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Broom snakeweed establishment following fire and herbicide treatments

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Abstract

Broom snakeweed (*Gutierrezia sarothrae* [Pursh] Britt & Rusby) propagation was monitored from 1990 through 1998 following burning and herbicide control practices conducted on blue grama (*Bouteloua gracilis* [H. B. K. Lag.]) grasslands near Corona, N.M. Broom snakeweed usually germinated in April, May, or June (83% of 394 total) and mostly in 1991 and 1992 (81% of total) when spring moisture was sufficient. The majority of broom snakeweed seedlings (52% of total) emerged the first or second year after summer burning, especially in areas where grass yield and cover declined and bare ground exposure increased as a result of intense fires. Spring fires caused less damage to blue grama than summer fires, and the number of broom snakeweed seedlings produced (18% of total) was similar to non-treated rangeland (22% of total), but lower than numbers on areas burned in the summer. Grass yield and cover increased within a year of herbicide spraying and treated plots had significantly ($P < 0.05$) fewer broom snakeweed seedlings (8% of total) than burned and non-treated areas.

Key Words: Shortgrass prairie, germination, emergence, prescribed burning, picloram

Resumen

De 1990 a 1998 se monitoreo la propagación "Broom snakeweed" (*Gutierrezia sarothrae* [Pursh] Britt & Rusby) después de aplicar quema y herbicidas como practicas de control en un pastizal de "Blue grama" (*Bouteloua gracilis* [H.B.K. Lag]) situado cerca de Corona, N.M. El "Broom snakeweed" usualmente germino en Abril, Mayo o Junio (83% de un total de 394), principalmente en 1991 y 1992 (81% del total) cuando la humedad en primavera fue suficiente. La mayoría de las plántulas de "Broom sankeweed" (52% del total) emergieron el primero o segundo año después de la quema de verano, especialmente en áreas donde el rendimiento y cobertura del zacate disminuyeron y la cantidad de suelo desnudo aumento como resultado de fuegos intensos. Los fuegos de primavera causaron menos daño al "Blue grama" que los fuegos de verano, y el número de plántulas producidas de "Broom sankeweed" (18% del total) fue similar al del pastizal no tratado (22% del total), pero menor que las producidas en otras áreas quemadas en verano. El rendimiento y cobertura del zacate se incrementaron dentro del año en que se asperjo el herbicida y las parcelas tratadas tuvieron significativamente ($P < 0.05$) menos plántulas de "Broom snakeweed" que las áreas quemadas y las no tratadas.

The historical burning frequency on New Mexico's blue grama grasslands is unknown but Wright and Bailey (1982) speculate wildfires to have periodically occurred during periods of drought and probably at 15 to 25 year intervals. Today, wildfires on these shortgrass rangelands are usually started by accident (railroad box fires, downed power lines, etc.) rather than by natural causes (McDaniel et al. 1989). Prescribed burns are uncommon but occasionally landowners will conduct planned fires to remove broom snakeweed and other undesirable weeds and brush.

When burning blue grama grasslands, the majority of mature broom snakeweed can be eliminated provided fuel and weather conditions are suitable to produce heat of sufficient intensity to destroy the entire canopy (McDaniel et al. 1997). Extremely hot fires, however, often damage blue grama and other perennial plants, thereby creating micro-sites potentially favorable for establishment of low seral species, including broom snakeweed. Establishment of broom snakeweed seedlings shortly after burning can negate the economic benefits that are expected to accrue from prescribed fire (Torell et al.1989).

Research investigating broom snakeweed germination (Kruse 1970, Mayeux and Leotta 1981, Mayeux 1983), dispersal (Wood et al. 1997), and seed bank storage (Osman and Pieper 1988) have provided insight into how this species establishes on southwestern U.S. rangelands. Other research has focused on seedling survival (Nadabo et al. 1980), longevity (McDaniel 1989), and population dynamics (Torell et al. 1992). Broom snakeweed control by herbicides and the subsequent establishment of herbage and broom snakeweed has been reported in a number of studies (McDaniel and Duncan 1987, McDaniel 1989). In this study we examine some of the circumstances under which broom snakeweed is likely to establish after prescribed fire relative to herbicide spraying or no treatment. We specifically addressed the following 3 questions concerning broom snakeweed establishment on blue grama grasslands: (1) Under what conditions is seedling emergence most likely to occur? (2) What fire characteristics are likely to produce micro-sites favorable for seed germination? and (3) Can prescribe fires be conducted in ways to minimize broom snakeweed establishment?

