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# VEGETATION AND SOIL SURFACE COVER ADJUSTMENTS TO INTERRILL SOIL ERODIBILITY ON RANGELAND

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## ABSTRACT

The USDA-Water Erosion Prediction Project (WEPP) model is based on fundamentals of hydrology, soil physics, plant science, hydraulics, and erosion mechanics. The WEPP model estimates erosion on uplands as a function of raindrop detachment (interrill processes) and excess hydraulic shear in concentrated flow paths (rill processes). Rangeland field experiments were designed to develop an adjustment to the baseline interrill soil erodibility equation as a function of canopy and soil surface cover. Twenty rangeland sites from a wide range of soil and vegetation types were evaluated using rainfall simulation techniques on paired plots (3 m wide by 10.7 m long). One hundred and twenty rainfall events (wet runs) were used to test the WEPP model under two scenarios: a) the rangeland option; and b) using adjustments from the cropland interrill erodibility equation. Total sediment yield values for each event were compared with the WEPP model predicted sediment yield. Results indicate that the current WEPP rangeland option under-estimates sediment yield, while the cropland option significantly over-estimates sediment yield on rangelands. A least-squares optimization technique was used in an attempt to improve the current interrill erodibility equation in WEPP, resulting in a slight lowering (from -7 to -6.6) of the interrill adjustment factor coefficient for rangelands. This optimization procedure slightly improved estimates of sediment yield. Until techniques are developed to define the inherent bare soil interrill erodibility independent of vegetation and land use influences, the ability to estimate soil erosion on rangelands will not be significantly improved.

## INTRODUCTION

Rangelands and permanent pasture comprise approximately 51% of the world's land surface and approximately 364 million hectares in 17 western states of the United States (Child and Frasier 1992). Rangeland ecosystems are complex and are affected by many interacting biotic and abiotic components; their health is dependent on the interaction of climate, topography, soils, hydrologic processes, vegetation, and plant species composition. To assess ecosystem status fully, hydrological and erosion processes need to be fully understood.

Management practices influence soil erosion on rangelands because of their effect on plant, litter, and soil properties (Blackburn et al. 1982). Plant and litter variables influence infiltration as well as the basic erosion process of soil detachment by raindrops and runoff, sediment transport, and sediment deposition. Infiltration and erosion research has demonstrated that human activity may significantly alter canopy cover, ground cover, and soil properties, thereby decreasing infiltration rates, increasing runoff rates, and accelerating erosion rates (Thurow et al.1986; Weltz and Wood 1986, 1989). In addition, many studies have shown that the spatial distribution of the amount and type of vegetation, canopy cover, and soil surface cover are important factors influencing runoff and sediment yield (Spaeth et al. 1996; Blackburn et al. 1992).

The USDA-Water Erosion Prediction Project (WEPP) model is based on fundamentals of hydrology, soil physics, ecology, hydraulics, and erosion mechanics (Flanagan and Nearing 1995). WEPP is a process based hydrologic and erosion simulation model, designed to be applicable on all U.S. rangelands and croplands, that operates on a daily time step or can be used to evaluate specific rainfall events. The model estimates soil erosion from two processes: rainfall detachment (interrill erosion) and excess hydraulic shear in concentrated flow paths (rill erosion). The interrill erodibility for rangeland soils is calculated in the model as:

$$K_i = K_{ib} \, (RK_{cov}) \tag{1}$$

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where $K_i$ is the interrill erodibility parameter *(kg·s·m⁻⁴)*, $K_{ib}$ is the baseline interrill erodibility parameter *(kg·s·m⁻⁴)*, and $RK_{cov}$ is the adjustment factor for rangeland cover (0-1). Data collected from the WEPP rangeland field study of 20 rangeland sites (Laflen et al. 1991; Simanton et al. 1991) were analyzed to develop a relationship between interrill erodibility and soil physical and chemical properties. The baseline interrill soil erodibility for rangelands is predicted from:

$$K_{ib} = 1810000 - 1910000\ sand - 6327000\ orgmat - 846000\ \theta_{fc} \tag{2}$$

