5 Temporal Variability in Rangeland Erosion Processes

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ABSTRACT

Rainfall simulation experiments conducted on large plots at various rangeland sites in southeastern Arizona were used to determine temporal variability in rangeland soil erosion. Measured soil erodibility varied monthly, seasonally, and yearly and appeared to depend on vegetation and soil type. Short term (monthly or seasonally) variability was greater than year to year variability unless treatment effects were interacting. The RUSLE K factor, computed within the RUSLE model from an algorithm based on frost-free period and annual R-values, cycles differently than the rainfall simulator measured erodibility; RUSLE estimates of K were the highest when measured erodibilities were the lowest. Time related changes in erosion rates associated with rangeland treatment need to be evaluated during a multiyear period using multiplot studies.

Temporal variability in the soil erosion process is both a rangeland and cropland phenomena. The most dramatic variability is observed on cropland areas where mechanical disturbance, growing and harvesting crops, and fallow conditions cause almost instantaneous changes in soil erodibility. Temporal variability of natural components within a rangeland site seem static year to year, day to day, and even hour to hour. The seasonal change is perceived to be the greatest because of variations in vegetation canopy and ground surface cover; however, the near soil surface and surface factors affecting soil erosion processes are changing continuously. For example, daily soil temperature fluctuations affect the soil moisture content and flux, which in turn influence soil infiltration capacity, biotic activity, and soil structural properties (Jaynes, 1990). Temporal variability can be compared with spatial variability in that soil properties, biotic activity, and surface cover characteristics in a heterogeneous rangeland landscape can change in very short distances and very short time frames.

Temporal varying factors affecting the rangeland erosion process include: (i) soil properties of infiltration capacity, porosity, bulk density, organic content, moisture, structure, and crusting; (ii) vegetation canopy cover and growth stage and surface cover; and (iii) surface microtopography. Many of the soil properties are affected temporally by frost action, wetting and drying, and rainfall compaction (Schumm & Lusby, 1963; Gifford, 1979; Simanton & Renard, 1982; Blackburn et al., 1990).

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Temporal variability in rangeland soil erosion may not be as dramatic as for cropland areas, but is critical because of the limited topsoil resource associated with rangeland ecosystems. This temporal variability is recognized in current soil erosion prediction models. If prediction of soil erosion variability can be achieved, then rangeland soil loss can be quantitatively assessed. This chapter reports temporal variability in rangeland soil erosion found during rainfall simulator studies conducted during the past 10 yr in southeastern Arizona.

MATERIALS AND METHODS

Rangeland experiments to quantify temporal variability in soil erosion have relied heavily on rainfall simulation techniques (Gifford, 1979; Devaurs & Gifford, 1984; Simanton & Renard, 1986; Lane et al., 1987; Johnson & Gordon, 1988; Seyfried, 1991; Wilcox et al., 1992). Rainfall simulators have been used extensively for evaluating the hydrologic and erosional responses of the natural environment (Neff, 1979). The advantages of rainfall simulation, especially on arid and semiarid rangelands, are that there is maximum control over where, when, and how data are collected and there is no need to wait for natural storms, which are usually very sporadic. Runoff and erosion responses can be compared both temporally and spatially because similar rainfall sequences, intensities, and amounts can be applied and antecedent conditions controlled.

Rangeland USLE Study (1981–1984)

The Southwest Watershed Research Center, of the USDA-ARS, began rangeland erosion plot studies in 1981 to develop rangeland soil loss factors for the Universal Soil Loss Equation (USLE) (Wischmeier & Smith, 1978). The plots were located in southeastern Arizona on the Walnut Gulch Experimental Watershed ≈90 km southeast of Tucson (Fig. 5–1). Average annual precipitation on the watershed is 320 mm and is bimodally distributed with 60 to 70% occurring during the summer thunderstorm season of July to mid-September (Osborn et al., 1979). In the winter, snowfall occurs periodically, but rarely remains on the

Fig. 5–1. Location of the Walnut Gulch, Santa Rita, and Empire Ranch study sites in southeastern Arizona.

ground for >2 d; soils may freeze to shallow depths (<20 mm) overnight, but thaw during the day. Soils are generally well drained, calcareous, gravelly loams with large percentages (>50%) of rock and gravel on the soil surface and up to 60%, by volume, gravel and cobbles in the surface 100 mm (Gelderman, 1970).

