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Nutrient dynamics of rangeland burns in Southeastern Arizona

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Abstract

Burning of vegetation generally increases surface runoff and erosion and potentially can change the nutrient dynamics of an ecosystem with loss of nutrients. Nitrogen, phosphorus, and potassium nutrient status of soil and aboveground biomass were determined before fall and spring burns and 1 year later at 2 different soil and vegetation type locations in southeastern Arizona. The evaluations were repeated in subsequent years to evaluate a year effect. Potential nutrient loss in surface runoff and sediment was assessed with rainfall simulations conducted immediately after prescribed burns and after a second burn one year later. Nutrient loss in the runoff water and sediment from burned areas was compared to paired unburned. The soil contained >98% of the total nutrient and was not significantly influenced by the burn treatment. The nutrient concentrations in the regrowth biomass were generally greater. Immediately after the first burn, nutrient loss in surface runoff and sediment was not affected by the burn treatment, but one location was greater than the other. After 1 year and a second burn, nutrient losses on the burn treatment were significantly greater than the unburned treatment and similar between locations. The nutrient loss in surface runoff was primarily associated with the sediment and influenced by an interaction between biomass and soil. The nutrient loss in runoff and sediment was small compared to the nutrient in the aboveground biomass and insignificant compared to the soil nutrient. The implication is that increased surface nutrient loss from burning could take place for many years before a significant amount of nutrient would be lost from the large soil pool and change the nutrient status of the ecosystem. Year and season were also important factors influencing nutrients in the soil, biomass, and in runoff and sediment losses, irrespective of a burn treatment effect.

Key Words: surface runoff nutrient, sediment nutrient, soil nutrient, biomass nutrient, enrichment ratios, spring and fall burn

Resumen

La quema de la vegetación generalmente incrementa el escurrimiento superficial y la erosión, y potencialmente puede cambiar la dinámica de nutrientes de un ecosistema con la perdida de ellos. Se determinó el contenido de nitrógeno, fósforo y potasio en el suelo y la biomasa aérea antes de quemas en otoño y primavera y 1 año después, las determinaciones se llevaron a cabo en 2 localidades del sudeste de Arizona en dos tipos de suelo y vegetación. La evaluación se repitio en años posteriores para conocer el efecto del tiempo. La perdida potencial de nutrientes en el escurrimiento superficial se evalúo utilizando lluvias simuladas aplicadas inmediatamente después del fuego prescrito y después de una segunda quema realizada en el año siguiente. La perdida de nutrientes en el escurrimiento y sedimento provenientes de áreas quemadas se comparó con áreas apareadas sin quemar. El suelo contuvó > 98% de los nutrientes totales y no fue afectado significativamente por los tratamientos de quema. La concentración de nutrientes en la biomasa de rebrote generalmente fue mayor. La perdida de nutrientes en el escurrimiento superficial y el sedimento, ocurrida inmediatamente después de la primer quema, no fue afectada por los tratamientos de quema, pero en una de las localidades fue mayor que en la otra. Después de 1 año y una segunda quema, la perdida de nutrientes en el tratamiento con quema fue significativamente mayor que en el tratamiento sin quema y similar entre localidades. La perdida de nutrientes en el escurrimiento superficial se asoció principalmente con el sedimento e influenciado por la interacción entre suelo y biomasa. La perdida de nutrientes en el escurrimiento superficial y sedimento fue poca comparada con el contenido de nutrientes en la biomasa aérea e insignificante comparada con los nutrientes del suelo. La implicación es que la perdida de nutrientes ocasionada por la quema puede ocurrir durante muchos años antes de que una cantidad importante de nutrientes sea perdida de las reservas del suelo y cambiar el estado de nutrientes del ecosistema. Independientemente del efecto del tratamiento de quema, el año y la estación también fueron factores importantes que influyen en los nutrientes del suelo, biomasa y las perdidas en el escurrimiento y sedimento.

