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Single and Repeated Burning Effects on New Mexico Blue Grama Range

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SUMMARY

Research from 1990 to 2006 investigated prescribed fire and herbicide applications for control of broom snakeweed (*Gutierrezia sarothrae* (Pursh) Britt. & Rusby) on blue grama (*Bouteloua gracilis* [Kunth in H.B.K.] Lag. ex Griffiths) rangeland near Corona, New Mexico. From 1990 through 1993 when broom snakeweed populations averaged >2 plants/m², herbicide (picloram) treatments eliminated most broom snakeweed and increased grass yield about 42% relative to untreated areas. Prescribed fires during this period also eliminated most broom snakeweed, but grass yield did not increase relative to untreated areas. Later repeat fires conducted at intervals <5 years in length resulted in a 25% decline in grass yield relative to untreated rangeland when averaged over the entire study. Fires repeated at >6 years intervals generally did not retard grass yield except when drought conditions occurred the first growing season after burning. At the study's end, burning treatments resulted in higher bareground cover (average interspace area, 23 cm) and less linear grass cover (27%) compared to herbicide-treated and untreated areas (average 16 cm and 36.5%, respectively). This gave the visual appearance of grass cover as being relatively clumpy and less uniform on burned areas compared to a more uniform and continuous grass cover appearance on herbicide-treated and untreated experimental areas. Of the minor grass species studied, only galleta (*Pleuraphis jamesii* Torrey) seemed to benefit from frequent fire—its linear basal cover nearly doubled relative to untreated areas at the study's end. Conversely, blue grama linear basal cover was about 9% less on burned areas compared to on nonburned grasslands. Winterfat (*Krascheninnikovia lanata* (Pursh) A. D. J. Meeuse & Smit) populations were sustained after most single fires, but repeated burns at <5 year intervals reduced this shrub's abundance and cover. Our study agrees with others that have shown an increase in grass yield following removal of snakeweed with herbicide spraying. However, we did not note a similar beneficial increase in grass yield after burning. Use of prescribed fire on blue grama range in central New Mexico should be viewed as a control alternative for removing broom snakeweed, but not as management practice for increasing forage production.

INTRODUCTION

In New Mexico, blue-grama–dominated grasslands are often referred to as shortgrass prairie (Allred, 1996), short-grass-steppe (Lauenroth and Mitchunas, 1992), plains-mesa grassland (Dick-Peddie et al., 1993) or simply, blue grama range (Pieper et al., 1971). In this region, blue grama is widespread across many plant communities and in certain areas comprises >90% of the grass composition (Donart, 1989). Blue grama's ability to withstand grazing and survive drought, along with its widespread distribution, makes it one of the most important forage species on the prairies east of the Rocky Mountains in the United States.

Broom snakeweed sometimes encroaches to undesirable levels on blue grama range, but the shrub can be controlled by herbicide spraying or prescribed fire (Gesink et al., 1973; Pieper et al., 1973; McDaniel et al., 2000). During the mid-1980s, broom snakeweed was exceptionally common on blue grama range in

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central and eastern New Mexico, and nearly 600,000 ha were commercially sprayed by fixed-wing aircraft in an effort to reduce the shrub's impact on forage growth (unpublished survey records, Williams, 1990; Townsend, 1995). During this same time, prescribed fire was employed, although to a much lesser extent than aerial spraying (McDaniel and Ross, 2002). Prescribed fire was not widely adopted, in part, because guidelines for burning and effects on blue grama range in New Mexico were poorly understood.

Considerable information has been accumulated about fire behavior and vegetation response on blue grama range (Wright and Bailey, 1982; White and Loftin, 2000; White et al., 2006). Determining effects from seasonal fires on blue grama is often confounded by localized environmental variables such as weather conditions, fuel type, soils and fire frequency. Jameson (1962) reported lethal temperatures for blue grama varied seasonally from a low of 16°C in June to 22°C in December. Trlica and Schuster (1969) reported that although herbage yields were less with spring and fall burning than on unburned areas, blue grama vigor was enhanced with spring fires. In mixed prairie of southern Nebraska, Schacht and Stubbendick (1985) reported late spring fires in April reduced basal cover and herbage yields of cool season species and favored the warm-season component of blue grama and buffalograss (*Buchloe dactyloides* [Nutt.] Englelm). Environmental conditions during burning events directly affect fire behavior and intensity, which influences its ability to remove woody plants (Wright and Bailey, 1982). Rasmussen and Wright (1988) offered a basic prescription for conducting fires on areas with low-volatile fuels and undesirable woody plants, such as broom snakeweed on blue grama range.

This research, in part, is a continuation of a study initiated in 1990 to develop burning guidelines for broom snakeweed control on blue grama range in New Mexico (Hart, 1992; McDaniel et al., 1993; McDaniel et al., 1997; McDaniel et al., 2000). In this paper we examine the longer term vegetation response to various single and repeated fire events that were monitored over a 17-year period on the New Mexico State University Corona Range and Livestock Research Center. Our objective for repeating burning events was to examine how fire might be employed through time on blue grama range without causing harmful effects to species other than broom snakeweed. Herbicide treatments are compared, in part, with burning treatments in this study. In a companion paper (Torell et al., 2011), herbaceous production is more closely examined in relation to rainfall, soil moisture and other environmental conditions observed each year at the study sites.

