	kg ha^{-1}	- - - - - - - - -	
None	0	323	298	149	391
None	2.2	44	61	48	53
Burn	0	—	756	—	198
Burn	2.2	—	173	—	296
	LSD (0.05)	271	258	48	258

[1]Standing crop averaged over burning and fertilizer treatments.
[2]Standing crop averaged over fertilizer treatments.

common only on the Virginia-G site and were completely eliminated from the community by burning or atrazine application. In contrast, smooth brome standing crop was reduced ($P \leq 0.05$) on only 2 of 7 sites following treatment with atrazine. Waller and Schmidt (1983) observed that smooth brome was more resistant to application of atrazine in late April than Kentucky bluegrass. The native cool-season grasses, Scribner's and Wilcox's panicum, were not adversely affected by atrazine application. Standing crop of these grasses actually increased ($P<0.01$) from 151 to 287 kg ha^{-1} following atrazine application at the site near Virginia in 1989. Atrazine deactivation by carbon in the ash residue remaining after burning did not appear to influence cool-season grass response to atrazine on plots that were burned. Engle et al. (1990) found that the phytotoxic activity of atrazine on prairie threeawn (*Aristida oligantha* Michx.), declined when the herbicide was applied within 30 days after burning a tallgrass prairie in Oklahoma. They suggested that the atrazine was adsorbed by the ash and immobilized, making it unavailable for uptake by prairie threeawn.

Forb standing crop was significantly reduced by atrazine or burning followed by atrazine application in 4 of the 7 grassland environments (Table 5). Similarly, atrazine reduced forb yields on rangeland in central Texas (Petersen et al. 1983) and tallgrass prairie in central Oklahoma (Gillen et al. 1987). The lack of forb response at the remaining 3 sites in these studies was related to composition of the forb component of the prairie communities. The dominant forbs on the site near Lincoln in 1988, lead plant (*Amorpha canescens* Pursh) and silver-leaf scurfpea (*Psoralea argophylla* Pursh), appeared to be resistant to atrazine application. Houston (1977) and Gillen et al. (1987) found that a native leguminous forb, slim-leaf scurfpea (*P. tenuiflora* Pursh), was resistant to atrazine. Forb response to the atrazine was difficult to assess at the grazed sites near Virginia in 1988 and 1989 because so few forbs were present. Low forb occurrence resulted from annual applications of 2,4-D at rates of 1.1 to 2.2 kg a.i. ha^{-1} to control musk thistle (*Carduus nutans* L.) for a 6-year period before this study was started.

Management Implications

Burning combined with fertilization improved productivity of the warm-season grass component of tallgrass prairie communities in good to excellent condition. The economic feasibility of using fire and fertilization to improve tallgrass prairie productivity will be determined in part by how much additional forage a producer needs to sustain livestock during the summer. Low availability of high quality forage during the summer is typically the factor that most limits livestock enterprises in the eastern Central Great Plains since cool-season forage and crop residues for fall, spring, and winter grazing are plentiful. Alleviating this forage shortage should benefit producers in this region. Additional research is needed to determine if delaying burning to later in May would reduce soil water loss early in the growing season and further improve warm-season grass yields. Atrazine applied in the spring was generally ineffective in improving warm-season grass standing crop and adversely affected forbs in the grassland communities studied. The primary utility of atrazine application appears to be as a practice to renovate degraded prairie communities dominated by introduced cool-season grasses (Samson and Moser 1982) and not to improve the productity of tallgrass prairies in good to excellent condition.

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