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HYDROLOGIC AND VEGETAL RESPONSES TO PRESCRIBED BURNING AND HERBICIDAL TREATMENT OF BROOM SNAKEWEED ON BLUE GRAMA RANGELAND IN NEW MEXICO

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ABSTRACT

Broom snakeweed (*Gutierrezia sorothrae* Shinners) control results in conversion from shrub-dominated land to grassland. Changes in the hydrologic cycle including reduced runoff and erosion can be realized. These changes are most often considered to be beneficial to onsite production and downstream uses. Broom snakeweed numbers significantly decreased from both burning and spraying with herbicide. However, the broom snakeweed was not eradicated, and numbers increased significantly the first year after treatment, especially on burned plots. Runoff volume was highest during a wet year following burning and lowest in a drought year following all treatments. Only one runoff event in 1996 on the burned plots was considered to be flooding. Sediment concentrations were highest during a drought on all plots, but most prominent after plots had been burned.

Runoff and sediment yield increased immediately after burning but those effects were not long lasting. Elevated sediment concentration levels only persisted the first year after both burns (1994 and 1996). Total sediment yield is a function of runoff volume and sediment concentration. Total sediment yield was highest during a wet year following burning.

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INTRODUCTION

Broom snakeweed (*Gutierrezia sarothrae* Shinners) is a serious perennial weed problem on rangelands in the southwestern United States and northern Mexico. There are two major problems with broom snakeweed: it is poisonous, with abortion being the most common problem in livestock (Sperry and Robinson 1963), and the weed competes with more valuable forage plants (Ueckert 1979, Ralphs 1985). Snakeweed plants begin growth in late winter and early spring when most forage plants are dormant or in short supply, so that most poison problems occur during this season. Livestock at this time are in their last trimester of gestation. Perennial shrubs such as broom snakeweed may out-compete warm and cool season grasses for soil moisture because of their early green-up (Costillo 1994). Platt (1959) estimated that species of the genus *Gutierrezia* occurred on more that 350 million ha of rangeland in the United States. In New Mexico, broom snakeweed is found in various densities on about 60% of the rangeland (McDaniel 1990).

Perennial snakeweeds were conspicuous components of range vegetation in the Southwest at the turn of the 20th century (Jardine and Forsling 1922, Talbot 1926, and Wooton 1915). However, interest in these plants has wavered over the decades, depending on their abundance. During the drought of the 1930s, Campbell and Bomberger (1934) discussed the ecological role of snakeweed on desert grassland in southern New Mexico, and Parker (1939) discussed snakeweed control. Drought conditions and subsequent increases in plant numbers in the 1950s, 1970s, and 1980s increased interest in perennial snakeweeds in the Southwest (Pieper 1967, McDaniel and Sosebee 1988, McDaniel 1990).

A major problem with shrubs occurs when the grass and forb components are degraded in a shrub-grassland community. This can occur from many influences such as wildlife, insects, or livestock. The shrubs may increase in size, but all too often, excessive erosion occurs in the bare interspaces between shrubs, which leaves a site unable to recover in decades or more, although the shrubs may be removed. Prevention is obviously the best solution to these problems. But millions of hectares in the West have already been degraded (McDaniel and Sosebee 1988). Different management strategies rather than complete rangeland rest from perturbations are needed. This involves removing the undesirable vegetation and establishing a protective cover. Removing undesirable vegetation has traditionally been accomplished by mechanical, chemical, burning, and some biological techniques. Mechanical treatments became expensive (mostly prohibitive) in 1973 when energy costs soared. Chemical controls with a petroleum base were also prohibitively expensive until the early 1980s and since as a result of further research and development that is continuing. Burning has much potential but biological controls need further study. The best solution for most snakeweed infested rangeland is probably a combination of several techniques prescribed over at least a 20-year period (Wood and Buchanan 1989). Augustine and Milchunas (2009) noted that snakeweed numbers follow climate cycles and burning in wet periods resulted in increases that were not as great as in controls, and burning during dry periods resulted in decreases that were greater than the controls. McDaniel and others (2002) found the herbicide picloram controlled an average of 88% of broom snakeweed plants and reduced seed production 99%. From an economic point of view, prescribed fire is often a better management choice than herbicide control because it is less costly where light amounts of snakeweed and sufficient grass occur (<300 kg ha^{-1} snakeweed and > 500 kg ha^{-1} of grass) (McDaniel and Ross 2002, Torrell et al. 1988).