Prescribed burns on rangelands have been used extensively as a vegetation management tool to increase herbage quality and yield, utilization and availability, improve wildlife habitat, control undesirable shrubs and prepare a mineral seedbed

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for germination (Wright 1974, Stoddart et al. 1975). Burning increases forage yields through the release of nutrients and reduced shrub competition (Cook et al. 1994). But burning can also cause loss of nutrients through volatilization to the atmosphere. The extent of the 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). Removal of plant cover, permits nutrient loss through changes in 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). The increase in runoff and soil erosion can increase nutrient concentrations in both the runoff water and sediment. This in effect adds to the potential for nutrient loss from burning (Buckhouse and Gifford 1976, Tiedemann et al. 1978, Saà et al. 1994). The losses for nitrogen and phosphorus have been shown to be predominately associated with sediment losses (Smith et al. 1983).

A burn may influence soil nutrient status by direct addition of nutrients from the burned biomass and by altering the soil microbial environment. Ash deposition of nutrients has been shown to 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 influences the amount of nutrient deposited onto and lost from the soil (Marion et al. 1991, DeBano et al. 1979). The intensity also influences the microbial populations in the soil which control nitrogen availability and transformations in the soil (Dunn et al. 1979). All these changes in soil nutrient status can influence regrowth and the nutrients in regrowth vegetation (Nimir and Payne 1978, Griffin and Friedel 1984, Cook et al. 1994).

In semiarid rangeland environments where nutrient inputs from precipitation are the major input and fertilization is impractical, information on nutrient dynamics associated with burning is needed for input to management decisions and for understanding the long term sustainability of rangeland environments. The objectives of this study were to: 1) evaluate preburn and postburn aboveground biomass and soil pools of nitrogen, phosphorus, and potassium (NPK) in 2 soil-vegetation communities; 2) determine the potential for loss of NPK in surface runoff and sediment following fall and spring burns.

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 soil contained 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. The Santa Rita location has an elevation of 1,250 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 soil contained 1.7% 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 year 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]. The Empire location has an elevation of 1,430 m and mean annual precipitation is 400 mm with 65% coming as summer thunderstorms. The location study areas were fenced to exclude grazing.

Experimental Design

Thirty-two, 25- by 25-m treatment evaluation areas were established at each location with two, 3.05 by 10.66-m rainfall simulator plots within each evaluation area. The evaluation areas were situated within each location to have as uniform slope, vegetation density, and soil surface characteristics as possible. The treatments were unburned and burned. Four paired unburned and burned treatment evaluation areas were randomly established in a 4 block experimental design at each location. The experimental variables at each location were treatment (i.e. unburned and burned season (i.e. fall and spring), year (i.e. year 1 and year 2), and replication (i.e. 4).

Burning Procedure

Starting in the fall (October) and then in the spring (April) on different treatment areas, the burned treatment was randomly applied to the burn half of 4 paired 25- by 25-m treatment evaluation areas, 1 in each bock at each location 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 sec^{-1}, temperature <25°C, and relative humidity >20%. The 2 rainfall simulator plots were located within the headfire burn area. One year after the fall and spring burns there was not enough aboveground biomass to carry a second fire. A second fire was then conducted with a drip or propane torch to remove the aboveground biomass on the burn treatment evaluation areas. The second fire removed aboveground vegetation that provided soil surface protection to allow for maximum expected treatment differences. The 2 time, fall and spring, burn sequence was duplicated in a later year on new treatment evaluation areas to evaluate year effects.

Preburn Sampling

Before the burns, standing biomass and litter samples were collected from six, 0.5 x 1.0 m biomass plots on each paired treatment evaluation area. Aboveground standing biomass was separated into standing live and dead based on color. The standing biomass and litter samples were oven dried at 65°C to a constant weight, weighed, and total biomass calculated for each plot. Standing live, dead, or litter from the 6 plots on each treatment evaluation area 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 4.0 N. HNO_3 acid for K analysis. A Technicon AutoAnalyzer II[1] and method No. 329-74W/B was used to analyze the samples for total N and P and a Perkin-Elmer 5000[1] atomic absorption, spectrophotometer for total K. The mean concentration from the 3 subsamples and the mean biomass weight from the 6 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.

