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ESTIMATING PRESCRIBED BURN IMPACTS ON SURFACE RUNOFF AND WATER QUALITY IN SOUTHEASTERN ARIZONA

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ABSTRACT: Prescribed burning of rangeland vegetation may substantially increase the potential for surface runoff, erosion, and cause a change in the ecosystem because of the loss of nutrients. Burning effects on surface runoff, sediment yield, and nutrient dynamics were evaluated with a large rainfall simulator following fall and spring burns at two different soil and vegetation type locations. Soil, aboveground biomass, and surface runoff samples were analyzed for nitrogen, phosphorus, and potassium to determine the nutrient pool sizes. Rainfall simulations were conducted after prescribed burns of four replicate areas and one year later following a repeated burn on the same areas. Results were compared with paired unburned areas. The complete study was replicated in a second year to evaluate differences in years. One year later and with the repeated burn, surface runoff, sediment yield, and nutrient loss became significantly greater than the unburned treatment. Surface runoff, sediment yield, and nutrient loss were controlled primarily by the soils and the soils interacting with the vegetation. Significant season and year effects were found for runoff, sediment yield, and nutrient loss irrespective of the burn treatment. The burning effects were much greater than the season or year effects one year after the first burn. The nutrient dynamics showed the magnitude of the nutrient pools to be soil>>>biomass>>surface runoff losses, implying there could be many burns before a significant amount of nutrient would be depleted from the soil, potentially changing the ecosystem. These results are important for understanding fire as a management tool at these and similar locations, and how fire impacts rangeland water resources. The research is continuing to determine the long term impacts of the burns on the resources.

KEY TERMS: fire; NPK; nutrient transport; grassland

INTRODUCTION

Prescribed burning is a vegetation management tool that removes plant cover and affects infiltration, surface runoff, erosion and nutrient dynamics (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; Emmerich and Cox, 1994). Factors such as vegetation, soil type, slope, and time and intensity of a burn could account for the effects of rangeland burning on surface runoff, erosion, and nutrient dynamics. After increases in surface runoff, erosion, and nutrient transport from a rangeland burn, the return to preburn levels has been correlated to regrowth of vegetation (Wright et al., 1976, 1982; Knight et al., 1983). This correlation suggests that vegetation cover is an important factor controlling surface runoff, erosion, and nutrient transport. If so, removal of cover by a prescribed burn should produce an immediate effect that remains as long as the vegetation is removed.

The management objectives of prescribed burns are to increase herbage yields, utilization and availability, improve wildlife habitat, control undesirable shrubs, and prepare a mineral seedbed for germination (Wright, 1974; Stoddart et al., 1975). A burn increases forage yields through the release of nutrients and reduced shrub competition (Cook et al., 1994). Burns also cause loss of nutrients through increased surface runoff and volatilization to the atmosphere. The extent of the volatilization loss is related to the specific nutrient, moisture content of the soil at burning, and the intensity of the burn (Ralson et al., 1985; Biederbeck et al., 1980; DeBano et al., 1979). Along with the increase in runoff and erosion, nutrient concentrations can increase both in the runoff water and sediment, significantly influencing the quality of runoff from burned areas (Buckhouse and Gifford, 1976; Tiedemann et al., 1978; Saà et al., 1994). Nitrogen and phosphorus losses have been shown to be predominately associated with sediment losses (Smith et al., 1983).

A burn influences soil nutrient status by direct addition of some nutrients and loss of nitrogen. Ash deposition of nutrients can increase availability of nutrients in the soil (Marion et al., 1991; Knighton, 1977), while other studies have indicated there is limited change in nutrient status (Sharrow and Wright, 1977; Griffin and Friedel, 1984). The burn intensity

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influences the amount of nutrient deposited onto and lost from the soil (Marion et al., 1991; DeBano et al., 1979). The intensity also influences soil microbial populations which control nitrogen availability and transformations (Dunn et al., 1979). These changes in surface runoff, erosion, and nutrient dynamics could influence vegetation regrowth and change the ecosystem.

In fragile semiarid rangeland environments where nutrient inputs from precipitation are minimal and fertilization impractical, information on nutrient dynamics associated with burning is needed for management decisions. The objectives of this study were to : 1) evaluate preburn pools of nitrogen, phosphorus, and potassium (NPK) in two different soil-vegetation communities; 2) determine changes in surface runoff, sediment yield, and the potential for loss of NPK in surface runoff and sediment following fall and spring burns; 3) measure changes in soil and aboveground biomass NPK status and; 4) repeat the study in different years to evaluate year to year variability.

