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Evaluation of USLE and RUSLE estimated soil loss on rangeland

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Abstract

The Universal Soil Loss Equation (USLE) and the Revised Universal Soil Loss Equation (RUSLE 1.06) were evaluated with rainfall simulation data from a diverse set of rangeland vegetation types (8 states, 22 sites, 132 plots). Dry, wet, and very-wet rainfall simulation treatments were applied to the study plots within a 2-day period. The rainfall simulation rate was 65mm/hr for the dry and wet simulation treatments and alternated between 65–130 mm/hr for the very-wet treatment. Average soil loss for all plots for the representative simulation runs were: 0.011 kg/m^2, 0.007 kg/m^2, and 0.035 kg/m^2 for the dry, wet, and very-wet simulation treatments, respectively. The Nash-Sutcliffe Model efficiencies (R^2*eff*) of the USLE for the dry, wet, very-wet simulation treatments and sum of all soil loss measured in the three composite simulation treatments (pooled data) were negative. This indicates that the observed mean measured soil loss from the field rainfall simulations is better than predicted USLE soil loss. The USLE tended to consistently overpredict soil loss for all 3 rainfall simulation treatments. As the USLE predicted values increased in magnitude, the error variance between predicted and observed soil loss increased. Nash-Sutcliffe model efficiency for the RUSLE was also negative, except for the dry run simulation treatment [R^2*eff* = 0.16 using RUSLE cover management (C) subfactor parameters from the RUSLE manual (C_{table}), NRCS soil erodibility factor (K); and R^2*eff* = 0.17 with C_{table} and K estimated from the soil-erodibility nomograph]. In comparison to the USLE, there was less error between observed and RUSLE predicted soil loss. The RUSLE error variances showed a consistent trend of underpredicted soil loss among the 3 rainfall simulation treatments. When actual field measured root biomass, plant production and soil random roughness values were used in calculating the RUSLE C subfactors: the R^2*eff* values for the dry, wet, very-wet rainfall simulation treatments and the pooled data were all negative.

Key Words: erosion models, sheet and rill erosion, rainfall simulation experiments, rangeland health

Resumen

La Ecuación Universal de Perdida de Suelo (EUPS) y la Ecuación Universal de Perdida de Suelo Revisada (EUPSR 1.06) fueron evaluadas con datos de simulación de lluvia de un grupo diverso de tipos de vegetación de pastizal (8 estados, 22 sitios y 132 parcelas). Los tratamientos de simulación de lluvia, seco, húmedo y muy húmedo se aplicaron en las parcelas de estudio dentro de un periodo de 2 años. Las tasa de simulación de lluvia fue de 65 mm/hr para los tratamientos de simulación seco y húmedo y alternada entre 65–130 mm/hr para el tratamiento muy húmedo. Los promedios de perdida de suelo para todas las parcelas en las corridas de simulación representativas fueron: 0.011 kg/m^2, 0.007 kg/m^2 y 0.035 kg/m^2 para los tratamientos seco húmedo y muy húmedo respectivamente. Las eficiencias del modelo Nash-Sutcliffe (R^2*eff*) de la EUPS para los tratamientos seco, húmedo y muy húmedo y la suma de todo el suelo perdido medido en los tres tratamientos compuestos de simulación (datos mezclados) fueron negativas. Esto indica que la media de perdida de suelo observada en las simulaciones de lluvia en el campo es mejor que la predicha por la EUPS. La EUPS tendió a sobepredecir constantemente la perdida de suelo para los 3 tratamientos de simulación de lluvia. Conforme los valores predichos por la EUPS se incrementaron en magnitud, la varianza del error entre la perdida de suelo predicha y observada se incrementó. La eficiencia del modelo Nash-Sutcliffe también fue negativa, excepto para el tratamiento de simulación seco [R^2*eff* = 0.16, usando los parámetros del subfactor el manejo de cobertura © del manual de la EUPSR (C_{tabla}), la erodabilidad del suelo, factor (K) de la EUPS y R^2*eff* = 0.17 con C_{tabla} y K estimados del nomográfo de la erodabilidad de suelo]. En comparación con la EUPS, hubo menos error entre la perdida de suelo observada y la predicha por la EUPSR. Las varianzas del error de la EUPSR mostraron un tendencia consistente de perdida de suelo no predicha entre los 3 tratamientos de simulación de lluvia. Conforme la cantidad e intensidad de la lluvia se incrementan y el suelo viene a estar mas saturado aumentó la propensión la subestimación. Cuando la biomasa radical actual, la producción de planta y la rugosidad aleatoria del suelo se usaron en calcular los subfactores C del EUPSR: los valores de R^2*eff* fueron negativos para los tratamientos seco, húmedo y muy húmedo y los datos promediados.

