This paper was peer-reviewed for scientific content.
Pages 261-265. In: D.E. Stott, R.H. Mohtar and G.C. Steinhardt (eds). 2001. Sustaining the Global Farm. Selected papers from the 10th International Soil Conservation Organization Meeting held May 24-29, 1999 at Purdue University and the USDA-ARS National Soil Erosion Research Laboratory.

Grazing, Burning, and Drought Influences on Rangeland Ecosystem Sustainability

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ABSTRACT

Processes of runoff, erosion, and nutrient transport influence the sustainability of rangeland ecosystems. Studies were conducted in the semiarid Northern Great Plains and Southwestern rangelands to evaluate the effects of grazing, burning, and drought on these processes. The worst case results for runoff, erosion, and NPK transport from the grazing, burning, and drought treatments were used to evaluate long-term sustainability by calculating time frame required to remove the nutrients in the top 5 cm of soil or the soil itself. The continuously grazed and burn treatments produced worst case significant increases in runoff, erosion, and nutrient transport at the two different study sites. These significant increases in nutrient transport were small when compared to the large nutrient pool in the soil. Calculated time frames to remove the NPK in top 5 cm of soil or the soil itself ranged from hundreds to thousands of years. From the standpoint of nutrient and soil, the sustainability of these ecosystems was concluded to be long-term even with the accelerated runoff, erosion, and nutrient loss caused by grazing and burning. Precipitation nutrient inputs were found to potentially replace an appreciable amount lost in runoff. Nutrient inputs from precipitation would consequently increase the sustainability of the ecosystems.

INTRODUCTION

Many factors, such as grazing, burning, drought, topography, and type and intensity of precipitation can influence runoff, erosion, and nutrient transport from rangelands. The amount of runoff, erosion, and nutrient transport has immediate impacts on water quality directly, and potentially long-term impacts on soil fertility and ultimately sustainability of the ecosystem. The immediate influences of grazing, burning, and drought on runoff, erosion, and nutrient transport have been examined (Gifford and Hawkins, 1978; McGinty et al., 1979; Wood and Blackburn, 1981; Jawson et al., 1982). Broad responses to grazing, burning, and drought are that as drought and grazing intensity increases, and burning occurs, an increase is observed in surface runoff, erosion, and nutrient transport (Wood and Blackburn, 1981; Schepers et al., 1982; Lloyd-Reilley et al., 1984; Thurow et al., 1988). The responses arise from vegetation removal and the alteration of soil structure by trampling and raindrop impact (McGinty et al., 1979; Thurow et al., 1986).

The long-term sustainability of rangelands with accelerated runoff, erosion, and nutrient loss is of ecological concern. A hypothesis was proposed that short-term grazing, burning, and drought study data were appropriate to calculate nutrient and erosion losses for long-term sustainability of rangelands. The objectives of this research were to: 1. conduct grazing, burning, and drought studies in different rangeland settings; 2. utilize the worst-case scenarios to calculate long-term nutrient and soil losses and 3. evaluate these losses in terms of sustainability based on soil and nutrient loss.

MATERIALS AND METHODS

Study Areas

Research on drought and grazing was conducted during the 1993-1995 growing seasons at the Fort Keogh Livestock and Range Research Laboratory located near Miles City, MT. The regional, natural vegetation is grama-needlegrass-wheatgrass (*Bouteloua-Stipa-Agropyron*) mixed grass community (Kuchler, 1964). The soil type at the site is Kobase silty clay loam (fine, montmorillonitic, frigid, Torretic Haplustepts) on a slope of <4%. Annual precipitation is highly variable, averaging 341 mm. Most erosion causing precipitation occurs in spring through summer as intense, short duration thunderstorms.