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 Haplargids) with 5 to 6% slope. The surface 10 cm contained 10 g kg^{-1} organic matter, 17% rock fragments (>2mm), and 68 % sand, 22% silt, and 10% clay in the <2mm 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 a year 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 Calciustolls) with 5 to 7% slope. Surface 10 cm contained 17 g kg^{-1} organic matter, 14% rock fragments, and 66% sand, 22% silt, and 12% clay in the <2mm fraction. The Empire site had not been grazed for 1.5 years preceding the study and was dominated by native grasses, including black grama [*Bouteloua eriopoda* (Torrey) Torrey], hairy grama (*Bouteloua hirsuta* Lagasca), and sideoats grama [*Bouteloua 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 each treatment evaluation area contained two, 3.05 by 10.66-m rainfall simulator plots. The evaluation areas were located within each location to keep slope, vegetation density, and soil surface characteristics as uniform 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 repeated fall and spring burn sequence was started in a second year on different areas to evaluate the year to year variability.

Starting in the fall 1987 (October) and spring (April), 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 one year 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 for a determination of the maximum expected difference between treatments and give an estimate of the maximum surface runoff, erosion, and changes in nutrient dynamics.

Before the burns, standing biomass and litter samples were collected from six 0.5 x 1.0 m plots on each treatment evaluation area. Aboveground standing biomass was separated into standing live and dead based on color. The standing biomass and litter samples were then oven dried at 65°C to a constant weight, weighed, and total biomass calculated for each plot. Standing live, dead, or litter from the six plots was composited and ground for analysis. Three subsamples from each component of biomass were digested according to Technicon procedure No. 376-75W/B for total N and P analysis and with

4.0N. HNO_3 acid for K analysis. A Technicon AutoAnalyzer II and method No. 329-74W/B was used to analyze the samples for total N and P and a Perkin-Elmer 5000 atomic absorption spectrophotometer for total K. The average concentration from the three subsamples and the average calculated biomass from the six plots was used to calculate concentration and total NPK in each component of biomass on each treatment evaluation area on a kg ha^{-1} basis.

Before the burns, soil samples were collected on each of the six biomass plots with a 5.4 cm diameter soil coring tool to a depth of 30 cm. Soil cores were taken through the largest grass crown and in the middle of the largest interspace area of each plot. The soil core samples represented both soil and belowground biomass nutrients and were sectioned into 10 cm increments and composited by depth and cover. The soil samples were frozen in the field to preserve the nutrients. Triplicate subsamples were digested according to Technicon procedure No. 376-75W/B and analyzed for total N and P with Technicon AutoAnalyzer II using method No. 329-74W/B. Ammonium, NO_3^{-1}, PO_4^{-3}, and K^+ in deionized water saturation extracts (Richards, 1954) of the soil samples were analyzed using a Technicon AutoAnalyzer II and methods No. 98-70/WA, No. 100-70W, and No. 155-71W, respectively, and with a Perkin-Elmer 5000 atomic absorption spectrophotometer for K. Total N and P and NH_4^+, NO_3^{-1}, PO_4^{-3}, and K^+ were calculated for each 10 cm increment on a kg ha^{-1} 10 cm^{-1} basis. Subsamples of the soil core samples were weighed, and dried at 105 °C to determine the initial soil water.

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. A Swanson rotating boom simulator modified to control the number of veejet 80100 nozzles (Spraying Systems Co., Wheaton, IL) open applied precipitation at 55 mm hr^{-1} for 45 min and then at 110 mm hr^{-1} for 15 min (Swanson, 1965; Simanton et al., 1985). A rain sample was collected for each simulation and analyzed for nutrient ions using the same methods as the soil extracts. Six small raingauges on each simulator plot measured the actual precipitation for each simulation. The average total precipitation for all simulation events was 70.5 mm with a standard deviation of 2.3 mm. The small uncontrollable variation in applied precipitation was considered to be random and part of the natural variability of the plots to be overcome in the determination of a treatment effect. Precipitation intensities of 55 mm hr^{-1} for 45 min and 110 mm hr^{-1} for 15 min were reported in precipitation intensity data from the Santa Rita location (unpublished data, 1975-1988), hence, they were judged appropriate intensities to test the burn treatment effect on surface runoff, sediment yield, and nutrient dynamics. 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. One liter runoff-sediment-nutrient samples were collected from the outlet 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-nutrient samples were collected in tared bottles, weighed, allowed to settle, decanted, dried at 60 °C to constant weight, reweighed and sediment concentrations calculated. Any litter material collected in the runoff-sediment-nutrient samples was analyzed as sediment. The product of the runoff rate and sediment concentration was integrated to estimate sediment yield from each rainfall simulator plot. The dried sediment was analyzed for total N and P using the same procedures and methods as the soil samples. The product of runoff rate, sediment concentration, and nutrient concentration in the sediment was integrated for the duration of the simulation event to estimate total N and P transported associated with sediment and referred to as sed-N and sed-P. Subsamples of the runoff water were collected from the runoff-sediment-nutrient samples and analyzed for NH_4^+, NO_3^{-1}, PO_4^{-3}, and K^+ using the same methods and procedures as the soil extracts. The product of runoff rate and nutrient ion concentration minus rainfall concentration was integrated for the duration of the simulation event to estimate nutrient transport in the runoff water. Total N and P transported was calculated as the sum of the nutrient ions plus sediment associated nutrient.