Many questions need study before adequate management of most broom snakeweed infested rangelands takes place. Little is known about the hydrologic cycle and water budget as they relate to broom snakeweed dominated sites and their changes. Those include interception volumes and quality changes in the resultant foliar drip and stem flow, infiltrations processes, amount of groundwater recharge, runoff rates and volumes, erosion, and shrub water use. Research priority should be given to broom snakeweed ecology with major emphasis on the hydrologic cycle, management techniques, and benefits and detriments of different techniques of management. The objectives of this study were to determine the effects of prescribed burning and herbicidal control of broom snakeweed on subsequent plant production, runoff, and soil erosion.

DESCRIPTION OF STUDY AREA

Study Site Location

The research site was located approximately 300 km northwest of Las Cruces and 15 km north of Winston, New Mexico on a native grassland that is subject to invasion by pinyon pines (*Pinus edulis* Engelmann) and alligator junipers (*Juniperus deppeana* Steudel). The site was located in the Black Range of the Gila National Forest, specifically in Section 1 of T10S, R9W at latitude N 33° 28.374' and longitude W 107° 42.920'. This site has a rolling landscape with 20% slope and an elevation of 2,175 meters. Wildfires occur every few years (Heisler et al. 2003).

Climate

This area has an arid, continental climate except in the mountainous western portion, which is semi-arid. Characteristics of the climate are low rainfall, low relative humidity, and plentiful sunshine. Summer is the rainy season, with half the annual precipitation falling during brief but sometimes heavy thunderstorms. During the warmest six months, May through October, 75% of the average annual precipitation occurs. Approximate mean annual precipitation is 300 millimeters, the average annual air temperature is 9°C to 12°C, and the average frost-free period is 120 to 170 days (USDA 2007).

Soils

Study site soils are in the Ildefonso series, which is a loamy-skeletal, mixed, mesic Ustollic Calcorthid on ridges and side slopes (Neher 1984). This soil is deep and well drained, and formed in mixed alluvium. The soil surface layer is typically brown gravelly loam about 10 cm thick with a brown gravelly loam subsoil 25 cm thick. The substratum is light brown and pink very gravelly loam to depth of about 150 cm. The permeability is moderately rapid, and runoff is medium. The hazard of water erosion and soil blowing is moderate. This area is used for livestock grazing, watershed, wildlife habitat, and recreation.

Vegetation

The potential natural community of this area is characterized by black grama (*Bouteloua eriopoda* (Torr.) Torr.), sideoats grama (*Bouteloua curtipendula* (Michx.) Torr.), New Mexico feathergrass (*Stipa neomexicana* (Thurb.) Scribn.), Halls panicum (*Panicum hallii* var. *hallii* Vasey), and scattered halfshrubs. Average annual vegetation production is 600 to 1,500 kg per hectare. The common vegetation consists of blue grama (*Bouteloua gracilis* (Willd. ex H.B.K.) Lag. ex Griffiths), broom snakeweed, Apache plume (*Fallugia paradoxa* (Don) Endl.), Louisiana wormwood (*Artemisia ludoviciana* Nutt.), and soaptree yucca (*Yucca elata* Engelm.).

Wildlife

Large wildlife in this area include pronghorn antelope (*Antilocapra americana* Vaughn) and occasionally mule deer (*Odocoileus hemionus* Vaughn), elk (*Cervus canadensis* Vaughn), black bears (*Ursus americanus* Vaughn), mountain lions (*Puma concolor* Linnaeus) and Mexican wolves (*Canis lupus* baileyi).

MATERIALS AND METHODS

Installation of Runoff Plots

A 1.0 ha study area was excluded from livestock by four strands of barbed wire fence. In the summer of 1993 (June thru August), 12 experimental plots were installed within the study area, nine on a north facing slope and three on a south facing slope. Each runoff plot was 4 m wide and 25 m long with 30 cm high borders made of 1.59 mm thick galvanized steel and buried 15 cm into the soil. This length is similar to plots used to develop the Universal Soil Loss Equation on cropland (Wischmeier and Smith 1978) while the width is twice as wide to accommodate more spatial variation found on rangelands than croplands. A drop box and H-flume (Brakensiek et al. 1979) were installed at the bottom of each experimental runoff plot. The drop box measurements were 4 m long, 15 cm wide with an outside to inside tapered depth of 13.75 to 20 cm. The H-flumes were 165 cm long, 60 cm wide and 30 cm in height. After the borders, flumes, and collection troughs were installed, the study sites were rested for 9 months, allowing for disturbed soil and vegetation to stabilize and return to their natural states prior to applying treatments on experimental plots.

