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UPLAND EROSION RESEARCH ON RANGELAND

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Abstract

Rangeland upland erosion research using rainfall simulation techniques has been conducted on a wide range of ecosystems in the Western United States. The initial research began in 1981 and was to parameterize rangeland conditions for use in the Universal Soil Loss Equation (USLE) and later the Water Erosion Prediction Project (WEPP) erosion model. The field experimental design has progressed from simple replicated plots needed to parameterize the empirically based USLE to multi-intensity rainfall rates and overland flow injections needed for the dynamic, processed based WEPP erosion model. Results from over ten years of research have shown that erosion pavement (surface rock fragments) plays a major role in reducing soil erosion; there are temporal changes in rangeland soil erodibility; and vegetative canopy cover has very little direct effect on soil erosion rates. The Revised Universal Soil Loss Equation (RUSLE) has been developed and includes results of these rangeland erosion studies. The WEPP erosion model is nearing completion and results of two years of intensive rangeland experiments are incorporated into the rangeland, infiltration, and soil modules of the model.

Introduction

Upland erosion from rangelands may seem relatively small compared to the very high rates reported for cropland areas. However, when viewed in terms of erosion rate per unit area and the vastness of rangelands worldwide, the magnitude of the situation can be appreciated. Furthermore, rangeland erosion rates are very critical because of the limited soil resource associated with many of the ecosystems involved. Rangelands cover extensive areas of the world and are an important land resource of the Western and Southwestern United States (Simanton 1991). Rangelands are usually used for livestock grazing, wildlife habitats, recreation areas, and water producing catchments. Precipitation is generally less than potential evapotranspiration, erratic, and, in areas where intense thunderstorms dominate, upland erosion can be significant (Branson et al. 1981). This paper traces the history of our efforts to develop technology for improved erosion prediction on rangelands of the Western United States.

Universal soil loss equation

Efforts to estimate or predict soil erosion from rangelands have centered on the Universal Soil Loss Equation (USLE) (Wischmeier & Smith 1978), an equation developed for cropland situations but applied to range and forest land conditions (Simanton et al. 1980, Dissmeyer & Foster 1980).

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)
LS = slope steepness-length factor,
C = cover and management factor, and
P = erosion control practice factor.

These factors reflect the major variables influencing soil erosion by rainfall and resultant overland flow. The equation is based on plot data collected mainly from cropland areas in the Eastern United States. The cropland rainfall simulation erosion research used relatively large plots, a standard plot tilled up-down slope, in fallow condition, with 9% plot slope and standard sequences of rainfall input (Wischmeier & Mannering 1969).

Rainfall Simulation
Rainfall simulation is a useful tool for evaluating the hydrologic and erosional responses of the natural environment. Pros and cons of rainfall simulation have been well documented (Neff 1979). The major objections to rainfall simulators are

that they do not produce natural rainfall energies or variable intensities, and in the case of larger simulators, the water used in the simulation can have water quality different than natural rainfall. However, the major advantage of simulators, especially in arid and semiarid environments, is that not only can maximum control be achieved over where, when, and how data are collected but also there is no need to wait for a natural storms which are usually very sporadically. Plot runoff and erosion responses can be easily compared among ecosystems because the same rainfall sequence, intensity, and amount can be applied and antecedent conditions controlled.

USLE rangeland experimental procedures

Rangeland Experiments
As part of an effort to improve the application of the USLE to a wide range of land types and uses, the United States Department of Agriculture's (USDA) Agricultural Research Service (ARS) initiated a program to update the technology. The Southwest Watershed Research Center's (SWRC) staff in Tucson, Arizona participated in this effort by developing rainfall simulation procedures to evaluate and quantify soil and management parameters for conditions in various Western United States rangeland ecosystems. Standards similar to those used for cropland studies were used in these simulator studies so direct comparison could be made to other USLE research.

Rainfall Simulator The SWRC began rangeland erosion plot studies in 1981 to develop rangeland soil loss factors for the USLE. These studies were conducted using a rotating boom rainfall simulator (Swanson 1965) on 3.05 m x 10.7 m plots (Fig. 1). The simulator is trailer mounted, has ten 7.6-m booms radiating from a central stem, and rotates about 4 rpm. The arms support 30 V-Jet 80100* nozzles positioned at various distances from the stem. The nozzles spray downward from an average height of 2.4 m, apply rainfall intensities of about 65 or 130 mm/hr and produce drop-size distributions similar to natural rainfall. Simulator energies are about 77% of those of natural rainfall and the simulator produces intermittent rainfall impulses at the plot surface as the booms pass over the plot. Rainfall spatial distribution over each plot has a coefficient of variation of less than 10%. Changes in rainfall intensities are produced by increasing or decreasing the number of open nozzles; 15 nozzles for 65 mm/hr and 30 nozzles for 130 mm/hr. Because of the simple design and portability of the simulator and

*Trade names are included for information only, and do not constitute endorsement by the authors or the US Department of Agriculture.

because two plots are covered during one run, many plots can be evaluated in a relatively short time (Fig. 2).

Rainfall/Runoff/Sediment Three rainfall simulation runs were made on each plot pair in the following sequence: Dry run- initial 60-min rainfall on dry soil conditions; Wet run- 30-min rainfall approximately 24 hr after the dry run and; Very wet run- 30-min rainfall 30-min after the completion of the wet run. Rainfall application rate was measured with a recording raingage and rainfall distribution on each plot was measured with six non-recording raingages. Plot runoff was measured by specially designed precalibrated flumes (4 l/sec maximum capacity) equipped with water level recorders that measured instantaneous flow depth. Continuous hydrographs were produced using the flume's depth/discharge rating table. During a run, times of ponding (0.5 of the plot surface had standing water), runoff initiation, sediment samples, and end of runoff were recorded on field notes for later comparisons to recorder charts. Plot sediment yield was calculated from periodic sediment samples taken throughout the hydrograph. Sampling intervals were dependent on changes in the runoff rate with more frequent sampling (1-2 min intervals) when discharge was changing rapidly. Sediment samples were analyzed for total concentration and particle size distribution. All rainfall, runoff, and sediment data were used in computer programs developed especially for the simulator studies.

Plot Characteristics Vegetation composition, foliar canopy cover and ground surface characteristics of each of the large plots were measured before and after treatment. Surface cover characteristics included: soil, gravel (5-20 mm), rock (>20 mm), litter, cryptogams, and basal plant cover. A 49 pin point-meter that was 3.05-m long with pin holes spaced every 60 mm was placed perpendicular to the plot slope and rested on the metal plot border at 10 positions evenly spaced along the plot. At each position, 49 pin-point surface and canopy measurements were made by dropping a pin through each pin hole. Ten permanent transects across each plot produced 490 point readings to describe each plot's surface and vegetation canopy cover.

USLE rangeland study sites and treatments

The initial rangeland USLE experiments began in 1981 on plots in southeastern Arizona and two years later on sites on the Nevada Test Site in southern Nevada. The general procedure included spring and fall rainfall application on at least two replications of three or four treatments on one or more soil types in each ecosystem studied (Simanton & Renard 1982).

Arizona Plots

The Arizona rangeland rainfall simulator USLE plots were located on the Walnut Gulch Experimental Watershed in southeastern Arizona (Fig. 3). The watershed 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. 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 (Osborn et al. 1979).

Soil Soils are generally well drained, calcareous, gravelly loams with large percentages of rock and gravel on the soil surface (Gelderman 1970). Three soil series selected were: Bernardino (a thermic Ustollic Haplargid), Cave (thermic, shallow Typic Paleorthid), and Hathaway (thermic Aridic Calciustoll). The Bernardino series is a deep, well-drained, fine textured soil formed in old calcareous alluvium and has 50%, by volume, gravel and cobbles in the surface 10 cm and usually less than 35% gravel in the remaining profile. 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 has 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, coarse-textured materials of moderate depths. This soil, formed from gravelly or very gravelly calcareous old alluvium, has 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 Major vegetation of the watershed includes: creosotebush (*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*).

Plot Treatment Treatments were initially imposed in the spring of 1981 and then reapplied, except for the tilled treatment, prior to subsequent season's rainfall simulations. These treatments were: natural cover or no treatment (both grass and shrub), clipped (vegetation clipped to a 20 mm height and clippings removed), bare (vegetation clipped to the soil surface and all surface litter and rock fragments greater than 5 mm removed), and tilled (up and down slope moldboard plowing and disking). The tilled treatment was intended to represent the standard USLE treatment for determination of the soil erodibility factor (K). The clipped treatment, not intended to represent grazing effects, was used to determine vegetation effects on erosion and the bare plot was to define the role of rock fragments (erosion pavement) on soil erosion.

Nevada Test Site Plots
The Nevada Test Site (NTS) plots were established in 1983 at Area 11, which is located in a transition zone between the Great Basin and Mojave Desert; and Mercury, Nevada, in the northern Mojave Desert (Fig 3). Annual precipitation generally varies from 125 to 175 mm of which about 75% occurs between mid-September and late-March and the remaining comes during the summer season as scattered thundershowers (Romney et al. 1973).

Soils The soils do not have official series names but are Typic Durorthid (shallow, mixed thermic). The primary differences between the two soils are in textural class and parent material. The soils at Area 11 is coarse-loamy and formed in material weathered from tuff, basalt, and limestone. The soil at the Mercury site is loamy with randomly dispersed clay pockets, and formed in material weathered from limestone, quartz, and tuff. Both study sites are underlain by a silica-lime hardpan; the soils are well drained with medium to rapid runoff, and both have moderate permeability. The soil at Mercury has higher water holding capacity because of the higher clay content and less coarse sand through the profile.

Vegetation The major vegetation of Area 11 includes: Mormon tea (*Ephedra nevadensis*), spiney hopsage (*Artemesia spinescens*), shadescale (*Atriplex confertifolia*), boxthorn (*Lycium andersonii*), and Indian ricegrass (*Oryzopsis hymenoides*). Vegetation at Mercury includes spiney menodora (*Menodora spinescens*), shadescale, Mormon tea, desert Alyssum (*Lepidium fremontii*), and creosotebush.

Plot Treatments Plot treatments were the same as the Arizona plots except that the tilled treatment was not made. Other than this difference, all aspects of the study were identical to the Arizona erosion plot study.

USLE results and discussion

Arizona Plots
Four years or eight seasonal rainfall simulations were made on the 24 Arizona erosion plots at Walnut Gulch. Summaries of runoff and erosion rates are given in Tables 1a and 1b. The tilled treatment proved to be of little value in evaluating all but the "P" factor in the USLE. Runoff and subsequent erosion from the tilled

plots were practically non-existent except for the very wet runs. Because of the unexpected response from the tilled plots, only one replication on each soil was retilled after the first year of runs. This deviation from the original plan was designed so that the recovery rate and response of the tilled plot could be determined. The tilled plot data have not been summarized because of complications involved with sequences of retreatment and invasion of vegetation.

Table 1a. Average spring (Sp) and fall (Fa) runoff rate (mm/EI) for three treatments on the Bernardino, Hathaway, and Cave soils.

		Runoff Rate (mm/EI)					
		Natural		Clipped		Bare	
Soil	Moisture	Sp	Fa	Sp	Fa	Sp	Fa
Bernardino	dry	0.017	0.012	0.021	0.038	0.052	0.066
	wet	0.016	0.018	0.029	0.052	0.055	0.060
	vwet	0.025	0.026	0.040	0.057	0.060	0.068
Cave	dry	0.022	0.043	0.028	0.062	0.053	0.069
	wet	0.025	0.044	0.044	0.062	0.055	0.068
	vwet	0.033	0.049	0.052	0.070	0.059	0.076
Hathaway	dry	0.020	0.046	0.028	0.060	0.042	0.064
	wet	0.018	0.035	0.032	0.056	0.039	0.059
	vwet	0.024	0.042	0.040	0.066	0.056	0.069

Seasonal Differences Seasonal (spring-fall) runoff and erosion differences were found throughout the four year study period. The magnitude of these differences appears to be both treatment and soil variable but the trend was toward more runoff and erosion from the fall simulations on the clipped and bare treated plots (Figs. 4a & 4b). These vegetative cover-free plots would be influenced by the soil surface compacting effects produced by the summer thunderstorm rainfall; an effect dissipated by the winter freeze-thaw process that tends to loosen the soil surface before the spring simulator runs. The natural cover plots had more runoff but lower sediment concentration in the fall (Figs. 5a & 5b).

period. Fall runoff rates were higher than the spring regardless of the soil. However, on the Mercury soil, the season of higher runoff rates (fall) was not the season of higher erosion rates (spring) indicating that some factor, such as soil erodibility, was influencing the erosion rate.

Soil differences Runoff and erosion rate differences were found between the two soils. The Mercury soil had higher runoff and erosion rates than the Area-11 soil regardless of the plot treatment.

Antecedent moisture effects Runoff rates increased as soil moisture increased (dry surface to wet to very wet) on both soils under all treatments. Erosion rates were more variable and decreased on the wet surface runs on the natural treatment.

Treatments Runoff rates varied among treatments and were affected by both soil and season. The bare plot always had the greatest runoff rate regardless of the soil or season; the rate was greater in the fall. The natural cover plot had the lowest runoff rate and again, the fall rates showed the larger treatment differences. Bare treatment erosion rates on the Mercury soil were about 20 times greater than the rates from the natural treatment and 10 times greater than the clipped treatment. The Area-11 bare treatment erosion rates were about 45 times greater than the natural treatment and about 25 times greater than the clipped treatment. These erosion rate differences between treatments are not as great as found on the Arizona plots but the general trend of treatment effect was the same.