Soil samples were collected on each of the 6 biomass plots with a 5.4 cm diameter soil coring tool to a depth of 30 cm. One soil core was taken through the largest grass crown and one in the middle of the largest interspace area of each plot. The cores were sectioned into 10 cm increments and composited by depth and cover for each treatment area. The soil samples were frozen in the field. Triplicate subsamples were digested using Technicon procedure No. 376-75W/B and analyzed for total N and P with Technicon AutoAnalyzer II using method No. 329-74W/B. Deionized water saturation extracts (Richards 1954) of the soil samples were analyzed for soluble NH^+_4 NO_3^{-1}, PO_4^{-3}, and K^+ 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 soluble 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

Rainfall simulations were conducted in the fall and spring seasons on the paired unburned and burned treatment evaluation areas immediately after the burn treatments were applied. The simulator was a Swanson rotating boom simulator modified to control the number of veejet 80100 nozzles (Spraying Systems Co., Wheaton, Ill) open at each rainfall rate and designed to apply precipitation at 65 mm hr^{-1} and 130 mm hr^{-1} (Swanson 1965, Simanton et al. 1985). A rain sample was collected for each simulation and analyzed for soluble nutrients using the same analytical methods as the soil extracts. Six small raingauges on each simulator plot measured the actual precipitation for each simulation and was found to be 55 mm hr^{-1} and 110 mm hr^{-1}. The average total precipitation for all simulations was 70.5 mm with a standard deviation of 2.3 mm. Precipitation was applied at 55 mm hr^{-1} for 45 min and then at 110 mm hr^{-1} for 15 min. 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. Actual rainfall 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 considered appropriate intensities to test the burn treatment effect on nutrient loss. Raindrop energies from the simulator are about 80% of natural precipitation and rainfall spatial depth distribution <10% over the plot area (Simanton et al. 1985, 1991). Plot boundaries were defined by metal borders inserted into the soil on the top and sides. A metal head wall and trough at the lower end collected and directed surface runoff through a calibrated flume. Flow depths were recorded and integrated for the duration of the event to calculate total runoff volume. One liter runoff-sediment samples were collected from the output of the flumes at sampling intervals of 1 to 5 min depending on flow depth, with more frequent sampling during rapidly changing flow depths. Runoff-sediment samples were collected in tared bottles, weighed, dried at 60 °C, reweighed. Litter material collected in the runoff-sediment samples was considered as sediment and analyzed as sediment. The dried sediment was analyzed for total N and P using the same analytical 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 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 bottles and analyzed for soluble NH^+_4 NO_3^{-1}, PO_4^{-3}, and K^+ using the same analytical methods and procedures as the soil extracts. The product of runoff rate and soluble nutrient runoff concentration minus rainfall concentration was integrated for the duration of the simulation event to estimate transport in the runoff water. Total N and P transported was calculated as the sum of the soluble plus sediment associated nutrient.

Statistical Design

The statistical experimental design was a split plot with location as main plots. Subplots consisted of season by year factors in 4 blocks randomized in a complete block design. The sub-subplot factor was the treatment effect of unburned vs burned. Two sub-subplot sample data values for the nutrient associated with the runoff water were obtained from each treatment evaluation area, 1 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 the second evaluation time was data collected one year after the first evaluation time. Separating the data into evaluation times allowed the statistical analysis to focus more on differences between the unburned and burned treatments. Table 1 presents the analysis of variances models used for the nutrient in the runoff water, soil, and biomass at the first and second treatment evaluation times. Location and treatment means were tested for homogeneity of variances at the first and second evaluation times and separated if necessary on that basis. The sub-subplot sample variance for the nutrient associated with the runoff water 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 ($P \leq 0.05$). The LSD test was used to separate means for treatment effects ($P \leq 0.05$). Effects with time were evaluated by comparison of treatment means between first and second treatment evaluation times.