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Materials and Methods

Description of Area

The study was conducted on the New Mexico State University Corona Ranch, about 23 km northeast of Corona, N. M. Two study sites were located about 10 km apart on blue grama dominated grasslands with level terrain and elevation near 1,870 m. Soils on both sites are comprised of the Taipa-Dean loam association, which are shallow and underlain by impervious limestone bedrock. The Taipa loam is classified as a fine-loamy, mixed, mesic, Ustollic Haplargid, and the Dean loam is a fine, carbonatic, mesic, Ustollic Caliciothid. Surface texture is a sandy loam to loam and soil depth is 0.5 m or less. Formed from piedmont deposits and derived from limestone quartzite and igneous rock, these soils are subject to wind erosion and are poorly drained, thus surface runoff is moderate to high (USDA 1970).

The NMSU Corona Ranch is characterized by a semiarid, continental climate with an average diurnal temperature range near 15°C (USDA 1970). Average daily maximum temperatures range from 6.4°C in January to 14.7°C in July. In summer, maximum daytime temperatures exceed 32° about 30 days each year. The growing season, or freeze-free season, is about 155 days a year. Average annual relative humidity is about 50%, but in late winter and early spring the daily average is about 30% and frequently falls below 15% by midday.

The primary sources of rain and snow in the region are from storms originating from the Pacific Ocean and the Gulf of Mexico. Winter precipitation is mainly snow, which averages 51 cm a year, and normally does not stay on the ground more than a few days (USDA 1970). Summer precipitation occurs mostly as intense, local, convectional thunderstorms of short duration. Mean annual precipitation averages 38 cm with about one-half this amount occurring from July to September.

Blue grama dominates the understory vegetation, but other important perennial grasses include wolftail (*Lycurus phleo - sides* [H.B.K.]), sand dropseed (*Sporobolus cryptandrus* [Torr.] A. Gray), squirreltail (*Elymus longifolius* [Smith] Gould), and three awns (*Aristida* sp.). Broadleaf herbs are relatively uncommon, with scarlet globe mallow (*Sphaeralcea coccinea* (Nutt.) Rybd.) and verbena (*Verbena bracteata* Lag. & Rodr.) most important. Winterfat (*Ceratoides lanata* [Pursh] J.T. Howell) and cholla are scattered throughout the area, but broom snakeweed dominates the over story vegetation. Mature broom snakeweed is 15 to 45 cm in height and its spatial distribution ranges from irregular dense patches to widely scattered individuals. The relative dominance of broom snakeweed in this area varies through time and may be viewed as an increaser on disturbed grasslands (Pieper and McDaniel 1989).

Fire and Herbicide Treatments

Treatments were applied to 20- by 26.5-m plots arranged in a randomized complete block with 3 replications within the 2 study enclosures. Treatments in 1990 consisted of prescribed burns on 17 March (spring) and 13–14 June (summer); a herbicide spray using picloram (4-amino 3,5,6,trichloro-2-pyridinecarboxylic acid) at 0.42 Kg ha^{-1} applied with a trailer-mounted broom sprayer (6.4-m boom) on 26 March; and untreated controls. These treatments were reapplied to adjacent plots in 1991. High winds in spring 1991 prevented us from applying treatments to both sites at the same time, so burns were conducted on 20–23 March and 25–27 June at Site 1; and 5–6 April and 7–8 July at Site 2. Herbicide sprays were applied on 11 March at Site 1 and 5 April at Site 2 using a hand held CO_2 sprayer (3.3-m boom).