Burning research 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 Ranch locations. The soil type at the Santa Rita location is White House gravelly loam (fine, mixed, thermic Ustic Haplargids) with 5 to 6% slope. Dominant vegetation is an introduced grass, Lehmann lovegrass (*Eragrostis lehmanniana* Nees). The elevation is

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1250 m and the mean annual precipitation is 420 mm with 65% occurring as summer thunderstorms. The soil type at the Empire Ranch location is Hathaway gravelly sandy loam (loamy-skeletal, mixed, thermic Aridic Calciustolls) with 5 to 7% slope. Empire Ranch dominant vegetation is native grass, including black grama [*Bouteloua eriopoda* (Torrey) Torrey], hairy grama (*Bouteloua hirsuta* Lagasca), and sideoats grama [*Bouteloua curtipendula* (Michaux) Torrey]. The elevation is 1430 m and the mean annual precipitation is 400 mm with 65% coming as summer thunderstorms. The burning location study areas were fenced to exclude grazing.

Fort Keogh Drought and Grazing Study Lysimeters and Treatments

The drought and grazing study was conducted on twelve, 5 m wide by 10 m long non-weighing lysimeters. At the lowest elevation point in each lysimeter, a drain was fitted to under ground piping to transport water and sediment to a fiberglass collection tank. The storage tanks were used to collect and accurately measure runoff volumes, and for collection of runoff and sediment samples. A 12 x 35-m automated metal framed rainout shelter was mounted on wheels and rails above 6 lysimeters for the drought treatment. The rainout shelter was equipped with a moisture sensitive conductance plate that when wet activated a small electric motor and its associated drive system to move the shelter over the lysimeters. The drought treatment reduced precipitation 85% and was imposed during the second year (1994) of the 3-year study.

Three grazing treatments were imposed randomly on both non-drought and drought treatment lysimeters and replicated twice. Grazing treatments were: 1) grazed both the year of and year after drought (94-95 grazed treatment); 2) grazed during the year of drought and rest the year after (94 grazed treatment); and 3) rest for all 3 years (ungrazed treatment). The grazing treatments consisted of grazing with 5 ewes and their twin lambs in early June and July. Grazing was heavy, as the standing plant biomass was reduced about 33% during each grazing treatment in 1994, and about 50% for each grazing treatment in 1995 (Heitschmidt et al., 1999). This resulted in October standing biomass of about 20% of the ungrazed treatment in both years.

Fort Keogh Sampling Procedures

Eight 5 cm deep soil samples were collected at stratified locations in each lysimeter in May 1993. Saturation extracts (Richards, 1954) were used to extract soluble nutrient ions of NH_4^+, NO_3^{-1}, PO_4^{-3}, and K^+. The anion and cation concentrations were analyzed using Technicon AutoAnalyzer II and atomic absorption spectrophotometer standard procedures. Subsamples of soil were digested and analyzed for total N and P. Total K was not determined. Soluble and total nutrient in the 5-cm soil surface was calculated for each lysimeter.

The aboveground biomass was clipped, dried, and weighed monthly throughout the growing season to determine biomass growth (Heitschmidt et al., 1999). The clipped biomass was not analyzed for nutrient content. Estimates for concentration values of the nutrient in the biomass were obtained from studies conducted near the Fort Keogh site with similar vegetation and soil (Heitschmidt et al., 1995; Grings et al., 1996). The measured biomass amounts and estimated concentration values were used to calculate nutrient in the biomass.

Precipitation was collected in a plastic rain gauge and analyzed for nutrient concentrations. Runoff and sediment samples were collected from each lysimeter after every runoff event. Sediment yields was estimated by collecting, decanting, centrifuging, drying at 65 °C, and weighing. A centrifuged runoff sub-sample was analyzed for soluble NH_4^+, NO_3^{-1}, PO_4^{-3}, and K^+. The dried sediment was analyzed for total N (sed-N) and P (sed-P) concentrations using the same procedures and methods as the soil samples. Volume of runoff, soluble ion, sediment, and sed-N and sed-P concentrations were used to calculate mass transport for each event and summed for annual losses.

Data was statistically analyzed using within years analysis of variance models. Main effects were drought and grazing treatment. The error term for testing for drought effects was replication (i.e., lysimeter) within drought treatment. The model residual was used to test for the main effects of grazing treatment and the drought by grazing treatment interaction effects. Main effects of drought and grazing 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 ($P \leq 0.05$).

