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Changes in Surface Runoff and Sediment Production after Repeated Rangeland Burns

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ABSTRACT

Prescribed burning of vegetation may increase the potential for surface runoff and erosion. Changes in surface runoff and sediment production were evaluated with time following fall and spring burns at two different soil and vegetation type locations in southeastern Arizona. Rainfall simulations were conducted immediately after prescribed burns on four replicate areas and 1 yr later following a repeat burn on the same areas, and compared with paired unburned areas. The burn treatment and evaluation sequence was repeated in a second year on new areas to evaluate differences in years. After the first burn, runoff and sediment production on unburned and burned areas were similar within locations, and were greater at one location than the other. One location showed significantly more runoff and sediment production in the fall season on both unburned and burned areas after the first burn treatment. There was significantly greater runoff and sediment production from the burned areas after the second burn and the burned areas were now similar between locations. Runoff and sediment production for the fall season and for the second year on the 1-yr-old areas was higher at both locations, regardless of treatment. The increases in runoff and sediment production were greater from the burning than the season or year effects after 1 yr. The management implications for these locations and conditions are that, immediately after a rangeland burn, runoff and sediment production maybe unchanged, but within 1 yr significant increases can occur and significant seasonal and yearly differences may occur irrespective of a burn.

PRESCRIBED BURNING is a vegetation management tool that removes plant cover which has variable effects on infiltration, surface runoff and erosion (Wright et al., 1976, 1982; Roundy et al., 1978; Ueckert et al., 1978; Bosch and Hewlett, 1982; Knight et al., 1983; Lloyd-Reilley et al., 1984). Many factors such as vegetation and soil types, slope, and time and intensity of burn could account for inconsistent effects of rangeland burning on runoff and erosion. When increases in runoff and erosion were reported, the return to preburn levels was often correlated with vegetation regrowth (Wright et al., 1976, 1982; Knight et al., 1983). The correlations suggest that vegetation cover is an important factor controlling surface runoff and erosion. If so, its removal by burning should produce an immediate effect that remains as long as the vegetation is removed and other factors remain constant. Evaluations of rangeland burns on different vegetation types are needed to quantify the effect of vegetation removal on surface runoff and erosion for input to management decisions.

The variable effects reported on surface runoff and erosion from rangeland burns maybe attributed to the time of the year that evaluations are conducted and the method used. Gifford (1979), using a small Rocky Mountain infiltrometer, reported significant infiltration changes within short and long time periods after various treatments with and without burning. Achouri and Gifford (1984) and Merzougui and Gifford (1987) have reported significant spatial variability in infiltration that will also influence burn evaluation results. Thus, evaluations of rangeland burns must be repeated at distinctive times, preferably during different seasons, and cover large areas to minimize the effect of spatial variability.

The objective of this study was to evaluate the effect of repeated seasonal rangeland burns on surface runoff and sediment production with time at two rangeland sites. The approach was to burn different vegetation on different soil types in the fall and spring and evaluate with a large rainfall simulator. The study was repeated in different years.

MATERIALS AND METHODS

Study Areas

This study was conducted at the Santa Rita Experimental Range and Empire–Cienega Resource Conservation Area in southeastern Arizona, hereafter known as the Santa Rita and Empire locations. Soil at the Santa Rita location is a White House gravelly loam (fine, mixed, thermic Ustollic Haplargid) with 5 to 6% slope. The surface 10 cm contains 10 g kg^{-1} organic matter, 17% rock fragments (>2 mm), and 68, 22, and 10% sand, silt, and clay, respectively, in the <2-mm fraction. Vegetation at the Santa Rita location is dominated by an introduced grass, Lehmann lovegrass (*Eragrostis lehmanniana* Nees). The location had not been grazed for 1 yr prior to the study. Mean aboveground standing biomass for the Santa Rita location was 4170 kg ha^{-1} and litter 1650 kg ha^{-1} as estimated by clipping six 0.5-m^2 plots in each evaluation area before treatment application. The biomass clipping plots were located systematically outside the rainfall simulator plots. The Santa Rita location has an elevation of 1250 m and a mean annual precipitation of 420 mm, with 65% coming as summer thunderstorms.

