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Time Related Changes in Rangeland Erosion

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Key Words: rainfall simulation, USLE, runoff

Abstract

Rainfall simulation studies on semiarid rangeland plots in southeastern Arizona have indicated that erosion rates per unit rainfall energy changed with time during a four-year study. Erosion rates changes corresponded to observed changes in runoff rate and were also reflected in changes in USLE erosion parameters. The study showed that at least two years of seasonal simulations are needed before erosion and runoff rates reach equilibrium with energy input.

Introduction

Erosion studies in cropland areas have indicated that erosion rates vary in time for various cover-management situations, and that these changes are often related to soil erodibility changes (Dissmeyer and Foster 1981, Van Doren et al. 1984). Most currently-used models assume soil erodibility is time invariant. Thus, some of the cover-management parameter temporal changes observed in field data are possibly reflecting soil erodibility changes. Very little information is currently available concerning erosion rate change within natural conditions on rangelands.

One method of estimating rangeland erosion is through the use of the Universal Soil Loss Equation, USLE (Wischmeier and Smith 1978). The equation has been used with various degrees of success to estimate rangeland erosion from small semiarid watersheds (Simanton et al. 1980, Renard and Foster 1985). Because of the relatively small amount of USLE compatible data available from rangelands, and the need for quantification of rangeland USLE factor values, rainfall simulation studies were conducted on rangeland sites at the Walnut Gulch Experimental Watershed in southeastern Arizona, during the spring and fall, for 4 years (see Simanton et al. in these proceedings for detailed description). Though the main objective of the rainfall simulations was to quantify USLE factors for rangelands, this paper reports interesting time dependent changes found to be occurring during the 4-year study.

The USLE estimates average annual soil loss using the equation:

$$A = RKLSCP$$

where A = estimated soil loss (tons/ha/yr),
R = rainfall erosivity factor (EI units/yr) (EI = MJ • mm/ha • h),
K = soil erodibility factor (tons/ha/EI unit) (t • ha • h/ha • MJ • mm),
LS = slope steepness-length factor,
C = cover and management factor, and
P = erosion control practice factor.

Of the five factors in the USLE (LS is usually considered one term), the rainfall factor is the only one that can be expected to significantly change naturally from one year to another on rangeland. This is also the factor over which man has no control. The cover-management factor may also change naturally from year to year, but not as drastically as that for the rainfall factor. Actual perennial vegetation cover changes are difficult to perceive on a year to year basis, and tend to leave the impression that a static cover condition exists on rangeland.

Rainfall simulator experiments, to evaluate the terms of the USLE, were initiated in the spring of 1981 on three soils at the Walnut Gulch Experimental Watershed (Simanton and Renard 1982). The experimental design included using a rotating boom rainfall simulator (Swanson 1965) on 10.7 m by 3.05 m plots, with two replications of natural, clipped, bare, and tilled treatments. Grazing was excluded from the plots throughout the study period. The clipped treatment consisted of clipping the vegetation at the ground surface, removing the clippings, and controlling any vegetation regrowth with a systemic herbicide. The bare treatment included vegetation clipping and removal, herbicide control, and removing all rock fragments larger than 5 mm in diameter from the soil surface that were not partially embedded in the soil. The tilled treatment was the standard up-and-down slope cultivation like that used to evaluate K-factor values for agricultural soils (Wischmeier and Smith 1978). This treatment was assumed to be the one standard that could be used for direct comparison to other rainfall simulation studies. The initial treatments were made prior to the rainfall simulations in the spring of 1981. Retreatments were made before each successive seasonal rainfall simulation (simulations were made in the spring and fall of each year). The tilled treatment was not repeated on one of the replications after the first year of the study, and then not repeated on the remaining replication after the second year of the study.