where *sand* is the fraction of sand (0-1) in the surface soil, *orgmat* is the fraction of organic matter (0-1) in the surface soil, and $\theta_{fc}$ is the volumetric water content of the soil surface at 0.033MPa ($m^3 \cdot m^{-3}$). The rangeland cover adjustment factor applied to interrill erodibility is calculated as:

$$RK_{cov} = e^{-7.0\ (inrcov\ -\ cancov)} \tag{3}$$

where *inrcov* is the total interrill ground cover (0-1) and *cancov* is the total canopy cover (0-1) (Flanagan and Nearing 1995).

The objective of this study was to evaluate sediment yield estimates from the WEPP model using data collected from rainfall simulation and soil erosion experiments conducted on twenty rangeland sites from a wide range of soil and vegetation types (Table 1). The specific focus was to evaluate and test variations of the rangeland interrill erodibility equation used in WEPP as a means to improve sediment yield predictions on rangelands. This study only evaluated the existing sediment detachment equations used in WEPP and did not evaluate alternative detachment or transport equations as possible mechanisms to improve estimates of sediment yields on rangelands.

Table 1. Site characteristics for plots used in this study from USDA-ARS and USDA-IRWET rangeland rainfall simulation experiments.

| Location | No. Sites | No. Plots | Rangeland Cover Type | Surface Texture |
|---|---|---|---|---|
| Prescott, Arizona | 2 | 12 | Grama-Galleta | Sandy loam |
| Tombstone, Arizona | 1 | 2 | Grama-Tobosa-Shrub | Sandy clay loam |
| Akron, Colorado | 3 | 18 | Wheatgrass-Grama-Needlegrass | Loam |
| Meeker, Colorado | 1 | 1 | Wyoming big sagebrush | Silty clay |
| Blackfoot, Idaho | 2 | 7 | Mountain big sagebrush | Silt loam |
| Eureka, Kansas | 3 | 10 | Bluestem prairie | Silty clay loam |
| Wahoo, Nebraska | 2 | 7 | Bluestem prairie | Loam |
| Cuba, New Mexico | 1 | 1 | Blue gram-Galleta | Sandy loam |
| Los Alamos, New Mexico | 1 | 2 | Juniper-Pinyon Woodland | Sandy loam |
| Kildeer, North Dakota | 2 | 12 | Wheatgrass-Needlegrass | Sandy loam |
| Chickasha, Oklahoma | 1 | 3 | Bluestem prairie | Loam |
| Chickasha, Oklahoma | 1 | 4 | Bluestem prairie | Sandy loam |
| Freedom, Oklahoma | 1 | 1 | Bluestem prairie | Loam |
| Woodward, Oklahoma | 1 | 1 | Bluestem-Grama | Loam |
| Cottonwood, South Dakota | 1 | 1 | Wheatgrass-Needlegrass | Clay |
| Cottonwood, South Dakota | 1 | 4 | Blue grama-Buffalograss | Clay |
| Amarillo, Texas | 2 | 11 | Blue grama-Buffalograss | Loam |
| Sonora, Texas | 1 | 2 | Juniper-Oak | Cobbly clay |
| Buffalo, Wyoming | 2 | 9 | Wyoming big sagebrush | Silt loam |
| Newcastle, Wyoming | 3 | 12 | Wheatgrass-Needlegrass | Sandy loam |

## FIELD PROCEDURES

The data sets used in this study were from two separate research projects: the USDA-National Resource Soil Conservation Service (NRCS)/Agricultural Research Service (ARS) Interagency Rangeland Water Erosion Team project (IRWET), and the ARS-Southwest Watershed Research Center (SWRC) WEPP rainfall simulator database. The rainfall simulator used in the field experiments was described by Simanton et. al. (1991). The simulator's nozzles spray continuously downward from an average height of about 3 m and move in a circular path over the plots. The simulator applies rainfall intensities of approximately 60 mm/hr and produces drop-size distributions similar to natural rainfall. Simulator rainfall energies are 77% of those of natural rainfall and intermittent rainfall impulses are produced on 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%. Six non-recording raingages were used on each plot to measure rainfall amounts and distribution. One recording raingage was placed between the paired plots to measure rainfall intensity.