The statistical experimental design for data analysis was a split plot with location as main plots. Subplots consisted of season by 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 for runoff, sediment, and nutrients 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 with the first burn treatment and will be referred to as the first treatment evaluation (FTE). The second evaluation time was data collected one year after the FTE and a second burn treatment and referred to as the second treatment evaluation (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.

RESULTS AND DISCUSSION

Surface Runoff, Sediment Yield, Nutrient Loss

The FTE runoff, sediment yield, and nutrient ions and sediment associated nutrient 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 and sediment yield. At the Empire location runoff and sediment yield were greater in the fall season (Table 1). For the nutrient ions and sediment associated nutrients, the Empire location had greater K loss from the burn treatment (Table 1). Phosphate had a season by treatment interaction with greater loss in the fall season from the burn treatment and K, NO_3, sed-P, total P had greater loss in the fall while sed-P also had a greater loss in the second year. The Santa Rita location did not have any significant treatment effects, but K, sed-N, sed-P, total N, and total P had significant year by season interaction. The absence of a significant burn effect can also be seen in the means of the variables (Table 1). In a study where clipping instead of fire was used to remove standing vegetation, Simanton et al.(1991) found similar results of no significant effect on runoff and erosion immediately after clipping.

Table 1. First treatment evaluation (FTE) average surface runoff, sediment yield, K loss in runoff, and total N&P loss in runoff-sediment from unburned and burned areas after fall and spring burns at Santa Rita and Empire locations.

Treatment	Surface Runoff		Sediment Yield		K Loss		Total N Loss		Total P Loss	
	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring
	------ mm ------		-------------------- kg ha^{-1} --------------------							
					Santa Rita Location					
Unburned	2.42a[1]	1.91a	20.5a	30.2a	0.04[3]	0.05	0.02[3]	0.05	0.01[3]	0.02
	(1.24)	(1.03)	(16.1)	(13.3)	(0.04)	(0.03)	(0.04)	(0.03)	(0.01)	(0.01)
Burned	1.56a	2.05a	29.1a	40.3a	0.05	0.08	0.07	0.13	0.02	0.03
	(1.03)	(1.03)	(13.1)	(13.1)	(0.03)	(0.03)	(0.03)	(0.03)	(0.01)	(0.01)
					Empire Location					
Unburned	13.9a	4.7b	162a	87b	0.20a	0.10b	0.29a	0.20a	0.06a	0.03b
	(4.2)	(4.2)	(59)	(59)	(0.14)	(0.14)	(0.18)	(0.18)	(0.04)	(0.04)
Burned	19.8a	8.1b	292a	112b	0.98a	0.30b	0.84a	0.44a	0.25a	0.08b
	(4.5)	(4.5)	(63)	(63)	(0.15)	(0.15)	(0.19)	(0.19)	(0.05)	(0.05)

[1] Values within location for runoff, sediment, K, Total N, or Total P followed by the same letter are not significantly different (P=0.05). Statistical separations for season effect presented were performed on pooled treatment data within location, as there were no treatment effects, except for greater K on the burned treatment at the Empire location.

[2] Values in parentheses are standard errors for treatment.

[3] Had significant season by year interaction.

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, probably contributing to a lack of a treatment effect through increased spatial and temporal variability. For the nutrients the lack of a detectable loss increases was due primarily to spatial and temporal variability in surface runoff and sediment yield. Large nutrient and sediment yield variability has been observed in other cropland and rangeland environments (Menzel et al., 1978). The driving force for nutrient loss is the volume of runoff and sediment yield. The measured increase in runoff and sediment was not large enough to overcome the natural variability to produce a consistent treatment effect for the nutrients. Even the deposition of nutrients on the soil surface from the burn treatment did not overcome the variability, to produce a treatment effect. The conclusion was made, that immediately after a burn, changes in runoff, sediment yield, and nutrient loss are not significant and that the vegetative cover by itself is not the dominate factor controlling runoff, erosion, and nutrient loss. The dominate factors influencing runoff, erosion, and nutrient loss at the FTE were the differences between years and seasons.