Research Location and Description

The Walnut Gulch Experimental Watershed is located in southeastern Arizona. The area is representative of millions of hectares of brush and grass rangeland found throughout the semiarid Southwest, and is considered a transition zone between the Chihuahuan and Sonoran Deserts (Hastings and Turner 1965). Average annual precipitation on the watershed is about 300 mm, and is bimodally distributed, with 70% occurring during the summer thunderstorm season of July to mid September. Soils are generally well drained, calcareous, gravelly loams with large percentages of rock and gravel on the soil surface. The three soil series selected were: Bernardino (a thermic *Ustollic Haplargid)*, Cave (thermic, shallow *Typic Paleorthid)*, and Hathaway (thermic *Aridic Calciustoll)*. These soils comprise nearly 45% of the Walnut Gulch Watershed area (Gelderman 1970), and are USDA-SCS benchmark soils for Arizona. The Bernardino series is a deep, well-drained, fine textured soil formed in old calcareous alluvium. Although this soil may have 50%, by volume, gravel and cobbles in the surface 10 cm, the remainder of the profile is usually less than 35% gravel. The Cave series is a shallow, well-drained, medium textured soil with indurated lime hardpans that have developed at less than 45 cm in old gravelly and cobbly calcareous alluvium. This soil can have up to 60%, by volume, gravel and cobbles in the surface 10 cm, and usually less than 40% gravel in the remaining profile. The Hathaway series is a deep, well-drained, gravelly medium and moderately coarse-textured soil over very gravelly,

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coarse-textured materials of moderate depths. This soil was formed from gravelly, or very gravelly, calcareous old alluvium, and can have up to 70%, by volume, gravel and occasional cobbles in the surface 10 cm, and usually less than 50% in the remainder of the profile. Vegetation of the area includes: creosote bush *(Larrea tridentata)*, white-thorn *(Acacia constricta)*, tarbush *(Flourensia cernua)*, snakeweed *(Gutierrezia sarothrae)*, burroweed *(Aplopappus tenuisectus)*, black grama *(Bouteloua eriopoda)*, blue grama *(B. gracilis)*, sideoats grama *(B. curtipendula)*, and bush muhly *(Muhlenbergia porteri)*. Typically, plant canopy averages 50% and plant basal area averages 2%.

Results and Discussion

The concept of using a tilled fallow plot as the reference for the simulator studies on rangeland was abandoned after a short time because: (1) tillage is not a common practice on semiarid rangelands; (2) the tilled rangeland plots did not yield appreciable runoff and subsequent erosion in contrast to that treatment's yield in agronomic cropped areas; and (3) the tilled plots remained artificially rough with tremendous surface depression storage because of the large amount of boulders, cobbles, and gravel material brought to the soil surface. Thus, after two seasons, only the clipped and bare treatments were left to compare to the natural plots.

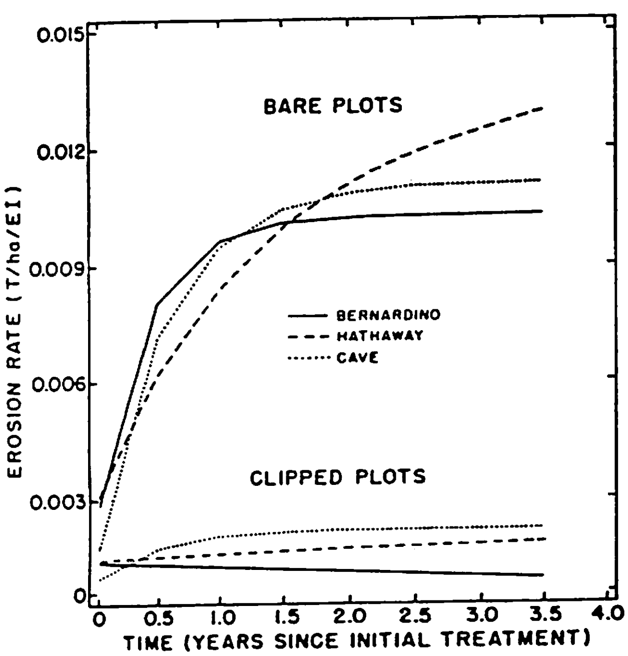

Figure 1. *Computer fitted function of actual erosion and time data for the 2 replication average for spring and fall runs with time zero equal to spring 1981 for the Walnut Gulch bare and clipped plots.*