A total collection trough for each experimental plot consisted of a 1.83 m diameter and 0.91 m high tank. Inside the tank was a 0.52 m diameter and 0.28 m high tub, and inside the tub was a 0.27 m diameter and 0.35 m high bucket. The bucket was placed to catch all outflow from the flume. When the bucket was full, water overflowed into the tub and when the tub was full, it overflowed into the tanks allowing accurate measurements of low, moderate, and high flows to be made to determine depth of each runoff event. A plywood cover was fitted over the tank to prevent rainfall from entering the collection area directly, retard evaporation, and prevent wildlife from drinking or becoming trapped. Water collected in the runoff collection tank was agitated with stirring boards, and a 1-liter grab sample from the tank was taken for determining sediment content. Runoff was measured and sediment was collected at 1-wk intervals after determining, before treatment, that rainfall events took place at most one to two times each week.

Plant Production

Plant production was determined by dividing the runoff plots into ten equal sections at the end of each growing season and randomly locating a 1.0 meter by 0.5 meter sub-plot in each section. The sub-plots were clipped to stubble height and separated by grasses, forbs, and shrubs. Samples were air dried in an oven at 60°C for 1 week and then weighed.

Treatments, Experimental Design, and Data Analysis

A randomized complete block experimental design was used, which had four blocks with three experimental plots (4 x 25 meters) in each block. Each block had selected treatments that included a non-treated control, a prescribed burn, and a recommended herbicide application of liquid picloram at 0.28 kg ha^{-1}. Data were analyzed with an analysis of variance, and means were separated with a least significant difference mean separation test.

Picloram is a selective, translocated, foliage or soil applied herbicide in the picolinic chemical grouping (Vallentine 1989). Picloram was foliar applied using a 4 meter wide hand held spray rig at a rate of 0.28 kg ha^{-1} (0.25 lbs $acre^{-1}$) of active ingredient as recommended by McDaniel and Duncan (1987). Prescribed burning and picloram application were conducted on March 31, 1994. Prescribed burning was conducted with a drip torch applied from the bottom to the top of each plot in that treatment with uniform results. The air temperature was 19°C, and the wind speed was 8 km per hour with gusts to 16 km per hour. Prescribed burning was applied in this season because Hart (1992) found snakeweed morality and subsequent grass production to be higher from spring than summer burns. And McDaniel and others (1997) found summer burns induced greater snakeweed mortality than spring burns, but summer burns also facilitated establishment of snakeweed seedlings while early-spring burns did not (McDaniel et al. 2000). Herbicide was applied in March because McDaniel and Duncan (1987) found nearly complete morality (99%) when picloram was applied in spring. A repeat prescribed burn on previously burned plots was conducted on April 3, 1996. The air temperature was 10°C and the wind speed was 9 km per hour with gusts to 18 km per hour. Relative humidity was 49% and the dew point was $^{-}$1°C.

RESULTS AND DISCUSSION

Precipitation

Precipitation on the study area followed the general trend of the region (Anon. 2001). The mean cumulative precipitation for June through September was 275 mm over the 7 year study period. Precipitation during the pre-treatment calibration year (1993) was 270 mm (Figure 1), which is very close to the mean. The year 1994 was a drought year with little precipitation during the previous winter and spring. This was the driest June through September period during the study. Precipitation in 1995 was slightly below the mean (231 mm), but precipitation in 1996 (470 mm) was way above the mean. Precipitation in 1997 (267 mm) was near the mean, while precipitation in 1998 (226 mm) was below the mean. Finally, precipitation in 1999 (331 mm) was above the mean. Overall, precipitation for the June through September period was below the mean for five of the years and above the mean for two of the years.