Burn Study Experimental Design and Procedure

Thirty-two, 25- by 25-m treatment evaluation areas were established at the Santa Rita and Empire Ranch location with two, 3.05 by 10.66 m rainfall simulator plots within each evaluation area. 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., 1 and 2), and replication (i.e., 4). 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, one in each block at each location for the first time. 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 two time fall and spring burn sequence was duplicated a year later on new treatment evaluation areas to evaluate the effect of a year.

Burn Study 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. The standing biomass and litter samples were oven dried at 65°C to a constant weight, weighed, and total biomass calculated for each plot. Subsamples from each component of biomass were digested and analyzed for total NPK. Biomass concentration and the mean biomass weight from the 6 plots were used to calculate total NPK in each component of biomass on each treatment evaluation area.

Soil samples were collected from each of the 6 biomass plots with a 5.4 cm diameter soil coring tool in 10 cm increments to a depth of 30 cm. Saturation extracts (Richards, 1954) of the soil samples were analyzed for soluble NH_4^+, NO_3^{-1}, PO_4^{-3}, and K^+ using Technicon AutoAnalyzer II and atomic absorption spectrophotometer standard procedures. Soil subsamples were digested and analyzed for total N and P. 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} 5 cm^{-1} basis.

Burn Study 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. Precipitation was applied with a Swanson rotating boom simulator (Swanson, 1965; Simanton et al., 1985) at 55 mm hr^{-1} for 45 min and then at 110 mm hr^{-1} for 15 min and this represented about 20% of the annual precipitation. Analysis of precipitation intensity data for Southeastern indicated the 55 mm hr^{-1} intensity for 45 min would be a 10 year event and the 110 mm hr^{-1} for 15 min would be a 20 year event (Osborn and Renard, 1988). Previous analysis of the runoff and sediment production data produced by rainfall simulations showed they were similar to eight 1-4 ha research watersheds near the Santa Rita site (Emmerich and Cox, 1994). Flow depths in a calibrated flume were recorded and integrated for the duration of the event to calculate total runoff volume for each simulator event. One liter runoff-sediment samples were collected from the outlet of the flume at sampling intervals of 1 to 5 min. The sediment was analyzed for total N and P and 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. Runoff subsamples were analyzed for soluble NH_4^+, NO_3^{-1}, PO_4^{-3}, and K^+ and 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 were calculated as the sum of the soluble plus sediment associated nutrient.

Burn Study Statistical Design

The statistical experimental design was a split plot with location as main plots. The data was divided into first and second burn times and analyzed separately with analysis of variance techniques. Separating the data into burn times allowed the statistical analysis to focus more on differences between the unburned and burned treatments. Main effects were either pooled or separated depending on the significance of the interactions ($P \leq 0.05$).

RESULTS AND DISCUSSION

An analysis of the runoff and soil data indicated that for N & P 80+% was associated with the sediment for the runoff and for the soil, associated with the soil itself. In most cases <5% was in soluble forms in the runoff or soil. Since most of the N & P was in the sediment or soil, total N & P values will be used to present N & P data for runoff and soil. Total K was not determined in the sediment and soil itself, but soluble K was determined in the runoff and soil, hence it will be used to present the K data in the runoff and soil.

Table 1. Mean runoff, sediment production, and nutrient loss at Fort Keogh, Santa Rita†, and Empire Ranch locations†.

	Fort Keogh	
	Ungrazed	**94-95 Grazed**
K‡ (g/ha)	0.2 (0.4)§	18 (10)
Total-N (g/ha)	0.2 (0.1)	26 (19)
Total-P (g/ha)	0.03 (0.04)	5 (4)
Runoff (mm)	0.007 (0.014)	0.470 (0.240)
Sediment (kg/ha)	0.31 (0.062)	8.7 (8.7)
	Santa Rita¶	
	Unburned	**Burned**
K‡ (g/ha)	35 (35)	562 (520)
Total-N (g/ha)	41 (32)	1845 (1600)
Total-P (g/ha)	16 (7)	405 (330)
Runoff (mm)	2 (2)	17 (12)
Sediment (kg/ha)	21 (29)	395 (359)
	Empire Ranch¶	
K‡ (g/ha)	143 (137)	817 (689)
Total-N (g/ha)	226 (150)	1935 (1630)
Total-P (g/ha)	55 (34)	389 (280)
Runoff (mm)	8 (8)	21 (14)
Sediment (kg/ha)	117 (118)	517 (417)

†Annual totals at Fort Keogh; Santa Rita and Empire Ranch per rainfall simulator event.
‡Soluble K in runoff.
§Values in parenthesis are standard deviations.
¶Santa Rita and Empire Ranch second burn treatment.