The bare soil treatment produced the largest erosion rates (tons/ha/EI) of all treatments, and the rates increased with time for about 2 years before reaching an "equilibrium" with the energy input for both the Bernardino and Cave soils (Fig. 1). After 4 years, the Hathaway soil erosion rate still had an upward trend. The erosion rate increase for this treatment closely emulated runoff changes (Fig. 2) which may be attributed to the decrease in root and residue material in the soil, which in turn decreased the soil macropore structure (Dixon 1975). Furthermore, the formation of a rill network that was observed to develop after the vegetation and rock fragments were removed would also cause the runoff and erosion to increase, as well as shorten the runoff response time to the simulated rainfall. Most likely, the increase in erosion rate is a combination of these and other factors. If the erosion rate increase was a function of plant and litter removal, the effect should be found in the clipped plot results.

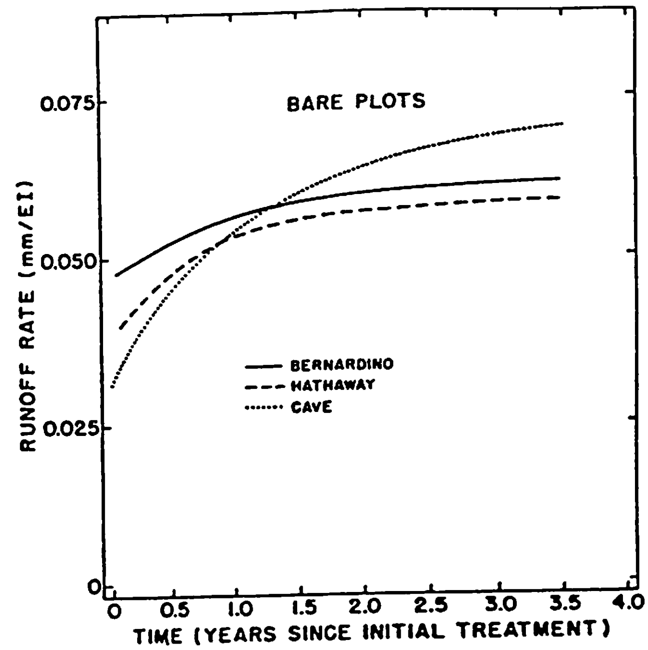

Figure 2. *Computer fitted function of actual runoff and time data for the 2 replication average for spring and fall runs with time zero equal to spring 1981 for the Walnut Gulch bare plots.*

The clipped plot's erosion rate indicated a small change with time (Fig. 1), and, as with the bare plot, the change was associated with the change in runoff rate (Fig. 3). This suggests a small influence of plant and litter cover removal on erosion rate, and that the rill network formation was probably dominating the process. In addition, the erosion pavement may be effective in maintaining a high infiltration capacity by preventing soil surface crusting or sealing, and also reducing overland flow velocity.

Erosion and runoff rates of the natural plots showed a downward trend for the Bernardino and Hathaway soils and an upward