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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 1. **Analysis of variance models used for nutrient in the runoff water, soil, and aboveground biomass at the first and second treatment evaluation times.**

Runoff Water		Soil		Biomass	
Source of Variation	df	Source of Variation	df	Source of Variation	df
Location (L)	1	Location (L)	1	Location (L)	1
Error A Replicate(L)	6	Error A Replicate(L)	6	Error A Replicate(L)	6
Season (S)	1	Season (S)	1	Season (S)	1
Year (Y)	1	Year (Y)	1	Year (Y)	1
S x Y	1	Plus two-three way interactions between L,S,Y	1	S x Y	1
L x Y	1			L x Y	1
L x S	1	Error B Y x SxRep(L)	18	L x S	1
L x S x Y	1			L x S x Y	1
Error B YxSxRep(L)	18	Treatment(T)	1	Error B YxSxRep(L)	18
		Plus T two-four way interactions with L,S,Y	1		
Treatment(T)	1			Treatment(T)	1
L x T	1	Error C TxYxSxRep(L)	24	L x T	1
S x T	1			S x T	1
Y x T	1	Cover (C)	1	Y x T	1
L x S x T	1	Plus C two-five way interactions with L, S, Y, T	1	L x S x T	1
L x Y x T	1			L x Y x T	1
S x Y x T	1	Error D CxSxYxTxRep(L)	48	S x Y x T	1
LxSxYxT	1			LxSxYxT	1
ERROR C TxSxYxRep(L)	24	Depth (D)	2	Error C TxSxYxRep(L)	24
Residual	64	Plus D two-six way interactions with L,S,Y,T,C	2		
		Error E DxCxSxYxTxRep(L)	182		

Results and Discussion

Runoff Nutrient

Location variances at the first treatment evaluation time for the soluble and sediment associated nutrients in the runoff water were significantly different, hence the locations were analyzed separately. The Santa Rita location did not have any significant burn treatment effects, but K, sed-N, sed-P, total N, and total P had significant year by season interactions. Potassium, sed-N, and total N had significant differences between years in the spring season and sed-P and total P differences in season in year 1 (Table 2).

The Empire location at the first treatment evaluation time had significantly greater K loss from the burn treatment (Table 3) and PO_4 showed a season by treatment interaction with greater loss in the fall season from the burn treatment. Potassium, NO_3, sed-P, and total P had significant season effects with greater loss in the fall. Sed-P also had significantly more loss in year 2.

Nutrient loss in the runoff water and associated with sediment at the first treatment evaluation time was expected to increase with the burn treatment. The increases detected in nutrient loss were not significant, except for K at the Empire location (Table 3). The major driving force for nutrient transport is the amount of runoff and sediment production. Analysis of the first treatment evaluation time runoff and sediment data has indicated that the treatment increases were not larger than the natural variability (Emmerich and Cox 1992) and this result contributed to a lack of an increase in nutrient loss. The deposition of nutrient on the soil surface from the burn treatment was also not able to overcome the natural variability to produce a treatment effect. The absence of a significant increase in nutrient loss immediately after the burn treatment removed the vegetation, indicated that the vegetation cover by itself was not controlling nutrient loss and that the soil is. Factors influencing nutrient loss at the first treatment evaluation time were year and season as they produced significant differences irrespective of a burn treatment.

The second treatment evaluation time analysis of variance for soluble and sediment associated nutrients in the runoff water was also conducted separately for each location. At the Santa Rita location, PO_4, sediment associated nutrients, and total N and P showed significantly greater losses from the burn treatments (Table 2). Potassium had a significant season by treatment interaction, and NO_3 and NH_3 had significant year by treatment interactions. The K, NO_3 and NH_3 nutrients had significantly greater losses on the burn treatments in the fall season or year 2. Second treatment evaluation time for the Empire location showed all the nutrient forms had significantly greater losses from the burn treatments, except K which had a significant season by treatment interaction with a significantly greater loss on the burn treatment in the fall season (Table 3).

An analysis of variance comparison could not be made between locations because the variances were different. Hence, mean soluble K and total N and P for the unburned and burn treatments were used to test for differences in locations using an accepted conservative procedure of nonoverlap of the 95% confidence intervals as being significantly different (Emmerich and Hardegree 1996). At the first treatment evaluation time, the Santa Rita location had significantly less nutrient loss than the Empire location (Tables 2 and 3). At the second treatment evaluation time, the burned treatment nutrient losses were similar. This indicated that the burn treatment from the first treatment evaluation time to the second produced a greater change in nutrient loss at the Santa Rita location than the Empire. The Santa Rita location had a much higher aboveground biomass than the Empire location (Table 4), lower surface runoff and sediment production (Emmerich and

Table 2. Santa Rita mean nutrient loss in runoff water for treatments at first and second treatment evaluation times.