Surface and vegetative characteristics effects Erosion pavement appeared to be an important factor in the erosion process but not as dominant as was found on the Arizona plots. Vegetation was more effective in reducing erosion rates at the NTS than on the Arizona plots. Analysis of the effect of erosion pavement on erosion rates indicated that the relationship was exponential, similar to the Arizona relationship, and based on data from the two soils for all runs over the 2-year period, had an exponent of -0.045 (Fig 6).

USLE parameter values Assuming the bare plot represented the USLE "unit plot" (corrected for LS) condition as the most erodible condition possible (C=1), the K-factor values from the simulator results were 0.016 and 0.010 for the Mercury and Area-11 soils, respectively. These measured K-values are 38% and 16% of the K-values derived from the soil erodibility nomograph developed by Wischmeier et al. (1971). If C = 0.45 (the maximum allowed for rangeland in Handbook 537) the K-values would have been 84% and 35% of the nomograph values.

Revised universal soil loss equation

Major Changes to the USLE
The USLE is in the process of being revised to be applicable to a wide range of land uses. Major improvements to the USLE incorporated into the Revised Universal Soil Loss Equation (RUSLE) include: expanded erosivity (R) map for the Western United States; seasonal variability of the soil erodibility (K) determination; varying topographic (LS) factors dependent on soil's susceptibility to rill erosion; a subfactor approach to determine the cover-management (C) factor; detailed procedures for estimating the conservation support practice (P) factor for cropland, including values for contouring, terracing, and stripcropping, and management practices on rangelands; and implementation of RUSLE using a computer program that will run on either DOS or UNIX computers (Renard et al. 1991).

R-Factor Rainfall information from over 1,000 locations in the Western United States were analyzed to produce the improved erosivity (R) map for the Western United States as well as EI distribution maps for the West and Hawaii. Because ponded water on the soil surface reduces the erosivity of the rain, the R-factor in RUSLE is reduced where flat slopes occur in regions of intense rain storms (i.e. high R-factor areas). Finally, an R equivalent is used in the Pacific Northwest region to reflect the combined effect of freezing soil, and rain on snow on partially frozen soil.

K-Factor Erodibility data from around the world have been reviewed, and an equation was developed that estimates soil erodibility (K) as a function of "average" soil particle diameter. This then gives an estimate of K for soils where the nomograph does not apply. Use of this function is recommended only where the nomograph or no other procedure apply. RUSLE varies K seasonally. Experimental data showed that K is not temporally constant and varies with season, being greatest in early spring and lowest in mid-fall. The seasonal variability is determined for 15 day intervals by weighting the instantaneous estimate of K in proportion to the EI for the same period. Instantaneous estimates of K are predicted from equations relating K to the frost-free period and annual R-factor. RUSLE K is adjusted for rock fragments in the soil to account for their effect on infiltration. Rock fragments on the soil surface are treated as mulch or ground cover in the C-factor. RUSLE also provides a procedure for identifying those soils that are highly, moderately, or slightly susceptible to rill erosion relative to their susceptibility to interrill erosion.

L & S-Factors RUSLE slope length (L) utilizes three separate slope length relationships that are functions of slope steepness and the susceptibility of the soil to rill erosion relative to interrill erosion. A slope length relationship specifically for the Palouse region of the Pacific Northwest area of the United States is also included in the RUSLE. Experimental data and field observations, especially on rangelands, do not support the current USLE quadratic relationship for slope steepness effects when extended to steep slopes. RUSLE slope steepness (S) relationships are much more linear than in the USLE with the biggest differences being found on slopes 50% or greater. Slope segments estimated as a single plane in the USLE were usually a poor representation of the topography. Complex slopes are represented in RUSLE to provide a closer approximation of the topography effect.

C-Factor RUSLE cover-management (C) is determined using a subfactor approach to compute soil loss ratios as a function of five subfactors; prior land use, canopy cover, ground cover, and within soil effects.

The subfactor relationship is given by:

$$C = PLU \cdot CC \cdot SC \cdot SR \cdot SM$$

where:

PLU	is a prior land use subfactor,
CC	is a canopy subfactor,
SC	is a surface cover subfactor,
SR	is a surface roughness subfactor, and
SM	is a soil moisture subfactor.

The surface cover (SC) term of the subfactors has the greatest effect on erosion estimates. The erosion reduction effect of surface cover can vary from 65 to 95% for a 50% surface cover. In the RUSLE this variable effectiveness is represented by the equation:

$$SC = \exp(-b\,M)$$

where:

SC	is mulch or ground cover subfactor value,
M	is per cent ground cover, and

the b coefficient can be 0.025, the value in the USLE; 0.035, the RUSLE "typical" value; 0.045 for rangelands; or 0.05 for conditions where rill erosion dominates. The value used is based on the ratio of rill to interrill erosion. Ground cover in the USLE consisted of only vegetation and litter cover, whereas, in RUSLE, ground cover (M) includes rock fragments with the vegetation and litter. Subfactor values for the within-soil effect are calculated from amount of biomass in the soil which accumulates from roots and incorporated residue. Rangeland options for this within soil component include default values, for 14 rangeland ecotypes, which can be used to estimate rootmass (Weltz et al. 1987). Grazing effects on rangeland, pasture, and meadows are reflected in the effect of canopy height, ground cover, and root biomass.

P Factor RUSLE P factors for rangeland are based on estimates of roughness and runoff reduction associated with the conservation practice and, for certain combinations of roughness and runoff reduction, the slope upon which the practice was implemented.

RUSLE Measured vs. Predicted Measured soil losses from rainfall simulation erosion plots from throughout the Western United States were compared to soil losses estimated by both the USLE and the RUSLE (Renard & Simanton 1990). Correlations between measured and estimated varied among the 17 sites tested. The agreement of the RUSLE estimated and measured was better than the USLE estimates for the natural and clipped treatments.

Water erosion prediction project

Processed based erosion prediction technology

The USLE, RUSLE, and other current erosion predicting procedures have been criticized as inadequately representing rangeland erosion processes. The USLE and RUSLE models are not process based and do not simulate interactions of water, soil, plant, and management responses in a realistic manner to assess soil erosion responses to rangeland management actions. Emerging and current technology coupled with faster, larger, and more readily available personal computers have focused the need for a new process based technology to predict and assess erosion and sedimentation rates on rangelands (Lane et al. 1988). In 1985 USDA and ARS identified the development of new erosion prediction technology as one of its top research goals. The erosion prediction technology was to be developed in three stages; development of a hillslope version that then could be incorporated into a watershed version with the ultimate version being a grid or multi-watershed version (Foster & Lane 1987, Stone et al. 1990). The Water

Erosion Prediction Project (WEPP) was initiated in 1985 to meet this goal and was designed to collect experimental field data from both crop and rangeland soil and vegetation complexes (Foster & Lane 1987, Lane & Nearing 1989, Nearing et al. 1990). Rainfall simulator plot data collected during this field effort would be used to parameterize the WEPP model through development of relationships among soil properties, vegetation, cover, erosion, runoff and infiltration. Because of the many ecosystems and land uses to be evaluated, the field experiments would allow the definition of management impacts on rangeland productivity and conservation.

Soil Property-Erodibility Relationships

One objective of the WEPP rainfall simulation experiments was to determine soil erodibility values for a wide range of soil types and conditions. Developing an equation that predicts soil erodibility from easily measured soil properties makes the WEPP model widely applicable. The soil erodibility nomograph used to estimate the K factor of the USLE illustrated that such relationships could be developed and applied to a wide range of soils. Uniform treatment of plots for erodibility measurements is imperative for valid soil property/erosion relationships to be developed. Many soils in arid and semiarid regions have thin horizons (2-5 cm) that would be mixed during tillage and the resulting mixture may not be representative of the soil surface subject to erosion. Additionally, large rocks in the soil may cause tillage to be impractical or unduly alter surface roughness and depressional storage. Because of these and other potential problems with tillage, soil erodibility was determined from the bare plot treatment previously described.

Rangeland Site Characteristics

Vegetation and soil surface characteristics may have a greater influence on erosion and runoff rates from rangelands than basic soil properties (bulk density, soil texture, soil strength, etc.). The WEPP rangeland field experiments were designed to separate the vegetation canopy cover effects on runoff and erosion from the surface cover effects. Algorithms expressing infiltration rates as functions of total foliar and ground cover are currently being evaluated and will be incorporated into a more complex infiltration routine in the WEPP model. Time to peak discharge, concentrated flow paths, overland flow velocities, and associated shear stresses on the soil surface are all affected by the type, quantity and distribution of vegetation and surface cover. Rootmass, standing biomass, litter, random roughness, ground surface cover and shrub density are important components of the plant community structure that may affect overland flow routing and sediment yields.

WEPP procedures

Modifications
The Aridland Watershed Management Research Unit in Tucson, Arizona was given the responsibility for development of rangeland erosion parameters to be incorporated in the WEPP erosion model. The WEPP field procedures used to evaluate the diversity of rangeland ecosystems were modifications of the rangeland USLE procedures previously described in this paper (Simanton et al. 1987). These modifications were necessary because WEPP was to produce a process based dynamic erosion model. Cooperating US Government agencies, Department of Energy laboratories, and universities in Nevada, Idaho, New Mexico, Washington, and Utah also use these new procedures for their WEPP related rangeland field experiments.

Equipment and Procedures Electric solenoid valves were attached to the 130 mm/hr nozzles on the rainfall simulator so that instantaneous changes in rainfall intensities could be made to better define infiltration and soil erodibility parameters. The very wet simulation had varying rainfall intensity (65 and 130 mm/hr) and an addition of overland flow for variable time periods. An example of the rainfall and overland flow application sequences for the very wet run is presented in Figure 14. Each water application rate remained constant until adequate sediment samples were taken at each runoff equilibrium rate. This very wet run sequence provided soil infiltration and erosion data needed to define the WEPP model infiltration process and define the interrill and rill soil erodibility parameters. Depending on soil erodibility, three or four rates of clear water flow were applied at the upper end of the bare plots during the final 65 mm/hr rainfall application of the very wet run (Fig. 14). Flow rates ranged from 45 to 200 mm/hr with the duration of application dependent on time to reach runoff equilibrium at each overland flow rate. Soil rill erodibility and critical shear were determined from erosion rates associated with these overland flow additions.

Large and Small Plots There were two large plots (3.05 x 10.7 m) of the natural, clipped and bare soil treatment for a total of six large plots installed at each rangeland site. All plots at a site were grouped within a 50 by 50 m area that was determined by the USDA Soil Conservation Service (SCS) to be in the same soil and vegetation type. As with the USLE plots, this plot size was necessary because it reduced the ratio of plot border effects to total plot area and the long length allowed evaluation of rill erosion and sediment transport and deposition associated with sheet and concentrated flow. Metal sheets (2 mm thick x 15 cm wide and 3 m long) were used to form the sides and upper end of each plot. These sheets were inserted 3 cm into the soil so that a 12 cm high border delineated each plot. The downslope end of the plot had a 20 cm wide metal sheet, with a sill plate formed on the upper edge, inserted into the soil so that the sill plate was flush with the soil surface. Runoff and sediment from the plot was diverted into the runoff measuring flume by troughs mounted below the sill plate. Interrill plots (0.6 x 1.2 m) were used to determine raindrop caused erosion rates (soil interrill erodibility) as compared to the combination of raindrop and overland flow detachment erosion rates as produced on the longer large plots. Also, effects of raindrop impact on soil crusting and infiltration were determined from comparisons between the two treatments on the interrill plots. Two interrill plots were installed next to each of the bare soil treatment large plot. The interrill plots were treated the same as the large bare plot with one of the interrill plots covered with window screen to dissipate raindrop impact and reduce soil surface crusting. Interrill runoff hydrographs and sediment yields were determined from periodic (every 2 min. during the rising hydrograph and 5 min. intervals during runoff equilibrium) volumetric samples manually collected during the rainfall simulations.

Biomass Vegetation canopy and plot surface characterizations were made with the same 49 pin point-meter described for the USLE experiments. Total aboveground herbaceous biomass was determined by clipping 3- 0.5 by 1.0 m quadrates from the clipped and bare plots before they were treated. Aboveground woody biomass was determined by dimensional analysis using relationships between plant volume and weight. Leaf area to leaf weight relationships were established from measurements taken at the time of simulation for the dominate plant species at each rangeland site. Below ground biomass (excluding fauna) at each site was determined from soil cores taken after the wet runs. Microtopography (random roughness) of each plot was determined with a roughness meter (Kincaid & Williams, 1966) and by photogrammetric methods.

Soils Detailed soil pedon description, sampling, and laboratory analysis were made by the SCS at each of the rangeland sites. Pedon analysis included particle-size distribution, soil moisture release curves, organic carbon, cation exchange capacity, clay mineralogy, and other physical and chemical properties. Soil surface (top 5 cm) bulk density was determined using the compliant cavity method before the dry and after the very wet runs. Soil surface (0-5 cm) and subsurface (5-20 cm) moisture contents were gravimetrically determined before the dry and wet runs and after the dry and very wet runs. Indices of soil strength were measured with the Torr Vane and pocket penetrometer after the dry and very wet runs. Bulk surface soil samples collected prior to the dry run were sent to various laboratories for storage and subsequent testing. Undisturbed soil core samples taken after the very wet run were used for detailed morphological descriptions of the soil surface horizon and surface crust characteristics.