STUDY AREAS AND METHODS

Two study sites (1 and 2)[1] were established in 1990 about 10 km apart on the Corona Range and Livestock Research Center, also known as the Corona Ranch. The ranch is operated by New Mexico State University and is approximately 22.5 km northeast of Corona, New Mexico. It encompasses 11,265 ha and lies at an elevation of about 1,900 m. The area receives on average 370 mm of annual precipitation, with about half occurring during the growing season as brief thunderstorms (Torell et al., 2008). Average annual and growing season precipitation recorded by weather stations[2] installed at each site was similar from 1990 through 2006, but yearly variation was high (Figure 1). Growing season precipitation was below average in 1990, 1993 and 1995, whereas precipitation was above or approximated the 17-year average in 1991, 1992, 1994, 1996, 1997 and 1998. Drought conditions were pronounced from late 1999 through 2003, as growing season precipitation was from 2% to 52% below average. In 2004, growing season rainfall was 37% above average and brought short-term relief from the drought. In 2005, growing season rainfall was about 25% below the study average, although winter precipitation was 271% above average. In contrast, 2006 growing season rainfall was well above average, whereas winter precipitation was nearly absent.

In addition to recording precipitation, the weather stations supported with CR-10 multi-port data loggers[2] collected hourly air temperature, soil temperature at 10 cm and 50 cm beneath the soil surface, wind speed and direction, and relative humidity data. In 2001, time domain reflectometer (TDR) soil moisture probes (CS 616-L)[2] were installed to continuously monitor volumetric soil water. All data recorded by these weather stations, in addition to other stations on the Corona Ranch, were summarized by Torell et al. (2008).

The study sites occupied similar level topography and had uniform vegetation described by USDA-SCS (1987) as within the blue grama–western wheatgrass (*Pascopyrum smithii* [Rydb.] A. Löve) association. Blue grama was the principal grass species, and western wheatgrass was only a rare cool-season component.

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[1] Corona Ranch weather data compiled at the research sites by Torell et al. (2008) refer to site 1 and site 2 as the South House (SH) and Oil Well (OW) sites, respectively.

[2] Campbell Scientific Instruments, Inc., 815 West 1800 North, Logan, Utah USA 84321-1784.

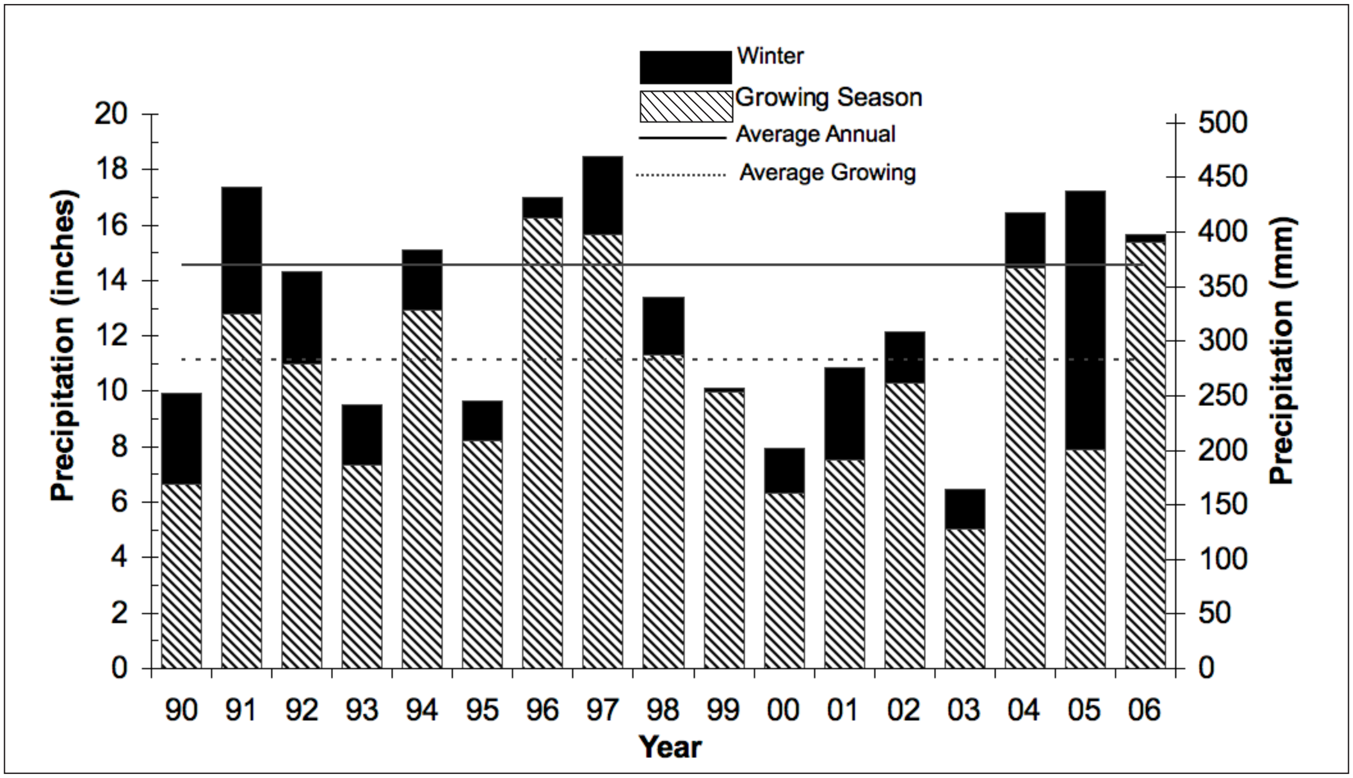


Figure 1. Average annual and growing season (April–October) rainfall recorded at the study sites (1990–2006).