Nutrient	Unburned				Burned			
	Fall		Spring		Fall		Spring	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
	(g ha^{-1})							
	First Treatment Evaluation Time							
NH_3-N	0.4	0.2	0.9	0.5	1.0	1.2	1.0	0.4
NO_3-N	–0.2[1]	–0.5	2.2	<0.1	–0.3	–0.9	–0.3	–0.1
PO_4-P	2.4	3.8	2.7	2.4	5.3	9.1	3.6	5.9
K	33.3	52.4	78.7	34.0	46.3	62.4	134.0	45.1
Sed-N	21.8	28.8	77.8	30.6	47.9	96.9	170.8	97.6
Sed-P	3.9	10.7	27.3	10.6	6.1	30.6	44.7	21.8
N-total	21.9	28.4	81.1	31.1	48.5	97.1	171.5	98.1
P-total	6.4	14.5	30.0	13.0	11.5	39.7	48.4	27.7
	Second Treatment Evaluation Time							
NH_3-N	-0.4	1.7	0.4	–2.6	0.3	25.5	5.0	31.2
NO_3-N	–0.4	3.5	0.1	1.1	–13.2	35.5	1.8	21.0
PO_4-P	5.6	1.4	2.9	1.3	89.2	42.5	38.1	47.0
K	12.3	85.1	35.5	7.2	622.5	1063.5	384.8	177.2
Sed-N	13.5	81.5	23.3	41.6	1331.0	2135.6	1315.7	2491.2
Sed-P	4.6	24.8	7.0	14.8	295.5	434.6	222.1	450.7
N-total	12.7	86.8	23.8	40.1	1318.0	2196.2	1321.7	2543.7
P-total	10.2	26.3	10.0	16.2	385.2	477.7	260.1	497.6

[1] Negative values resulted from soil adsorption of nutrient from rain water.

Cox 1992) and lower nutrient transport at the first treatment evaluation time (Table 2 and 3). The large increase in nutrient loss from the Santa Rita location correlated to similar increases in runoff and sediment production (Emmerich and Cox 1994) and a larger biomass removal at the second treatment evaluation time. With time biomass seems to interact with the soil to control surface runoff, sediment, and nutrient loss. Immediately after the removal of biomass nutrient loss was not significant, but at the second treatment evaluation time with the vegetation removed, there were the significant increases. As the vegetation regrows and interacts with the soil, the effect of the burn treatment on nutrient loss should diminish. Further research is needed to determine how long the burn treatment effect will continue to influence nutrient loss.

Nitrogen and P were transported predominately with the sediment. The Santa Rita location at the first treatment evaluation time had a mean 103% of the total N and 76% of the total P transported with the sediment and 100% and 86%, respectively for the second treatment evaluation time (Table 2). The 103% N resulted from absorption of NO_3 and NH_4 from the rain water during runoff. The absorption produced a calculated negative concentration in the runoff, as the rainfall concentration was subtracted from the runoff concentration and this reduced the total sum of the N forms transported to less than that in the sediment. First treatment evaluation time at the Empire location had a mean 99% of the total N and 82% of the total P transported with the sediment and 99% and 86%, respectively for the second treatment evaluation time (Table 3).

Surface runoff and sediment production from the burn treatment at the second treatment evaluation time has been shown to be significantly greater than the unburned treatment at the locations (Emmerich and Cox 1994). This increase in the nutrient transport driving force on the burned treatment corresponded directly to the increases in nutrient loss at the second treatment evaluation time (Tables 2 and 3). The same correlation between runoff and sediment, and the loss of nutrients has been observed for other soil and vegetation types (White et al. 1977, and Schuman et al. 1973). Since a large percentage of N and P is sediment associated, measuring sediment removals and associated nutrient would produce a good estimate of total nutrient transport.

Soil Nutrients

The2 locations were analyzed separately for soil nutrients due to variance differences. The first and second treatment evaluation times had many significant 2 through 5 way interactions for the nutrients involving season, year, cover, depth, and treatment at both locations. The interactions showed no biologically

Table 3. Empire Ranch mean nutrient loss in runoff water for treatments at first and second treatment evaluation times.