Three sites were selected that had different soil and vegetation complexes. The soil series and descriptive classification were: Bernardino (fine, mixed, thermic Ustollic Haplargid), Cave (loamy, mixed, thermic, shallow Typic Paleorthid), and Hathaway (loamy-skeletal, mixed, thermic Aridic Calciustoll). Table 5–1 lists general soil properties of the surface 5 cm of these three soil series. Vegetation on the Bernardino soil series site was grass dominated; blue grama [*Bouteloua gracilis* (H.B.K.) Lag], sideoats grama [*B. curtipendula* (Michx) Torr.]. Shrubs dominated the Cave soil series site and consisted of creosotebush [*Larrea tridentata* (DC.) Coville], white-thorn (*Acacia constricta* Benth.), tarbush (*Flourensia cernua* DC.), and burroweed [*Aplopappus tenuisectus* (Green) Blake]. The Hathaway soil series site contained grasses; blue grama, sideoats grama, and bush muhly (*Muhlenbergia Porteri* Scribn.), and shrubs; snakeweed [*Gutierrezia Sarothrae* (Pursh) Britt. & Rusby], creosotebush, white-thorn and burroweed. Canopy cover averaged 65, 30, and 50% for the Bernardino, Cave, and Hathaway soil series sites respectively.

Procedures used in these studies are described by Simanton and Renard (1986) and included the use of a rotating boom rainfall simulator (Swanson, 1965) that applied rainfall intensities of 65 or 130 mm h^{-1}. Rainfall simulations were made in the spring and fall on plots 10.7 m long by 3.05 m wide, with three treatments under three soil moisture conditions [dry (existing soil moisture condition), wet (field capacity), and very wet (saturated)]. The treatments were: natural cover (control); clipped (vegetation clipped to a 20 mm height and clippings removed); bare (vegetation clipped at the soil surface and all clipping, surface litter and rock fragments >5 mm removed). Each site was fenced to exclude grazing and plot treatments were made prior to each season's rainfall simulations. Detailed plot characterizations of vegetation composition, foliar canopy cover and ground surface cover were measured before and after treatment. Surface cover characteristics included: soil, gravel (5–20 mm), rock (>20 mm), litter, and basal plant cover. Ten 3.05-m long line transects, perpendicular to the plot and equally spaced along the plot, were measured to produce 490 point readings to describe each plot's surface and vegetation canopy cover.

Table 5–1. General soil properties of the Bernardino, Cave, Hathaway, and White House soil series evaluated with the rainfall simulator.

Series	General Soil Properties			
	Sand	Silt	Clay	Organic matter
	%			
Bernardino	84	10	6	0.8
Cave	66	26	8	1.8
Hathaway	74	17	9	1.5
White House	68	22	10	1.0
Hathaway (Empire)	66	22	12	1.7

Burn Study (1987–1991)

Rainfall simulation studies to determine vegetation burning effects on runoff, erosion, and nutrient cycling were conducted on the Santa Rita Experimental Range and Empire Ranch-Cienega Resource Conservation Area in southeastern Arizona (Fig. 5–1). Average annual precipitation at these areas is 420 mm. Both areas have similar yearly precipitation and temperature characteristics as those found at the Walnut Gulch Experimental Watershed. Soils are generally well drained, calcareous, gravelly loams with up to 25% rock and gravel on the soil surface and ≈20% in the surface 100 mm. The soil series at the Santa Rita site was a White House (fine, mixed, thermic Ustollic Haplargid). The soil series at the Empire Ranch site was a Hathaway. Table 5–1 lists general soil properties of the surface 10 cm of these two soil series. Vegetation at the Santa Rita site was dominated by an introduced grass, Lehmann lovegrass (*Eragrostis Lehmanniana* Nees.). Mean live and dead standing biomass was 4170 kg ha^{-1} and ground litter was 1650 kg ha^{-1}. Native grasses dominated the Empire Ranch site and included black grama (*B. eriopoda* Torr.), hairy grama (*B. hirsuta* Lag.), and sideoats grama. Mean live and dead standing biomass was 2310 kg ha^{-1} and ground litter was 420 kg ha^{-1}.

The rainfall simulation procedures used are described in detail by Emmerich and Cox (1992) and were similar to Simanton and Renard (1986), except rainfall simulations were made only at initial soil moisture conditions. The simulations were conducted in the fall and spring seasons for 2 yr. Treatments at both sites included a natural (control) and a first-year burned treatment (all litter and vegetation burned just prior to the rainfall simulation). Amounts of live and dead standing biomass and ground litter were determined prior to burning and rainfall simulation; plot surface characterizations were not made.

Erodibility Study (1991–1992)

A temporal rangeland soil erodibility study began in 1991 at the Walnut Gulch Experimental Watershed using rainfall simulation techniques described by Simanton et al. (1991). This study was conducted on the Bernardino soil adjacent to the 1981–1984 USLE Bernardino soil site. Monthly evaluations of erosion rates were made on two treatments at the three soil moisture conditions described for the 1981–1984 study. The treatments included a natural (control) and a clipped (vegetation clipped to a 20 mm height and clippings removed) treatment.