Broom snakeweed was dominant when the study was initiated and was uniformly distributed across both study areas. Other minor grass species included wolftail (*Lycurus phleoides* [H.B.K.]), sand dropseed (*Sporobolus cryptandrus* [Torr.] A. Gray), squirrel tail (*Elymus longifolius* [Smith] Gould), galleta, ring muhly (*Muhlenbergia torreyi* [Kunth] A.S. Hitchcock ex Bush), and threeawns (*Aristida* spp.). Scattered cacti included cane cholla (*Cylindropuntia imbricata* [Haworth] F.M. Knuth) and plains prickly-pear (*Opuntia phaeacantha* Engelmann); shrubs included winterfat and Bigelow sage (*Artemisia bigelovii* Gray). Soils on both study sites are of the Tapia–Dean association on slopes less than 5%. The Tapia loam is a brown, medium-textured clay loam with a surface layer that is about 10 cm deep, grading into a subsoil about 50 cm to very limy caliche. The Dean loam is a light brownish gray limy loam that is not as deep as the Tapia loam. Over this 17-year study, livestock were excluded from grazing at both study sites via fencing of an 8-ha area encompassing all treatments, but there was minor herbivory from native wildlife (mostly rodents). Thus, plant growth was largely influenced by soil moisture and other environmental conditions. Prior to this study, both sites were grazed at a moderate to heavy rate with an unknown history by cattle and sheep.

TREATMENTS

Treatments previously described by McDaniel et al. (1997; 2000), along with burns conducted in subsequent years, were examined to evaluate broom snakeweed control and vegetation response. A completely randomized design with treatments replicated 3 times on 20-by-26.5-m plots (~0.05 ha) was installed at each site. Treatments were broken into four categories: single burns; repeated (multiple) burns; herbicide sprays; and untreated (or controls). General descriptions of weather, fuel, and fire conditions when burns were conducted in 1990, 1991, 1993, 1996, 1998, and 2003 are given in Table 1.

Burning treatments in 1990 and 1991 were conducted in spring (March–April) and early summer (June), but in this paper only results from spring fires are presented. Partly because of damage observed to blue grama with summer fires (McDaniel et al., 1997), further burning in 1993, 1996, 1998 and 2003 was only conducted in the spring. During every burning event, fire characteristics and detailed environmental measurements, described by McDaniel et al. (1997), were monitored and recorded using a CR-10 data logger and SM-192 storage module[2]. Before each burn, five thermocouples were secured 10 cm above the soil surface on metal stakes in an arranged sequence across plots designated for treatment (Hart, 1992). During burning

Table 1. Summary of Weather, Fuel, and Fire Characterization During Spring (March–April) Burning on Blue Grama Grassland on the New Mexico State University Corona Research Ranch

	1990	1991	1993	1996	1998	2003[1]
Air temperature (°C)	4–24	6–25	18–25	19–23	17–24	16–18
Soil temperature (°C)	4–23	6–18	11–20	13–15	7–9	8–10
Soil moisture (%)	7–11	2–11	4–10	7–9	8–15	9–12
Relative humidity (%)	19–26	13–45	12–14	13–16	12–20	8–14
Wind speed (m/s)	3–5	3–10	3–6	2–8	3–8	4–12
Fine fuel biomass (kg/ha)	176–392	386–977	500–783	326–444	710–820	260–315
Broom snakeweed biomass (kg/ha)	484–985	16–977	276–2510	10–128	10–22	0–12
Fine fuel moisture (%)	5–16	27–32	4–10	6–9	8–10	17–30
Avg. max. fire temp. (°C)	-	250	420	362	291	232
Average duration of fire heat (s)	-	37	55	48	46	0–36
Number of completed burns	6	25	6	3	6	6

[1] 2003 average values are computed only from 6 of 12 attempted burns that were successful in experimental plots.

events, thermocouples relayed monitored temperature data to the SM-192 storage module for downloading to a laptop computer. Average maximum fire temperatures and average duration of heat recorded during burning events are given in Table 1. All burns were conducted as head fires using a handheld drip torch with a 1:1 gasoline:diesel mixture for ignition. Prior to burning, a bare soil fire break approximately 10 m wide was graded around each plot. Wind speeds during fires varied but averaged about 5.5 m/sec, and maximum wind speeds never exceeded 10 m/sec. Fuel and soil moisture measurements were taken immediately before every burn. Our goal in 1993, 1996, 1998 and 2003 was to conduct burning treatments under a prescription developed, in part, from 1990 and 1991 fires (Hart, 1992; McDaniel et al., 1997). Prescription guidelines included wind speed of 2–8 m/sec; air temperature of 18–28°C; relative humidity of 10–20%; fine fuel moisture <15%; soil moisture of 3–10%; and soil temperature <18°C. Strict adherence to this prescription was at times impractical, and some experimental plots were burned outside of specified ranges.

Herbicide treatments consisted of a single foliar application of picloram (4-amino-3,5,6-trichloro-2-pyridinecarboxylic acid) mixed in an aqueous solution. Herbicide plots were sprayed with picloram at a rate of 0.28 kg a.e./ha in March 1990 using a trailer-mounted spray rig with a 6.7-m boom delivering 140 liters/ha total volume (Hart, 1992). March 1991 herbicide treatments were applied at the same rate, using a hand-held CO_2 pressurized sprayer as a source for product expulsion.