Nutrient	Unburned				Burned			
	Fall		Spring		Fall		Spring	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
	(g ha^{-1})							
	First Treatment Evaluation Time							
NH_3-N	4.6	1.9	2.8	2.8	26.2	–25.7[1]	7.3	4.3
NO_3-N	–8.9	–23.7	–0.6	5.8	–9.9	–57.4	–3.3	–15.5
PO_4-P	15.0	5.8	0.9	0.7	71.6	85.6	4.5	25.9
K	364.8	87.2	142.2	69.6	1024.2	961.8	315.0	296.0
Sed-N	242.4	353.0	268.0	150.3	857.2	910.3	389.0	497.3
Sed-P	30.5	78.5	49.7	30.3	92.1	211.2	57.6	74.5
N-total	238.3	331.4	270.1	159.0	870.7	826.3	393.1	487.0
P-total	45.6	84.4	50.6	31.0	163.8	296.9	62.1	100.5
	Second Treatment Evaluation Time							
NH_3-N	–9.7	8.8	5.0	2.2	9.1	17.0	9.0	6.7
NO_3-N	–2.7	–9.4	3.9	2.6	–31.7	–19.0	–20.2	<0.1
PO_4-P	3.1	5.0	3.5	5.4	104.4	51.1	48.6	26.3
K	54.9	325.3	172.6	20.9	1307.2	1206.2	646.0	111.3
Sed-N	67.9	416.9	247.0	174.8	1934.2	3007.8	1366.9	1461.7
Sed-P	14.3	96.9	48.6	43.3	295.7	545.3	226.0	263.2
N-total	55.4	415.8	255.9	179.5	1911.6	3006.7	1354.0	1469.7
P-total	17.4	102.0	52.3	48.7	400.1	595.5	274.5	289.6

[1] Negative values resulted from soil adsorption of nutrient from rain water.

Table 4. Santa Rita and Empire location mean litter, standing live, standing dead, and total biomass on unburned and burned treatments at first and second treatment evaluation times.

Biomass	First Treatment Evaluation		Second Treatment Evaluation	
	Unburned	Burned	Unburned	Burned
	(kg ha^{-1})			
		Santa Rita		
Litter	1606a[1]	1700a	1226a	8b
	(237)[2]	(150)	(108)	(8)
Standing	913a	954a	574[3]	528
Live	(149)	(156)	(121)	(50)
Standing	3220a	3300a	3284a	640b
Dead	(231)	(245)	(267)	(137)
Total	5739a	5955a	5086a	1177b
	(413)	(312)	(310)	(155)
		Empire		
Litter	453a	356a	395a	22b
	(78)	(55)	(48)	(11)
Standing	545a	417a	389a	262b
Live	(125)	(65)	(63)	(45)
Standing	1479a	1209a	1458a	567b
Dead	(150)	(138)	(132)	(78)
Total	2477a	1983a	2243a	852b
	(264)	(207)	(154)	(80)

[1] Values within row and treatment evaluation time followed by the same letter are not significantly different ($P=0.05$).
[2] Values in parentheses are standard error n=16.
[3] Santa Rita location second treatment evaluation time had a significant year by season by treatment interaction and the unburned treatment was significantly higher in year 1 and fall season.

meaningful patterns and those involving treatment showed no dominance for significance in the unburned or burned treatments. These first and second treatment evaluation time results indicated that the soil nutrients had substantial variability and treatment effects were not large enough to produce a consistent significant effect on the nutrient status of the soil above the natural variability found in years, seasons, covers, and depths.

The soluble soil nutrient represented a small percentage of the nutrient in the soil at both locations. Soluble N was between 3–6% of the total N and soluble P<0.01% of the total P. A comparison of means for soluble K and total N and P at first and second treatment evaluation times was used to further evaluate for a burn treatment effect. There was still no indication of a burn treatment effect on soil nutrient status (Table 5). From nonoverlap of 95% confident intervals, there was greater soluble K and total P in the soil at the Santa Rita location and greater total N at the Empire. The absence of a measurable change in soil nutrient with 1 year of removals by burning and runoff was not unusual. Other studies evaluating 20 years of repeated burns or 78 years of heavy grazing produced small reductions in soil N (Biederbeck et al. 1980; Frank et al. 1995). High spatial and temporal variation in nutrient content has also been implicated as a reason for unmeasurable changes in soil nutrient (Sharrow and Wright 1977) and probably was an important factor in this study.