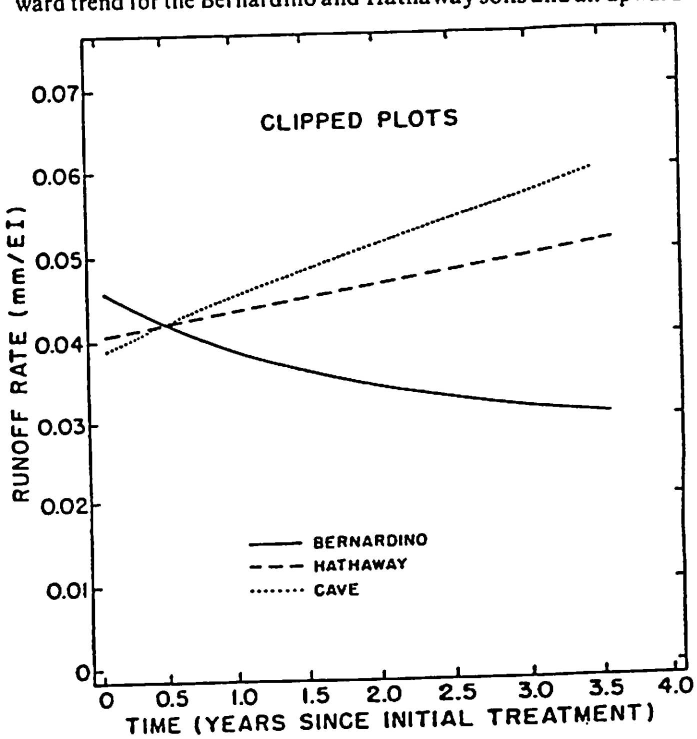

Figure 3. *Computer fitted function of actual runoff rate and time data for the 2 replication average for spring and fall runs with time zero equal to spring 1981 for the Walnut Gulch clipped plots.*

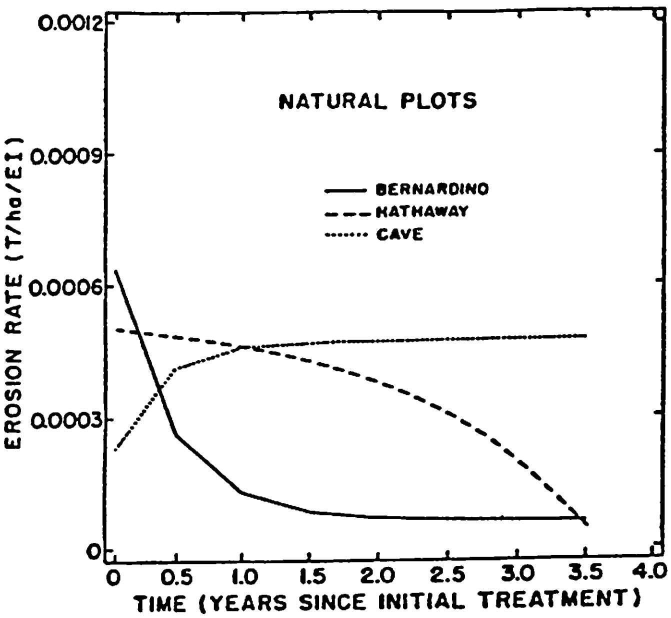

Figure 4. *Computer fitted function of actual erosion rate and time data for the 2 replication average for spring and fall runs with time zero equal to spring 1981 for the Walnut Gulch natural plots.*

trend on the Cave soil for about the first 2 years (Fig. 4 and 5). The shapes of the erosion and runoff rate curves are probably reflecting vegetation differences. The Bernardino natural plots were dominated by perennial grasses; the Cave natural plots were shrub and forb dominated; and the Hathaway natural plots had both grass and shrub canopy cover (see Simanton et al. in these proceedings).

Results from these four years of simulation indicate the importance of multi-year simulations in that erosion rates do change in time. If the data are to be used in models estimating long term