FIELD SAMPLING

Plant yield data were collected from all experimental plots near the end of every growing season from 1990 through 2006. Standing crop estimates were made in ten 31.5-by-61-cm sample subplots that were permanently staked and placed along two transects within each plot. To allow repeated annual data collection within permanent subplots, a nondestructive double sampling procedure was employed (Bonham and Ahmed, 1989). Ocular estimates of in-field plant weight in grams were made within each subplot separately for grass, snakeweed, and forbs. To determine moisture content and to verify yield estimates, a subplot was periodically clipped randomly next to the permanent subplot. Grass, snakeweed, and forb weight was estimated before clipping to a 2.5-cm height, and then the material was bagged and weighed separately in the field using hand-held scales. Weight estimates were later compared by regression to clipped data and adjusted when necessary following Bonham and Ahmed (1989). A moisture correction factor was derived by oven drying and reweighing clipped samples in the lab. Estimated weights were later corrected to a dry weight basis using the moisture correction factor.

Grass, forbs, broom snakeweed, litter, and bare ground cover were estimated in the permanent subplots as a proportion of 100% surface cover (Bonham and Ahmed, 1989). Estimates were made in July 1990, 1991, 1992, 1993, 1995, 1996, 2002, 2004, and 2005. Further, percent cover by grass species was estimated to determine species composition. The sampling technique considered only plants that were rooted within a subplot. In this paper, cover data is presented only for the following selected treatments: control, herbicide (sprayed in 1991), 1-burn (burned in spring 1991), and 5-burn (burned repeatedly in spring 1991, 1993, 1996, 1998, and 2003).

In August 2004 and 2005, linear basal grass and inter-space cover data were acquired using a modified version of the gap intercept method described by Herrick et al. (2002). Measurements were made only in the control, herbicide, 1-burn and 5-burn treatments (Ebel, 2006). Three 1-m subsections, starting at 5-, 10-, and 15-m marks, were sampled along five evenly spaced 20-m intercept lines located east and west across each treatment plot. Gaps between grass clumps at least 3 cm in length were considered interspace areas. This sampling procedure resulted in fifteen 1-m subsections per experimental plot. Winterfat density was determined by counting plants in a 1-by-20-m belt along these same transects and measuring plant intercept cover along a 20-m line placed at the center of each belt.

STATISTICAL ANALYSIS

Grass and snakeweed (kg/ha) yield data collected annually throughout the study (17 years) was analyzed using the MIXED procedure of SAS version 9.1 (Littell et al., 1996) Data were included in a repeated measures analysis with site, treatment, year and all interactions as fixed effects. Correlation among repeated measures taken off the same plot were taken into account with year as the repeated measure using the "unstructured" (type=UN) covariance structure. In addition to modeling covariance or correlation, this structure accounted for variability among years. Treatment mean separations ($P < 0.05$) were performed by year. Snakeweed was nearly absent in 2003 and 2006, and the mixed model incorporating all years' data would not converge. Thus, data from these years are only summarized descriptively. Foliar (surface) cover (% cover) data for all species and cover categories except squirrel tail were also analyzed using the MIXED procedure with the "unstructured" covariance structure (site and treatment as fixed effects and year as the repeated factor in a repeated measures analysis). Foliar cover of squirrel tail was analyzed in the same manner using the SP (POW) covariance structure. Treatment mean separations for foliar cover were considered significant at $P < 0.05$.

Winterfat density (plants/m^2) determined from belt transects was analyzed using GLM and MIXED procedures in SAS software. Each year of data was first analyzed separately and then together with a fixed effects model using GLM, but because there was no significant year or site effect, data were combined. The MIXED procedure was used to analyze all data with **year**, **treatment** and their interaction as fixed effects and **plot** (the experimental unit) as the random effect. Treatment means were declared significantly different at $P < 0.05$.

The MIXED procedure of SAS was used to assess grass clump–interspace (linear basal cover) data that was not different by year or site to determine treatment effects. Dependent variables included: size of grass clumps (cm), number of grass clumps (no./m), size of interspaces (cm), number of interspaces (no./m), and total grass or interspace linear cover (cm/m). The model included as fixed effects **site**, **treatment**, **year** and **all interactions**, with plot as the random effect. Treatment means separation was at $P < 0.05$.

RESULTS

Plant Response Within Untreated and Herbicide-Sprayed Areas

Over the 17-year study, native fauna (rabbits, deer, rodents etc.) had access to our two fenced study sites, but livestock were excluded from grazing. Thus, plant growth was influenced to a minor extent by small herbivore grazing, but more importantly grass yield and cover were affected by soil moisture and other environmental conditions. Annual grass yield in untreated areas was particularly sensitive to precipitation received and ranged from <200 kg/ha under drought conditions (i.e., in 2000) to >1,400 kg/ha under favorable growing season rainfall (i.e., in 1996–1998) (Figure 1, Table 2). Grass yield in untreated areas was not different ($P < 0.05$) among the two study sites and from 1990 through 1995 averaged about 425 kg/ha. From 1996 through 1998 when growing season precipitation was near or above the long-term normal, grass yield in untreated areas increased and averaged about 950 kg/ha. Under summer rainfall conditions that were well below normal from late 1999 through 2003, grass yield fell sharply and averaged about 320 kg/ha. In 2005 and 2006 rainfall was again favorable and grass yield on untreated areas increased to about 900 kg/ha. Grass yield on herbicide treatments was significantly higher ($P < 0.05$), irrespective of site, than untreated areas in six of the first seven years of the study (Table 2). During this period (1990 to 1996), grass yield on herbicide plots averaged 722 kg/ha compared to 424 kg/ha on untreated areas.