RESULTS AND DISCUSSION

Results from all these studies in southeastern Arizona showed that there was monthly, seasonally, and yearly temporal variability in rangeland soil erosion.

Monthly Erodibility

The 1991–1992 erodibility study showed that the clipped plot erosion rate, per millimeter of runoff, cycled through the year by a factor of three between the

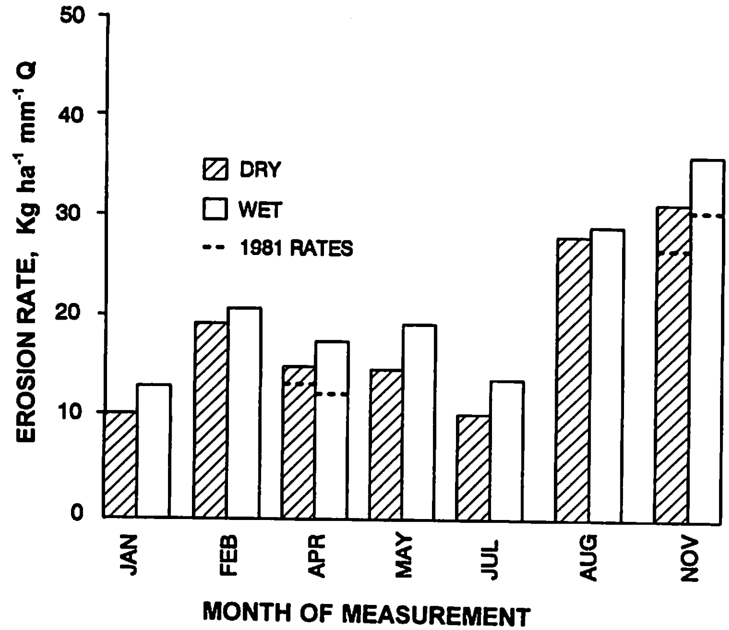

Fig. 5–2. Erosion rates per millimeter of runoff for the clipped plots at dry and wet soil moisture conditions on the 1991 to 1992 and the April and November 1981 Bernardino soil series site.

highest and lowest erosion rates (Fig. 5–2). This same cycle was found for all three soil moisture conditions with erosion rates increasing with increasing soil moisture. The dry and wet soil moisture erosion rates of the 1991–1992 April and November simulations were very near those of the April and November 1981 dry and wet soil moisture erosion rates. The agreement between the 1991–1992 and 1981 erosion rates implies that the monthly cycle is repeatable and that the within year erosion rates are greater than between years. The monthly erosion rate on the control plots was slightly less than the clipped plot erosion rate, but followed a similar cycle. The large decrease in erosion rate from November to January was attributed to the first freeze–thaw sequence that usually occurs in December. The freeze–thaw would loosen the soil surface that had been compacted and sealed during the high intensity summer thunderstorms and the wetting and drying cycles that start in July. July also marked the change from a relative constant erosion rate to an increasing rate during the summer rainstorm period.

Seasonal Erodibility

Four years of spring and fall rainfall simulations were made on the 1981–1984 USLE Walnut Gulch study site plots and 2 yr on the burn study plots at the Santa Rita and Empire Ranch sites. Seasonal runoff and erosion differences were found at all sites. The magnitude of these differences appears to be both treatment and soil type dependent. Greater runoff and erosion occurred from the fall simulations on the nonvegetated (clipped, bare, and burned) plots compared