The experimental design consisted of two rainfall simulation events. Rainfall was applied to dry soil at 60 mm/hr for one hour (dry run). Twenty-four hours later a 30-min rainfall simulation was conducted at 60 mm/hr (wet run). Only the wet run data were used in this analysis for two reasons. The majority of the dry runs yielded total runoff of less than 2 mm. In addition, the variability in antecedent moisture condition from plot to plot and site to site results in uncontrollable experimental error. As a result of the application of water from the dry runs, antecedent moisture constraints are lessened because the plots are at or near field capacity before the initiation of the wet run. Each plot was 3.05 by 10.7 m in size with the long axis parallel to the slope. The plots were arranged in pairs so that two plots were evaluated simultaneously. A precalibrated runoff measuring flume was set at the plot trough exit and flow depths were continuously recorded using pressure transducer bubble gages. Hydrographs and sedigraphs were produced using depth/discharge rating tables and sediment sample concentrations. These graphs were later integrated to determine runoff volumes and total sediment yields. During runoff, periodic water/sediment samples (1 liter in volume) were collected from the exit of the flumes. Sampling intervals were dependent on hydrograph shape, with 1-2 minute intervals between samples on the rising and falling portions of the hydrograph and longer intervals during runoff equilibrium. Sediment concentration samples were placed in a drying oven at 105°C until all liquid was evaporated; then the sample was weighed to the nearest 0.01g.

At each site a complete soil profile description by horizon was determined by the NRCS. All plots evaluated were in natural cover conditions. The SWRC study evaluated two plots per site and the IRWET study evaluated six plots per site, although not all plots could be used in the present study. Plots with total runoff of less than 2 mm were excluded from this study, resulting in unequal sample numbers per site (Table 1). IRWET estimated standing biomass using the NRCS double sampling procedure (SCS 1976). Five sample quadrats were evaluated per erosion plot. The quadrats were clipped to a height of 1 cm above the ground surface. Biomass was separated by species into three categories: 1) previous year's growth; 2) current year growth; and, 3) standing dead. The ARS estimated standing biomass by clipping six 0.5 m by 1 m quadrats outside the erosion plots. The quadrats were clipped to 1 cm of the soil surface and categorized by lifeform (grass, forb, shrubs, cacti). For both studies all litter on the plot was collected after standing biomass was removed. All biomass and litter samples were dried at 60°C for 72 hours and weighed.

Cover was defined as the percentage of the percentage of soil surface protected by litter, plant, rock and cryptogamic material. The percentage of soil surface area protected from raindrop impact by standing plant material looking straight down into the canopy. Ground cover was defined as the amount of litter, cryptogams, plant basal area, and impervious material protecting the soil surface from raindrop impact (0-100%). Canopy and ground cover were estimated with a 49-pin point-sampling frame for both studies. The frame was placed at ten evenly spaced intervals (1 m) on each plot, starting at 0.5 m from the outlet of the plot. Canopy cover was recorded by lifeform and ground cover by class (soil, rock, litter, basal cover, and cryptogams).

## ANALYSIS

Sediment yield estimates from the single event option of the WEPP model were compared to measured sediment yield from the wet run rainfall simulations to evaluate interrill erodibility using both the adjustment factors for rangeland and cropland. Model predictions were first tested using the rangeland erodibility equations (Eqs. 1-3) in the WEPP model version 95.7 (Flanagan and Nearing 1995). The cropland option in WEPP uses an alternative series of factors to estimate the influence of canopy and ground cover on interrill erodibility. The cropland adjusted interrill erodibility term in WEPP is calculated in a similar manner to the rangeland erodibility term. A baseline term is calculated as a function of soil texture and is adjusted by a number of terms used to represent various effects including canopy cover, ground cover, live and dead roots, sealing and crusting, slope, and freezing and thawing. For the present study, two of the cropland factors were calculated from the rangeland plot data and used to adjust the baseline rangeland interrill erodibility values for each plot. The cropland canopy adjustment factor ($Ck_{can}$) (0-1) was predicted from:

$$CK_{can} = 1 - 2.941 \frac{cancov}{h} [1 - e^{-0.34h}] \quad (4)$$

where *cancov* is total canopy cover (0-1) and *h* is canopy height (m). The cropland ground cover adjustment factor ($Ck_{gc}$) was predicted from:

$$CK_{gc} = e^{-2.5\, inrcov} \quad (5)$$

where *inrcov* is the total interrill ground cover (0-1) (Flanagan and Nearing 1995).

Effective hydraulic conductivity values were optimized using the method developed by Weltz et al. (1992) to minimize the potential of error propagation from peak runoff and total discharge estimates affecting the estimated sediment yield. The objective function sum of squares (Eq. 6) was minimized to obtain the optimal coefficient for the exponential term in Eq. 3. Least-squares criteria were used to test the possibility of improving the estimation of sediment yield on rangelands.

$$\min = \sum [sediment(i)_{observed} - sediment(i)_{predicted}]^2 \tag{6}$$

## RESULTS AND DISCUSSION

The original WEPP interrill erodibility adjustment factor was developed from rainfall simulation data collected from ten sites and 44 plots. The addition of 76 plots from ten new soil/plant associations only slightly improved sediment yield predictions. The WEPP model under-estimates sediment yield when the rangeland interrill erodibility equation was used (Fig. 1a), and significantly over-estimates sediment yield when the cropland rangeland erodibility parameters were used (Fig. 1b). The optimization procedure resulted in a slight lowering of the coefficient in Eq. 3 from -7.0 to -6.6. The optimization procedure on the rangeland interrill erodibility adjustment factors only slightly improved estimates of sediment yield ($r^2 = 0.276$).

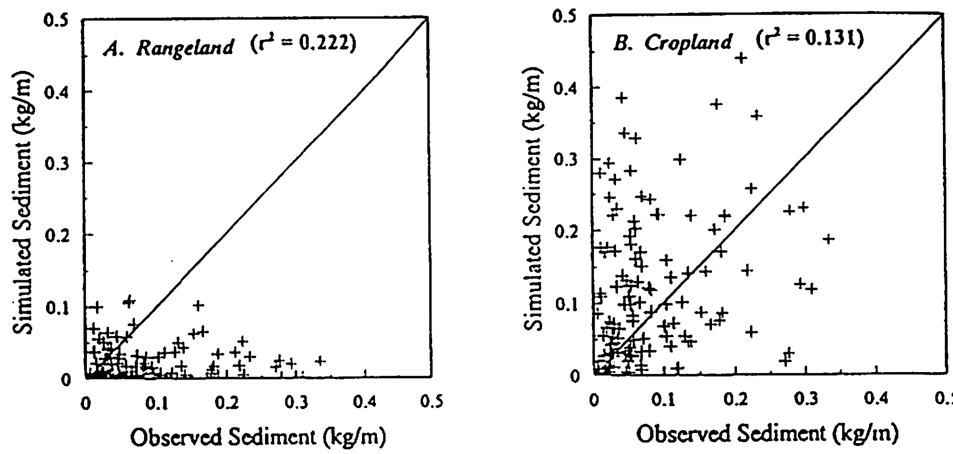


Figure 1. Comparison of observed sediment yield and WEPP model estimated sediment yield using the rangeland interrill erodibility adjustment factors (1a) and cropland interrill erodibility adjustment factors (1b).