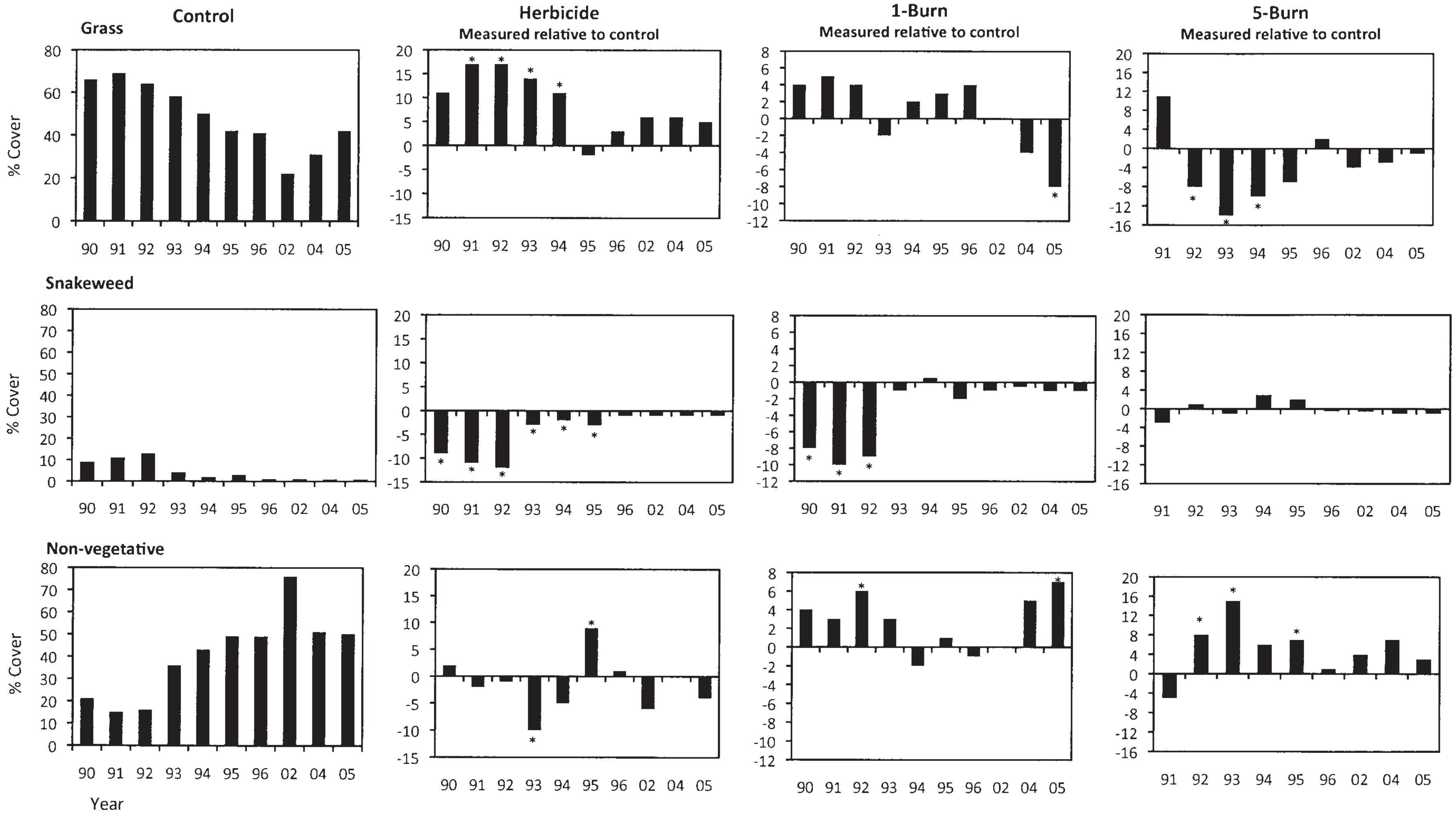
Foliar grass cover on untreated areas declined from 66% to 41% from 1990 to 1996 and further diminished under drought conditions to about 22% when sampled in 2002 (Figure 2). Moisture received in 2005–2006 increased grass cover to about 42% at the study's end. Blue grama comprised >95% of the total grass cover in untreated and herbicide-treated experimental plots throughout the study. Minor grass cover (grasses other than blue grama) averaged about 3.8% on untreated areas from 1990 through 1996, and 3.2% from 2002 through 2005 (data not shown). Foliar grass cover was higher on herbicide treatments than untreated areas from 1991 through 1994 but thereafter was not different (Table 3). Blue grama cover was 11% higher the first year, and about 17% higher the second and third years on herbicide treatments relative to untreated rangeland. Conversely, forb cover was reduced ($P < 0.05$) on herbicide treatments from 1991 through 1994. Litter and bare ground cover varied from year to year but were always the same on herbicide and untreated areas.