Burns were started as head fires using a hand-held drip torch containing a 1:1 gasoline-diesel oil mixture. Around each plot a 6.7-m buffer was installed using a grader to remove vegetation and to create a mineral break. A detailed description of the methods used to characterize each burning event has been described elsewhere (McDaniel et al. 1997). Burns for this experiment were conducted near the prescribed environmental conditions recommended by Wright and Bailey (1982) for general burning of low-volatile fuels typical of blue grama grasslands. They suggested burning a head fire with air temperatures between 21 to 27°C, relative humidity 20 to 40%, wind speed from 3.6 to 6.5 m sec^{-1} and wind direction from the southwest. While we tried to adhere to this prescription, we rarely experienced all of the weather requirements. Thus some burns were conducted outside the recommended air temperatures or relative humidity ranges (Carroll 1994, Hart1992).

Seedling Monitoring

After treatments were applied, nine, 1-m^2 permanent subplots were arranged inside every main plot using 3 by 3 equally spaced rows to monitor broom snakeweed seedling emergence and survival. Metal spikes (10 cm) marked the corners and nylon twine defined the perimeter of each subplot. Mature broom snakeweed plants within each subplot were initially mapped in a notebook and tagged with a common colored (telephone) wire secured around the plant's base for future identification. Beginning 1 month after treatment, subplots were visited near mid-month through October 1998 to mark and map newly emerged seedlings and to census survival of previously tagged plants. New seedlings were color coded to indicate the month of emergence on the subplot diagram. Death of a seedling was similarly denoted by circling the colored mark with the corresponding month of death. Thus, individual life spans for each seedling could be determined. The proximity of each newly emerged seedling was measured in relation to the nearest live grass plant and later was grouped as emerging within grass or emerging outside grass (bare ground). Data collected within the subplots allowed us to compare broom snakeweed emergence and survival over time, and to determine seedling differences among burned, herbicide, or nontreated areas. Differences in the total seedling number produced by treatment over the various collection dates were analyzed using the GLM procedure within SAS (1984). The experimental design was a randomized complete block with site by replication by year as the error term. Means were compared by Fisher's Protected LSD test using the 5% probability level.

Influence of Burning on Seedling Emergence

In 1991, 27 fires were conducted in spring (20 March to 6 April) and 15 fires in summer (25 June to 8 July) under varying fuel load and air temperature regimes for the purpose of developing a burning prescription for maximizing broom snakeweed control with fire (McDaniel et al. 1997). Burning procedures and simple statistics related to conditions before, during, and after these fires have been discussed elsewhere (Hart 1992, McDaniel et al. 1997). The next year (August 1992) it was visibly obvious after walking across burned plots that broom snakeweed seedlings were more abundant on areas burned in summer than spring. Also, we noticed that seedling numbers were not equal among plots burned during the same season, and this offered us the opportunity to compare differences in broom snakeweed emergence after these fires.

Pre-burn vegetation measurements had been obtained in each plot using ten, 31.5 by 61 cm permanently marked quadrats (McDaniel et al. 1997). These quadrats were placed along 2 diagonal lines across each plot from corner to opposite corner. Pre-burn measurements included aerial cover, density, and yield of broom snakeweed and grass. The same vegetational information collected during pre-burn measurements was also obtained every October from 1991 through 1998. Environmental variables monitored during each burn, and reported in McDaniel et al. (1997), included air temperature, soil temperature at 10 cm, relative humidity, wind speed, and wind direction. Fire characteristics evaluated included fire temperatures measured with thermocouples and heat sensitive tablets, rate of fire spread, duration of heat, and degree seconds of heat (Hart 1992, McDaniel et al. 1997).

For purposes of this study, broom snakeweed seedlings were counted in each plot in August 1991, 1992, and 1993 using the same 10 permanent quadrats used to obtain other pre- and post-burn vegetation data. This allowed a comparison of seedling density after burning to average pre-burn, climatic, fire, and post-burn measurements in each plot. Few seedlings were counted in 1991 and 1993; thus only 1992 data are reported. Simple linear and nonlinear regression analyses, and stepwise discriminant analyses (SAS 1984), were conducted with total seedling number per plot as the dependent variable. Environmental, fire, and pre- and post-burn vegetation measurements were used as independent explanatory variables to relate seedling establishment separately and combined across burning seasons. To examine these differences, least squares regression analysis were performed to evaluate the relationship between the 1992 seedling counts and 1991 burning information. The 1991 post-burn vegetation data were used because 83% of seedlings counted in 1992 emerged during the second quarter of the year (April to June). Thus, peak emergence had taken place before the growth of warm season perennial grasses in 1992.