The grazing, burning, and drought data showed that in 1995 the 94-95 grazed treatment and second burn treatment produced the most significant increases in runoff, sediment, and nutrient loss at the two study sites and were the worst case scenarios used to evaluate long-term sustainability (Table 1). The significant increases in runoff, sediment, and nutrient loss would suggest that the ecosystems are degenerating from the grazing and burning treatments. To evaluate sustainability in terms of nutrient loss, the total amounts in the system must be evaluated. The top 5 cm of soil and aboveground biomass contained many times more NPK than was lost in the runoff water (Table 2). The top 5 cm of soil also contained more nutrient than in the aboveground biomass. The soil contained the dominant pool of nutrient and its dominance would increase more if more of the soil profiles were considered. The total K in the soil was not measured, but it should contain much more than was lost in the runoff and contained in the biomass, as there are many K compounds and minerals contained in soils.

As a measure of sustainability, the soil as the major ecosystem reservoir of nutrients was used to determine the time frame to deplete the nutrient reservoir by runoff and erosion. The percentages of NPK removed from the top 5 cm of soil by the runoff and erosion were small, except for K as totals in the soil were not determined (Table 3). The large percentages of soluble K being removed indicate that there could be a nutrient shortage for plants if the soil could not replace the lost soluble K. The calculated number of years to remove the NPK in the top 5 cm of soil produced a wide

Table 2. Mean nutrient in soil, aboveground biomass, and removed in runoff.

Nutrient	Soil kg/ha/5 cm	Aboveground Biomass kg/ha	Runoff† kg/ha
		Fort Keogh	
K‡	3.9 (0.7)§	14.6 (11.7)	0.018 (0.010)
Total-N	1133 (211)	29.8 (17.0)	0.026 (0.019)
Total-P	295 (35)	3.2 (1.3)	0.005 (0.004)
		Santa Rita	
K‡	2.1 (1.0)	10.7 (2.8)	0.562 (0.520)
Total-N	451 (106)	40.7 (13.6)	1.84 (1.60)
Total-P	379 (107)	5.9 (1.8)	0.40 (0.33)
		Empire Ranch	
K‡	1.3 (0.5)	6.1 (3.0)	0.817 (0.689)
Total-N	715 (202)	18.5 (9.3)	1.93 (1.63)
Total-P	270 (59)	2.2 (1.2)	0.38 (0.28)

†1995 runoff Fort Keogh 94-95 grazed treatment, Santa Rita and Empire Ranch second burned treatment.
‡ In biomass.
§Values in parenthesis are standard deviations.

Table 3. Percent nutrient in top 5 cm soil lost in runoff, years to remove nutrient in top 5 cm soil by runoff, years to remove nutrient in top 5 cm soil by aboveground biomass, and years to erode top 5 cm soil by runoff at Fort Keogh, Santa Rita, and Empire Ranch locations.

Nutrient	Percent nutrient lost in runoff†	Years to remove nutrient by runoff	Years to remove nutrient by biomass	Years to erode top five cm soil by runoff
		Fort Keogh		
K‡	0.4	230	0.3	
Total-N	<0.01	44000	38	63000
Total-P	<0.01	59000	92	
		Santa Rita		
K‡	27	4	0.2	
Total-N	0.4	250	11	2000
Total-P	0.1	950	64	
		Empire Ranch		
K‡	63	2	0.2	
Total-N	0.3	370	39	1400
Total-P	0.1	710	123	

†1995 runoff Fort Keogh 94-95 grazed treatment, Santa Rita and Empire Ranch second burned treatment.
‡Soluble K in soil used as total.