The two locations could not be compared directly at the FTE because of the differences in variances. The Empire location was judged to have significantly higher surface runoff, sediment yield, and nutrient loss than the Santa Rita location, because of the large differences between locations (Table 1). The location differences were not caused by the differences in aboveground vegetation as the burned areas showed the same difference between locations as the unburned areas. Other factors that could account for the location differences were soils, soil water content, and belowground biomass. The mean initial soil water content at the locations were 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 contained carbonates that may seal the surface thus causing increased runoff, sediment yield, and nutrient loss.

The STE data contained similar variances for the burned treatment at both locations for runoff and sediment, but 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 being analyzed together. The nutrient data was analyzed within location. The STE unburned areas at the locations generally showed similar runoff, sediment yield, and nutrient loss as the FTE, except the seasonal effect was not significant (Tables 1 & 2). The STE burned data showed a significant increase in surface runoff and K loss in the fall season (Table 2). In general the runoff, sediment yield, and nutrient loss was greater in the fall. Other studies have found higher infiltration rates in the spring season and have been postulated to result from frost action and soil biological activity (Achouri and Gifford, 1984; Tricker, 1981). Frost action most likely occurred at the locations and probably contributed to the lower spring runoff, sediment yield, and nutrient loss. The spring rainfall simulations were on a soil surface with opened pores caused 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).

Table 2. Second treatment evaluation (STE) average surface runoff, sediment yield, K loss in runoff, and total N&P loss in runoff-sediment from unburned and burned areas after fall and spring burns at Santa Rita and Empire locations.

Treatment	Surface Runoff		Sediment Yield		K Loss		Total N Loss		Total P Loss	
	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring
	------ mm ------		------ kg ha^{-1} ------							
					Santa Rita Location					
Unburned	1.91a[1]	1.09a	26.5a	15.6a	0.04a	0.02a	0.04a	0.03a	0.01a	0.01a
	(0.50)[2]	(0.50)	(7.4)	(7.4)	(0.10)	(0.10)	(0.39)	(0.39)	(0.09)	(0.09)
Burned	20.9a	13.2b	392a	391a	0.84a	0.28b	1.75a	1.93a	0.43a	0.37a
	(2.7)	(2.7)	(83)	(83)	(0.10)	(0.10)	(0.39)	(0.39)	(0.09)	(0.09)
					Empire Location					
Unburned	10.2a	5.3a	133a	103a	0.20a	0.09a	0.26a	0.21a	0.06a	0.05a
	(2.6)	(2.4)	(33)	(31)	(0.18)	(0.17)	(0.49)	(0.45)	(0.08)	(0.04)
Burned	26.9a	14.4b	591a	440a	1.25a	0.37b	2.45a	1.41a	0.49a	0.28a
	(2.7)	(2.7)	(83)	(83)	(0.17)	(0.17)	(0.45)	(0.45)	(0.08)	(0.08)

[1] Values within location for runoff, sediment, K, Total N, or Total P followed by the same letter are not significantly different (P=0.05). Unburned treatment statistical separations for runoff and sediment presented here for the season effect were performed within location as the variances were different and burned treatment separation for season effect were performed on pooled data between locations. Separations for K, total N&P were performed on pooled treatment data within location.
[2] Values in parentheses are standard errors for treatment.

The variance differences for surface runoff and sediment yield 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 and sediment yield from the burned areas compared to the unburned at both locations and were judged significant (Table 2). At the Empire location all the nutrient forms had significantly greater losses from the burn treatment, except K which had a season by treatment interaction with significantly greater loss in the fall season on the burn treatment. At the Santa Rita location, K had a season by treatment interaction, NO_3 and NH_3 had year by treatment interaction, and PO_4 and sediment associated nutrients showed significantly greater losses from the burn treatments. The K, NO_3 and NH_3 nutrients had significantly greater loss on the burn treatment in the fall season or second year. The burned areas showed increases in runoff, sediment yield, and nutrient loss from the FTE to the STE, and many were judged significant (Tables 1 & 2). The burned areas also changed from being significantly different between locations at the FTE, to similar between locations at the STE for runoff, sediment yield, and nutrient loss. The driving forces of runoff and sediment yield for nutrient transport were now significantly greater on the burn treatment. A correlation between runoff and sediment yield and the loss of nutrients has been observed for other soil and vegetation types (White et al., 1977; Schuman et al., 1973). A change in nutrient concentrations could increase loss, but a calculation of nutrient concentrations based on nutrient loss and the runoff volume or sediment amount indicated slight increases in concentrations from the burns.