Results and Discussion

Seedling Emergence and Survival

During the 9-year study period (1990–1998), annual precipitation at Corona, N.M. was near or slightly above the long-term average every year except 1993 and 1995, which were 28% and 38% below normal (Fig. 1); thus moisture conditions were seemingly favorable for broom snakeweed propagation and survival. Broom snakeweed seed can potentially germinate any month (Lane 1985), but during the course of this study fewer than 2% of new seedlings were counted in the first (January–March) or fourth (October–December) quarters of the year (Table 1). About 15% of seedlings emerged in the third quarter (July–September) when rain fall is usually most abundant. Air and soil temperatures, however, are elevated in these summer months and this probably reduces germination (Fig. 1). Kruse (1979) and Mayeux (1983) reported that broom snakeweed germination ceases when growth chamber temperatures exceed about 30°C.

The majority (83%) of broom snakeweed seedlings emerged during the second quarter (April–June), irrespective of year, site, or treatment (Table 1). This period roughly coincides to when alternating air and surface soil temperatures (10 cm depth) on our study area are near a 10 to 25°C range (Fig. 1). Kruse (1979) and Mayeux (1989) reported that optimal broom snakeweed germination occurs when growth chamber temperatures range between 10 to 25°C, under an 8-hour light period. An examination of average minimum and maximum soil temperatures during the second quarter indicates this optimal range occurs in the spring for about 6 to 8 weeks (about mid April to mid June). Interestingly, soil temperatures on our study area increase gradually in spring but decline rapidly in the fall; thus the optimal temperature range is shorter in autumn (Fig. 1). This may partially explain why few seedlings were counted in the fourth

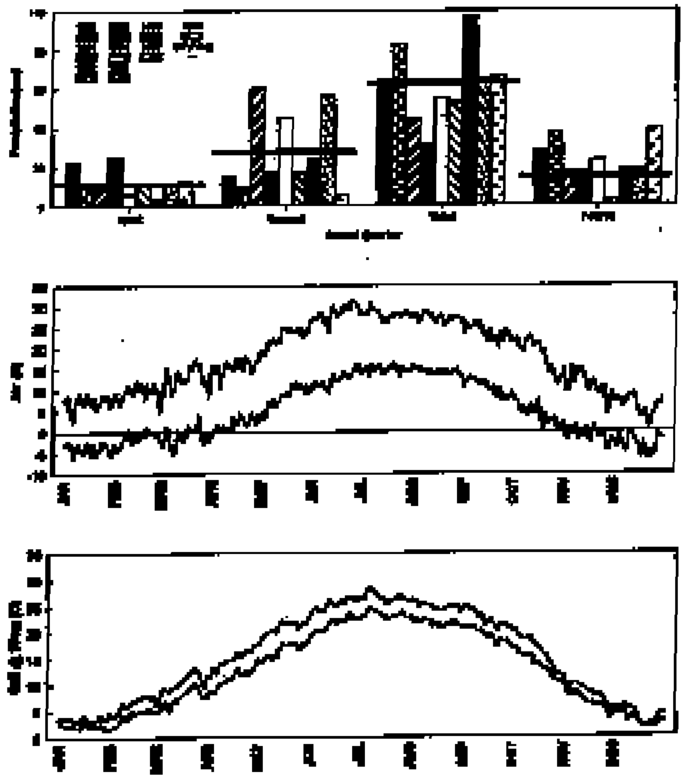

Fig. 1. Precipitation by quarters, and average minimum and maximum air and soil temperatures from 1990 to 1998 on the NMSU Corona Ranch.

Table 1. Absolute number of broom snakeweed seedlings counted, irrespective of treatment, from 2 study sites on the NMSU Corona Research Ranch. Counts were made monthly in nine, 1-m^2 subplots placed in each main plot (3 reps x 4 treatments x 3 months per quarter).