Table 4. Precipitation added mean annual nutrient

Nutrient	Fort Keogh	Santa Rita & Empire Ranch†
	---------------- kg/ha	--------------
NH_3	1.57	1.20
NO_3-N	0.86	0.77
PO_4-P	0.19	0.06
K	1.17	1.28

†Emmerich 1990, data collected near Santa Rita and Empire Ranch locations.

range of values for the nutrients (Table 3). The measured soluble K was a fraction of the estimated total in the soil and this resulted in short time frames for removal. The long time frames calculated to remove the N and P under accelerated losses suggests, the ecosystems will have long term sustainability as measured by nutrient in the soil.

The aboveground biomass contained sizeable amounts of the total NPK in the ecosystems (Table 2). The grazing and burning treatments themselves would remove part of the nutrient in the system. The amount of removal would depend on many factors. Taking the worst case scenario that all the nutrient is lost in the treatments, the time frame required to remove all the NPK in the top 5 cm of soil is still long (Table 3). The time frames to remove K were short as only soluble K was used as measure of K in the soil. If total K were known, similar time frames calculated for N and P would have been expected. The treatments probably would not remove all the NPK in the biomass. The grazing animals recycle nutrients to the soil and the burning would do the same in the ash depending on the nutrient. The N would volatilize to the atmosphere, while the other nutrients would mostly return to the soil. The return of nutrients to the soil would extend the time frame for depleting soil nutrient. Even the larger removal of the nutrients by the biomass showed that there was a substantial time frame before the top 5 cm of soil would be nutrient depleted. These results imply that the ecosystems would be sustainable in nutrients for a reasonable time period, even with this extreme scenario.

The results indicating sustainability due to the long times to deplete the nutrients from the soil do not take into consideration the availability of the nutrients to plants for long term plant sustainability (Table 3). The plant-available nutrients probably would be removed sooner and the sustainability for plants lost while there still could be substantial nutrient in the soil. Time for mineralization and chemical transformation is required to change the nutrients to forms that are plant available. Plant sustainability time would therefore be less than the sustainability based on the total nutrient in the soil.

The treatments greatly accelerated the rate of soil erosion (Table 1). The calculated time frames to remove the top 5 cm of soil at the study sites by erosion were notably long (Table 3). The large calculated time differences between Fort Keogh, and Santa Rita and Empire Ranch were influenced by the method of evaluations. The times were longer than the times calculated for nutrient loss in the runoff water. This indicates that the runoff water is selectively removing the nutrient. The selectivity comes as a result of the runoff water preferentially removing the soluble nutrient and the smaller soil particles associated with more nutrient. For the soil, this indicates long-term sustainability because of the long time periods required to remove the soil and the plant support and water holding capacity that the soil provides to the ecosystems. A large episodic event, say a 1000 year event, could potentially greatly shorten the time to remove the soil and reduce long-term sustainability.

There is an input of nutrients into the ecosystems from precipitation that can potentially replace some NPK lost in the surface runoff water. Nutrient inputs were measured at

Fort Keogh, and near the Santa Rita and Empire Ranch study sites (Emmerich, 1990) to estimate the magnitude of the inputs for ecosystem sustainability (Table 4). Measured precipitation inputs of NPK at the Fort Keogh site were considerably greater than the losses in the runoff (Table 2 and 4). At the Santa Rita and Empire Ranch sites N & K inputs were close to that lost in runoff while P was less. Caution must be taken when looking at nutrient inputs from precipitation, as unknown amounts of dust containing nutrients are washed into the samples. With the dust contribution into or out of the sites unknown, the measured nutrient inputs could have some errors associated with them. Without grazing and burning causing the accelerated nutrient loss, the results indicate there could be an accumulation of nutrients and possible improvement in the nutrient status.

ACKNOWLEDGMENTS

Authors thank Dr. Gary Richardson for assistance in statistical analysis, and Cheryl Murphy and Charmaine Verdugo for field and laboratory assistance.

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