Biomass Nutrient

The 2 locations were analyzed separately for aboveground biomass types. At the first treatment evaluation time there was no difference in the amount of biomass types on the treatment plots (Table 4). At the second treatment evaluation time the unburned plots were significantly greater in aboveground biomass, except the standing live biomass at the Santa Rita location. The Santa Rita standing live biomass had a significant year by season by treatment interaction and the unburned treatment was greater only in year 1 and fall season. The interaction was attributed to differences in summer precipitation, 305 mm and 84 mm for the 2 years, which produced the fall biomass. Even though the standing live biomass regrowth was significantly less it was approaching preburn levels at the second treatment evaluation time for both locations and total biomass was at 23% at the Santa Rita location and 38% at the Empire of preburn levels (Table 4).

The first treatment evaluation time total nutrient and nutrient concentration in the different aboveground biomass types at both locations had significant interactions and main effects. The significant burn 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 type to evaluate for a treatment effect on total nutrient and nutrient concentration at the first treatment evaluation time, because the live biomass, especially nutrient concentrations would be the most likely to have a response from the burn treatment at the second treatment evaluation time. The Santa Rita location had a significant season by treatment interaction for N concentration in the standing live biomass. The unburned treatment was higher in the spring with

Table 5. Santa Rita and Empire location mean soluble K and total N & P in 30 cm depth of soil on unburned and burned treatments at first and second treatment evaluation times.

Nutrient	First Treatment Evaluation		Second Treatment Evaluation	
	Unburned	Burned	Unburned	Burned
	(kg ha^{-1})			
		Santa Rita		
K	7.10	7.92	7.15	8.06
	(0.73)[1]	(0.56)	(0.57)	(0.72)
N-total	2265	2198	2496	2361
	(72)	(65)	(77)	(71)
P-total	2092	2116	2347	2380
	(77)	(65)	(70)	(73)
		Empire		
K	5.25	5.71	6.22	5.12
	(0.37)	(0.35)	(1.22)	(0.35)
N-total	3641	3351	3872	3641
	(138)	(91)	(136)	(125)
P-total	1512	1566	1617	1663
	(36)	(33)	(26)	(23)

[1] Values in parentheses are standard error n=96.

Table 6. Santa Rita and Empire location second treatment evaluation time mean NPK nutrient in litter, standing live, and standing dead biomass on unburned and burned treatments.

Nutrient	Unburned Litter	Unburned Standing live	Unburned Standing dead	Burned Litter	Burned Standing live	Burned Standing dead
	(kg ha^{-1})					
			Santa Rita			
K	1.33a[1] (0.10)[2]	4.313 (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 year 1, while the burned treatment was greater in the fall and spring in year 2.
[4] P Had a year by season by treatment interaction, the unburned treatment was greater in the fall season in year 1.
[5] P Had a season by treatment interaction, the unburned treatment was greater in the fall season.

14.1 vs 11.9 mg N g^{-1} for the burned. There were no other significant treatment effects for total nutrient or nutrient concentrations in the standing live biomass.

Santa Rita total NPK in standing live biomass had significant year by season by treatment interactions at the second treatment evaluation time (Table 6). Total N and K in the standing live biomass was greater in the unburned treatment only in the fall season and year 1, while the burned treatment was greater in the fall and spring in year 2. For P the unburned treatment was greater only in the fall season in year 1. The Empire location total N and K in the standing live biomass was significantly greater in the unburned treatment at the second treatment evaluation time (Table 6). For P, the unburned treatment was greater in only the fall season.

Empire standing live total NPK in the burned treatment was at least 65% of the unburned treatment Both location total NPK in litter and standing dead at the second treatment evaluation time was significantly greater in the unburned treatment, primarily due to the small amount of biomass on the burned plots (Table 4 and 6).

Table 7. Santa Rita location second treatment evaluation time mean NPK standing live biomass concentrations separated for significant season by treatment and year by treatment interactions.