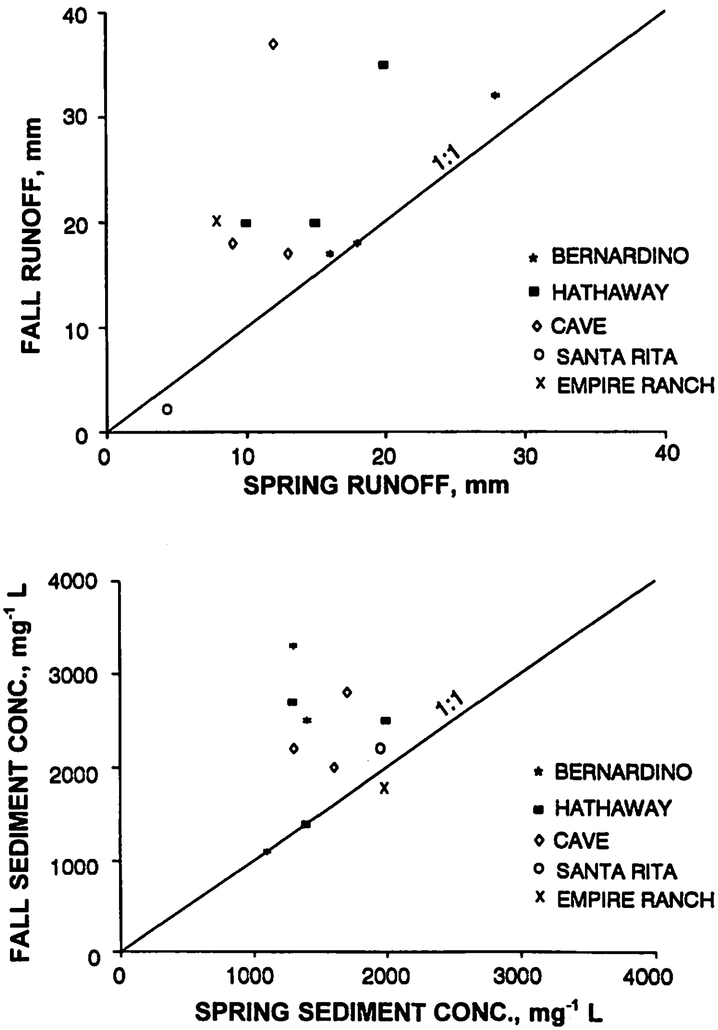

Fig. 5–3. Relation between spring and fall runoff volumes and average sediment concentrations on nonvegetated (bare, clipped, and burned) plots for all study sites.

with the vegetated control plots (Fig. 5–3). Except for the 1981–1984 Bernardino site, the vegetated (control) plots had more runoff in the fall than the spring (Fig. 5–4). Vegetated plots at all sites had lower sediment concentrations in the fall than the spring (Fig. 5–4). Similar seasonal runoff differences have been reported for other rangeland sites (Schumm & Lusby, 1963; Achouri & Gifford, 1984; Simanton et al., 1986; Blackburn et al., 1990). Inadequate data prevent specific explanations for these seasonal differences at the Arizona sites; however, the differences could be related to soil surface aggregate destruction and compaction caused by raindrop impact, wetting and drying cycles with crust formation, and vegetation growth cycles.

Sediment yields from the vegetated plots at the Walnut Gulch sites were lower in the fall than spring whereas the nonvegetated plots had higher yields in the fall

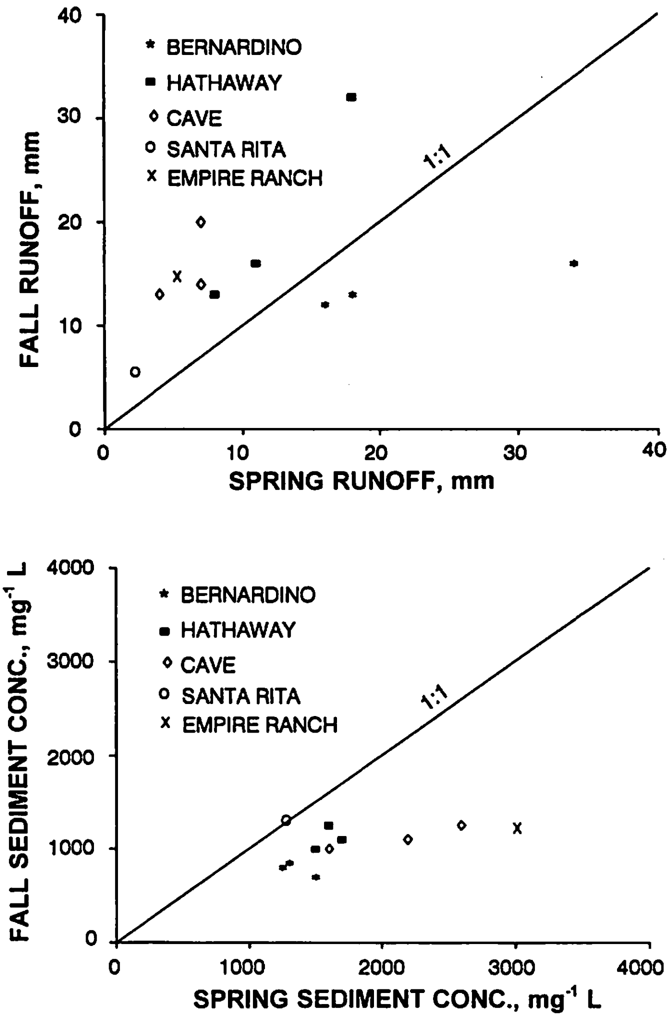

Fig. 5–4. Relation between spring and fall runoff volumes and average sediment concentrations on vegetated (control) plots for all study sites.

than spring (Fig. 5–5). At the Santa Rita site there was no difference between the spring and fall sediment yields, but the Empire Ranch site had significantly more sediment yield in the fall than spring (Table 5–2). The vegetated and burn plot data from the Santa Rita and Empire Ranch sites were pooled for seasonal evaluation as there was no difference between treatments evaluated immediately after the burn.