The original baseline soil erodibility equation was developed from plots that had been bared of all vegetation (Laflen et al. 1991). The vegetation was clipped and all biomass and ground surface cover were removed (rocks, litter, cryptogams, standing biomass, and plant crowns). Residual plant crowns were removed by scalping the soil surface beneath the plant crown (removal of 1 to 3 mm from the soil surface with a sharpened shovel). For some locations this resulted in complete disturbance of the soil surface (Cottonwood, SD and Cuba, NM). Less than 10% of the soil surface was disturbed at other sites (Meeker, CO). This treatment was imposed to develop a standard bare soil treatment that could be evaluated across all rangeland soil/plant associations, but does not represent naturally occurring bare soil on rangelands. We propose that baring the plot by scalping the vegetation resulted in baseline soil erodibilities that reflected neither the natural undisturbed bare soil erodibility nor the most erosive condition for bare rangeland soils.

Simanton and Renard (1986), using a similar experimental design, evaluated the effect of baring the soil surface

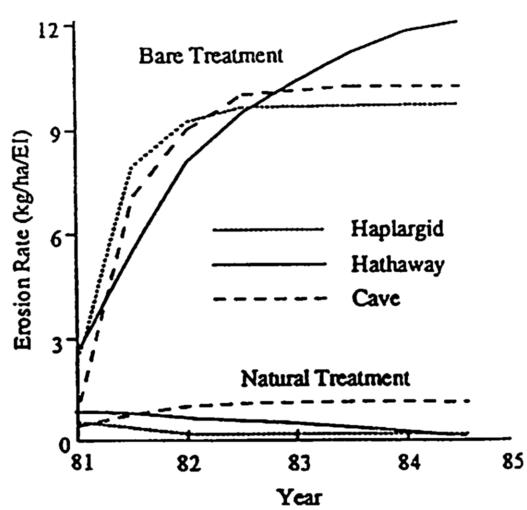


Figure 2. Comparison of rangeland natural vegetation and bare unit plot erosion rates (from Simanton and Renard 1986).

compared to natural vegetation on soil loss on three soil/plant associations in the spring and fall for four years. The soils evaluated were a *Ustollic Haplargid, Typic Paleorthid,* and *Aridic Calciustoll.* Vegetation on the Haplargid site was grass-dominated, shrubs dominated the Paleorthid site, and the Calciustoll site contained a mixture of grass and half-shrubs. They concluded that the magnitude of soil loss was both treatment and soil type dependent. Greater runoff and erosion occurred from the bare plots than from the natural plots. The bare soil plots produced the greatest change in erosion rate with time (Fig. 2). The erosion rate increased for the bare soil plots with time for about two years before approaching a new equilibrium with the rainfall energy input. Another reason for the erosion rate increase was the formation of well defined concentrated flow paths that were more efficient in transporting sediment offsite. The different shapes of the erosion rate curves probably reflected soil/plant differences. The initial increase in erosion rate on the natural plots for the Paleorthid site was attributed to the removal of loose unconsolidated material from the coppice dunes beneath the shrubs as a function of the high rainfall energy applied during the first year of the experiment. The decrease in erosion rate at two of the sites for the natural plots was probably due to increases in soil porosity and organic matter associated with increases in plant basal and canopy cover that occurred because of addition of spring and fall moisture from the rainfall simulations (applied rainfall was equal to annual precipitation). We hypothesize that root growth in the natural plots was better able to maintain the soil structure and aggregate stability thus preventing the accelerated erosion exhibited on the bare plots.

The WEPP model estimates soil erosion from both interrill and rill processes. The experimental design used in this study and by Simanton and Renard (1986) only measured total sediment yield at the end of the plot. There was no direct measurement of the contribution of soil loss from either rill or interrill erosion processes on the natural plots. Less than 7% of the natural plots evaluated as part of this study were estimated to have erosion resulting from excess hydraulic shear forces (rill erosion) by the WEPP model. The ability to conceptualize and develop erosion models has exceeded the ability to design and quantify the component processes of interrill and rill erosion with field experiments. With two unknowns, soil detachment from interrill and rill erosion processes, and only one known value (total sediment yield), there is no direct way to validate the WEPP model estimate of sediment yield on rangelands from natural plots. Field experiments need to be designed to directly allow for internal validation of soil detachment simultaneously from interrill and rill erosion process in order to fully validate process based erosion models. Limitations with data from these field studies prevent the evaluation of the WEPP model to determine if the under-prediction of sediment yield on rangelands is the result of representing the erosion process with inappropriate functional equations or if the limitation is in having an adequate sample size to address the variability in soil erodibility of native rangelands. The current form of the interrill erodibility equation (Eq. 2) does not capture the inherent differences in soil erodibilities that result from chemical interactions (i.e. dispersability of the soil as a function of sodium content). New equations or adjustment factors need to be explored to account for chemical as well as physical factors that affect interrill erodibility of rangelands.