The increased surface runoff, sediment yield, and nutrient loss on the STE burned areas may be attributed to soil surface morphological changes during the one year time period after the burn. Litter and aboveground standing biomass serves to maintain high infiltration rates by protecting the soil surface aggregates and structure from destruction by raindrop impact and 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 longer than 5 years (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 yield increased from the canopy areas (Roundy et al., 1978). One year later in the unprotected canopy areas, infiltration decreased and sediment yield 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 yield, and associated nutrient loss from the FTE burned areas were unaffected, while the STE year-old burned areas had significant changes (Tables 1 & 2).

Nitrogen and P were transported predominately with the sediment. Means for the Empire location plots showed FTE had 99% of the total N and 82% of the total P transported in the runoff water associated with the sediment and 99% and 86%, respectively for the STE. The Santa Rita location FTE had 103% of the total N and 76% of the total P associated with the sediment and 100% and 86%, respectively for the STE. The 103% N resulted from the absorption of NO_3 from the rain water during runoff resulting in a calculated negative concentration in the runoff. This reduced the total sum of the N forms transported to less than that in the sediment. Both NO_3 and to a lessor extent NH_4 were absorbed from the rain water by the soil at both locations during the evaluations. Since a large percentage of the transported N and P is associated with the sediment, measuring sediment removals and associated nutrient would produce a good estimate of total nutrient transport.

Biomass Nutrients

The two locations were separated for statistical analysis of biomass types and nutrient content. At the FTE time there was no difference in the amount of biomass types on the treatment plots. One year later at the STE the unburned plots were significantly greater in biomass types, except the standing live biomass at the Santa Rita location. The standing live biomass at the Santa Rita location had a year by season by treatment interaction and the unburned treatment was greater only in one year and fall season.

The FTE nutrient concentrations and total nutrient in the different biomass types at the locations had significant year, season, and treatment main effects and interactions among them. The significant treatment effects within the interactions or as a main effect were not easily explainable and were attributed to random variation. The standing live biomass was the most important to test for a treatment effects on nutrient concentration at the FTE, because the live biomass would be the most likely to respond in the regrowth from the burn treatment at the STE. The Santa Rita location had a season by treatment interaction for N concentration in the standing live biomass. The unburned treatment was higher in the spring with 14.1 vs 11.9 mg N g^{-1} for the burned. There were no other significant treatment effects for nutrient concentrations or total nutrient in the standing live biomass.

The STE total nutrients in litter and standing dead was significantly greater in the unburned treatment at both locations due primarily to the small amount of biomass on the burned plots (Table 3). The total N and K nutrient in the standing live at the Empire location was significantly greater in the unburned treatment, but burned treatment was at least 65% of the unburned treatment. For P, the unburned treatment was greater only in the fall season. The total NPK nutrient in the standing live biomass at the Santa Rita location had year by season by treatment interaction. The total N and K in the standing live biomass was greater in the unburned treatment only in the fall season and one year, while the burned treatment was greater in the fall and spring in the other year. For P the unburned treatment was greater only in the fall season in one year.

Table 3. Santa Rita and Empire location second treatment evaluation (STE) mean NPK nutrient in litter, standing live, and standing dead biomass on unburned and burned treatments.

Nutrient	UNBURNED			BURNED		
	Litter	Standing Live	Standing Dead	Litter	Standing Live	Standing Dead
	---------- kg ha^{-1} ----------					
			Santa Rita			
K	1.33a[1] (0.10)[2]	4.31[3] (0.35)	3.11a (.033)	0.01b (0.01)	5.01 (0.54)	1.29b (0.24)
N	10.66a (1.13)	5.26[3] (0.57)	20.32a (1.68)	0.09b (0.08)	6.72 (0.78)	4.30b (0.80)
P	0.737a (0.09)	1.53[4] (0.27)	1.94a (0.20)	0.004b (0.004)	1.19 (0.11)	0.59b (0.15)
			Empire			
K	0.64a (0.09)	2.80a (0.34)	1.95a (0.19)	0.04b (0.02)	1.83b (0.24)	0.87b (0.09)
N	3.98a (0.53)	4.29a (0.48)	10.96a (1.12)	0.17b (0.10)	3.05b (0.41)	3.62b (0.56)
P	0.30a (0.05)	0.67[5] (0.12)	1.04a (0.10)	0.01b (0.01)	0.45 (0.07)	0.38b (0.11)

[1] Values within row and biomass type followed by the same letter are not significantly different ($P=0.05$).

[2] Values in parentheses are standard error n=16.

[3] K & N Had year by season by treatment interactions, the unburned treatment was greater in the fall season and one year, while the burned treatment was greater in the fall and spring in the other year.