Rangeland Sites A 2-year field program began in 1987 to evaluate a wide range of rangeland soil/vegetation complexes in the Western United States (Fig. 3, Table 3). Soils at the sites are in the orders of Mollisols, Alfisols, Entisols, and Inceptisols (Table 4). Moisture regimes are ustic, xeric, and aridic. Surface textures range from loamy sand to clay and many of the soils have appreciable contents of coarse rock fragments.

Table 3. Code, location, and plant comunity of the Water Erosion Prediction Project's (WEPP) rangeland erosion plots.

WEPP code	Location	Plant community
A1	Walnut Gulch, AZ	Chihuahuan Desert Shrub
A2	Walnut Gulch, AZ	Chihuahuan Desert Grass
B1	Nevada Test Site, NV	Great Basin Shrub
B2	Nevada Test Site, NV	Mohave Desert Shrub
C1	Sonora, TX	Oak Savanna Grass
D1	Chickasha, OK	Tallgrass Prairie
D2	Chickasha, OK	Mixedgrass Prairie (reverted)
E1	Ft. Supply, OK	Mixedgrass Prairie
E2	Woodward, OK	Mixedgrass Prairie (cont. graze)
E3	Ft. Supply, OK	Mixedgrass Prairie
E4	Freedom, OK	Tallgrass Prairie (no graze)
E5	Freedom, OK	Mixedgrass Prairie (heavy graze)
F1	Sidney, MT	Mixedgrass Prairie (club moss)
G1	Meeker, CO	Salt Desert Brush
H1	Cottonwood, SD	Mixedgrass Prairie (light graze)
H2	Cottonwood, SD	Shortgrass Prairie (heavy graze)
I1	Los Alamos, NM	Pinyon-Juniper Interspace
J1	Cuba, NM	Shortgrass Desert Grassland
K1	Susanville, CA	Great Basin Shrubsteppe
L1	Fresno, CA	Annual Grassland

Table 4. Code, series, classification, and texture of soils of the Water Erosion Prediction Project's (WEPP) rangeland erosion plots.

WEPP Code	Soil series	Soil classification	Soil texture
A1	Stronghold	Coarse, loamy, mixed, thermic Ustochreptic Calciorthid	Gravelly sandy loam
A2	Forrest	Fine, mixed, thermic, Ustollic Haplargid	Sandy clay loam
B1	NA	Shallow, mixed, thermic, Typic Durorthid	Gravelly fine sandy loam
B2	NA	Clayey-skeletal, montmorillonitic thermic Haplic Nadurargid	Fine sandy loam
C1	Purves	Clayey, montmorillonitic, thermic Calciustoll	Silty clay loam
D1	Grant	Fine-silty, mixed, thermic Udic Argiustoll	Loam
D2	Grant, eroded	Fine-silty, mixed, thermic Udic Argiustoll	Very fine sandy loam
E1	Pratt	Sandy, mixed, thermic, Psammentic Haplustalf	Loamy fine sand
E2	Quinlan	Loamy, mixed, thermic, shallow Typic Ustochrept	Loam
E3	Tivoli	Mixed, thermic, Typic Ustipsamment	Fine sand
E4	Woodward	Coarse-silty, mixed, thermic, Typic Ustochrept	Very fine sandy loam
E5	Woodward	Coarse-silty, mixed, thermic, Typic Ustochrept	Very fine sandy loam
F1	Vida	Fine-loamy, mixed Typic Argiboroll	Loam
G1	Degater	Fine, mixed, mesic Typic Camborthid	Silty clay
H1	Pierre	Very-fine, montmorillonitic, mesic Typic Torrent	Clay
H2	Pierre	Very-fine, montmorillonitic, mesic Typic Torrent	Clay
I1	Hackroy	Loamy, mixed, mesic, shallow Aridic Haplustalf	Fine sandy loam
J1	Querencia	Coarse-silty, mixed, mesic Ustollic Camborthid	Fine sandy loam
K1	Jauriga	Fine-loamy, mixed, mesic Typic Argixeroll	Gravelly sandy loam
L1	Apollo	Fine-loamy, mixed, thermic, Calcic Haploxeroll	Loam

WEPP rangeland field data

Results

Preliminary results from these WEPP field studies include the determination of rangeland rill and interrill soil erodibility values for the WEPP model (Nearing et al. 1989, Laflen et al. 1991), and the development of a crust factor for a Green Ampt infiltration model (Rawls et al. 1990).

Vegetation Effects Because such a diverse range of soil/vegetation complexes were evaluated, the WEPP rangeland data base provides an excellent opportunity to evaluate the direct effects of vegetation canopy cover on runoff and erosion (Simanton et al. 1991). Direct physical effects include interception losses, raindrop energy dissipation, and surface roughness. Indirect effects include desirable levels of soil structure, organic matter, macro-porosity, and litter cover. Separation of the direct and indirect effects of vegetation on runoff and erosion is possible by comparing responses of the natural and clipped plots within a site. To normalize soil moisture content differences that could be possible for the dry run only runoff and erosion results from the wet run (field capacity) were analyzed. Although run times and rainfall intensities were to be the same for each rainfall simulation and plot, water supply and wind problems sometimes caused different rainfall volumes to be applied. To account for these application differences in comparing plot runoff responses, a runoff ratio (Q/P) was determined for each plot by dividing total runoff volume (Q) by total rainfall volume (P) applied during the simulation.

Erosion rates (Kg/ha/Qmm) were calculated by dividing the plot total sediment yield by the total runoff volume. Final infiltration rate (mm/hr) was the difference between the rainfall rate and equilibrium runoff rate. Initial rainfall abstraction (mm) was calculated as the rainfall volume applied to the plot before runoff occurred. Initial infiltration rate was calculated as the difference between the rainfall rate (mm/hr) and the runoff rate 5 minutes after runoff began. Comparisons of runoff ratios, erosion rates, initial and final infiltration rates, initial rainfall abstraction, soil moisture content, and plot surface characteristics between paired natural and clipped plots were made using linear regression analysis and the corresponding 95% confidence interval of the regression line slope and intercept.

Except for comparisons of random roughness, soil moisture, and plot slope, 21 natural/clipped pairs were available for comparison. Random roughness was measured only in 1988 so there were only seven pairs available. Soil moisture data were lost for one thus giving only 19 pairs for comparison. Plot slopes did not change between 1987 and 1988 so the plots reevaluated in 1988 were not included in the slope comparisons.

Five rangeland sites were selected in Oklahoma and represent grass prairies and shrub steppes of the Great Plains. The site near Chickasha (D1) is typical of native tallgrass prairie and had been lightly grazed prior to the 1987 evaluation and moderately grazed prior to the 1988 evaluation. The site is located on ARS watershed R-5 which has been used for extensive hydrologic and erosion studies (Sharma, et al. 1980). The two sites at Ft. Supply (E1 and E3) represent different range conditions on mixed grass prairie that had intermixed brush. The sites are less than 1 km apart and both had been grazed. Two sites at Freedom (E4 and E5) were adjacent to one another separated only by a fence. E4 had not been grazed in over 10 years, whereas, E5 had been continuously heavily grazed. The site near Sidney, Montana (F1) had been lightly grazed and represents rangelands whose soil surface cover includes large amounts of club mosses. The salt desert shrub site near Meeker, Colorado (G1) had not been grazed within a year of the evaluation. This site represents a rangeland soil that is susceptible to rill formation. The grassland site near Cottonwood, South Dakota (H1) was lightly grazed prior to 1987 and moderately grazed prior to the 1988 evaluations. The brush site (K1) near Susanville, California had not been grazed for one year prior to evaluation.

Within-site Effects Even though there was considerable effort in the site selection process to ensure homogeneity in soil and vegetation properties, variability within the site can occur (Devaurs & Gifford 1984). Comparisons of natural and clipped plot characteristics of per cent litter, exposed soil, slope, and random roughness were made to strengthen the assumption that each site was homogeneous.

Plot characteristic comparisons of litter, bare soil, random roughness, and slope are shown in Figure 15. The regressions of these comparisons have line slope coefficients of nearly 1.0 and relatively small intercepts. Confidence interval tests at the 95% level showed that in all plot characteristic comparisons the regression intercept was not different than zero and the regression slope was not different than one; indicating that measured plot characteristics were not significantly different between the two treatments.

Natural vs. Clipped Regression analysis indicated no difference between the natural and clipped plots' runoff ratios, final infiltration rates, soil moisture contents, initial abstractions, and initial infiltration rates (Fig. 16). Erosion rates between the natural and clipped plots were different (Fig. 16). Through the intercept of the erosion rate comparison was not different than zero, the regression line slope was different than one. The regression line slope of less than one and the relatively small intercept indicate that the clipped plots had an erosion rate less than the natural plots.

The initial abstraction graph in Figure 16 shows two distinct groupings of points. The high initial abstractions were associated with sites with either very porous soil (E1 and E3) or had been lightly or ungrazed two or more years prior to our evaluations (E4 and 1987 H1). The two extreme erosion rate points on the erosion rate graph in Figure 16 represent erosion rates from the G1 site. These relatively high erosion rates were ascribed to rill erosion. This site was the only site with noticeable rills on the plots before and after the rainfall simulations. Meyer et al. (1975) found, in rainfall simulation studies on tilled 6% sloped plots, that rilled plots produced about 3.4 times the soil loss as non-rilled plots. The G1 plots, sloped at 9 to 11%, produced 3.3 times the average erosion rate of comparably sloped plots at other sites evaluated (sites F1 and K1).

WEPP discussion

Site homogeneity is demonstrated by comparisons made of litter, exposed soil, slope, and random roughness. The similarity in soil moisture eliminates moisture effects and helps isolate the canopy cover effects. Factors not quantified such as distribution of vegetation and ground surface cover on each plot could have an effect on plot runoff and erosion response. Because plot treatments were randomly imposed at each site, these effects should also be random and not be biased for either treatment.

Final infiltration rate is a function of soil properties, ground surface cover, and rainfall application rate. If, in a rainfall simulation under field capacity soil moisture conditions, application rate does not substantially exceed the infiltration rate, runoff equilibrium may not occur or occur late in the rainfall simulation. This indicates that the final infiltration rate was limited by the application rate rather than inherent soil or cover properties. This was the situation at sites E1 and E3 where runoff did not occur during the simulation and the infiltration rates for these soils have been reported to range from 55 to 270 mm/hr (Rhoades et al. 1964). Runoff equilibrium was usually reached 10 to 15 minutes into our 30 minute wet run. This relatively short period to reach equilibrium indicates that soil properties were controlling the final infiltration rate and rainfall application rate was not limiting.

Initial rainfall abstractions are a function of the soil initial infiltration rate, surface roughness and storage, and interception losses to vegetation canopy (USDA, SCS 1972). These abstractions were nearly identical for the natural and clipped plots as indicated by the very low intercept (-0.84) and 0.99 regression slope. Infiltration rate affects initial abstractions but comparisons of initial infiltration rate indicated that there were no differences in the rate between the natural and clipped plots. There was no difference in litter, bare soil, random roughness or initial abstractions between treatments. As a result, it can be inferred that interception loss to canopy cover was not a significant component to initial abstraction. Interception losses are more significant under conditions of lower rainfall intensities and amounts than those used in this study (Thurow et al. 1987).

The significance of canopy cover in erosion prediction models is small compared to ground surface cover (Table 10, Wischmeier & Smith 1978). Canopy cover's direct influence on erosion is through its dissipation of raindrop energy with the magnitude of this influence dependent on the ground surface condition found under the canopy. The more bare soil under the canopy the larger the canopy cover effect (Wischmeier & Smith 1978). Bare soil on the rangeland natural and clipped plots averaged 30.6% and of this, only 8% was under canopy. Under this condition and assuming only bare soil would be detached by raindrops, the clipped plot sediment yield would not be significantly affected by the soil eroded from the now canopy free bare soil. Khan, et al (1988) found that as canopy cover height increased from 0.25 m to 1.0 m the erosion rate also increased. The clipped plots had a canopy height of 0.02 m and the natural plots canopy height could be as great as 1 meter. This may explain the slightly greater erosion rates from our natural plots.

The clipped treatment in the WEPP rangeland experiments was designed to separate, into direct and indirect effects, the interacting relationships among vegetation canopy cover, runoff, infiltration and erosion. Because the same procedures, plot size and rainfall simulator were used in the WEPP rangeland experiments, the unique data set allows direct comparisons of runoff and erosion responses over a wide variety of rangeland soils and vegetation types. Comparisons indicate that, under the simulated rainfall conditions and soil and vegetation types evaluated, canopy cover had little direct effect on runoff, infiltration, initial abstractions and erosion rate. Canopy cover's direct contributions to interception losses and soil surface protection from raindrop impact are not large in rangeland runoff and erosion responses.

Summary

Significant Findings

Ten years of rainfall simulation studies on rangeland erosion plots have produced a large data base used to parameterize soil erosion prediction models. These studies, conducted over a very wide range of rangeland ecosystems represent a unique data base that will be very difficult to duplicate. Rangeland erosion studies are a relatively new research area and the results from our studies have only begun to answer some of the basic questions regarding erosion estimating techniques on rangelands. Additional studies, research approaches, and analyses are still needed to fully understand the rangeland erosion processes.

USLE 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 changes in the USLE K (bare plots) and C factors, vegetation canopy, and amount of bare soil accumulation on the plot surface (natural plot). If data are to be used in erosion models that estimate long-term management effects on erosion, the rainfall simulation data base needs to extend for more than one year. The importance of erosion pavement on the erosion process of Western rangelands has been demonstrated and appears to be more dominant than vegetation canopy.