The concept of the unit fallow bare plot from repeated plowing as used in cropland to define baseline soil erodibility does not apply to rangelands. Interrill soil erodibilities on a single phase of a Pierre soil series near Cottonwood, SD and a Woodward series near Woodward, OK under different historic land uses (cropland and grazed rangelands) that were evaluated as part of this study are compared in Fig. 3. The cropland baseline soil erodibility is calculated from fallow plots in the soil's most erosive state (i.e., immediately following plowing) (Laflen et al. 1991). The severity of this treatment removed any residual influence of previous soil consolidation, land use, and vegetation. The baring of the soil surface under different rangeland treatments resulted in variable disturbance for similar phases of a soil series due to the variation in vegetation (both type and amount) and rock content of the soil. This treatment causes non-reproducible experimental results for a given phase of a soil series and does not necessarily produce the most erosive state of the soil series. The residual root biomass and organic matter left in the soil after baring rangeland plots greatly influences the baseline soil interrill erodibility. However, there is currently no way to separate the historic and current vegetation influence, land use, and management effects from the inherent soil interrill erodibility.

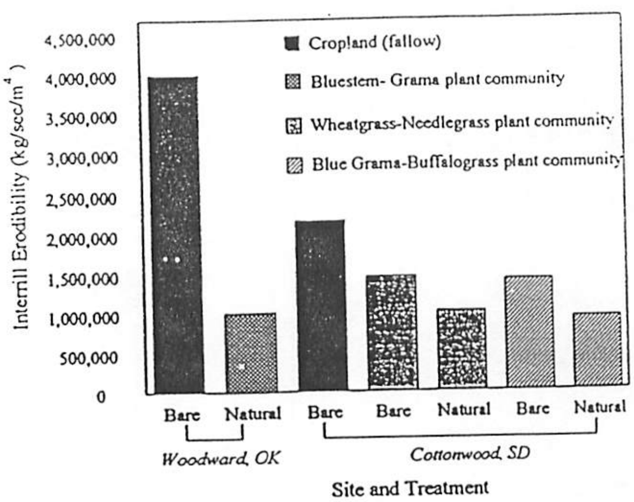


Figure 3 Comparison of fallow cropland and natural and recently bared rangeland soil interrill erodibilities on comparable phases of a soil series at two locations (from Laflen et al. 1991).

Soil erodibility measured by rainfall simulation experiments conducted at various rangeland sites varied yearly and depended on vegetation and soil type (Figs. 2 and 3). Time related changes in erosion rates associated with rangelands need to be evaluated over a multi-year period using multi-plot studies. Biotic factors, both flora and fauna, significantly influence the variability of soil interrill erodibility and need to be considered before the interactions between soil interrill erodibility and soil erosion on rangelands can adequately be defined. Baseline soil erodibility is calculated as a function of sand, organic matter content, and volumetric water content of the soil (Eq. 2) in the rangeland option of WEPP. The estimated baseline soil interrill erodibility value is reduced as a function of canopy and ground surface cover to calculate an effective soil interrill erodibility value. If the baseline soil interrill erodibility value is higher than that of a naturally occurring bare soil, then the adjustment factors must over compensate for the influence of cover to estimate the effective soil interrill erodibility. Until techniques are developed to define the inherent soil interrill erodibility independent of vegetation and land use influences, the ability to improve significantly soil erosion estimates on rangelands will not be achieved. New field procedures to evaluate in situ soil interrill erodibilites are required to separate the interactions of biotic and abiotic processes before appropriate interrill erodibility values for naturally occurring bare soil on rangelands can be developed.

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