	Seedling emergence by annual quarters[1]				
Year	First	Second	Third	Fourth	Total
1990	0	3	4	0	7
1991	0	52	14	0	66
1992	2	211	34	6	253
1993	1	7	1	0	9
1994	0	17	2	0	19
1995	0	6	2	0	8
1996	0	7	0	0	7
1997	0	5	1	0	6
1998	0	18	1	0	19
Total	3	326	59	6	394

[1]First quarter, January, February, March; second, April, May, June; third, July, August, September; fourth, October, November, December

Table 2. Broom snakeweed emergence in relation to distance from individual grass plants, and seedling survival through the first growing season, irrespective of year, site, or treatment, on the NMSU Corona Research Ranch.

Distance	Seedlings	
	Emergence[1]	Survival[2]
(cm)	(%)	(%)
0 (within grass clump)	29	80
1–3	54	74
4–6	15	83
7–11	2	83

[1]Percent based on 394 seedlings.
[2]Percent of seedlings alive through first growing season.

quarter. Also, minimum air temperatures when broom snakeweed seed normally begins to disperse in late October are often near freezing, which probably impedes germination (Wood et al. 1997). Contributing to low fall germination may be the need for an after ripening period, which Mayeux and Leotta (1981) reported favors broom snakeweed germination.

In 1992, second quarter rainfall was 224% above normal and resulted in the highest yearly number of seedlings counted (64% of study total, Table 1). Relatively few seedlings emerged in 1990, 1993, 1995, or 1996 (4% of total) when second quarter precipitation was below the 30-yr average (Fig. 1). Precipitation was also below normal in the second quarter of 1991 but a single rain event on 13 May provided 26 mm of moisture and led to the second highest annual seedling total with most counted in mid-June. After this storm we noted the soil surface was saturated and remained wet for about 5 days. We speculate a storm of this intensity is near the minimum required to provide sufficient moisture to imbide seed and to allow germination. In greenhouse studies, Wood et al. (1997) reported optimum broom snakeweed germination occurs when soils are maintained at a minimum matric potential > -180 kPA for at least 4 days. In contrast, 1997 second quarter precipitation was nearly 200% above normal and only 6 seedlings emerged within all study plots at both sites. The low number of seedlings produced in 1997 may be because the seed bank held few viable broom snakeweed seed to support a new population. We speculate on this possibility because precipitation was below normal from beginning the first quarter of 1995 through the second quarter of 1996 and this drought caused the death of most adult broom snakeweed plants and resulted in a lack of seed production. Additionally, in 1995 highest average summer air temperatures ever recorded near Corona occurred and this contributed to a lack of flowering and loss of adult broom snakeweed plants. Broom snakeweed seed under natural conditions are not long-lived as most become non-viable within a year of being dispersed (Wood et al. 1997); thus, with essentially 2 years of no seed production it is likely that the seed bank was largely depleted when adequate soil moisture became available in spring 1997.

Irrespective of site, year, or treatment, the emergence of broom snakeweed seedlings in relation to a ground cover was distinct. About 71% germinated in open bare ground areas, whereas the remainder emerged directly within surrounding grass (Table 2). Percent aerial grass cover was variable over years and treatments, but usually exceeded 60%, whereas bare ground cover was below 25% (data not shown). A higher proportion of seedling emergence within open areas suggest a negative association with the grass overstory, which agrees with the observation that broom snakeweed is less prominent under increasing grass cover than in open disturbed areas (Jameson 1966, 1970, Ueckert 1979, Pieper and McDaniel 1989). Reduced emergence within grass may partially be related to a light requirement needed for normal germination by this species (Mayeux 1989). Interestingly, broom snakeweed survival through the first 2 growing seasons was equal (about 80%) among seedlings that emerged either within or outside grass plants (Table 2). This suggests that, once established, seedling survival to an adult may be more dependent on soil moisture and other environmental conditions than the presence of grass.