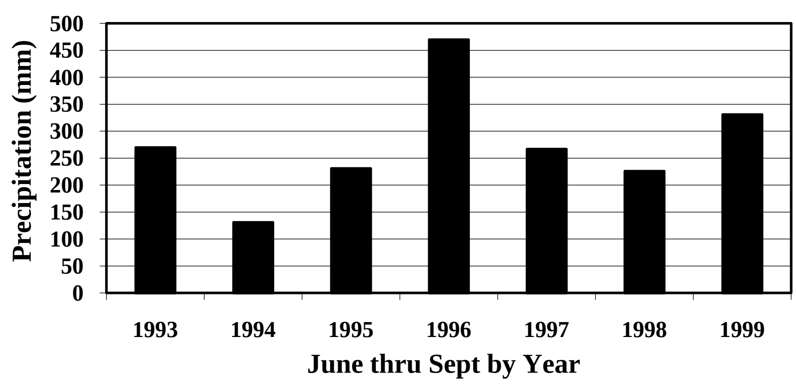

Figure 1. Total precipitation from June through September for each year.

Broom Snakeweed Population Trends

Prior to treatment (1993), there was less than one mature broom snakeweed plant for every 2 m^2. It is difficult to compare broom snakeweed numbers between studies because seedlings are often counted as well as mature plants. The number of mature snakeweed plants found in this study would probably be considered a light infestation compared to numbers found by McDaniel (1990) on 10 study sites in southern and eastern New Mexico. The control plots did not have significantly more broom snakeweed plants than plots to be burned or sprayed with herbicide ($p<0.20$) (Figure 2). The number of snakeweed plants in each treatment declined from the beginning of the study to the end even in the control plots. But numbers were cyclic within the study period. The greatest change occurred from 1993 to 1994. This corresponded to the drought conditions of 1994. Broom snakeweed numbers in the burned and sprayed plots were significantly lower than the controls ($p<0.05$) in 1994, which represent treatment effects in addition to drought influences. In 1993, 1994, and 1995 broom snakeweed plants of all sizes were observed, but only mature plants were found after 1995. The plots that were burned had the fewest plants in 1994, but numbers increased significantly ($p<0.10$) in 1995 in this treatment. Broom snakeweed numbers declined in the burned plots after 1996. Plots sprayed with herbicide experienced a reduction in 1994 from 1993 and then an increase in 1995. After 1995 broom snakeweed number declined until 1998 with a small increase in 1999. In 1999, all treatments and the control plots had a mean number of broom snakeweed plants that were less than 1 plant per 5 m^2. Broom snakeweed numbers in the treated plots were significantly lower ($p<0.10$) than in the control plots until 1998.

These results on cyclic trends parallel those of McDaniel (1990) who found that age of stand and dry weather patterns are important in natural die-off of broom snakeweed with a 7-year old broom snakeweed stand having a high probability of natural die-off. Conversely, rainfall that is consistently above average in the spring and summer favors a reinvasion of broom snakeweed. Torell and others (1990) recommended that because of short cycle natural die-off, money potentially used on fire and/or pesticides for control of mature stands of broom snakeweed would be better spent elsewhere, whereas controlling a young stand may be money well spent.