Yearly Erodibility

Nonlinear least squares fits of measured erosion rate per unit erosion index vs. time data for the control and clipped plots from the Walnut Gulch 1981–1984 study are shown in Fig. 5–6. EI, the product of rainfall energy and maximum 30 min. intensity and a measure of rainfall erosivity (Wischmeier & Smith, 1978),

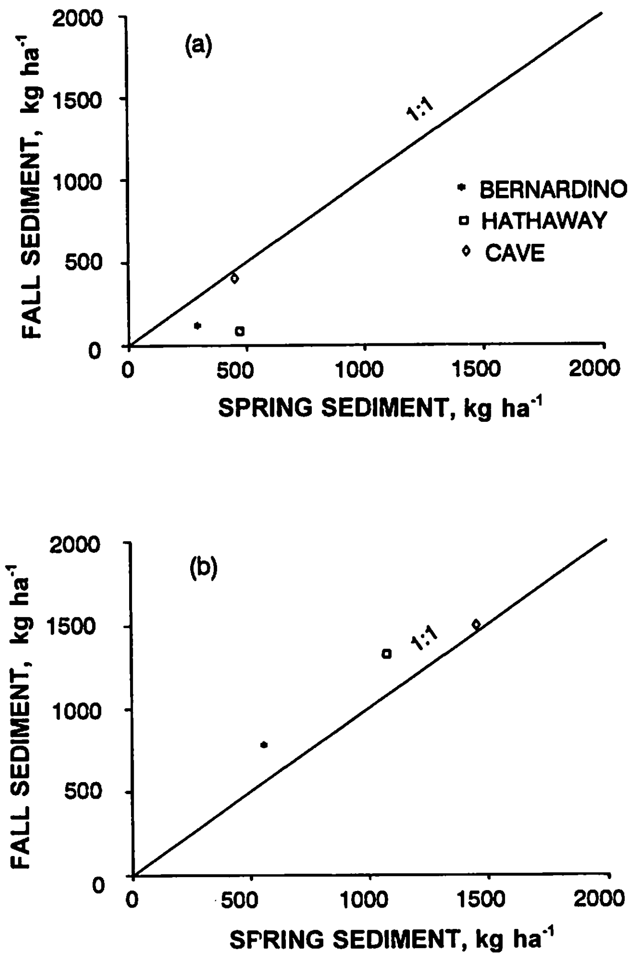

Fig. 5–5. Relation between spring and fall sediment yields for the vegetated (a) and nonvegetated (b) plots for the 1981 to 1984 Walnut Gulch study sites.

Table 5–2. Mean sediment yield per rainfall simulator event from pooled control and burn treatment data for the Santa Rita and Empire Ranch study sites.

Site	Season: Fall	Season: Spring
	kg ha^{-1}	
Santa Rita	26a† (30)	32a (46)
Empire Ranch	222a (169)	98b (97)

†Within rows, data followed by different letters are significantly different ($P < 0.05$). Values in parenthesis are standard deviations.

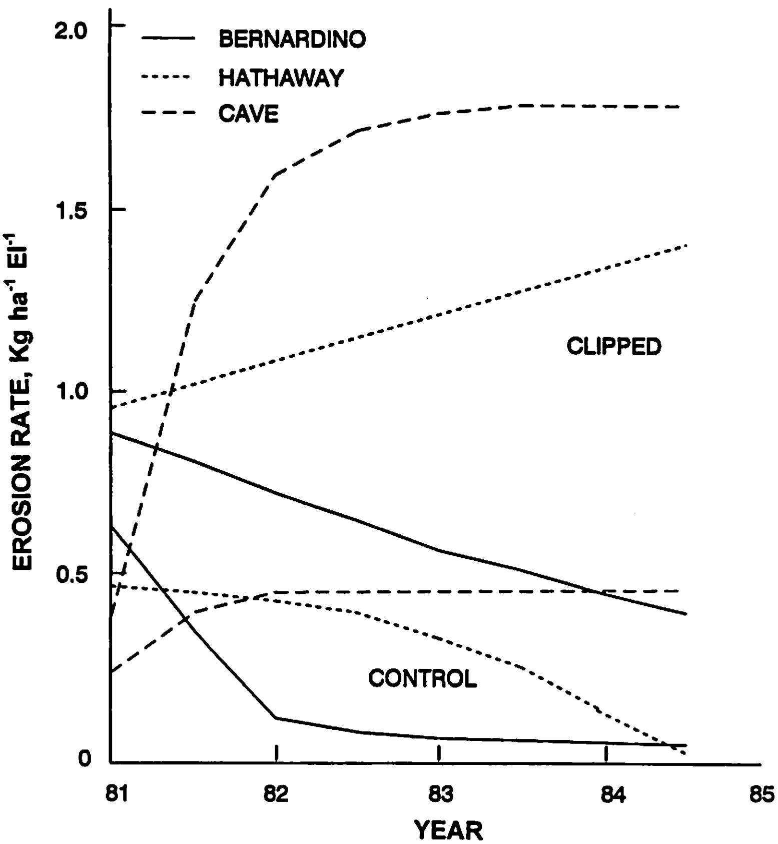

Fig. 5–6. Nonlinear least squares fit of measured erosion rate vs. time for the control and clipped plots from the 1981 to 1984 Walnut Gulch study (Simanton & Renard, 1992).