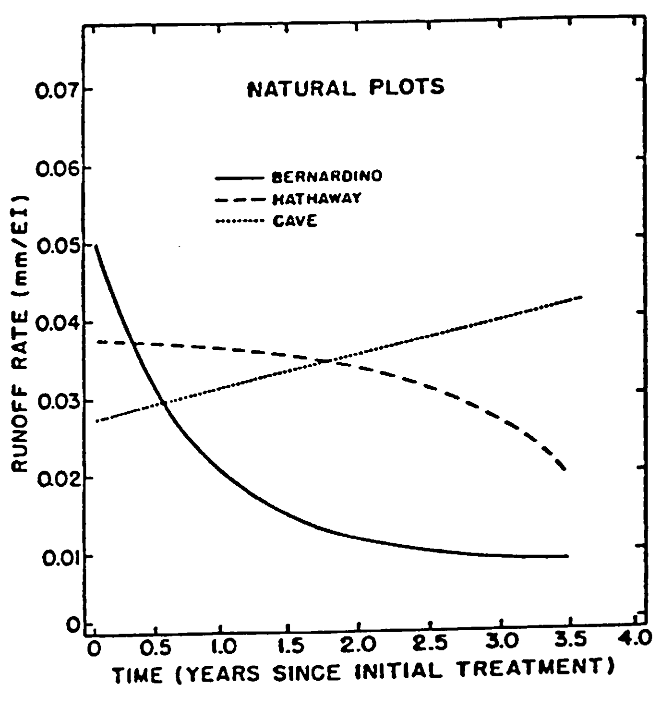

Figure 5. *Computer fitted function of actual runoff rate and time data for the 2 replication average for spring and fall runs with time zero equal to spring 1981 for the Walnut Gulch natural plots.*

management effects on erosion, the data base needs to extend for more than 1 year.

Because the tilled plot did not have significant runoff or erosion, the bare plot was used as the rangeland "standard plot" to determine K values (t • ha • h/ha • MJ • mm) for the three soils used in the study (assume C equaled 1 for the bare condition). Soil K values increased with time and, for the Bernardino and Cave soils, leveled out after about 2 years (Fig. 6). The calculation to determine K from actual soil loss for the bare plot on each soil is,

$$K = A/RCLSP$$

where:

A = actual soil loss from the bare plot,
R = rainfall energy to produce the soil loss,
LS = slope and length correction for each plot,
P = 1 for rangeland conditions, and
C = 1 for the bare plot.

When C = 1 for the bare plot, the simulator derived K values were 0.009, 0.012, and 0.011 (t • ha • h/ha • MJ • mm) for the Bernardino, Hathaway, and Cave soils, respectively. The nomograph values (derived from soil characteristics as described by Wischmeier et al., 1971) for these same three soils were 0.021, 0.028, and 0.036 (t • ha • h/ha • MJ • mm), respectively. If the bare plot C value is assumed to be 0.45, as given in Table 10 of Agricultural Handbook 537 (Wischmeier and Smith 1978), and used to calculate K from the simulator bare plot data, K values would be 0.020, 0.027, and 0.024 (t • ha • h/ha • MJ • mm), respectively. These are fairly consistant with the nomograph K values for the three soils. However, the 0.45 maximum C value in Table 10 of Handbook 537 was determined from an agricultural soil, and represents

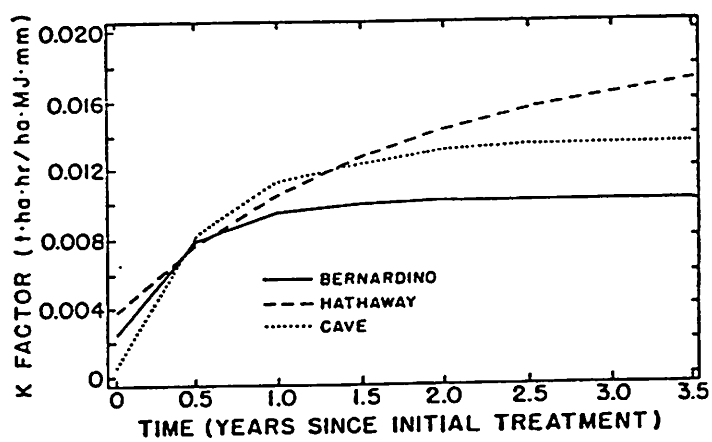

Figure 6. *Computer fitted function of USLE K factor change with time for the Walnut Gulch bare plots. Time zero equals spring 1981 and C was assumed 1 for the bare surface condition.*