[4] P Had a year by season by treatment interaction, the unburned treatment was greater only in the fall season in one year.

[5] P Had a season by treatment interaction, the unburned treatment was greater only in the fall season.

The STE nutrient concentrations in litter and standing dead biomass at both locations had all combinations of significant interactions, and season and treatment main effects. The significant litter concentrations were almost exclusively greater in the unburned treatment. The small amount of litter that formed on the burn treatment was the first regrowth and was easily leached of nutrients. The significant standing dead concentrations were almost exclusively greater in the burned treatment. The new standing dead biomass on the burn treatment had only a short time to be leached of nutrients, hence the higher concentrations.

The nutrient concentrations in the standing live biomass at STE was expected to be most responsive to the treatment. The Santa Rita location NPK nutrient concentration had significant season by treatment and year by treatment interactions, except for K which did not have the year by treatment, but a year effect. The N and K concentrations were significantly greater on the burned treatment in the fall but less in the spring and K was significantly greater in one year only, while N was greater in one year and on the burned treatment. The P concentration was significantly greater in the spring on the burned treatment and in one year on the unburned treatment. The significantly greater N on the unburned treatment in the spring with the season by treatment interaction was the same result as at the FTE and could be unique to those treatment areas. For the Empire location STE standing live biomass, only K concentration was significantly greater on the unburned treatment.

One of the objectives in conducting rangeland burns is to improve the quality of the vegetation by releasing nutrients for increased uptake in regrowth (Stoddart et al., 1975; Wright, 1974). At the STE the total aboveground biomass was significantly less on the burned treatment, and regrowth of biomass was 23% of the unburned treatment at the Santa Rita location and 38% at the Empire. A calculation of the total amount of NPK in the aboveground biomass on the burn treatment at the STE ranged from 31% to 72% of the unburned treatment at the two locations. There was a general increase in the nutrient quality of the new biomass, as a higher percentage of the total nutrient was in a smaller percentage of the biomass. Only at Santa Rita location was there a significant increase in standing live nutrient concentrations on the burn treatment. The increases were not consistent throughout the study with the significant year and season interactions with treatment, as there were significantly greater unburned and burned treatment nutrient concentrations. In a mountain-shrub burn there was consistently greater crude protein in the herbaceous regrowth for two years after the burn (Cook et al., 1994). Total N and P in the regrowth from shrubland and woodland burns showed significant increases, but were not consistent across vegetation types (Griffin and Friedel, 1984). Seasonal fluctuations were also significant and were of the same magnitude as pre- and post-burn changes. The results of this study and the others indicate that there is a nutrient increase in vegetation after a burn, but it may or may not be significant because of natural spatial and temporal variability.

Soil Nutrient

The two locations were separated for statistical analysis of soil nutrients. The FTE and STE had many significant two through five way interactions for the nutrients involving season, year, cover, depth, and treatment at both locations. The interactions involving treatment showed no dominance for significance in the unburned or burned treatments. These results and all of the interactions for the nutrients at both FTE and STE indicated there was substantial variability in soil nutrients. Any treatment effect was not large enough to produce a consistent significant effect on the nutrient status of the soil above the variability found in years, seasons, covers, and depths.

The soil nutrient ions represented a small percentage of the nutrient in the soil at both locations. Nutrient N ions were between 3-6% of the total N and P <0.01% of the total P. A calculation of total N&P at the locations indicated the soil contained >98% while the aboveground biomass the remaining (Table 3 & 4). A comparison of means for K ion and total N and P at FTE and STE, and between unburned and burned treatments further indicates there was no treatment effect on soil nutrient status (Table 4). From the magnitude of the means and the nonoverlap of the 95% confidence intervals, the Empire location was judged to have greater total N in the soil while the Santa Rita location had greater K ion and total P.

Table 4. Santa Rita and Empire location mean K ion and total N&P in soil (0-30 cm) on unburned and burned treatments at first and second treatment evaluation times (FTE and STE).

Nutrient	FTE		STE	
	Unburned	Burned	Unburned	Burned
	---------- kg ha^{-1} ----------			
		Santa Rita		
K	7.10 (7.20)[1]	7.92 (5.47)	7.15 (5.57)	8.06 (7.06)
N-total	2265 (705)	2198 (633)	2496 (753)	2361 (696)
P-total	2092 (753)	2116 (637)	2347 (681)	2380 (715)
		Empire		
K	5.25 (3.61)	5.71 (3.40)	6.22 (11.97)	5.12 (3.40)
N-total	3641 (1352)	3351 (894)	3872 (1331)	3641 (1225)
P-total	1512 (350)	1566 (327)	1617 (254)	1663 (227)

[1] Values in parentheses are standard deviations.