was used to normalize the rainfall energy inputs to the different treatments. Each soil had a different shaped erosion rate vs. time curve. Erosion rates of the control plots decreased for the Bernardino and Hathaway soils and increased for the Cave soil (Fig. 5–6). The different shapes of the erosion rate curves probably reflected vegetation differences. The Bernardino control plots were dominated by perennial grasses, the Cave control plots were shrub and forb dominated, and the Hathaway control plots had both grass and shrub canopy cover.

The decrease in erosion rate on the Bernardino and Hathaway soils was probably due to increases in soil porosity and organic matter associated with increases in plant basal and canopy cover that occurred because of release from grazing and addition of spring and fall moisture from the rainfall simulations. The initial increase in erosion rate on the Cave soil could be the result of additional rainfall energy added during the rainfall simulations on the shrub dominated site. This would force the relatively unstable mounds found under the shrubs to reach a new equilibrium with the additional energy inputs of the rainfall simulation.

The clipped plots response to the loss of vegetation canopy produced three different trends in erosion rate (Fig. 5–6). The Cave soil (shrub vegetation) erosion rate increased with time after the initial clipping and then leveled out in ≈2 yr. This type of response indicated a new equilibrium was being established with the rainfall energy inputs the same way the control plots responded, only to a greater extent due to the vegetation canopy removal. The Hathaway soil (grass and shrub vegetation) erosion rate continued to increase throughout the four year study whereas the Bernardino (grass vegetation) erosion rate curve decreased with time over the four year period. The decrease in erosion rate of both the control and clipped plots at the Bernardino site could be reflected in a soil response to grazing release. Prior to exclusion from grazing at the beginning of the study, the Bernardino site was the most heavily grazed of the three Walnut Gulch sites.

The bare soil plots produced the greatest erosion rate changes with time of all the treatments (Fig. 5–7). The rates for the Bernardino and Cave soils increased with time for ≈2 yr before reaching a new equilibrium with the energy input. As with the clipped plots, the Hathaway bare soil treatment erosion rate was still increasing after 4 yr. The erosion rate increase for the bare soil treatment

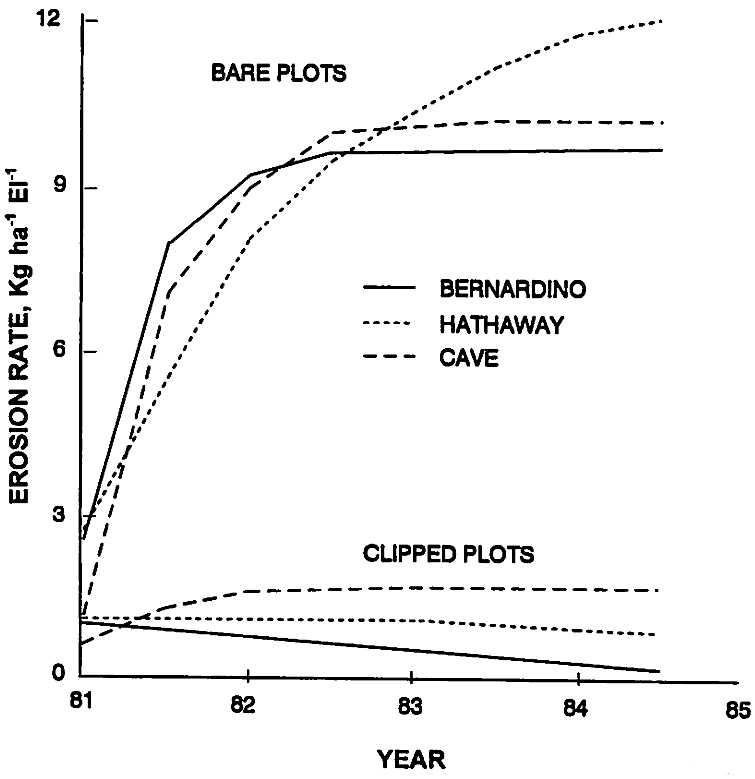

Fig. 5–7. Nonlinear least squares fit of measured erosion rate vs. time for the bare and clipped plots from the 1981 to 1984 Walnut Gulch study (Simanton & Renard, 1992).