Soil at the Empire location is a Hathaway gravelly sandy loam (loamy-skeletal, mixed, thermic Aridic Calciustoll) with 5 to 7% slope. The surface 10 cm contains 17 g kg^{-1} organic matter, 14% rock fragments, and 66, 22, and 12%, sand, silt, and clay, respectively, in the <2-mm fraction. The Empire site had not been grazed for 1.5 yr preceding the study and was dominated by native grasses, including black grama [*Bouteloua eriopoda* (Torrey) Torrey], hairy grama (*B. hirsuta* Lagasca), and side-oats grama [*B. curtipendula* (Michaux) Torrey]. Mean aboveground standing biomass was 2310 kg ha;$^{-1}$ and litter 420 kg ha^{-1} as estimated by clipping six 0.5-m^2 plots in each evaluation area before treatment application. The biomass clipping plots were located systematically outside the rainfall simulator plots. The Empire location has an elevation of 1430 m and mean annual precipitation is 400 mm, with 65% coming as summer thunderstorms.

Experimental Design, Procedure, and Data Analysis

Thirty-two 25 by 25 m treatment evaluation areas were established at each location and contained two 3.05 by 10.66 m rainfall simulator plots. The evaluation areas were located within each location to have as uniform slope, vegetation density, and

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Abbreviations: FTE, first treatment evaluation; STE, second treatment evaluation.

soil surface characteristics as possible. The locations were fenced to exclude grazing for the duration of the study. The treatments were unburned and burned. Paired unburned and burned treatment evaluation areas were randomly established in a four-block experimental design at each location with eight areas in each block. The block design was used to further minimize the within-location variability caused by soil, slope, and vegetation in the analysis of a treatment effect. The burning treatment was repeated for two fall and spring seasons. The two-time fall and spring burn sequence was repeated in a second year on different areas to evaluate the effect of year.

In the fall (October 1987 and 1988) and spring (April 1988 and 1989), four 25 by 25 m areas at each location were burned for the first time. The burns started with a backfire burning 3 m into the treatment evaluation area and then completed with a headfire (Wright, 1974). All the burns were conducted with winds <2.4 m s^{-1}, temperature <25 °C, and relative humidity $>20\%$. The rainfall simulator plots were then located within the headfire burn area. The aboveground biomass 1 yr after the burns was not sufficient to carry a second fire. Therefore, the second burn was conducted with a drip or propane torch to remove the aboveground biomass. Vegetation was removed with the second fire to maintain the soil in an unprotected condition, which would allow a determination of the maximum expected difference between treatments.

Rainfall simulations were conducted at each location in the fall and spring seasons on the paired unburned and burned treatment evaluation areas within each block. The simulations were conducted the same day the first and second burn treatments were applied. The burn sequence and simulations was repeated on different treatment evaluation areas in a second year. Before each simulation, 12 soil core samples were collected to 10-cm depth in each area and composited, weighed, and dried at 105 °C to determine the initial soil water before simulation. A Swanson rotating boom simulator, modified to control the number of Veejet 80100 nozzles (Spraying Systems Co., Wheaton, IL)[1] open, applied precipitation at 55 mm h^{-1} for 45 min and then at 110 mm h^{-1} for 15 min (Swanson, 1965; Simanton et al., 1985). These precipitation intensities were reported in precipitation intensity data from the Santa Rita location (1975–1978, unpublished data); hence, they were considered appropriate intensities to test the burn treatment effect on surface runoff and sediment production. Raindrop energies from the simulator are about 80% of natural precipitation (Simanton et al., 1985). Metal borders inserted into the soil prevented surface inflow and outflow on the rainfall simulator plots. At the lower plot end, a metal head wall and trough collected and directed surface runoff through a calibrated flume. Runoff rates were recorded throughout each simulation event. The time runoff started after initiation of rainfall was recorded and runoff rates were integrated for the duration of the simulation event to calculate runoff volume. The time to runoff was used as an indicator of initial infiltration and microroughness on the plots (Dunne et al., 1991). One-liter runoff–sediment samples were collected from the output of the flumes. Sampling intervals were dependent on runoff rate and ranged from 1 to 5 min, with more frequent sampling during rapidly changing runoff rate. Runoff–sediment samples were collected in tared bottles, weighed, allowed to settle, decanted, dried at 60 °C, and reweighed and sediment concentrations were calculated. Any litter material collected in the runoff–sediment samples was considered as sediment. The product of the runoff rate and sediment concentration was integrated to estimate sediment production from each rainfall simulator plot.