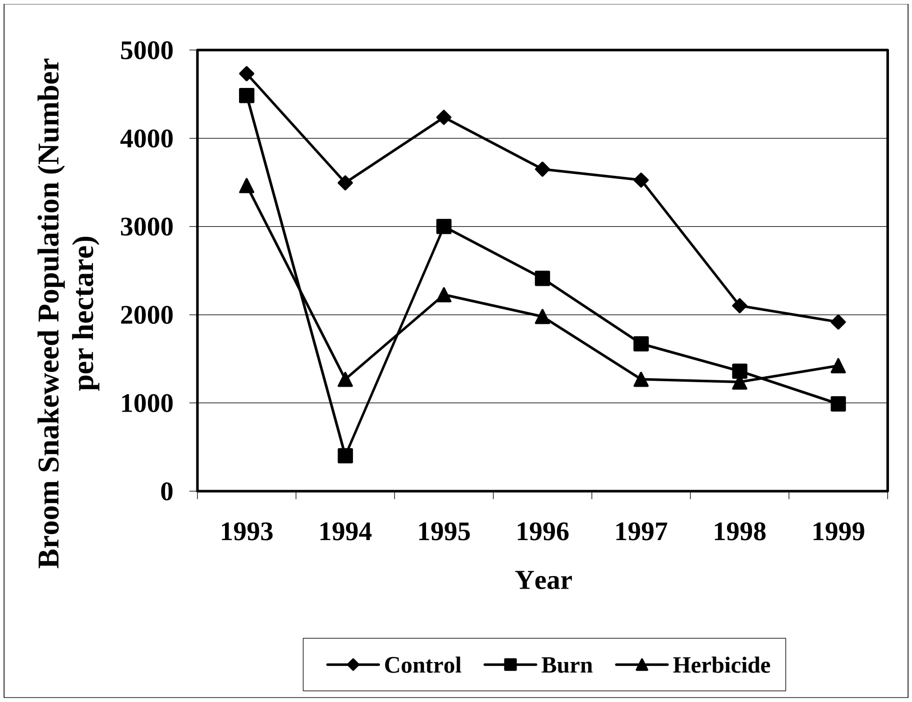

Figure 2. Broom snakeweed numbers per hectare for each treatment and year.

Vegetation Production

Vegetation production across treatments grass production, as measured at the end of the growing season, was low in 1993 although precipitation was average (Table 1). This low production may be due to several millennia of wildlife grazing, over 100 years of livestock grazing, and climate. Grass production decreased slightly from 1993 to 1994 in the control and sprayed treatments. This was expected because of the drought. Even in drought years, there was some late summer monsoon moisture that produced some grass. However, grass production in burned plots increased slightly from 1993 to 1994 although the increase was not significant. Then grass production increased across all treatments from 1994 through 1995 and 1996 with a decrease in 1997 and a peak amount in 1998. Much of the overall year to year increase is attributed to livestock exclusion. However, wildlife still has access to the study area. The burning treatment had grass production values that were higher than the control in 1996, 1997, and 1999, but the differences were only significant in 1996. Within 1993, there were no significant differences between treatments at any level of probability. In 1994 the control and burn treatment had significantly more grass than the sprayed treatment at $p<0.20$. In 1995 the control had more grass than the burn or sprayed treatments at $p<0.20$. In 1996 there was significantly more grass in the burned treatment than the sprayed treatment ($p<0.05$) and significantly more grass in the burned treatment than the control and sprayed treatment ($p<0.20$). In 1997 and 1998 there were no significant difference between the control and treatments. In 1999 there was significantly more grass in the burned treatment than in the sprayed treatment ($p<0.10$) and significantly more grass in the control than the sprayed treatment ($p<0.20$).

Across treatments forb production, as measured at the end of the growing season, was low in 1993 although precipitation was average (Table 1). In 1993, forb production across all treatments (179.6 kg ha^{-1}) was not different from grass production across all treatments (256.1 kg ha^{-1}). While grass production increased throughout the study, forb production remained relatively the same. The only year with significant differences in forb production between treatments was in 1995 when forb production in the burn and sprayed treatments were lower than in the control ($p<0.20$).

Table 1. Mean annual grass, forb, and total grass and forb production (kg ha^{-1}).

	Grass				Forb				Total			
	Level of Probability				Level of Probability				Level of Probability			
Year & Treatment	Mean	0.05	0.10	0.20	Mean	0.05	0.10	0.20	Mean	0.05	0.10	0.20
1993												
Control	318.5*	a	a	a	248.0	a	a	a	566.5	a	a	a
Burn	211.6	a	a	a	164.0	a	a	a	375.6	a	a	a
Spray	238.3	a	a	a	126.7	a	a	a	365.0	a	a	a
1994												
Control	244.7	a	a	a	212.2	a	a	a	456.8	a	a	a
Burn	224.3	a	a	a	234.2	a	a	a	458.5	a	a	a
Spray	143.2	a	a	b	85.5	a	a	a	228.7	a	a	b
1995												
Control	669.6	a	a	a	252.5	a	a	a	922.1	a	a	a
Burn	404.1	a	a	b	98.5	a	a	b	502.6	a	a	b
Spray	456.4	a	a	b	113.0	a	a	b	569.4	a	a	b
1996												
Control	765.3	ab	ab	b	175.1	a	a	a	940.4	ab	ab	b
Burn	930.7	a	a	a	152.8	a	a	a	1,083.5	a	a	a
Spray	620.1	b	b	b	168.9	a	a	a	789.0	b	b	c
1997												
Control	556.4	a	a	a	401.3	a	a	a	957.7	a	a	a
Burn	660.1	a	a	a	439.6	a	a	a	1,099.7	a	a	a
Spray	592.5	a	a	a	258.8	a	a	a	851.2	a	a	a
1998												
Control	1,278.9	a	a	a	554.7	a	a	a	1,833.6	a	a	a
Burn	1,275.7	a	a	a	543.5	a	a	a	1,819.1	a	a	a
Spray	1,171.2	a	a	a	547.2	a	a	a	1,718.4	a	a	a
1999												
Control	1,206.2	a	ab	a	321.3	a	a	a	1,518.5	a	a	a
Burn	1,255.6	a	a	a	229.1	a	a	a	1,484.7	a	a	a
Spray	1,055.3	a	b	b	269.0	a	a	a	1,324.2	a	a	a