Table 5–3. Mean surface runoff and sediment yield for the control and burned plots after treatment and 1 yr later on pooled data for the Santa Rita and Empire Ranch study sites.

Treatment	Surface runoff	Sediment yield
	—— mm ——	— kg ha^{-1} —
	After burn	
Control	5.8 (7.5)†	76 (98)
Burn	7.0 (10)	106 (145)
	1 yr later	
Control	4.4 (6.7)	67 (97)
Burn	19 (13)	454 (388)

†Values in parenthesis are standard deviations

closely emulated runoff changes that may be attributed to the decrease in root and residue material in the soil, which in turn decreased the soil macropore structure (Dixon & Simanton, 1979). Other reasons for the erosion rate increase could be the formation of better defined concentrated flow paths that would be more efficient in sediment transport and a decrease in surface roughness associated with vegetation and rock fragment removal. Most likely, the increase in runoff and erosion rates is a combination of these factors rather than the result of any single factor. The bare soil plots on the Bernardino soil had an erosion rate ≈90 times greater than the control at the end of 4 yr. For the other two soils, the bare soil plots had erosion rates that were ≈30 times greater than the control.

If the vegetative canopy cover was a dominate factor controlling erosion rates, a dramatic increase should have been found immediately in the clipped plot results. The clipped plot's erosion rate did change with time, but not as drastically as the bare plot (Fig. 5–6 and 5–7). This suggests a small influence on erosion rate of vegetative canopy cover removal and a more dominate effect of soil surface cover controlling (i.e., rock fragment cover) erosion rates. Similar results have been reported by Simanton et al. (1991) for nine other rangeland sites throughout the western USA. The clipped plot response also suggests that the loss of soil surface cover from the bare plots and increase in concentrated flow paths were probably dominating the bare plot response.

There were no significant differences in runoff or sediment yield between the control and burned treatments after the burn treatments were imposed at the Santa Rita and Empire Ranch sites (Emmerich & Cox, 1992) (Table 5–3). One year after the burn there was over four times the runoff from the burned plots compared with the control and more than six times the sediment yield. These results agree with the Walnut Gulch data in that increases in erosion will occur with time once the soil surface protection is removed. The Santa Rita and Empire Ranch sites did not have rock cover to protect the soil surface and within a year increases in erosion rates were observed. The Walnut Gulch clipped plots had soil surface rock fragment cover to protect the soil surface and prevent an erosion rate increase with time.

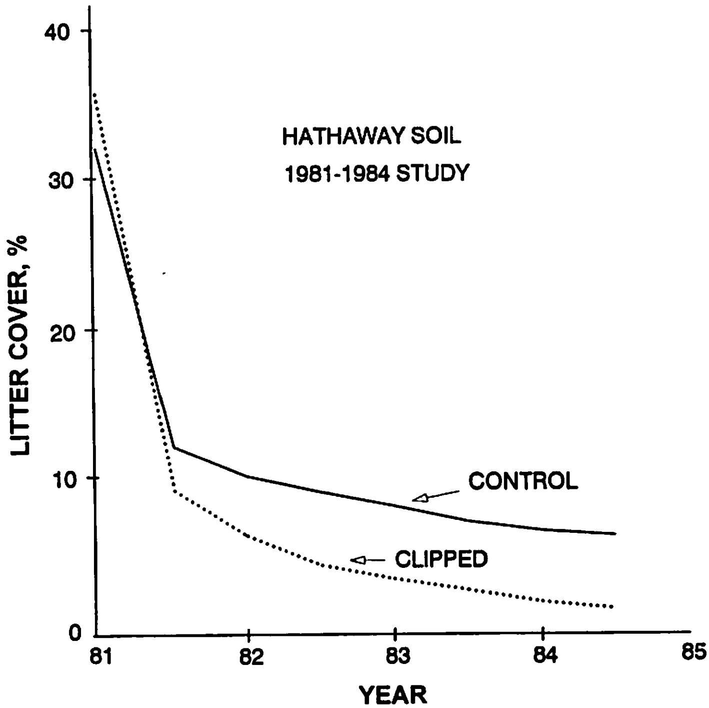

Fig. 5–8. Change in percentage litter cover of the control and clipped plots from the Hathaway site of the 1981 to 1984 Walnut Gulch study.