the ratio of soil loss from a 7-year reconsolidated tilled soil to the 2-year average soil loss just after tillage (i.e., soil loss from the tilled soil was 2.2 times greater than the soil loss from the same soil 7 years after its last tillage). Results from our rangeland tilled treatment indicated that both runoff and erosion were reduced just after tillage, as compared to the natural condition, and that erosion increased with time as the soil reconsolidated, vegetation invaded, and rock fragments worked to the soil surface.

Assuming that a complete series of runs (each season) represented a year's total natural R (average R for Walnut Gulch is about 1020, and a season's simulated rainfall R is about 1150), then each season's simulation represented a year, and time-related changes in erosion rates could be made. The third and fourth year average soil loss was 71, 84, and 56% of the average soil loss during the first and second year after tillage for the Bernardino, Hathaway, and Cave soils, respectively.

Vegetation effects on erosion rates were determined from erosion rate differences between the clipped and natural treatments on all soils. By the end of the 4 year study, the clipped plots had an average equilibrium erosion rate almost 5 times greater than the average erosion rate of the natural plots. However, the bare plots had an average equilibrium erosion rate of more than 25 times the average rate of natural plots. Even though the clipped plots did not have vegetation after the first year of treatment, the erosion rate changed very little with time, suggesting that the erosion reducing effect of vegetation was not as significant as the effect of surface rock fragments, as shown by Simanton et al. in these proceedings.

Canopy cover of the natural plots tripled on the Bernardino and Hathaway plots, and nearly doubled on the Cave plots over the 4-year study (Fig. 7). This increase is, undoubtedly, a result of the

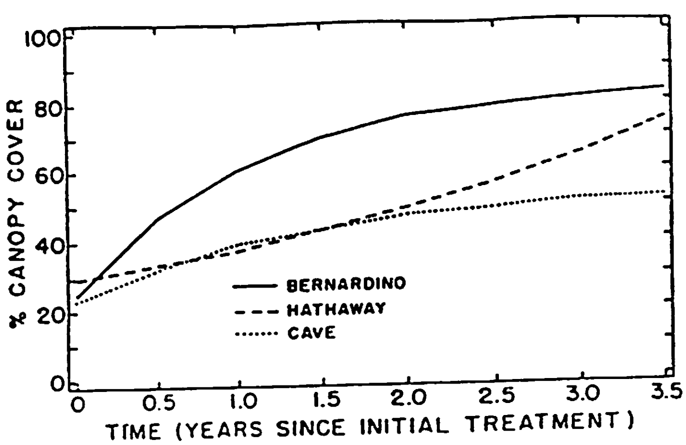

Figure 7. Computer fitted function of percent canopy cover and time where time zero equals spring 1981 for the Walnut Gulch natural plots.

increased water applied, but also may be reflecting response to no livestock grazing. Litter cover on the natural plot's soil surface decreased with increasing vegetation canopy but the amount of bare soil more than doubled over the 4-year study period (Fig. 8). This increase in surface soil on the natural plots could be caused by vegetation trapping of wind blown soil or, as evidenced by the