RUSLE New algorithms have been developed to reflect rangeland response to the rainfall (R), topography (LS), cover-management (C), and conservation practice (P) factors of the RUSLE.

WEPP Data from the WEPP rangeland experiments represent a wide range of soils and vegetation types and can provide a better understanding of the processes involved in the interactions among vegetation, soil, runoff, and erosion.

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Figure Captions:

Fig.	Caption
1	Operation of the rotating boom rainfall simulator used on rangeland erosion plots.
2	Plot layout of large plots used in rangeland field experiments.
3	Rangeland erosion study sites in the western United States.
4a	Relation between runoff volume (mm) as measured in the spring and fall. Bare and clipped plots for 1981 on the Bernardino, Hathaway and Cave soils.
4b	Relation between average sediment concentration (mg/l) as measured in the spring and fall. Bare and clipped plots for 1981 on the Bernardino, Hathaway, and Cave soils.
5a	Relation between runoff volume (mm) as measured in the spring and fall. Natural plots for 1981 on the Bernardino, Hathaway, and Cave soils.
5b	Relation between average sediment concentration (mg/l) as measured in the spring and fall. Natural plots for 1981 on the Bernardino, Hathaway, and Cave soils.
6	Exponential fit of relation between erosion rate (T/ha/EI) and erosion pavement for the Arizona and Nevada Test Site rangeland erosion plots. (From Simanton et al. 1985).
7a	Non-linear least squares fit of natural plot measured runoff rate (mm/EI) change with time for the replicated run average of spring and fall runs with time zero equal to spring 1981 for the Bernardino, Hathaway, and Cave soils.
7b	Non-linear least squares fit of clipped plot measured runoff rate (mm/EI) change with time for the replicated run average of spring and fall runs with time zero equal to spring 1981 for the Bernardino, Hathaway, and Cave soils.
8a	Non-linear least squares fit of natural plot measured erosion rate (T/ha/EI) change with time for the replicated run average of spring and fall runs with time zero equal to spring 1981 for the Bernardino, Hathaway, and Cave soils.
8b	Non-linear least squares fit of clipped plot measured erosion rate (T/ha/EI) change with time for the replicated run average of spring and fall runs with time zero equal to spring 1981 for the Bernardino, Hathaway, and Cave soils.
9	Non-linear least squares fit of the USLE K-factor change with time for the bare plots on the Bernardino, Hathaway, and Cave soils. Time zero equals spring 1981 and C was assumed 1 for the bare surface condition.

10 Non-linear least squares fit of the bare and clipped plots' measured erosion rates (T/ha/EI) change with time for the replicated run average of spring and fall runs with time zero equal to spring 1981 for the Bernardino, Hathaway, and Cave soils.

11 Non-linear least squares fit of the natural plot percent canopy cover change with time where time zero equals spring 1981 for the Bernardino, Hathaway, and Cave soils.

12 Non-linear least squares fit of the natural plot percent bare soil change with time where time zero equals spring 1981 for the Bernardino, Hathaway, and Cave soils.

13 Non-linear least squares fit of the USLE C-factor change with time for the natural plots on the Bernardino, Hathaway, and Cave soils. Time zero equals spring 1981. The C-factor was calculated using the simulator derived K-value from the bare plot whose C-value was assumed to be 1.

14 Sequence of rainfall application and overland flow additions used during the very wet run of the Water Erosion Prediction Project's rangeland field experiments.

15 Comparison of natural and clipped plot litter and bare soil cover, random roughness, and slope with regression equation, coefficient of determination, and 95% confidence interval (C.I.). (From Simanton et al. 1991).

16 Comparison of natural and clipped plot runoff ratios, erosion rates, final infiltration rate, soil moisture, initial rainfall abstractions, and initial infiltration with regression equation, coefficient of determination, and 95% confidence interval (C.I.). (From Simanton et al. 1991).

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EROSION ON RANGELANDS:
EMERGING TECHNOLOGY AND
DATA BASE

Proceedings of the Rainfall Simulator Workshop
January 14-15, 1985
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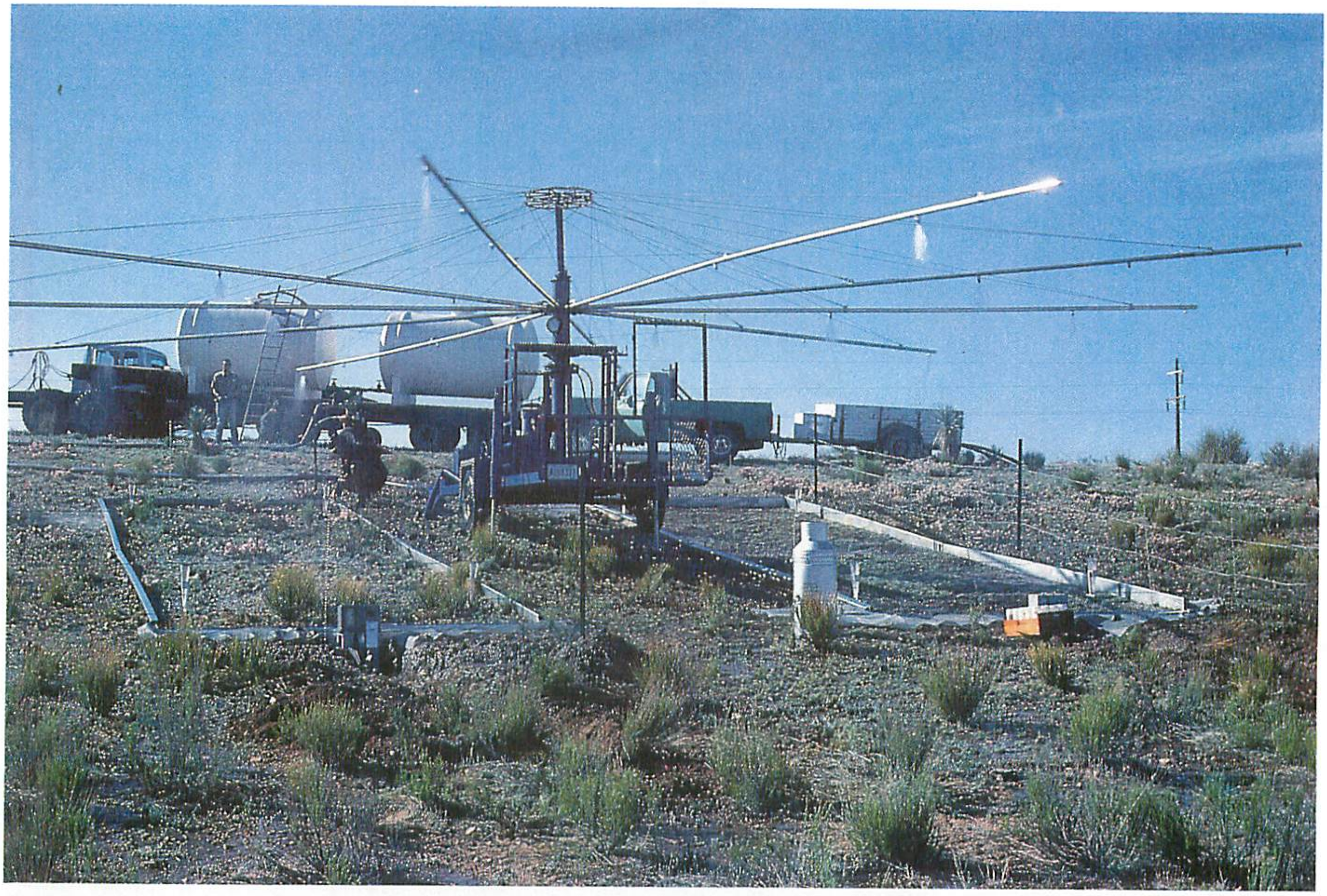

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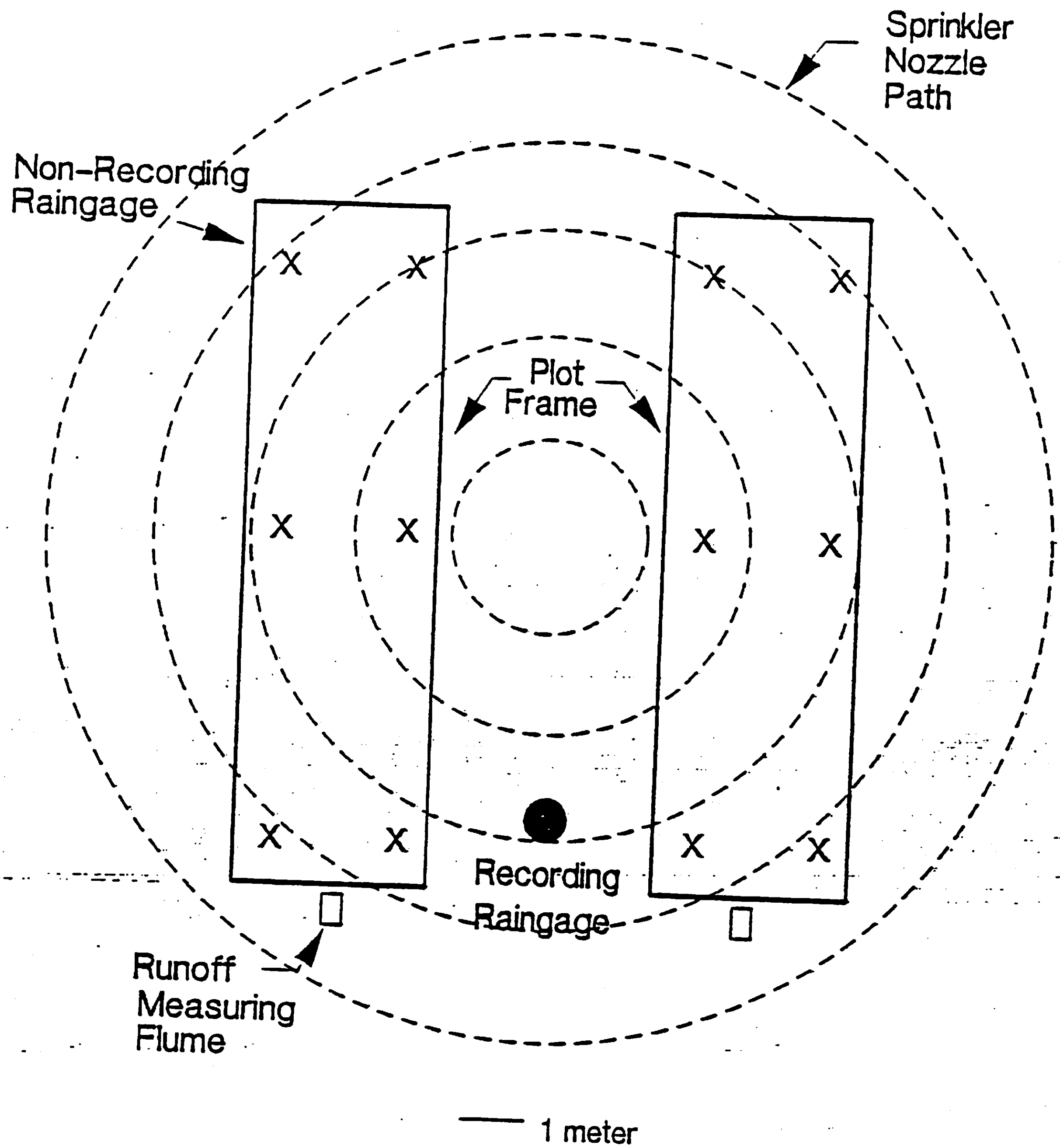
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Plot Frame
Recording Raingage
Runoff Measuring Flume
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Fig. 2