Table 2. Grass and Snakeweed Yield (kg/ha) Within Treatments from 1990 Through 2006 on the NMSU Corona Research Ranch

TREATMENT	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Grass:									(kg/ha)								
Untreated	387 b	304 cd	634 c	437 de	329 abc	394 bc	835 bcd	917 ab	1127 ab	724 ab	150 b	221 ab	459 bc	378 abc	796 ab	905 abcd	974ab
Herbicide																	
1990	633 a	509 a	1161 a	890 a	421 a	715 a	1020 a	987 a	1487 a	1015 a	278 a	312 a	674 a	423 a	992 a	944 abc	1142ab
1991	-	385 b	904 b	590 b	312 bc	500 b	820 bc	805 bc	1279 bc	752 bc	159 bc	218 bcd	412 bcd	352 ab	708 bcd	771 cdef	1093ab
Single burns																	
1990	389 b	364 bc	777 bc	494 cd	393 ab	504 b	824 bc	901 abc	1285 bc	838 ab	169 bc	206 bcde	485 bc	391 a	759 bcd	754 def	864b
1991	-	292 d	682 c	485 cd	396 ab	484 b	780 bcd	823 abc	1287 bc	691 bcd	123 cd	187 bcde	466 bc	315 abc	820 abc	904 abcd	1000ab
1993	-	—	—	310 f	287 c	359 cd	888 ab	877 abc	1267 bc	638 bcd	138 bcd	179 cdef	474 bc	—	—	—	
1996	-	-	—	—	—	—	716 cd	739 c	1328 abc	661 bcd	173 bc	152 def	434 bcd	260 bc	753 bcd	969 ab	1096ab
2003	-	-	—	—	—	—	—	—	—	—	—	—	—	242 bc	493 e	608 f	1097ab
Repeat burns																	
91, 98	-	312 cd	675 c	493 cd	354 abc	421 bcd	828 bc	785 bc	910 d	552 cd	87 d	130 ef	300 d	251 bc	579 de	709 ef	1034ab
93, 03	—	—	—	—	—	—	—	—	—	—	—	—	—	233 c	852 ab	1015 a	1265ab
91, 96, 03	-	334 bcd	691 c	521 bc	375 abc	463 b	627 d	805 bc	1208 c	696 bcd	157 bc	171 cdef	496 bc	256 bc	660 bcde	893 abcd	1091ab
91, 93, 96, 98, 03	-	324 bcd	663 c	382 ef	287 c	326 d	774 bcd	792 bc	818 d	452 d	78 d	109 f	359 cd	203 c	620 cde	694 ef	1006ab
SE*	21	25	60	34	36	36	55	61	65	87	23	27	53	40	73	61	46
Snakeweed:									(kg/ha)								
Untreated	411 a	465 a	446 a	427 a	163 b	145 bc	50 ab	18 b	71 ab	297 abc	149 ab	289 a	8 b	18	0 b	70 abc	0
Herbicide																	
1990	0 b	0 d	0 b	0 c	0 b	0 c	0 b	13 abc	0 b	51 abc	55 ab	65 a	24 ab	0	12 b	16 c	7
1991	-	33 cd	84 b	96 ab	47 b	73 bc	21 b	12 abc	66 ab	66 abc	41 ab	198 a	2 b	0	23 b	81 abc	0
Single burns																	
1990	18 b	31 cd	117 b	148 ab	69 b	18 bc	0 b	23 ab	50 ab	2 c	24 b	171 a	12 b	0	14 b	37 c	0
1991	-	94 cd	140 b	140 abc	68 b	163 b	21 b	19 ab	125 a	135 abc	33 ab	182 a	6 b	11	24 b	32 c	0
1993	-	—	—	61 bc	59 b	133 bc	51 ab	28 ab	43 ab	195 a	93 ab	238 a	9 b	—	—	—	
1996	-	—	—	—	—	—	0 c	1 b	26 ab	160 abc	78 ab	117 a	5 b	28	5 b	20 c	
2003	-	—	—	—	—	—	—	—	—	—	—	—	—	6	18 b	176 ab	4
Repeat burns																	
91, 98	-	99 cd	182 b	232 a	102 ab	171 b	77 a	22 abc	4 b	24 bc	25 b	67 a	8 b	11	79 a	210 a	26
93, 03	-	—	—	—	—	—	—	—	—	—	—	—	—	13	0 b	41 c	0
91, 96, 03	-	162 c	122 b	100 abc	92 b	27 bc	0 b	39 ab	0 b	16 bc	9 b	29 a	0 b	6	18 b	45 bc	0
91, 93, 96, 98, 03	-	308 b	517 a	134 abc	227 a	443 a	11 b	2 b	10 b	55 bc	73 ab	150 a	59 a	0	0 b	39 c	0
SE*	51	51	87	51	46	56	18	13	37	58	37	89	16	-	16	47	-

Grass or snakeweed means in the same column followed by the same letter are not significantly different at P = 0.05.

*SE are model based standard errors.



Note: * above or below bars indicate that herbicide, 1-burn, and 5-burn means are different from the control at α = 0.05 level.

Figure 2. **Grass, snakeweed, and non-vegetative aerial cover for control and treated plots with treatments measured as difference from control.**

Snakeweed cover on untreated areas was not different among sites ($P < 0.05$) and averaged about 11% the first three years of the study. However, through natural mortality, snakeweed cover declined to <4% from 1993 to 1995, and further declined to <1% for the remainder of the study (Figure 2). Similarly, while snakeweed yield on untreated areas averaged about 440 kg/ha from 1990 through 1992, it sharply declined by about 50% in 1993. There was only minor recruitment of new plants in the years that followed, and snakeweed yield on untreated areas remained <150 kg/ha for the remainder of the study (Table 2). There was a similar decline in the snakeweed population across the Corona Ranch, as well as a wider regional decline on rangelands throughout central New Mexico (McDaniel and Ross, 2002).