*Means followed by the same letter within a row and probability level are not significantly different

Similar to grass and forb production across treatments, total plant (grass and forb) production was low in 1993 and similar between treatments (Table 1). Total production decreased slightly from 1993 to 1994 in the control and sprayed plots. However, total production in burned plots increased slightly from 1993 to 1994, although the increase was not significant at the levels of probability that were tested. Total production in the sprayed plots was significantly less than in the other treatments in 1994 ($p<0.20$). Then total production increased across all treatments from 1994 through 1998 with the greatest increase being on control plots in 1995 and on burned plots in 1996. In 1995, total production in the control plots was significantly greater than in plots of the other treatments ($p<0.20$). In 1996, total production was significantly higher on the burned plots than the sprayed plots at $p<0.05$ and significantly different between all treatments at $p<0.20$. Increases from end of growing season 1996 to end of growing season 1997 were small on all treatments. Large increases were found from end of growing season 1997 to end of growing season 1998 on all treatments. A significant decrease occurred across all treatments from end of growing season 1998 to end of growing season 1999 ($p<0.05$). There were no significant differences between treatments within the years of 1997 through 1999. Neher (1984) reported that this soil series produces 1450 kg ha^{-1} of air-dry vegetation in favorable years and 600 kg ha^{-1} in unfavorable years. Therefore, the values found within this study compare to the expected values.

Runoff

The volume of runoff was similar between treatments except in 1996 (Figure 3). Four plots were burned in Spring 1994, and this burning treatment was followed by a drought the remainder of 1994. Therefore, runoff was slight from all treatments because precipitation was slight. In 1996, precipitation was highest of all the years and it followed the second burning treatment. Soils in the burned plots were bare, and much runoff occurred within the first year after burning (1996). By the second year following burning (1997), runoff volumes were low and similar among treatments. This relationship continued through the remainder of the study.

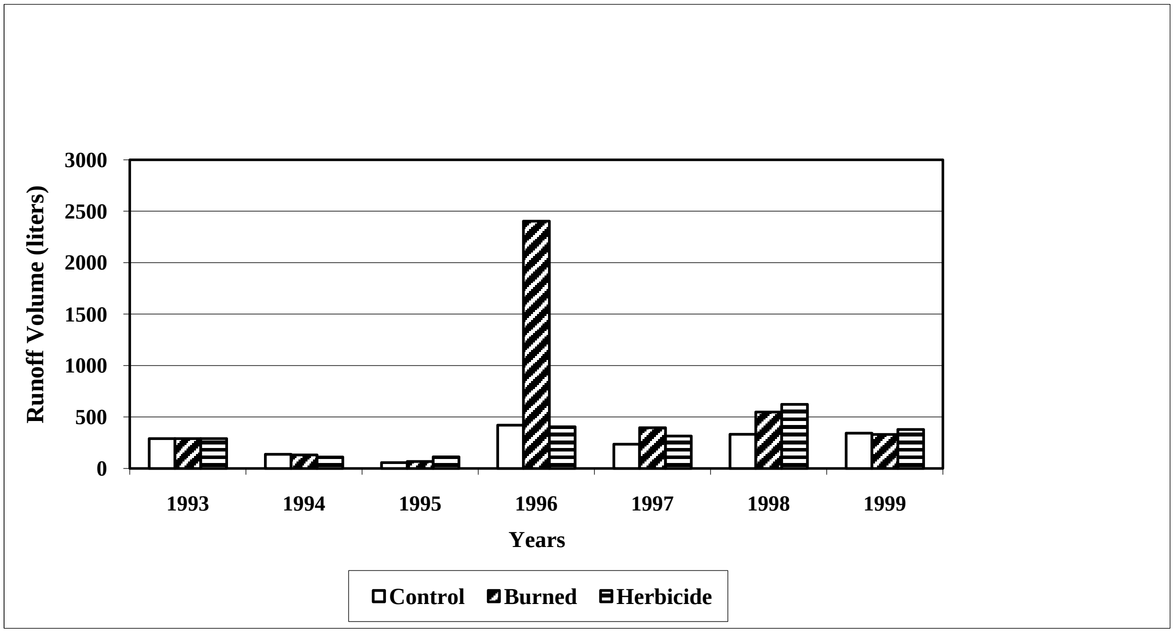

Figure 3. Runoff volume for each treatment and year.