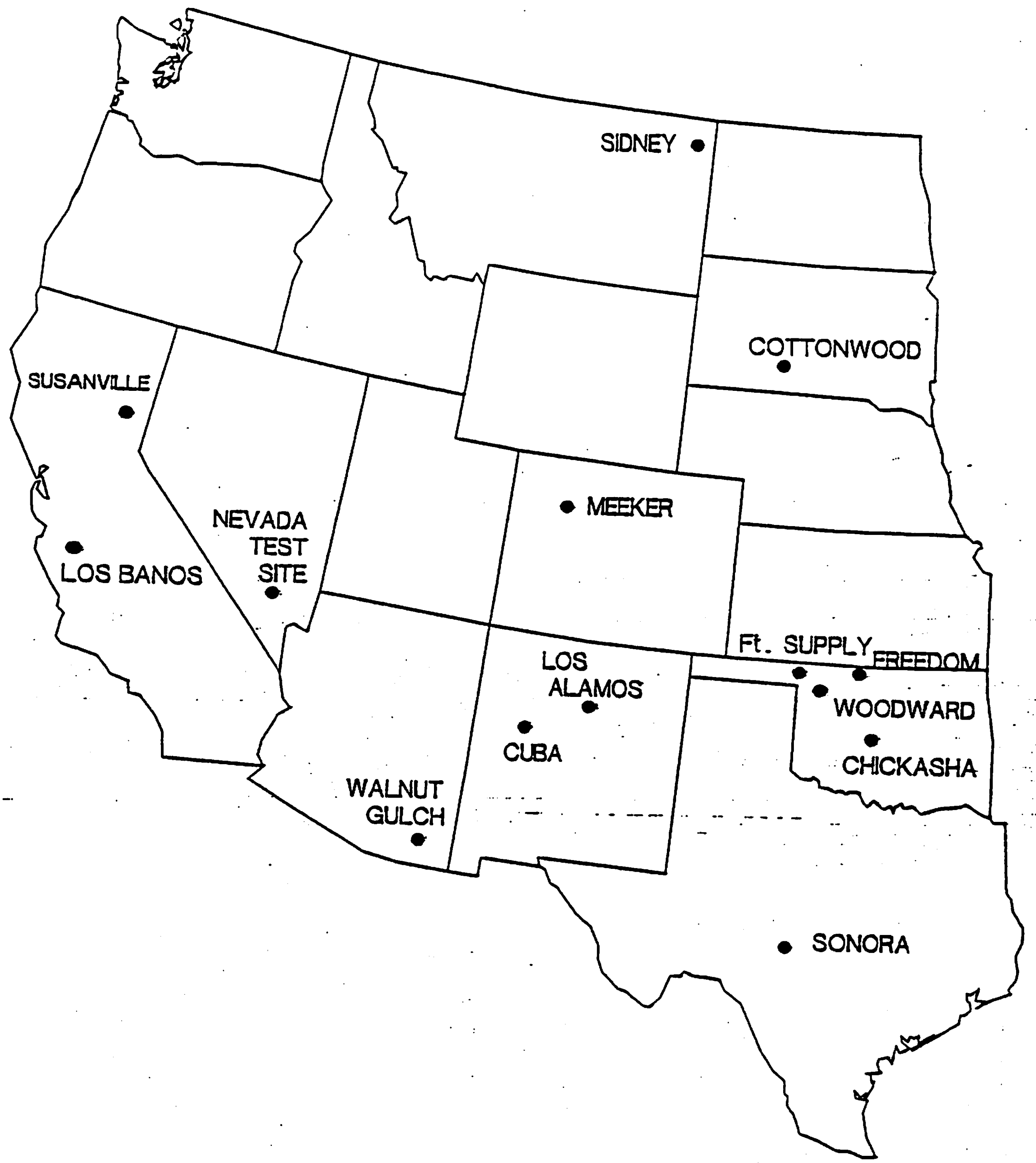
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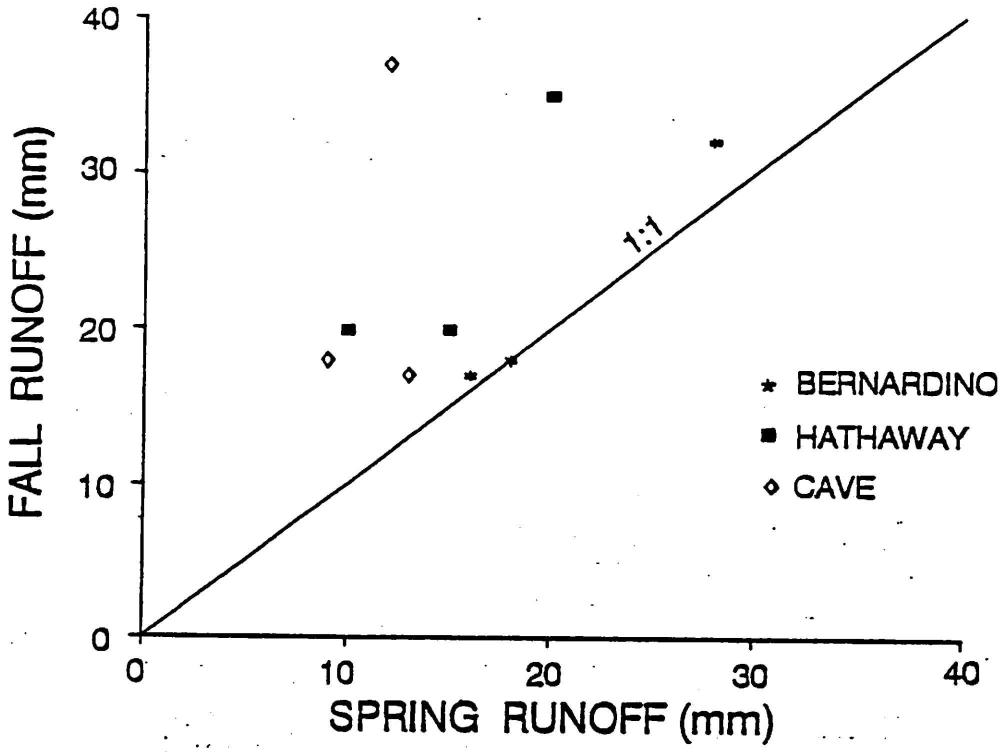
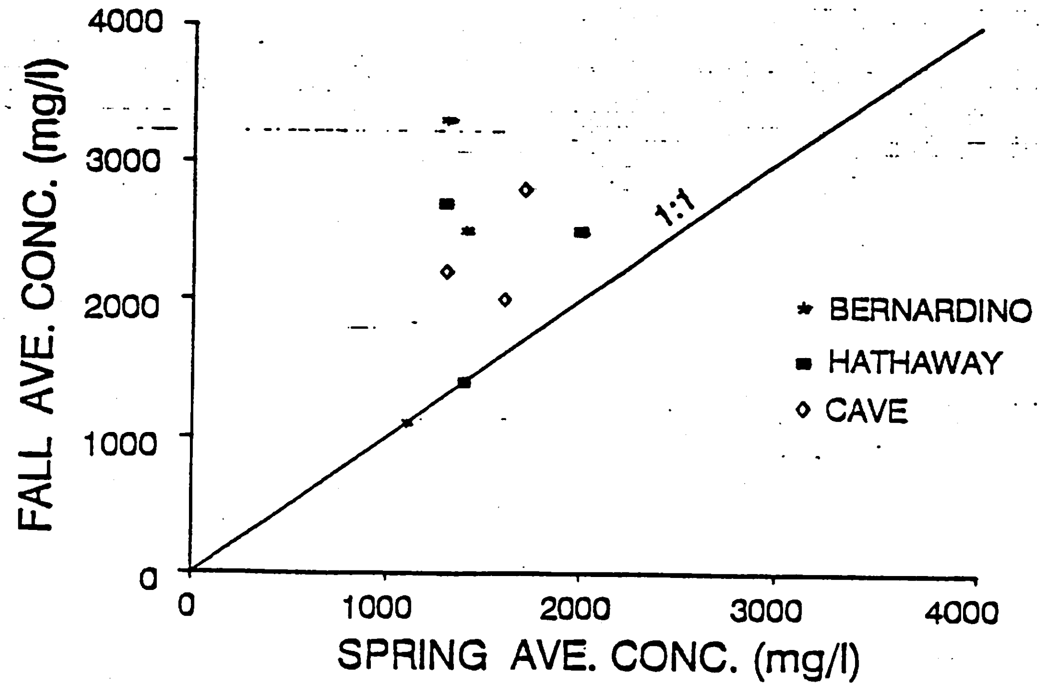
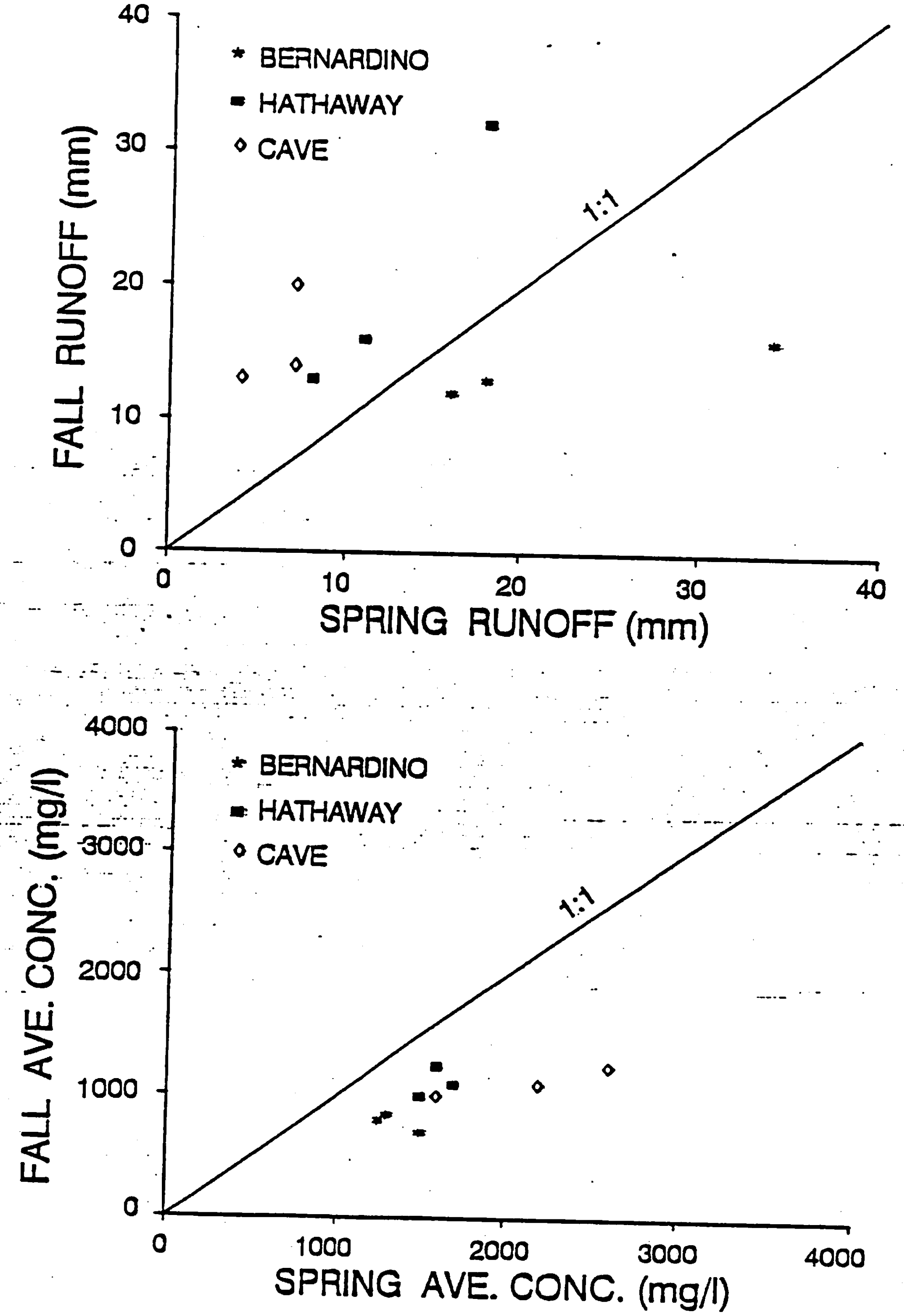
Fig. 3