Plot Characteristics

Of the yearly changes in measured plot surface characteristics, the change in litter cover was most surprising. As would be expected, the clipped plot litter cover decreased with time as the canopy cover was continually being clipped. However, the litter cover of the control plots from all three 1981 to 1984 Walnut Gulch sites also decreased with time, though at a slower rate (Fig. 5–8). Only results from the Hathaway site are shown, but the results from the other sites followed a similar trend. Associated with this litter cover decrease was a corresponding increase in plot surface bare soil. Litter being removed by the runoff was not evaluated, but this mechanism for litter disappearance is possible. The reason for the corresponding increase in bare soil, however, is not clear. These two changes in plot surface characteristics could both be explained by increases in termite activity. In the Chihuahuan desert, under conditions of high relative humidity, termites have been shown to remove a large fraction of surface plant material, while moving large amounts of mineral soil to the surface (Whitford et al., 1982; Elkins et al., 1986). The spring and fall rainfall simulations were made during naturally dry periods, thus extending the period of termite activity. The disappearance of litter, forage for termites; and an increase in surface soil, a by-product of termite foraging; may be evidence enough to explain the decrease in litter cover and corresponding increase in surface soil.

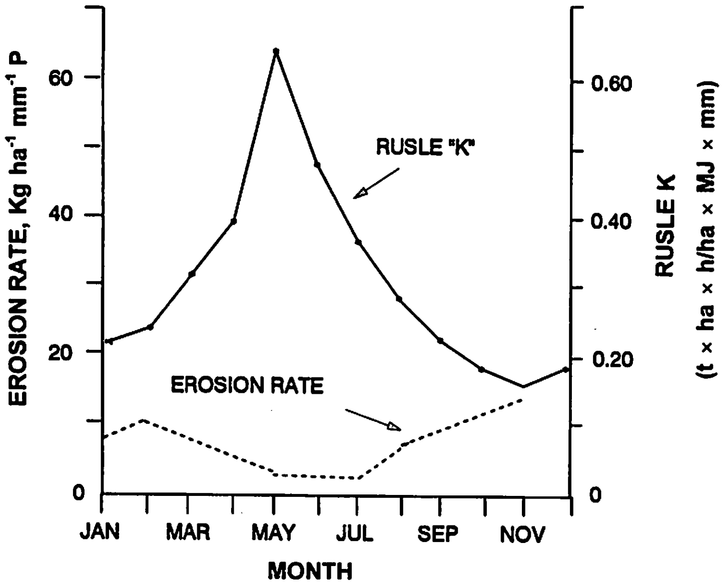

Fig. 5–9. Monthly measured erosion rate per millimeter of precipitation for the wet soil moisture condition on the clipped plots of the 1991 to 1992 Bernardino study and the RUSLE estimated monthly *K*.

RUSLE Soil Erodibility Factor *K*

The Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1991) is the soil loss prediction equation developed to replace the USLE. The equation is:

$$A = R \times K \times \mathrm{LS} \times C \times P \text{ where,}$$

A = average annual soil loss (t ha^{-1}),
R = average annual erosivity (MJ × mm/ha × h × y),
K = soil erodibility (t × ha × h/ha × MJ × mm),
LS = topographic effect,
C = cover-management, and
P = conservation practice.

The soil erodibility factor (K) of the RUSLE is varied throughout the year and the variance is described by an algorithm dependent on length of frost-free period and average annual R. Monthly measured erosion rates, kilogram per hectare per millimeter precipitation, for the Bernardino soil at field capacity (wet soil moisture), from the 1991 to 1992 Bernardino erodibility study are plotted with the RUSLE estimated K factor for that soil (Fig. 5–9). The measured erosion rates are lowest between May and July when RUSLE estimates the K factor to be at its highest. Also, RUSLE estimated K to be lowest in November when the highest measured erosion rate occurred. This period of highest soil erodibility, however, coincides with the period of lowest rainfall erosivity. This discrepancy in the cycle of soil erodibility extremes may be due to the lack of freeze–thaw intensity in the Bernardino soil as compared with the soils from which the RUSLE *K* algorithm was developed. The RUSLE *K* algorithm was developed on cropland soils from the east and midwestern USA. The Bernardino soil was not in the standard plot (continuous fallow, up-down slope cultivation) condition (Wischmeier & Smith, 1978) as required for a *K* factor determination, therefore, the plot erosion rate and the *K* factor cannot be compared directly, but yearly trends in the cycle should be in agreement.

CONCLUSIONS

Soil erodibility, measured by rainfall simulation experiments conducted at various rangeland sites in southeastern Arizona, varied monthly, seasonally, and yearly and appears to depend on vegetation and soil type. Short-term (monthly or seasonally) variability is greater than year-to-year variability unless treatment effects are interacting. The RUSLE *K* factor cycles differently than measured erodibility and estimates the highest erodibilities when, in fact, they have been measured to be at their lowest. Time related changes in erosion rates associated with rangeland treatment need to be evaluated during a multiyear period using multiplot studies. Biotic, both flora and fauna, influences can play a major role in the temporal variability of the rangeland soil erosion process.

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