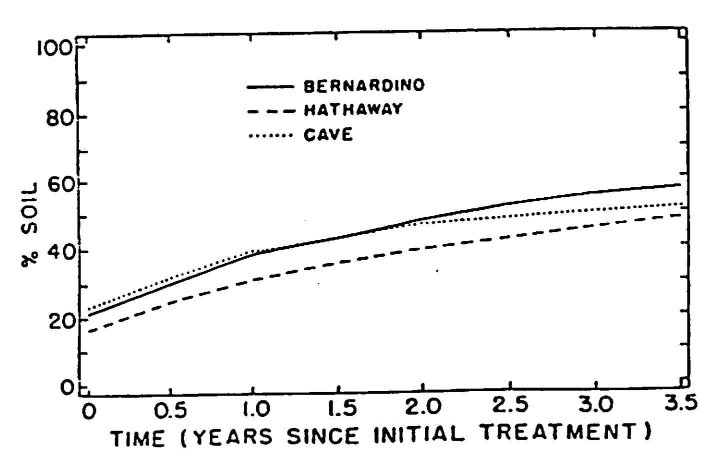

Figure 8. Computer fitted function of percent bare soil and time where time zero equals spring 1981 for the Walnut Gulch natural plots.

almost complete lack of litter cover, termite activity. Termites bring soil to the surface, and use it to coat litter particles so they can utilize the litter daylong out of the direct rays of the sun (Whitford et al. 1982). With weathering, these termite casts break down, and the soil remains on the surface. Protected by the vegetation canopy, the soil brought to the surface is not eroded from the natural plot as rapidly as from a plot without vegetation.

The USLE C factor, or cover-management factor, was calculated for the natural plots assuming that the bare plot C value was unity, and that the calculated K, or soil erodibility factor, of the bare plot was valid for each of the soils. Because of the method of calculation, the C and K factors are not independent, and a decrease in one will produce an increase in the other. The C value decreased with time, but at different rates for each soil-vegetation complex (Fig. 9). The rate of decrease for C on the Bernardino soil

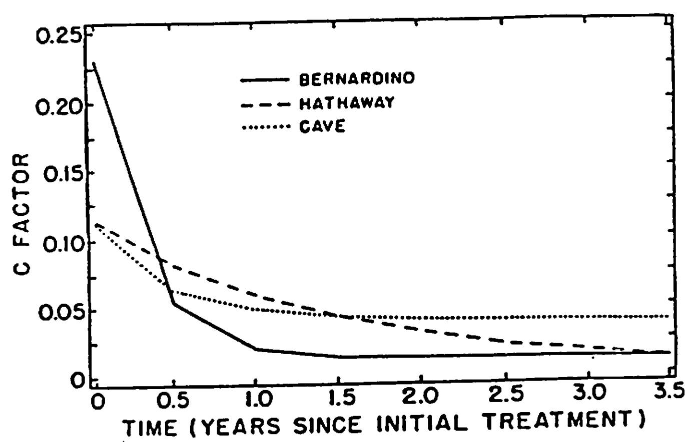

Figure 9. Computer fitted function of USLE C factor change with time where time zero equals spring 1981 for the Walnut Gulch natural plots. The C factor was calculated using the simulator derived K value from the bare plots whose C value was assumed to be 1.

natural plot (grass vegetation) was over 2 times the increasing rate of the K value during the first year of the study. The decrease in the C value of the Hathaway soil natural plot (shrub and grass vegetation) was about the same as the increase in the K value. The Cave soil natural plot (shrub and forbs) had a C value change that was 6 times less than the corresponding increase in the K value during the first year of study. The C value of the Bernardino and Cave soils reached equilibrium around 2 years after the start of the simulation study, whereas the Hathaway soil natural plot still had a slight downward trend after 4 years. The differences in C factor response reflect the effect of vegetation canopy types, with the grass canopy being more important in erosion control than a shrub canopy. However, the effect of the vegetation type also influences runoff, which is interrelated with erosion.

Summary

Four years of seasonal rainfall simulation studies on rangeland USLE-type plots have indicated that erosion and runoff rates per unit of EI change with time for the first one to two years, and then tend to reach an equilibrium rate. Associated with these changes, were rate changes in the USLE K (bare treatment) and C factors, vegetation canopy, and amount of bare soil accumulation on the plot surface (natural plot). This study indicates tht at least two years of spring and fall rainfall simulation runs are necessary to adequately define relatively long-term responses of rangeland runoff and erosion.

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