Seedling longevity was influenced by the date propagules emerged, and the amount and frequency of rainfall received, especially through the first growing season (Table 3). Broom snakeweed seedlings are vulnerable to dessication because they do not quickly develop an extensive root system to exploit soil water and nutrient resources (Osman and Pieper 1988). Excavations of entire seedlings in the field indicate root penetration is about 9.5 cm after 5 weeks, but only 27 cm after 29 weeks in southern New Mexico (Osman 1982). As the plant matures, it develops an efficient, shallow, fibrous root system that gives it access to soil water at about the same depth as associated perennial grasses (Ragsdale 1969, DePuit and Caldwell 1975). In this study, all seedlings that emerged in 1990 died the first season. However, most seedlings produced between 1991 to 1995 survived (60 to 89%) through the first growing season and later matured to flower the second year. Some 1991 to 1995 seedlings died annually (Table 3), mostly as a result of dry hot conditions in June or July; all but 11 of the original 365 seedlings produced through this time succumbed to 1995–1996 drought conditions. Eight of these seedlings were still alive when the study terminated in October 1998.

Broom Snakeweed Emergence After Treatment

In the study, most broom snakeweed seedlings emerged in 1991 and 1992; thus statistical comparisons between treatments were only made for these years (Table 4). Plots burned in summer 1990 had significantly ($P < 0.05$) more broom snakeweed seedlings the next year than untreated areas; and more seedlings than spring burned and herbicide treated areas the next 2 years. There was an equivalent number of broom snakeweed seedlings in 1990 spring burned and non-treated areas the first year, but fewer seedlings emerged in the spring burned plots the second year. Only 11 seedlings emerged over the 9-year study in plots sprayed with herbicide in 1990, which was less than those counted in spring and summer burned and non-treated areas.

Table 3. Broom snakeweed seedling survival by year, irrespective of treatment or site on the NMSU Corona Research Ranch.

Year Emerged	Number Emerged	Survival at end of growing season								
		1990	1991	1992	1993	1994	1995	1996	1997	1998
1990	7	0	0	0	0	0	0	0	0	0
1991	66	—	40	30	28	24	10	0	0	0
1992	253	—	—	220	195	167	99	8	6	5
1993	9	—	—	—	7	6	3	1	1	1
1994	19	—	—	—	—	16	11	1	1	1
1995	8	—	—	—	—	—	11	1	1	1
1996	7	—	—	—	—	—	—	1	1	1
1997	6	—	—	—	—	—	—	—	2	2
1998	19	—	—	—	—	—	—	—	—	17

Table 4. Total number of broom snakeweed seedlings produced annually within treatments from 1990 through 1998 on the NMSU Corona Research Ranch.

Treatment	Year Applied	1990	1991	1992	1993	1994	1995	1996	1997	1998	Total
		Annual Seedling Total[1]									
		(no.)									
Non-Treated		3	11b	20b	1	6	2	2	0	4	49
Spring burn	90	3	12b	14c	2	1	1	0	2	4	39
Summer burn	90	1	42a	21b	0	2	0	5	0	1	72
Herbicide	90	0	1c	3d	1	2	0	0	4	0	11
Spring burn	91	—	—	35b	1	1	0	0	0	3	40
Summer burn	91	—	—	146a	2	5	3	0	0	4	160
Herbicide	91	—	—	14c	2	2	2	0	0	3	23

[1]Observations were made in nine, 1-m^2 frames per plot with each treament replicated 3 times at 2 sites. Total measurement area is 54-m^2. Treatments within columns followed by the same letter are not significantly different (P<0.05).

From treatments applied in 1991, summer burned areas accounted for nearly 68% of the total number of broom snakeweed seedlings that emerged the next year (i.e. 1992; Table 4). New seedlings in 1991 spring burned and non-treated areas were similar, and again the fewest number of seedlings were produced in herbicide-sprayed plots. The trend of a relatively high number of seedlings the year after summer burning compared to other treatments indicates that fire probably does not harm seed already distributed on the surface, nor does it later impede broom snakeweed germination. The relatively low number of seedlings in herbicide treated areas compared to burned areas may partially be attributed to the enhancement of grass cover after spraying (Mc Daniel and Duncan 1987). Although spring and summer fires and herbicide spraying eliminated most of the mature broom snakeweed plants after one year (Mc Daniel et al. 1997), the fires always increased bare ground exposure and reduced grass cover relative to herbicide spraying (Table 5; Hart 1992, Carroll 1994).