IMPLICATIONS AND CONCLUSIONS

The loss of nutrients from burning and associated increases in surface runoff and sediment yield could have an impact on the nutrient status of the ecosystem. In estimating ecosystem impact, this investigation has shown that the soil contained >98% of the total nutrient with the remaining in the aboveground biomass . If all the nutrient in the biomass is lost in the burn, this would represent a very small amount of the total. The loss in nutrient from the rainfall simulation events was even much smaller than the nutrient in the biomass. At the Santa Rita location there are small 1 to 4 ha research watersheds with a 15 year annual runoff measurements from natural precipitation ranging from 1 to 30 mm (unpublished data). This is within the range of runoff from the rainfall simulations on the unburned and burned treatments, therefore the runoff, sediment yield, and nutrient loss under natural precipitation would be expected to be similar to the simulations. Nutrient additions from precipitation could be expected to replace some of the loss. Other studies indicate precipitation replaces N loss, while P losses are greater (Knighton, 1977). In southeastern Arizona, NPK annual inputs in precipitation have been measured at 1.97, 0.055, and 1.28 kg ha^{-1}, respectively (Emmerich, 1990). For N and K this would replace the loss as measured by the simulator evaluation or possibly natural runoff.

The overall conclusions of this study are that with time the effect of burning is to increase runoff, sediment yield, and nutrient loss. The increases are not primarily controlled by vegetation, but by the soil with an interaction with the vegetation. In relation to the total nutrients in the system, nutrient loss in the runoff-sediment was a small amount and a portion of the nutrients would be replaced by nutrients in precipitation. The soil contained most of the nutrients, and its nutrient pool was not affected by the burn treatment. The burn regrowth aboveground biomass nutrient concentration was generally higher than biomass on unburned plots. The greater nutrient concentrations in the aboveground biomass were not consistent in that there were significantly greater concentrations in both burned and unburned treatments plus significant interactions with year and season. Year and season effects produced significant differences in surface runoff, sediment yield, soil and biomass nutrients, and nutrient losses in the runoff-sediment, irrespective of a burn treatment effect. The next research question is how long will the increases in runoff, sediment yield, and nutrient losses continue after the burn.

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REFERENCES

Achouri, M. and G.F. Gifford. 1984. Spatial and seasonal variability of field measured infiltration rates on a rangeland site in Utah. J. Range Manage. 37:451-455.

Biederbeck, V.O., C.A. Campbell, K.E. Bowren, M. Schnitzer, and R.N. McIver. 1980. Effect of burning cereal straw on soil properties and grain yield in Saskatchewan. Soil Sci. Soc. Am. J. 44:103-111.

Bosch, J.M. and J.D. Hewlett 1982. A review of catchment experiments to determine the effect of vegetation changes on water yield and evaporation. J. Hydrol. 55:3-23.

Buckhouse, J.C., and G.F. Gifford. 1976. Grazing and debris burning on pinyon-juniper sites-- Some chemical water quality implications. J. Range Manage. 29:299-301.

Cook, J.G., T.J. Hershey, and L.L. Irwin. 1994. Vegetation response to burning on Wyoming mountain-shrub big game ranges. J. Range Manage. 47:296-302.

DeBano, L.F., G.E. Eberlein, and P.H. Dunn. 1979. Effects of burning on chaparral soils: I. Soil nitrogen. Soil Sci. Soc. Am. J. 43:504-509.

Dunn, P.H., L.F. DeBano, and G.E. Eberlein. 1979. Effects of burning on chaparral soils: II. Soil microbes and nitrogen mineralization. Soil Sci. Soc. Am. J. 43:509-514.

Emmerich, W.E. 1990. Precipitation nutrient inputs in semiarid environments. J. Environ. Qual. 19:621-624.

Emmerich, W.E., and J.R. Cox. 1994. Changes in surface runoff and sediment production after repeated rangeland burns. Soil Sci. Soc. Am. J. 58:199-203.

Griffin, G.F., and M.H. Friedel. 1984. Effects of fire on central Australian rangeland. I Fire and fuel characteristics and changes in herbage and nutrients. Australian J. of Ecol. 9:381-393.

Knight, R.W., W.H. Blackburn, and C.J. Scifres. 1983. Infiltration rates and sediment production following herbicide/fire brush treatments. J. Range Manage. 36:154-157.

Knighton, M.K. 1977. Hydrologic response and nutrient concentrations following spring burns in an oak-hickory forest. Soil Sci. Soc. Am J. 41:627-632.