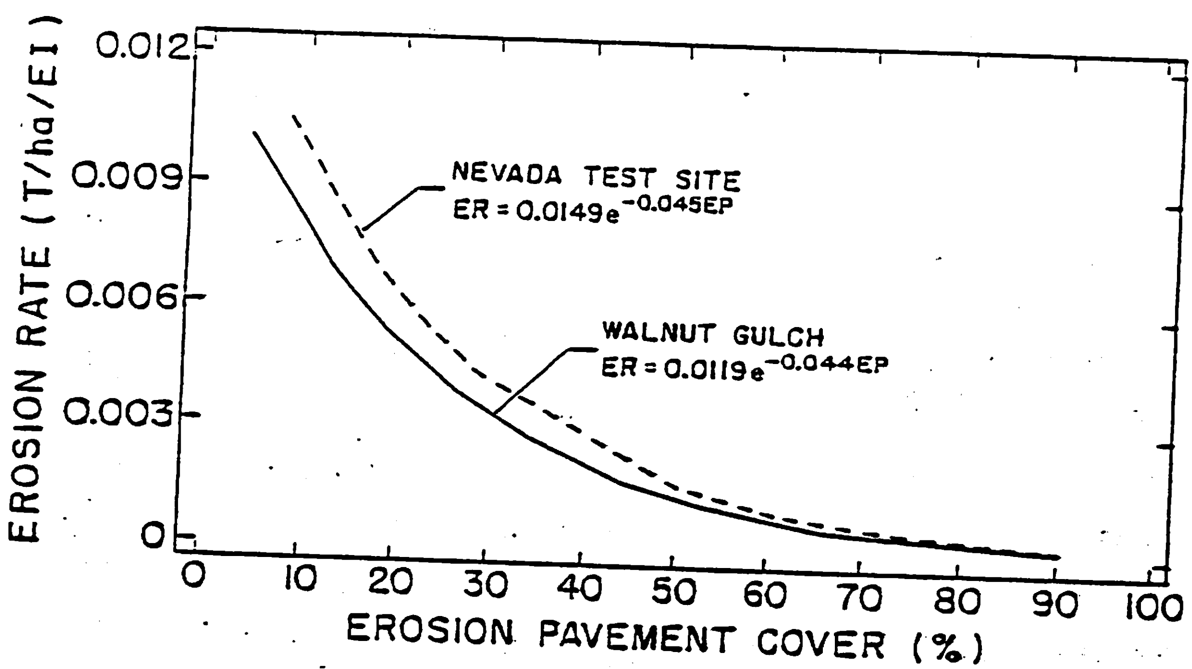
NON-VEGETATED

4a +b



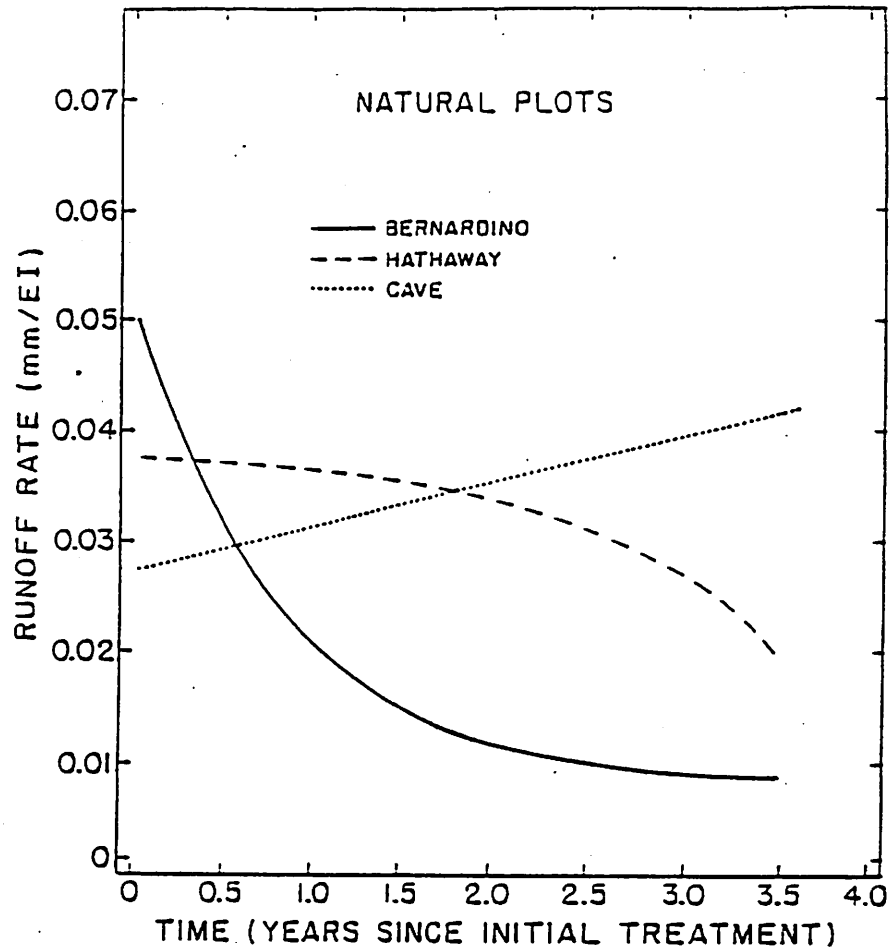
VEGETATED PLOTS

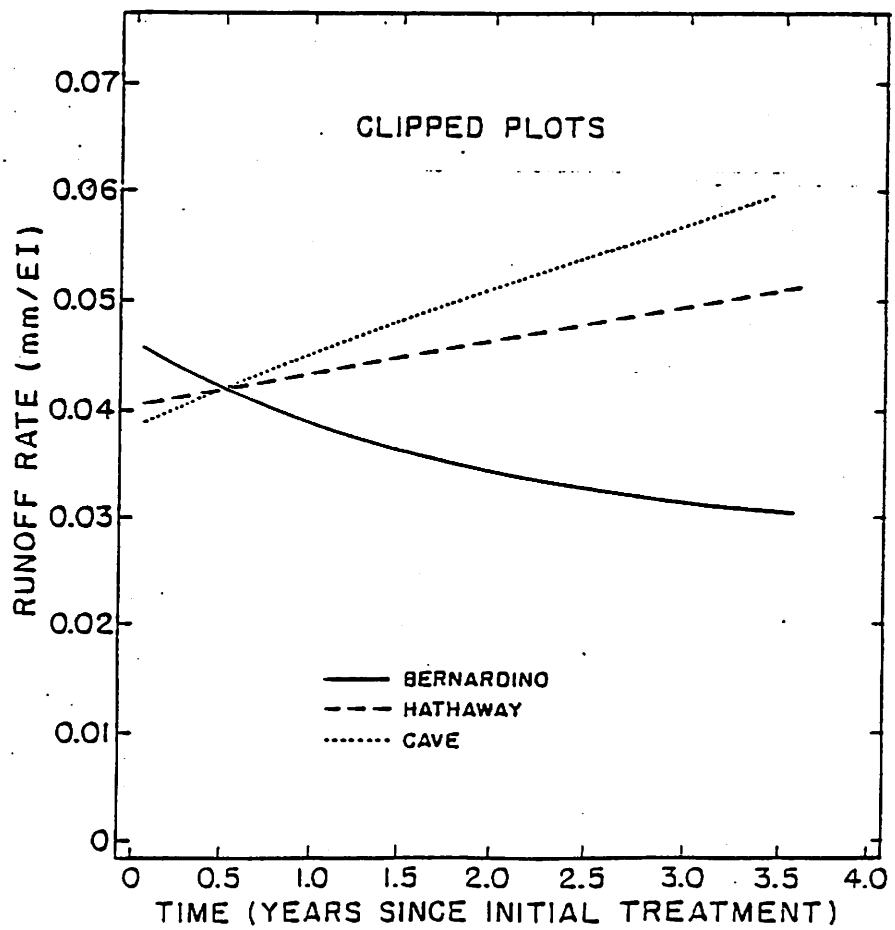
5a+b



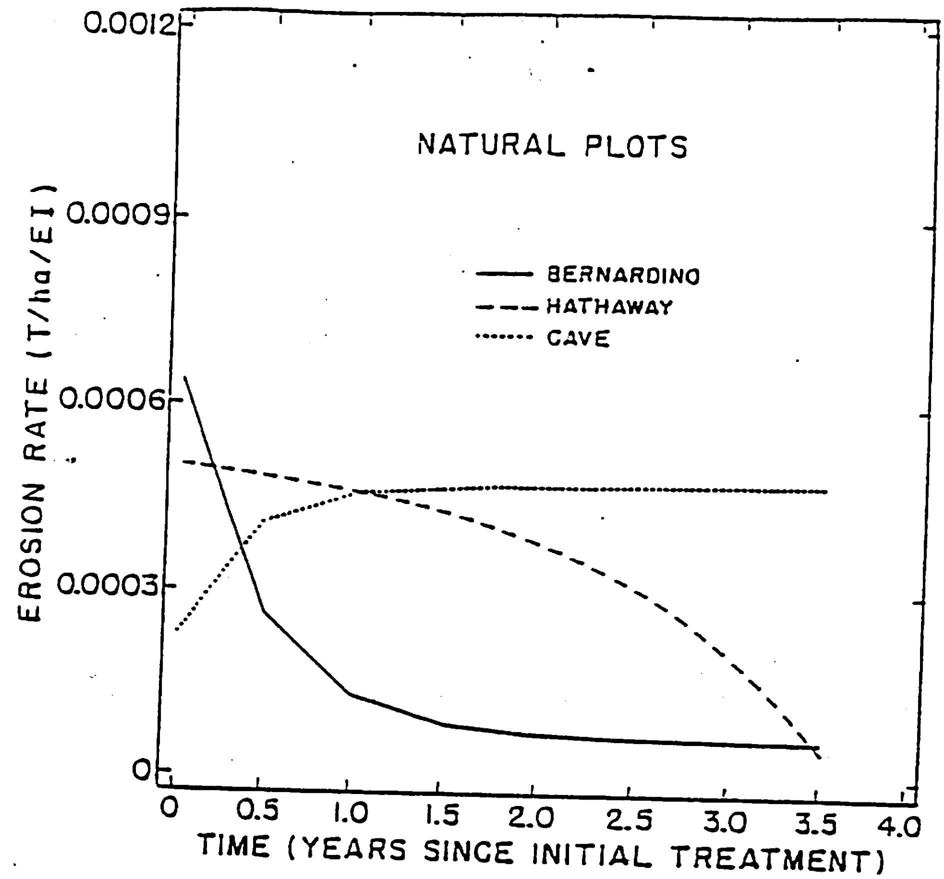
EROSION RATE (T/ha/EI)
0.012
0.009
0.006
0.003
0
NEVADA TEST SITE
ER = 0.0149e^-0.045EP
WALNUT GULCH
ER = 0.0119e^-0.044EP
0
10
20
30
40
50
60
70
80
90
100
EROSION PAVEMENT COVER (%)

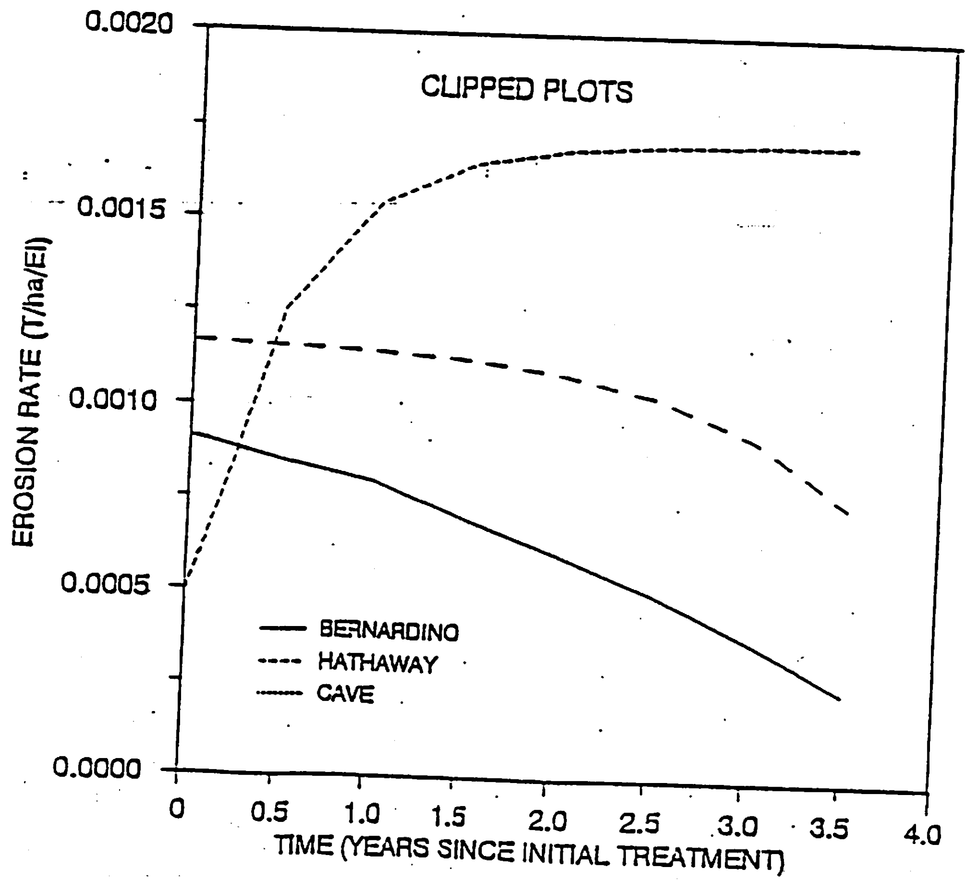
Fig. 6


NATURAL PLOTS
BERNARDINO
HATHAWAY
CAVE
RUNOFF RATE (mm/EI)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
TIME (YEARS SINCE INITIAL TREATMENT)

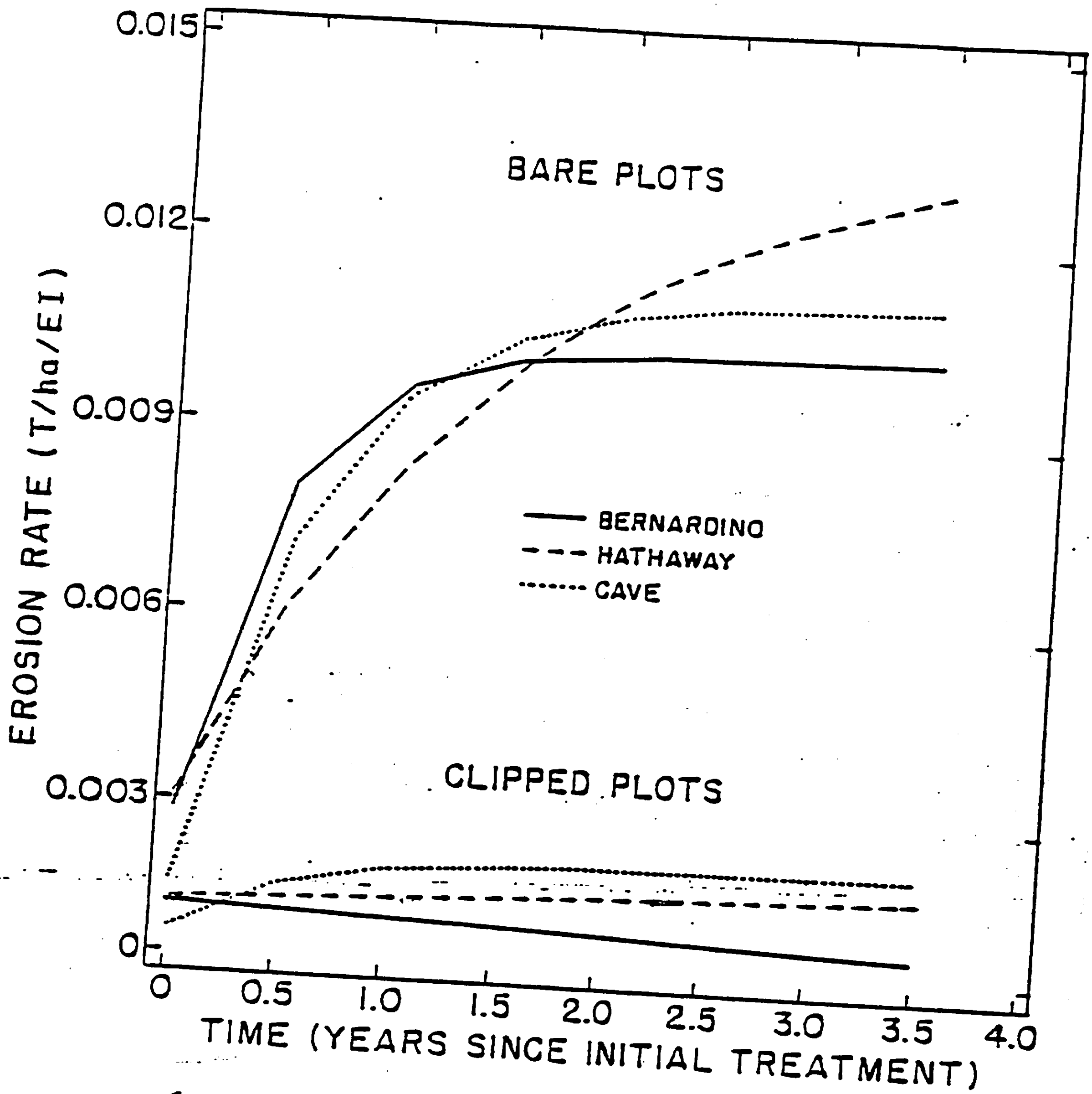

CLIPPED PLOTS
BERNARDINO
HATHAWAY
CAVE
RUNOFF RATE (mm/EI)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
TIME (YEARS SINCE INITIAL TREATMENT)