Influence of Fire on Emergence

In August 1992, broom snakeweed seedlings were more abundant (P < 0.05) in the 15 plots burned in summer than the 27 plots burned in the spring 1991 (2.0 ± 1.9 and 0.59 ± 0.83 seedling m^{-2} respectively). There was wide variability among plots in seedling emergence ranging from 0 to 3 seedlings m^{-2} after spring burning, and 0 to 6 seedlings m^{-2} after summer burning.

Least squares regression analysis revealed no significant correlation between broom snakeweed emergence and any of the climatic, fire, or pre-and post-burn vegetation data from spring-burned plots (Table 6). Multiple regression analysis with fire and post-burn vegetation variables accounted for less than 20% of the variation in seedling density following spring burning (data not shown). It was noted by McDaniel et al. (1997) that fires in spring moved faster and burned cooler relative to summer fires, and subsequently resulted in less damage to blue grama. We speculate that when grass growth recovers quickly after fire, then the likelihood for broom snakeweed reestablishment is reduced.

As air temperatures and total fuel biomass increased during summer burning, so too did fire temperatures, total burn time, duration of heat, and degree-seconds of heat (McDaniel et al. 1997). When fires became very intense and produced excessive heat, then post-burn grass yield and cover was reduced for 2 or more years (Hart 1992). Broom snakeweed seedlings were negatively related to increasing grass yield (r = -0.73) and positively related to increasing bare ground cover (r = 0.69). About 9% of seedlings emerged in spring and summer burned plots averaging less than 10% bare ground cover, whereas the remainder emerged where bare ground exposure was higher.

Management Implication

On our study area near Corona, NM, broom snakeweed propagation was most common in the second quarter (April, May, and June) with moist surface soil temperatures ranging between 10 to 25°C. Broom snakeweed seed can potentially germinate any time during a year, and we suspect that propagation elsewhere will depend on localized soil temperature and moisture conditions. For example, while little propagation was noted on our study area during the first or fourth quarters of the year, under a milder climate near Las Cruces, N.M. broom snakeweed emergence was common in January and February (Barnett 1996).

Over this 9-year study broom snakeweed propagation was irregular with only 1991 and 1992 having a substantial number of seedlings produced. There are several possible explanations for why germination was higher in these years than others. Rainfall was plentiful the year after treatments were established. Also, although most adult broom snakeweed plants were killed by the burning and herbicide treatments, there was still a high number of potential progeny in the seed bank the first

Table 5. Percent aerial cover of broom snakeweed, grass, herbs, winterfat, litter, and bare ground when sampled in September 1990 and 1991 after broom snakeweed control on the NMSU Corona Research Ranch.

	Aerial Cover[1]							
	September 1990				September 1991			
	Non-treated	Spring Burn	Summer Burn	Herbicide	Non-treated	Spring Burn	Summer Burn	Herbicide
	(%.)							
1990 Treatments								
Broom Snakeweed	8a	0.7b	0.7b	0.0b	11a	1b	1b	0.0b
Grass	66c	70b	62c	76a	70b	74b	72b	86a
Herbs	4b	4b	7a	0.03c	3bc	4ab	6a	1c
Winterfat	1a	1a	1a	0.2a	2a	1a	1a	1a
Litter	5b	3c	2c	12a	6a	5a	6a	5a
Bare ground	15bc	22ab	27a	12c	9bc	13ab	15a	7c
1991 Treatments								
Broom Snakeweed	—	—	—	—	11a	4b	1b	2b
Grass	—	—	—	—	70b	70b	60c	80a
Herbs	—	—	—	—	3b	4b	15a	2b
Winterfat	—	—	—	—	2a	2a	0a	2a
Litter	—	—	—	—	6a	7a	8a	7a
Bare ground	—	—	—	—	9ab	13a	15a	7b

[1]Means within rows and sample date with the same letters are not different (P < 0.01). Treatments were replicated 3 times at 2 sites within years. Analysis of variance revealed no difference (P < 0.01) among sites so data were pooled for final analyses.