Lloyd-Reilley, J., C.J. Scifres, and W.H. Blackburn. 1984. Hydrologic impacts of brush management with tebuthiuron and prescribed burning on post oak savannah watersheds, Texas. Agriculture, Ecosystems and Environment. 11:213-224.

Marion, G.M., J.M. Moreno, and W.C. Oechel. 1991. Fire severity, ash deposition, and clipping on soil nutrients in chaparral. Soil Sci. Soc. Am. J. 55:235-240.

Menzel, R.G., E.D. Rhoades, A.E. Olness, and S.J. Smith. 1978. Variability of annual nutrient and sediment discharges in runoff from Oklahoma cropland and rangeland. J Environ. Qual. 7:401-406.

Ralson, R.J., P.K. Khanna, and P.V. Woods. 1985. Mechanisms of element transfer to the atmosphere during vegetation fires. Can. J. For. Res. 15:132-140.

Richards, L.A. 1954. Diagnosis and improvement of saline and alkali soils. Agric. Handbook. 60. USDA-ARS, Washington D.C. Pg. 84.

Roundy, B.A., W.H. Blackburn, and R.E. Eckert, Jr. 1978. Influence of prescribed burning on infiltration and sediment production in the pinyon-juniper woodland, Nevada. J. Range Manage. 31:250-253.

Saà, A., M.C. Trasar-Cepeda, B. Soto, F. Gil-Sotres, and F. Dìaz-Fierros. 1994. Forms of phosphorus in sediments eroded from burnt soils. J. Environ. Qual. 23:739-746.

Schuman, G.E., R.E. Burwell, R.F. Piest, and R.G. Spomer. 1973. Nitrogen losses in surface runoff from agricultural watersheds on Missouri valley loess. J Environ. Qual. 2:299-302.

Sharrow, S.H. and H.A. Wright. 1977. Proper burning intervals for tobosagrass in west Texas based on nitrogen dynamics. J. Range Manage. 30:343-346.

Simanton, J.R., C.W. Johnson, J.W. Nyhan, and E.M. Romney. 1985. Rainfall simulation of rangeland erosion plots, p.11-17. In: Proc. Rainfall Simulator Workshop January 14-15, 1985. Tucson, Arizona. (ed. L.J. Lane), Soc. Range Manage. Denver, Colo. USA.

Simanton, J.R., M.A. Weltz, and H.D. Larsen. 1991. Rangeland experiments to parameterize the water erosion prediction project model: vegetation canopy cover effects. J. Range Manage. 44:276-282.

Smith, H.J.C., G.J. Levy, and I. Shainberg. 1990. Water-droplet energy and soil amendments: Effect on infiltration and erosion. Soil Sci. Soc. Am. J. 54:1084-1087.

Smith, S.J., R.G. Menzel, E.D. Rhoades, J.R. Williams, and H.V. Eck. 1983. Nutrient and sediment discharge from southern plains grasslands. J. Range Manage. 36:435-439.

Stoddart, L.A., A.D. Smith, and T.W. Box 1975. Range Management Third Edition. McGraw-Hill Book Company, New York, NY.

Swanson, H.P. 1965. Rotating-boom rainfall simulator. Trans. Amer. Soc. Agr. Engr. 8:71-72.

Thurow, T.L., W.H. Blackburn, and C.A. Taylor Jr. 1986. Hydrologic characteristics of vegetation types as affected by livestock grazing systems, Edwards Plateau, Texas. J. Range Manage. 39:505-509.

Tiedemann, A.R., J.D. Helvey, and T.D. Anderson. 1978. Stream chemistry and watershed nutrient economy following wildfire and fertilization in eastern Washington. J. Environ. Qual. 7:580-588.

Tricker, A.S. 1981. Spatial and temporal patterns of infiltration. J. Hydrol. 49:261-277.

Ueckert, D.N., T.L. Whigham, and B.M. Spears. 1978. Effects of burning on infiltration, sediment, and other soil properties in a mesquite--tobosagrass community. J. Range Manage. 31:420-425.

White, E.M., E.J. Williamson, and Q. Kingsley. 1977. Correlation between rain and runoff amounts and composition in eastern South Dakota. J. Environ. Qual. 6:251-254.

Wright, H.A. 1974. Range Burning. J. Range Manage. 27:5-11.

Wright, H.A., F.M. Churchill, and W.C. Stevens. 1976. Effects of prescribed burning on sediment, water yield, and water quality from dozed juniper lands in central Texas. J. Range Manage. 29:294-298.

Wright, H.A., F.M. Churchill, and W.C. Stevens. 1982. Soil loss, runoff, and water quality of seeded and unseeded steep watersheds following prescribed burning. J. Range Manage. 35:382-385.