Herbicide spraying in 1990 completely eliminated snakeweed from all experimental plots, and its yield was significantly ($P < 0.05$) less than on untreated areas the first 4 years of the study (Table 2). Spraying in 1991 resulted in about 80% snakeweed mortality, and yield was less than on untreated area for 2 years after the herbicide application. After 1993 there was no difference in snakeweed yield among sprayed and nonsprayed treatments. Winterfat density and cover were not different on herbicide- and untreated areas at either study site throughout the study (data not shown).

Plant Response to Initial or Single Burns

Initial burns carried out in 1990 and 1991 resulted in about 65% snakeweed mortality (McDaniel et al., 1997) and significantly reduced its yield and cover from 80 to 100% relative to on untreated areas (Table 2 and Figure 2). Burning in 1993 and 1996 also eliminated most snakeweed the first season. However, because the population naturally declined, snakeweed yield and cover in later years on burned areas was only moderately different from on untreated areas. Similarly, burns in 1998 and 2003 had few live snakeweed plants on plots that were burned, thus fire effects on the shrub were inconclusive. Winterfat cover was slightly reduced immediately after initial burns, but no significant long-lasting difference in cover compared to untreated areas was noted after any burning year.

After single spring fires, grass cover was always similar among burned and untreated experimental plots by the end of the first growing season, irrespective of year burned (Figure 2). Similarly, grass yield after 1990 and 1991 spring burn treatments was not different from on untreated rangeland the first season or when averaged over the entire study period (i.e., from 1990 through 2006 the average grass yield was 601, versus 594 kg/ha on burned and untreated rangeland, respectively) (Table 2). Grass yield was reduced the first season after the 1993 spring burn but was not different from untreated areas in later years. In experimental plots initially burned in 1996, grass yield was not different the first season but was reduced the second year. Similarly, grass yield was not different the first season after the 2003 spring burn but was reduced the second and third seasons compared to untreated areas.

Plant Response to Repeated Burns

While initial fires in 1990, 1991 and 1993 provided reductions in snakeweed yield, later fires on the same plots did not encounter enough snakeweed to allow evaluation of the merits of further reducing shrubs or new plants via repeated burning (Table 2). This was an important objective of our study, and further research is needed to determine if repeat burning is a reasonable approach for maintaining blue grama range free from snakeweed.

Grass yield on experimental plots initially burned in 1991 and later burned in either 1993, 1996, 1998 or 2003 did not increase relative to untreated areas. Grass yield was less the first season after second burns in 1993 and 1996 compared to on untreated areas, but generally was not affected in later years (Table 2). Plots burned first in 1991 and again in 1998 resulted in a significant decline in grass yield in 7 of the next 9 years. Grass growth was especially retarded during the 1998 growing season, as no precipitation was received on the study sites for 72 d after late March burning dates, and <50 mm was received until late July. In addition, average daily air temperatures in May and June were the highest recorded during this study (Torell et. al., 2008). This combination of dry soils and high air temperatures immediately after 1998 fires particularly damaged blue grama growth and vigor (data not shown). From late July through September, precipitation was above normal, but blue grama growth remained retarded through the remainder of the 1998 growing season. Similarly, grass yield in the 5-burn treatment was generally not affected after the first 3 repeat fires (1991, 1993, 1996), but was reduced substantially in years after 1998 fires (Table 2).

The most pronounced decline in grass cover in the 5-burn treatment relative to untreated areas was during the first growing season after the second fire in 1993 (Figure 2). There was not, however, a further cover decline following subsequent burns in 1996, 1998 and 2003. Conversely, non-vegetative cover increased about 10% after fires in 1993 relative to untreated areas. By the study's end, galleta foliar cover was slightly (about 2%) higher than in untreated areas, but squirrel tail and three-awn cover were not noticeably different with frequent burning. Winterfat was common on Site 1, and by the study's end its density and cover was less in the 5-burn treatment (0.31 plants/m^2; 0.9% cover) than in untreated areas (1.39 plants/m^2; 4.5% cover). No difference in winterfat cover was noted at Site 2 between treatments, but the shrub was much less common here than at Site 1.

Table 3. Average Number, Size and Linear Cover of Grass and Interspace Areas Within Selected Treatments on the NMSU Corona Research Ranch

	Control[1]	Herbicide	1-Burn	5-Burn
Linear Cover (%)				
Blue grama	34.3	33.0	23.9	24.7
Squirreltail	1.8	3.0	1.9	1.2
Galleta	0.2	0.1	0.1	2.2
Threeawn	0.2	0.3	0.2	0.4
Total grass	36.7a	36.4a	26.1b	28.6b
Interspace	62.5b	63.4b	72.9a	69.9a
Number (no./m)				
Blue grama	3.5	3.7	3.8	2.7
Squirreltail	0.4	0.4	0.5	0.3
Galleta	0.1	0.1	0.1	0.4
Threeawn	0.1	0.1	0.1	0.1
Total grass	3.8a	4.1a	3.2b	3.3b
Interspace	3.9a	4.1a	3.4b	3.4b
Size (cm)				
Blue grama	9.9	9.2	8.7	9.2
Squirreltail	6.0	7.9	4.6	5.0
Galleta	8.0	4.5	5.0	7.4
Threeawn	9.3	9.0	4.6	7.3
Total grass	9.6a	9.0a	8.2a	8.6a
Interspace	16.8b	15.5b	22.5a	23.1a

[1] Data collected along five 20-m linear tape transects placed parallel and 10 m apart in each experimental plot. Data is averaged across sites and collection years (2004 and 2005). Total grass and interspace means in the same row followed by the same letter are not significantly different at P = 0.05.