Sediment Concentration

Sediment concentration was similar between treatments except in 1994 and 1996 (Figure 4). Four plots were burned in Spring 1994, and this burning treatment was followed by a drought the remainder of 1994. Sediment concentration was high from all treatments in 1994 and 1996 and significantly highest from the burned plots within those years. During the study, the least amount of precipitation occurred in 1994, and the most precipitation occurred in 1996 (Figure 1). High sediment concentration was expected in 1994 during a drought as protective vegetal cover was minimal. High sediment concentration was expected in 1996 because of the high depth of precipitation. Most sediment is detached as a result of the energy from raindrop impact versus the erosive energy from runoff. Therefore, the highest sediment concentration occurred during the years with the extreme high and low precipitation.

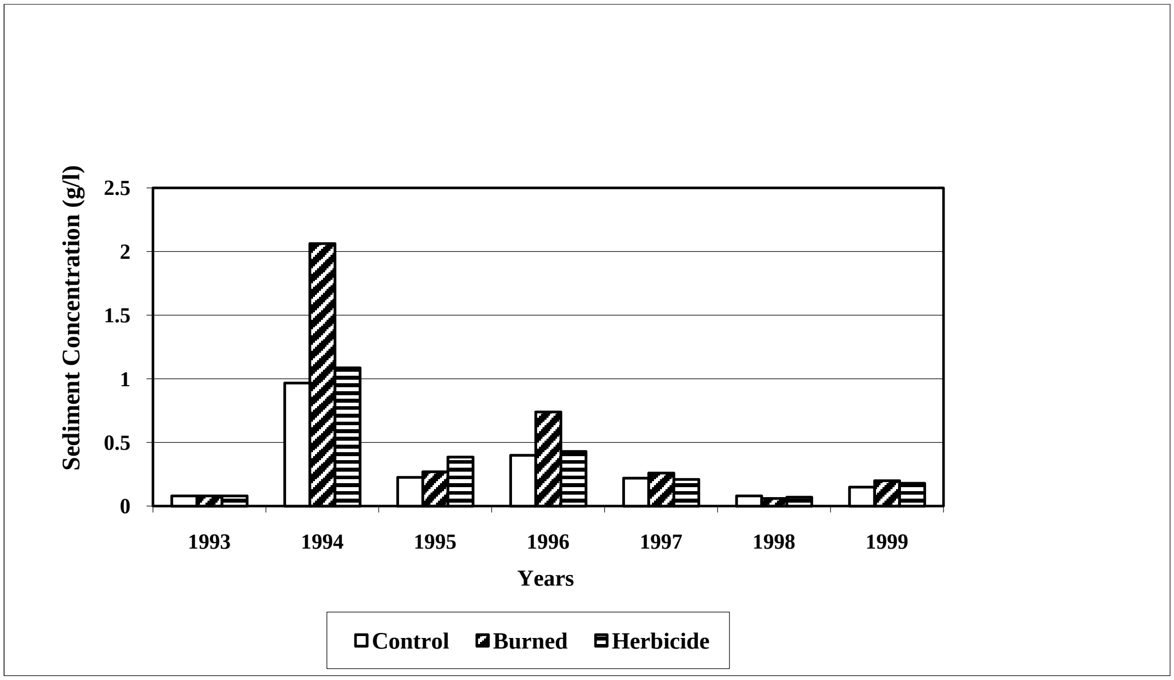

Figure 4. Sediment concentration for each treatment and year.

Total Sediment Yield

Total sediment yield is shown in Figure 5 on a logarithmic scale. Values for all years except 1996 are near or under 10 kg ha^{-1}. These values are far less than a metric tonne per hectare or what is often considered as tolerable levels for rangelands (Debano and Wood 1990). A tolerable soil loss is the maximum annual amount of soil, which can be removed before the long-term natural soil productivity is adversely affected. A value less than 6,725 kg ha^{-1} yr^{-1} is classified in the very low erosion class or tolerable. The highest total sediment yield occurred in the burned plots in 1996. This value is slightly less than a metric tonne per hectare. During this highest year of total sediment yield, the least amount of sediment came from plots that were sprayed with herbicide to kill the broom snakeweed. Means of all treatments in 1996 were significantly different.