Fab


NATURAL PLOTS
BERNARDINO
HATHAWAY
CAVE
EROSION RATE (T/ha/EI)
0.0012
0.0009
0.0006
0.0003
0
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
TIME (YEARS SINCE INITIAL TREATMENT)


CLIPPED PLOTS
BERNARDINO
HATHAWAY
CAVE
EROSION RATE (T/ha/EI)
0.0020
0.0015
0.0010
0.0005
0.0000
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
TIME (YEARS SINCE INITIAL TREATMENT)

8ab



0.015
0.012
0.009
0.006
0.003
0
ERROSION RATE (T/ha/EI)
BARE PLOTS
BERNARDINO
HATHAWAY
CAVE
CLIPPED PLOTS
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
TIME (YEARS SINCE INITIAL TREATMENT)

Fig. 10

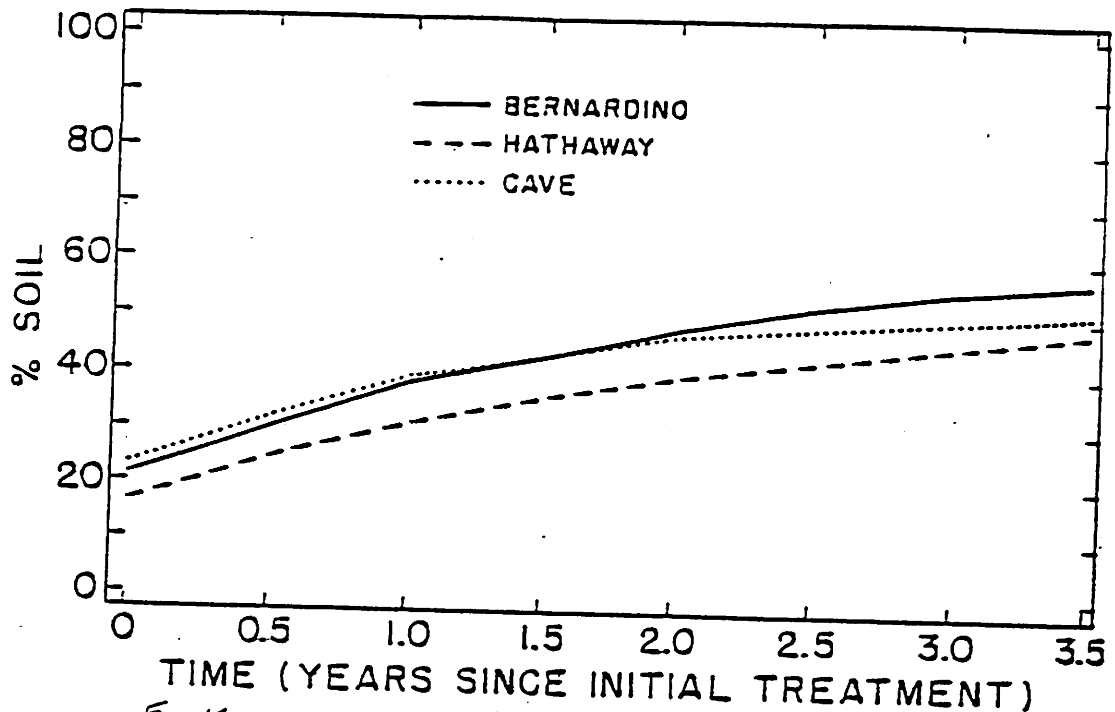

100
80
60
40
20
0
% SOIL
BERNARDINO
HATHAWAY
CAVE
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
TIME (YEARS SINCE INITIAL TREATMENT)

Fig. 12

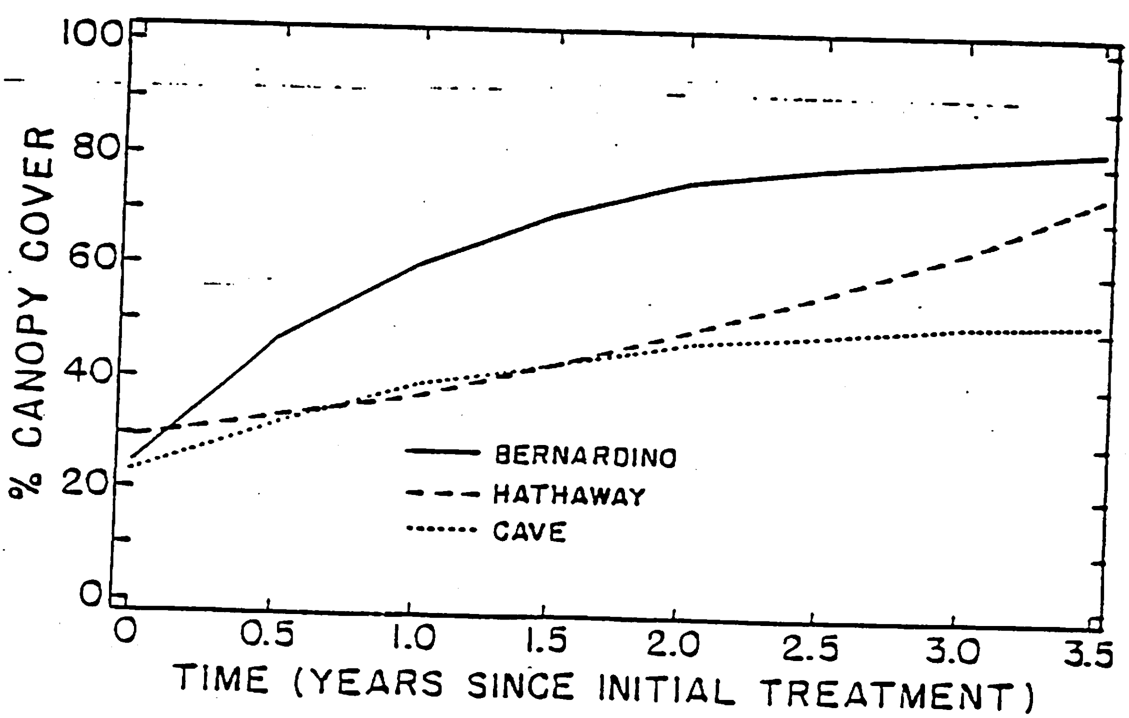

100
80
60
40
20
0
% CANOPY COVER
BERNARDINO
HATHAWAY
CAVE
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
TIME (YEARS SINCE INITIAL TREATMENT)

Fig. 11

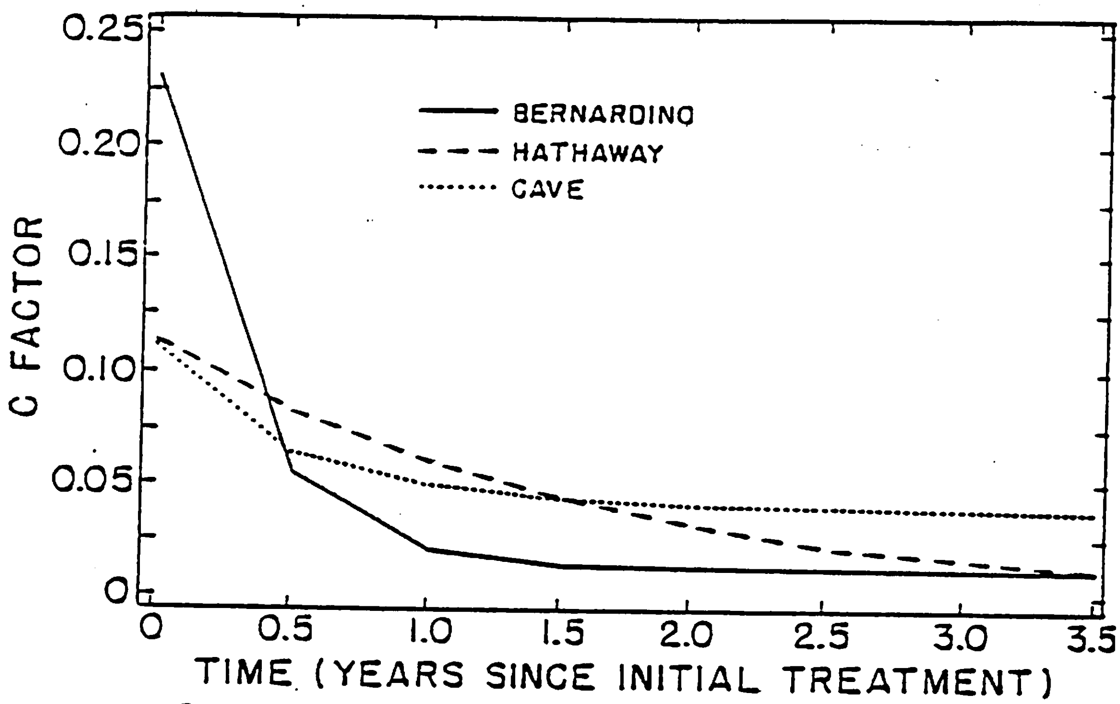

0.25
0.20
0.15
0.10
0.05
0
C FACTOR
BERNARDINO
HATHAWAY
CAVE
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
TIME (YEARS SINCE INITIAL TREATMENT)