Table 6. Simple linear correlation coefficients obtained on 1991 spring and summer burns with dependent variable snakeweed seedlings m^{-2}.

Variables	Correlation Coefficients Spring	Summer	Combined
Pre-burn Data			
Grass Cover	–.09	–.33	–.05
Snakeweed Cover	–.02	.26	.08
Litter Cover	.12	.26	–.23*
Bareground Cover	.15	.25	.10
Grass Yield	–.18	–.28	–.01
Snakeweed Yield	–.15	.33	–.04
Snakeweed Density	–.07	.33	.06
Grass Moisture	–.25	–.43	–.05
Snakeweed Moisture	.25	–.43	.07
Soil Moisture	.25	.43	–.30**
Climatic Data			
Air Temperature	.11	.59**	.51***
Soil Temperature	.16	.29	.48***
Wind Speed	–.07	.34	.16
Relative Humidity	–.12	–.50*	–.32**
Wind Direction	–.18	.58**	–.25*
Fire Measurements			
Total Burn Time	.07	–.59**	–.12
Max. Therm. Temp.	.02	.58**	.41***
Tempil-Strip-Temp.	.16	.65***	.60***
Rate of Spread	.20	.65***	.29*
Duration of Heat	.13	.22	.31*
Deg. Seconds Heat	–.003	.46*	.44***
Post-Burn Data			
Grass Cover	.03	–.23	–.20
Snakeweed Cover	–.31	–.39	–.21
Litter Cover	.19	.48*	.50***
Bareground Cover	–.09	.69***	.03
Grass Yield	–.30	–.73***	.12
Snakeweed Yield	–.26	–.46*	–.28**
Snakeweed Density	–.27	–.47*	–.30**

*Significant at P < .10.
**Significant at P < .05
***Significant at P < .01.

year after treatment. Broom snakeweed seed is not long-lived, with most becoming non-viable within a year of dispersal (Wood et al 1997). Thus, if adult plants are eliminated by fire, herbicide, or natural causes, the greatest opportunity for a large number of seedlings to become established should be shortly after the death of mature plants. We speculate, based on our study, that if 1 or 2 years lapse without seedling establishment, then the return of broom snakeweed to an area will be retarded and occur only after a slow year-by-year build up of the population.

Broom snakeweed control practices that provide for greater grass yield and less bare ground exposure should act to minimize, but not necessarily prevent, future broom snakeweed propagation. In this study, herbicide spraying was the only treatment to significantly increase grass yield and cover relative to non-treated rangeland, and was the most effective control practice examined for reducing broom snakeweed establishment. Other research and commercial spraying experience has shown that with time, broom snakeweed may reestablish after herbicide control, even with a 4 to 6 fold increase in grass production (McDaniel and Duncan 1987). However, the magnitude of broom snakeweed establishment on herbicide treated areas should be less than if the rangeland were burned or not treated.

When prescribed fires are conducted in a manner so as to eliminate mature broom snakeweed plants but minimize damage to associated grasses, then there is a greater likelihood for long-lasting broom snakeweed control. In McDaniel et al. (1997) we reported less broom snakeweed control with spring fires (65% average mortality) than summer fires (92% average mortality). In this study, fewer broom snakeweed seedlings emerged after these same spring fires than summer fires, which brings into question, what is the optimal burning time for long-lasting broom snakeweed control? Our recommended conditions for burning blue gramma grasslands in central New Mexico (McDaniel et al. 1997) includes air temperatures from 22°C, relative humidity 10–20%, soil moisture 3–10%, and pre-burn fine-fuel moisture below 15%. The fine-fuel should be uniformly distributed and exceed 500 kg ha^{-1}. Obtaining these prescribed conditions was difficult on our study area at all times of the year. However, we believe these conditions, irrespective of burning time, are capable of maximizing both broom snakeweed control while lowering the risk of seedling emergence after fire.

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