Grassland Canopy Fragmentation Following Treatments

When measurements related to grass patchiness were taken (2004 and 2005) on herbicide-treated and untreated plots, the number and size of grass clumps was nearly the same (Table 3). To the casual observer, an examination of these experimental plots gave a visually similar appearance, with grass growth that appeared uniform and continuous. This similarity was further supported by linear basal grass and interspace cover data that was nearly identical on these two treatments. In contrast, 1-burned and 5-burned plots visually gave a non-uniform or clumpy grass growth appearance (Figure 3). Linear basal cover was not different on 1-burn or 5-burn treatments, but these experimental plots had less grass and more interspace cover than herbicide and untreated areas. Interspace gaps on burned areas were about 30% greater, and the number of grass clumps about 18% lower than on untreated rangeland. Blue grama comprised about 90% of total linear basal grass cover and, as expected, was less on 1-burn and 5-burn treatments compared to on herbicide-treated and untreated areas. Linear basal cover of minor grasses was sparse; however, galleta cover was about 2% higher on 5-burn plots than on plots with other treatments.

***Figure 3.* Visual appearance of a 5-burn plot (top) and herbicide treated rangeland (bottom) on the NMSU Corona Research Ranch, NM.** Photo taken May 2007.

DISCUSSION AND MANAGEMENT IMPLICATIONS

Burning and herbicide treatments applied during this study were designed to investigate their effectiveness for reducing broom snakeweed on blue grama range (McDaniel et al. [1997; 2000]). Plant response to these treatments was overwhelmingly influenced by the pervasive dominance of blue grama and to a lesser extent the presence or absence of broom snakeweed. Though the role of minor grass species on our study area seemed much less important than the roles of blue grama and snakeweed, herbicide and burning effects on their individual status should be further studied.

Research on burning blue grama range for broom snakeweed control is limited, and mortality is usually reported as a secondary result. The earliest literature we found pertaining to burning broom snakeweed was by Wooton (1916), who observed that the shrub was easily killed by fire. Humphrey and Everson (1951) described an "extremely hot" controlled fire conducted in June in Arizona as killing more than 95% of snakeweed. Wright (1980) classified broom snakeweed as "not tolerant" of fire and easily killed, with a recovery time of 5 to 10 years depending on winter–spring precipitation. Dwyer (1969) conducted prescribed fires on blue grama range in central New Mexico and reported broom snakeweed to increase by 25% after January fires, while plant density was reduced by 35, 45, and 96% after October, April and June fires, respectively. Dwyer reported blue grama yield as 9, 11, 16, and 56% higher on plots burned during October, January, June and April, respectively, compared to untreated rangeland.

Rainfall received and other environmental factors often dictate whether or not the use of prescribed fire is practical or even possible in a given year. During this study, an insufficient quantity of fine fuel during dry periods, and unsuitable weather conditions during planned burning periods were found to be substantial obstacles to implementing fires at predetermined intervals. Many planned burns were rescheduled numerous times because of unsuitable environmental or plant growing conditions. To illustrate, in 1991 several experimental plots with dense broom snakeweed burned unevenly or simply would not burn except under high wind and high air-temperature conditions (Hart, 1992). In contrast, in 2003 we burned under drought conditions, and the pre-burn fine-fuel source was non-uniform and near or less than 300 kg/ha. Nearly half of the 12 experimental plots that were scheduled for burning in 2003 only weakly carried the fire or would not burn. In many ways, the resulting fires under drought conditions were similar to those which occur in a dense stand of broom snakeweed, because of low fine-fuel availability.

Early in this study it was anticipated that herbicide and burning treatments would eliminate most mature broom snakeweed plants and that in later years under favorable environmental conditions new plants would propagate and reoccupy the area. This would give the opportunity to evaluate the advantages of a follow-up treatment. We were especially interested in examining if fire could be used to eliminate new invading seedlings as a tool for maintaining blue grama grassland. However, broom snakeweed never reoccupied our study areas at levels comparable to when the study began in 1990. Thus, while we had planned to examine the merits of integrating treatments over time (i.e., herbicide spraying followed later by control of snakeweed seedlings with fire) our study did not accomplish this objective.

Repeating prescribed fires at any interval on blue grama range involves risk related to weather before, during and especially after the burn (McDaniel et al. 1997). Data from our study suggest that trying to define an optimal fixed repeat burning schedule on blue grama grassland is probably futile at best. In general, repeat spring burns we conducted did not markedly retard or enhance grass growth. An exception was after fires conducted in 1998, where blue grama in particular failed to recover for nearly 9 years compared to on non-burned areas. What exacerbated this situation was that growing season drought conditions were severe the first 4 months after burning in 1998. Regional drought generally prevailed for the next 5 years.

The choice of which method (herbicide or fire) to employ for managing broom snakeweed on blue grama range should be based, in part, on the degree to which broom snakeweed occupies the area (McDaniel and Ross 2002). Herbicide treatment is more suitable than burning when the shrub is densely populated because a continuous fine-fuel source is mostly lacking beneath and precludes the fire option. Burning is a viable option only when there is a sufficient continuous fine-fuel source available to carry the fire.

Our study agrees with others that have shown an increase in grass yield following removal of snakeweed with herbicide spraying (McDaniel and Duncan, 1987). However, we did not find a similar beneficial increase in grass yield after burning. This may partially be explained through an understanding of the overstory–understory dynamics of snakeweed growing on blue grama range (McDaniel et al., 1993). As described further in McDaniel and Ross (2002), fire should be viewed as a control alternative for removing broom snakeweed, but not as a management practice for increasing forage production on blue grama range in central New Mexico.

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