Fig. 13

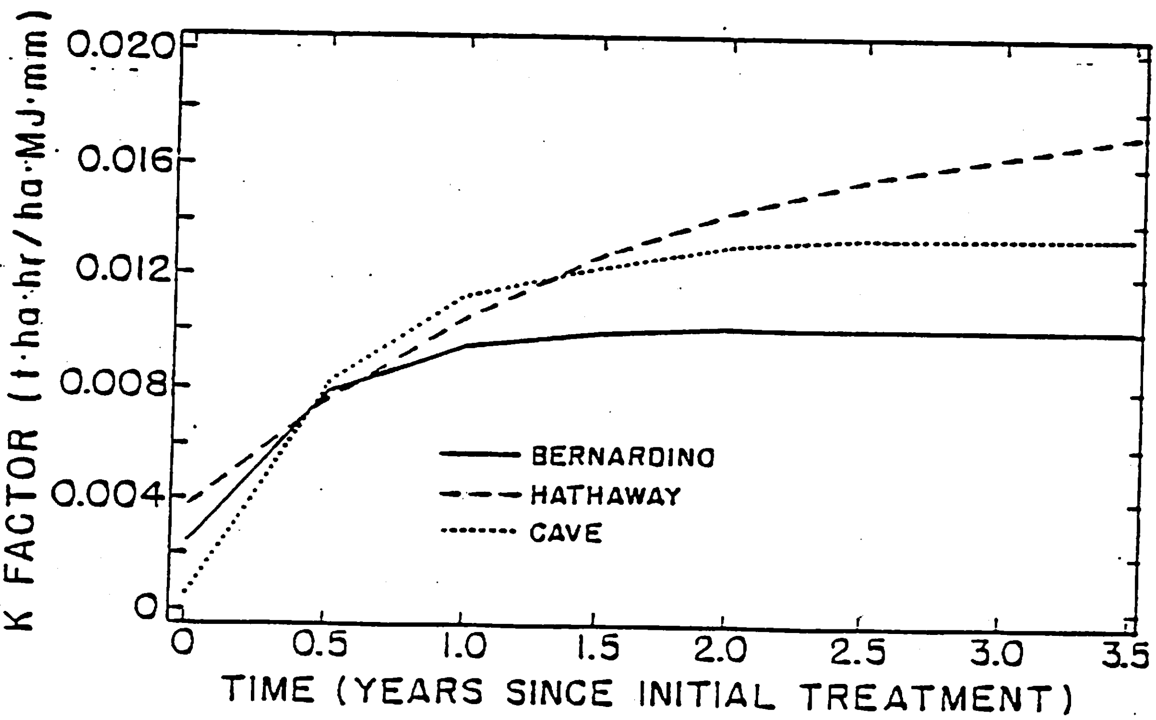
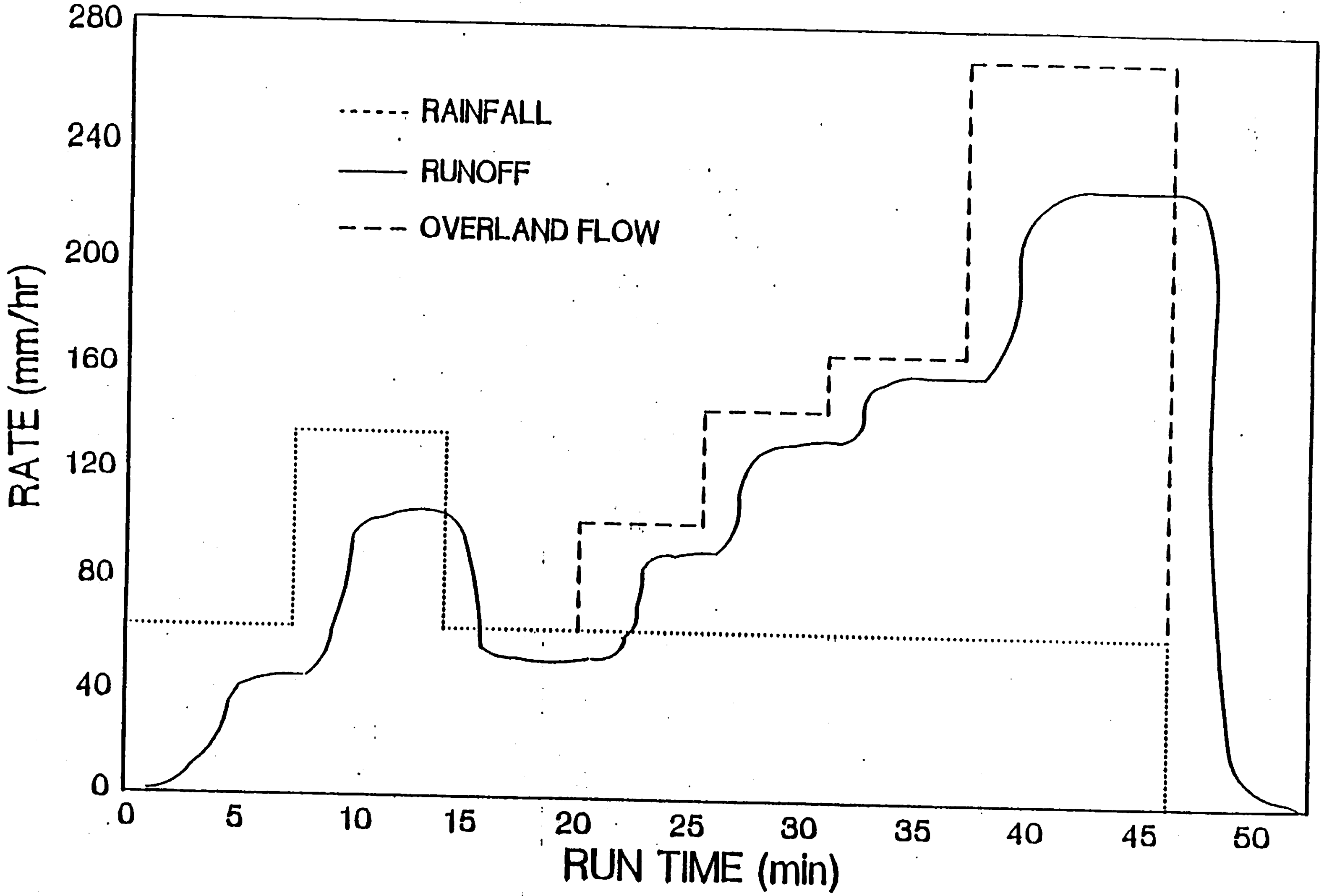

0.020
0.016
0.012
0.008
0.004
0
K FACTOR (t·ha·hr/ha·MJ·mm)
BERNARDINO
HATHAWAY
CAVE
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
TIME (YEARS SINCE INITIAL TREATMENT)

Fig. 9



RAINFALL
RUNOFF
OVERLAND FLOW
RATE (mm/hr)
0
40
80
120
160
200
240
280
0
5
10
15
20
25
30
35
40
45
50
RUN TIME (min)

Fig. 14

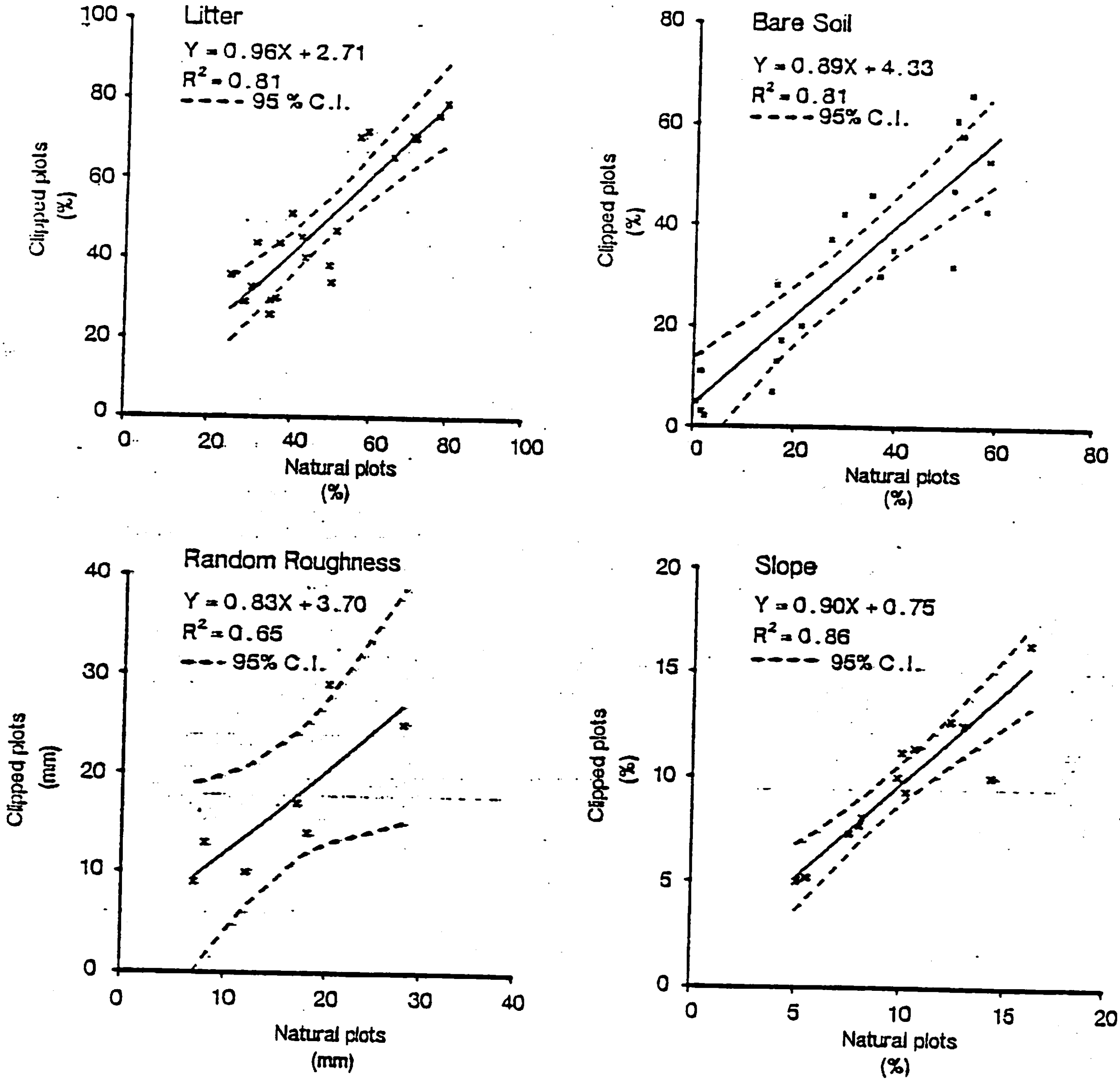
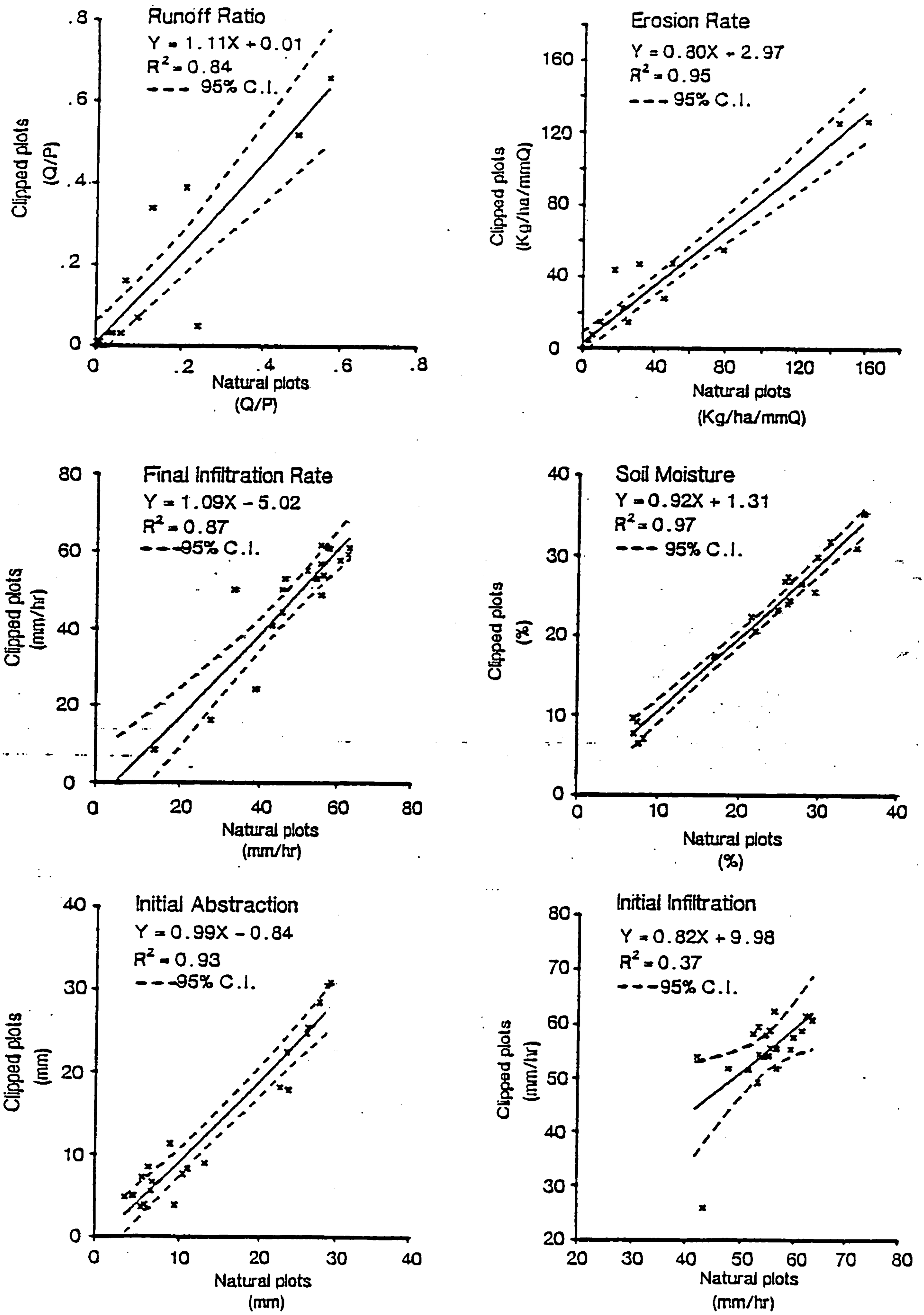

Litter
Y = 0.96X + 2.71
R^2 = 0.81
95 % C.I.
Clipped plots (%)
Natural plots (%)
Bare Soil
Y = 0.89X + 4.33
R^2 = 0.81
95% C.I.
Clipped plots (%)
Natural plots (%)
Random Roughness
Y = 0.83X + 3.70
R^2 = 0.65
95% C.I.
Clipped plots (mm)
Natural plots (mm)
Slope
Y = 0.90X + 0.75
R^2 = 0.86
95% C.I.
Clipped plots (%)
Natural plots (%)

Fig. 15


Runoff Ratio
Y = 1.11X + 0.01
R² = 0.84
95% C.I.
Clipped plots (Q/P)
Natural plots (Q/P)
Erosion Rate
Y = 0.80X + 2.97
R² = 0.95
95% C.I.
Clipped plots (Kg/ha/mmQ)
Natural plots (Kg/ha/mmQ)
Final Infiltration Rate
Y = 1.09X - 5.02
R² = 0.87
95% C.I.
Clipped plots (mm/hr)
Natural plots (mm/hr)
Soil Moisture
Y = 0.92X + 1.31
R² = 0.97
95% C.I.
Clipped plots (%)
Natural plots (%)
Initial Abstraction
Y = 0.99X - 0.84
R² = 0.93
95% C.I.
Clipped plots (mm)
Natural plots (mm)
Initial Infiltration
Y = 0.82X + 9.98
R² = 0.37
95% C.I.
Clipped plots (mm/hr)
Natural plots (mm/hr)

Fi. 11