The statistical experimental design for data analysis was a split plot, with location as main plots. Subplots consisted of season × year factors in four blocks randomized in a complete block design. The sub-subplot factor was treatment effect of unburned vs. burned. Two sub-subplot sample data values were obtained from each treatment evaluation area, one from each rainfall simulator plot, providing a measure of subsampling error. The data was divided into first and second treatment evaluation times and analyzed separately with analysis of variance techniques. The first evaluation time consisted of data collected after the first burn treatment (FTE). The second evaluation time was data collected 1 yr after the FTE and a second burn treatment (STE). Separating the data into evaluation times allowed the statistical analysis to focus more on differences between the unburned and burned treatments. On the divided data, location and treatment means were tested for homogeneity of variances and separated if necessary on that basis. The sub-subplot sample variance was significantly less than the split error term. Therefore, the appropriate split-plot error terms were used to test all effects. Main effects were either pooled or separated depending on the significance of the interactions ($P \leq 0.05$). Effects with time were evaluated by comparison of treatment means between FTE and STE.

Table 1. Two-year first treatment evaluation (FTE) average surface runoff, sediment production, and time to runoff on unburned and burned areas after fall and spring burns at two locations in southeastern Arizona.

	Surface runoff		Sediment production		Time to runoff	
Treatment	Fall	Spring	Fall	Spring	Fall	Spring
	—— mm ——		— kg ha^{-1} —		—— min ——	
			Santa Rita location			
Unburned	2.42a†	1.91a	20.5a	30.2a	16.5a	20.1a
	(1.24)‡	(1.03)	(16.1)	(13.3)	(8.7)	(7.2)
Burned	1.56a	2.05a	29.1a	40.1a	16.3a	20.4a
	(1.03)	(1.03)	(13.1)	(13.1)	(8.7)	(8.7)
			Empire location			
Unburned	13.9a	4.7b	162a	87b	6.3a	17.9b
	(4.2)	(4.2)	(59)	(59)	(3.6)	(3.6)
Burned	19.8a	8.1b	292a	112b	5.0a	13.9b
	(4.5)	(4.5)	(63)	(63)	(3.9)	(3.9)

† Values within location for runoff, sediment, or time followed by the same letter are not significantly different ($P = 0.05$). Statistical separations for season effect presented here were performed on pooled treatment data within location, as there was no treatment effect.

‡ Values in parentheses are standard errors.

RESULTS AND DISCUSSION

The FTE runoff and sediment production variances for the two locations were significantly different, hence the locations were analyzed separately. The analysis of variance indicated that both locations had no treatment effect or interaction between season and year for surface runoff, sediment production, and time to runoff. Table 1 presents FTE fall and spring unburned and burned area means for surface runoff, sediment production, and time to runoff. The absence of a significant burn effect can be seen in the means of these variables. Simanton et al. (1991) found similar results of no significant effect on runoff and erosion immediately after clipping to remove aboveground standing biomass. The absence of a treatment effect on the burned areas was probably influenced by observed microdebris dams that formed between grass crowns. Surface runoff water transported small amounts of remaining biomass material to form the dams. These dams retarded runoff and sediment transport and protected the soil surface from raindrop impact, which probably contributed to a lack of a treatment effect.

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[1] Mention of trade names or proprietary products does not indicate endorsement by USDA, and does not imply its approval to the exclusion of other products that may also be suitable.

Table 2. Two-year second treatment evaluation (STE) average surface runoff, sediment production, and time to runoff on unburned and burned areas after fall and spring burns at two locations in southeastern Arizona.

	Surface runoff		Sediment production		Time to runoff	
Treatment	Fall	Spring	Fall	Spring	Fall	Spring
	—— mm ——		— kg ha^{-1} —		—— min ——	
			Santa Rita location			
Unburned	1.91a† (0.50)‡	1.09a (0.50)	26.5a (7.4)	15.6a (7.4)	13.3a (4.5)	7.8a (4.5)
Burned	20.9a (2.7)	13.2b (2.7)	392a (83)	391a (83)	5.8a (0.63)	6.7a (0.63)
			Empire location			
Unburned	10.2a (2.6)	5.3a (2.4)	133a (33)	103a (31)	10.2a (5.8)	11.0a (5.4)
Burned	26.9a (2.7)	14.4b (2.7)	591a (83)	440a (83)	5.0a (0.63)	5.2a (0.63)

† Values within row for runoff, sediment, or time followed by the same letter are not significantly different ($P = 0.05$). Unburned treatment statistical separations presented here for the season effect were performed within location as the variances were different and burned treatment separations for season effect were performed on pooled data between locations.