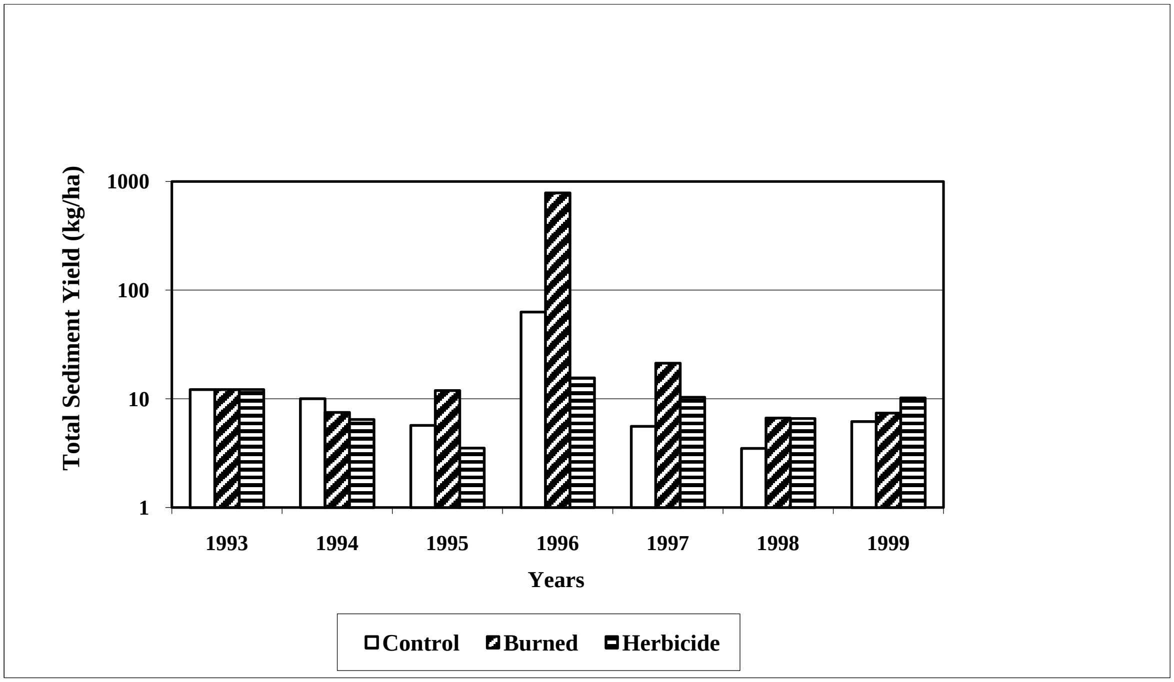

Figure 5. Total sediment yield for each year and treatment.

CONCLUSIONS

Broom snakeweed numbers significantly decreased from both burning and spraying with herbicide. However, the broom snakeweed was not eradicated, and numbers increased significantly the first year after treatment especially on burned plots.

Grass production increased and decreased through time similar to precipitation patterns. Burning resulted in slight increases in grass production for a short period after treatment. Spraying with herbicide did not result in any significant increase or decrease in grass production in any year. Forb production was more dynamic than grass production from year to year. Differences between treatments were erratic during most years.

Runoff volume was highest during a wet year following burning and lowest in a drought year following all treatments. Only one runoff event in 1996 on the burned plots was considered to be flooding. Sediment concentrations were highest during a drought on all plots, but most prominent after plots had been burned. Elevated sediment concentration levels only persisted the first year after both burns (1994 and 1996). Total sediment yield is a function of runoff volume and sediment concentration. Total sediment yield was highest during a wet year following burning.

This study was conducted on an area with significant grass and forb components in addition to broom snakeweed. Plots were adequately protected from unsustainable erosion by grasses and forbs when broom snakeweed numbers were reduced. The effects of reducing broom snakeweeds on sites with sparse other vegetation is not known. Overall, controlling broom snakeweed by burning and spraying was long lasting and not detrimental to the environment as expressed by runoff, sediment concentration, and total sediment yield.

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