Nutrient	Unburned Fall	Unburned Spring	Burned Fall	Burned Spring
	(mg g^{-1})			
K	7.08a[1] (0.95)[2]	13.87a (0.69)	8.23b (0.85)	10.84b (0.58)
N	8.98a (1.50)	16.17a (0.89)	12.03b (1.67)	13.67b (1.03)
P	2.50a (0.07)	3.34a (0.12)	2.28a (0.19)	2.32b (0.10)
	Year 1	Year 2	Year 1	Year 2
K[3]	8.20a (1.13)	11.81b (0.89)		
N	9.92a (1.72)	15.23a (1.32)	9.43a (0.69)	16.26b (0.47)
P	2.92a (0.21)	2.91a (0.17)	2.59a (0.12)	2.01b (0.10)

[1] Values within row and season or year followed by the same letter are not significantly different (P=0.05).
[2] Values in parentheses are standard error n=8.
[3] For K the year by treatment interaction was not significant, there was a significant year effect.

Standing live nutrient concentration was expected to be most responsive to treatment at the second treatment evaluation time. The Santa Rita location standing live NPK concentrations 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 (Table 7). The N and K concentrations were significantly greater on the burned treatment in the fall and significantly less in the spring. Nitrogen concentration was also greater in year 2 on the burned treatment. The P concentration was significantly greater in the spring and year 2 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 first treatment evaluation time and could be unique to those treatment areas. For the Empire location second treatment evaluation time standing live biomass concentrations, only K was significantly greater on the unburned treatment.

One objective of rangeland burns is to increase nutrient quality of the vegetation by releasing nutrients for uptake in regrowth (Stoddart et al. 1975, Wright 1974). At the second treatment evaluation time the total aboveground biomass at both locations was significantly less on the burned treatment (Table 4). The regrowth of biomass was 23% of the unburned at the Santa Rita and 38% at the Empire location. The total amount of NPK in the aboveground biomass on the burn treatment at the second treatment evaluation time ranged from 31% to 72% of the unburned treatment at the 2 locations (Table 6). Therefore, 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. Santa Rita was the only location to have significant increases in standing live nutrient concentrations on the burn treatment (Table 7). This study and others are indicating nutrient increases in the vegetation after a burn and it may or may not be significant because of natural variability, plus the influence of seasons and years (Cook et al. 1994, Griffin and Friedel 1984).

Ecosystem Nutrient

The nutrients lost from the burning in this study would probably not impact the nutrient status of the ecosystem. The soil contained >98% of the total nutrient with the remaining in the aboveground biomass (Tables 5 and 6). If all the nutrient in the biomass was lost in a burn, this would represent a small amount of the total. The loss in nutrients from the rainfall simulation events was even smaller than the nutrient in the biomass (Tables 2, 3, and 6). At the Santa Rita location there are eight small 1 to 4 ha research watersheds located close to where the simulations were conducted. Fifteen years of annual runoff from natural precipitation ranged from 1 to 30 mm (unpublished data). A similar range of runoff from the rainfall simulations was observed for the unburned and burned treatments (Emmerich and Cox 1994). Hence, nutrient loss under natural precipitation should be similar to the losses during the simulations. Precipitation would be expected to replace some of the nutrient loss. Other studies have indicated precipitation replaces N runoff losses, while P losses are greater (Klausner et al. 1974, Knighton 1977). In southeastern Arizona, annual NPK inputs from 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 from the simulator evaluations or possibly natural runoff.

Summary

Surface runoff-sediment nutrient loss was not significantly increased at the first treatment evaluation time by the burn treatment, while at the second treatment evaluation time it was significant. This implied that aboveground vegetation by itself was not the primary factor controlling nutrient loss and there was an interaction with the soil to control the loss. The soil contained most of the nutrient and total nutrient was not changed by the burn treatment. In relation to the total nutrient in the ecosystem, the runoff-sediment loss was a small amount and some would be replaced by nutrient in precipitation. Many years of increased nutrient loss caused by burning would have to occur before changes in soil nutrient could be measured. The burn regrowth biomass nutrient concentration was generally higher. Year and season effects produced significant differences in soil and biomass nutrient, and in surface runoff-sediment nutrient loss, irrespective of a burn treatment effect.

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