‡ Values in parentheses are standard errors.

Table 3. Two-season second treatment evaluation (STE) average surface runoff, sediment production, and time to runoff on unburned and burned areas after 1988 and 1989 burns at two locations in southeastern Arizona.

	Surface runoff		Sediment production		Time to runoff	
Treatment	1988	1989	1988	1989	1988	1989
	—— mm ——		— kg ha^{-1} —		—— min ——	
			Santa Rita location			
Unburned	0.90a† (0.50)‡	2.10a (0.50)	8.0a (7.4)	34.1b (7.4)	15.6a (4.5)	5.5a (4.5)
Burned	15.4a (2.7)	18.7a (2.7)	249a (83)	534b (83)	8.3a (0.63)	4.3b (0.63)
			Empire location			
Unburned	5.6a (2.6)	9.3a (2.4)	76a (33)	154a (31)	17.7a (5.8)	4.5a (5.4)
Burned	19.1a (2.7)	22.2a (2.7)	389a (83)	642b (83)	5.6a (0.63)	4.7b (0.63)

† Values within row for runoff, sediment, or time followed by the same letter are not significantly different ($P = 0.05$). Unburned treatment statistical separations presented here for the year effect were performed within location as the variances were different and burned treatment separations for year effect were performed on pooled data between locations.

‡ Values in parentheses are standard errors.

The two locations could not be compared directly at the FTE because of the differences in variances. The Empire location was considered to have significantly higher surface runoff, sediment production, and shorter time to runoff than the Santa Rita location, because of the large differences (Table 1). The location differences were not caused by the differences in aboveground vegetation, as the burned areas showed the same difference as the unburned areas. Other factors that could account for the location differences are soils, soil water, and belowground biomass. The mean initial soil water at the locations was similar, as the Santa Rita location had 52 g kg^{-1} and the Empire 60 g kg^{-1}. The measured surface soil characteristics at the two locations were similar, but the Hathaway soil at the Empire location contains carbonates that may seal the surface, thus causing increased runoff and sediment production.

Significantly higher runoff, sediment production, and shorter time to runoff were found on both unburned and burned areas in the fall compared with the spring season for FTE at the Empire location (Table 1). Other studies have found higher infiltration rates in the spring season (Achouri and Gifford, 1984; Schumm and Lusby, 1963; Simanton and Renard, 1982; Tricker, 1981). Seasonal differences in infiltration have been postulated to result from frost action and soil biological activity (Achouri and Gifford, 1984; Simanton and Renard, 1982). Frost action observed on the Hathaway soil surface at the Empire location probably contributed to the lower spring runoff and sediment production. The spring rainfall simulations were on a soil surface loosened by the frost action. Raindrop impact energy from summer thunderstorms would compact the surface soil by the fall season and fill the surface soil pores to reduce infiltration rates (Smith et al., 1990).

The STE unburned areas from Santa Rita location showed similar runoff, sediment production, and time to runoff as the FTE (Tables 1 and 2). The STE Empire location unburned data exhibited the same seasonal changes in runoff, sediment production, and time to runoff as the FTE data did, but the seasonal effect was not significant. The absence of a seasonal effect was attributed to the smaller number of data values in the STE analysis, as the burned data was not pooled with the unburned data because the variances were different.

The STE data contained similar variances for the burned treatment at both locations and different variances for the unburned treatments. This resulted in the unburned treatment data from each location being analyzed separately and the burned treatment data from both locations analyzed together. The STE burned data showed a significant increase in surface runoff in the fall season (Table 2). The burned treatment also tended to have higher sediment production and shorter time to runoff in the fall, but the difference was not significant. The burned treatment had a significant year effect, with increased sediment production and decreased time to runoff in 1989 (Table 3). A year effect was also evident in the unburned data, with increased surface runoff and sediment production and decreased time to runoff in year 1989. Higher runoff and sediment production and shorter time to runoff for the STE data in 1989 was reasoned to result from differences in summer precipitation (June–September). Summer precipitation in 1988 at the Santa Rita and Empire locations was 305 and 297 mm, respectively, while in 1989 it was 84 and 106 mm. The lower than normal precipitation in the summer of 1989 left sediment on the soil surface that would have normally been transported off site in summer runoff events. This available sediment was transported during the rainfall simulations and produced the higher sediment in 1989 STE data. Initial soil water and aboveground biomass could account for the year effect; however, the soil water and biomass were similar (Table 4).

The variance differences in the STE data prevented a direct statistical comparison of the unburned and burned areas for a treatment effect. The STE data indicated a substantial increase in surface runoff, sediment produc-

Table 4. Two-season second treatment evaluation (STE) average soil water and total biomass in 1988 and 1989 at two locations in southeastern Arizona.

Treatment	Soil water 1988	Soil water 1989	Total biomass 1988	Total biomass 1989
	g kg^{-1}		kg ha^{-1}	
		Santa Rita location		
Unburned	61 (25)†	43 (12)	5200 (1370)	5000 (1100)
Burned‡	54 (23)	32 (18)	1300 (750)	1100 (410)
		Empire location		
Unburned	64 (20)	65 (40)	2400 (410)	2200 (770)
Burned	61 (9)	49 (28)	900 (300)	800 (320)

† Values in parentheses are standard deviations.
‡ Data for the burned treatment collected before the second burn.

tion, and decrease in time to runoff for the burned areas compared with the unburned at both locations and were considered significant (Table 2 and 3). The burned areas showed increases in runoff and sediment production, and decreased time to runoff, from the FTE to the STE; the differences were considered significant (Tables 1 and 2). The burned areas also changed from being significantly different between locations at the FTE to similar between locations at the STE.

The increased surface runoff and sediment production on the STE burned areas was attributed to soil surface morphological changes during the 1-yr time period. Litter and aboveground standing biomass serves to maintain high infiltration rates by protecting the soil surface aggregates and structure from destruction by raindrop impact, thus reducing crust formation (Thurow et al., 1986; Smith et al., 1990). Reductions in soil aggregate sizes after a burn has been shown to occur and persist for >5 yr (Ueckert et al., 1978). Infiltration under tree and shrub canopies and interspace areas in a pinyon–juniper woodland plant community after a prescribed burn was unaffected and sediment production increased from the canopy areas (Roundy et al., 1978). One year later in the unprotected canopy areas, infiltration decreased and sediment production significantly increased over unburned canopy areas while interspace areas remained unchanged. Canopy removal in the woodland plant community and repeated rangeland burning in this study maintained the soil surface free of cover and permitted raindrop impact energy to influence the soil surface structure. If a soil aggregate destruction process occurred on the burned areas, it occurred with time, as runoff, sediment production, and time to runoff from the FTE burned areas were unaffected, while the STE 1-yr-old burned areas had significant changes (Tables 1, 2, and 3).

Less impedance to runoff and sediment transport probably contributed to increased runoff, sediment production, and decreased time to runoff on the burned areas. The observed microdebris dams that formed on the burned areas at the FTE were almost nonexistent at the STE. The absence of these dams reduced the impedance to surface runoff and sediment production. A separate study in the same area that removed all aboveground biomass before the summer rains showed there was less soil water in the soil profile compared with an undisturbed area 48 h after a 55-mm precipitation event (Cox et al., 1992). The lower soil water was attributed to the lack of obstacles (i.e., standing biomass and litter) that would slow surface runoff and enhance infiltration.

SUMMARY AND CONCLUSIONS

Based on the FTE of the unburned and burned areas, surface runoff and sediment production were significantly different at the two locations. The FTE conducted immediately after the burn showed no effect of burning on runoff and sediment production. This result indicated that aboveground vegetation by itself was not controlling surface runoff and sediment production, as there was no treatment effect on the FTE burned areas with the vegetation removed.

The STE on 1-yr-old areas at the two locations show significant increases in surface runoff and sediment production from the burned areas compared with the unburned. The burned areas that were significantly different between the two locations at the FTE were similar at the STE. The implications of these results was that soil surface structure was probably the primary factor controlling surface runoff and sediment production, while vegetation functioned to protect and interact with the soil surface to preserve high infiltration rates. This agrees with other researchers who have emphasized the importance of vegetation and litter cover in preserving infiltration capacity and soil surface structural stability (Meeuwig, 1970; Thurow et al., 1986).

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