Since the mid 1940's, the United States Department of Agriculture (USDA) has been using erosion prediction equations as a guide in conservation planning to select suitable structural and field management practices on cropland. The USDA-Natural Resources Conservation Service (NRCS) first applied the Universal Soil Loss Equation (USLE) on cropland in the early 1960' s to predict sheet and rill erosion. The USLE soil loss estimation and erosion research progressed with 2 Agricultural Handbook publications for predicting rainfall erosion losses

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(Wischmeier and Smith 1965, 1978). Wischmeier (1976) stated: "the USLE was designed to predict soil loss from sheet and rill erosion" and soil loss predicted by the USLE is "that soil moved off the particular slope segment represented by the selected topographic factor." The USLE provided conservation planners with the ability to predict longtime average rates of soil erosion for different cropping systems and management practices in association with a specified soil type, rainfall pattern, and topography. When these predicted losses were compared with NRCS soil loss tolerances (T), they provided specific guidelines for implementing erosion control within specified limits (Wischmeier and Smith 1978).

Wischmeier (1976) stated that the USLE "permits methodical decision-making in soil conservation planning on a site basis." Renard et al. (1997) state that for more than 4 decades, the technology has been valuable as a conservation-planning guide. Government agencies have used the technology for this purpose—to evaluate the benefits of various conservation practices; however, other uses have emerged over the years such as ascertaining compliance with a soil loss standard and a means to prioritize programs based on soil loss. These other uses, whether appropriate or inappropriate have been a point of debate for almost as long as the technology has existed (Wischmeier 1976, Blackburn 1980, Wight and Siddoway 1982).

During the early 1970's, the NRCS and the USDA-Forest Service met to discuss the extension of USLE to undisturbed land, which included rangeland. Since no field data was available on rangelands (as was for cropland: 10,000 plot-years over 40 years), Wischmeier developed a subfactor method for determining permanent pasture, rangeland, and woodland cover-management factors (C) by extrapolating crop residue to vegetation cover on range and woodland (Wischmeier 1975). In the early 1980's, the NRCS was concerned with the adequacy of the USLE because of anticipated Congressional legislation, which would affect USDA policies. The 1985 Farm Bill required that conservation plans on highly erodible cropland were necessary in order to participate in certain USDA farm programs and cost/share programs. It was becoming increasingly clear that the NRCS needed and desired improved erosion prediction technology. A plan was developed in USDA to update the USLE and begin developing improved erosion prediction technology based on process-based concepts (the Water Erosion Prediction Project, WEPP; Foster and Lane 1987, Flanagan and Livingston 1995). The USLE was evolving using subfactor methods and the USDA recognized the value of incorporating this technology into a computer program format and extending the technology beyond the original objectives of the early 1980's. The result of this effort was the Revised Universal Soil Loss Equation (RUSLE) (Renard et al. 1997).

Several studies have evaluated the USLE on rangelands. Simanton et al. (1980) compared observed and USLE predicted soil loss on 3 brush-covered and 1 grassland-covered watershed in southeastern Arizona. On brushland watersheds, they concluded that the USLE tended to over predict soil loss during small runoff events and under predicted soil loss with large runoff events. On a grass-covered watershed, soil loss was over predicted. Hart (1984) conducted rainfall simulation studies on sagebrush/grass plant communities in northern Utah. On vegetated plots, the USLE overestimated soil loss on 10% and 32% slope plots. The USLE estimates were less accurate on the steeper slope. In rangeland rainfall simulation experiments on 28 sagebrush and shadscale sites in southwest Idaho and north-central Nevada, Johnson et al. (1984) compared soil loss from field plots with the USLE predicted values for tilled, clipped, grazed, and ungrazed plots. They found good relationships (r^2=0.89) between observed and predicted soil loss on tilled (vegetation removed and soil rototilled) rangeland sites. On all vegetated plots combined (clipped, grazed, and ungrazed plots), coefficients of determination were low (r^2 = 0.27) between observed and predicted soil loss. Simulated soil loss from ungrazed sites (10 years deferment) showed consistently lower values than the USLE predicted values. Johnson et al. (1984) summarized that "variability in predicted soil losses from sagebrush rangelands indicates a need for more accurate quantification of cover and management conditions."

Renard and Foster (1985) stated: "fundamentally, the USLE is scientifically sound, although clearly, its factor values can be improved for western rangelands." Hawkins (1985) stated: the USLE "does not lead directly to erosion, but produces the intermediate product of storm runoff . . . the complications of time and spatial variations in site properties are usually not considered, even when of known consequence." Weltz et al. (1998) reviewed several limitations regarding the USLE: "USLE is a lumped empirical model that does not separate factors that influence soil erosion, such as plant growth, decomposition, infiltration, runoff, soil detachment, or soil transport. The USLE was designed to estimate sheet and rill erosion from hillslope areas. It was not designed to address soil deposition and channel or gully erosion within watersheds." Renard et al. (1991) summarized, "the fundamental erosion processes and their interactions are not represented, explicitly" in the USLE.

Advancements in hydrology and erosion research have been incorporated into the RUSLE 1.06 (hereon, RUSLE is version 1.06) (Renard et al. 1997). Specific advancements since the USLE include techniques to address slopes over 20%, compound slopes, and time variance adjustments for soil erodibility (Weltz et al. 1998). The RUSLE is an index method containing factors that represent how climate, soil, topography, and land use affect rill and interrill soil erosion caused by raindrop impact and surface runoff. The RUSLE, however, does not explicitly represent the fundamental processes of detachment, deposition, and transport by rainfall and runoff, but represents the effects of these processes on soil loss. The RUSLE is based on 6 factors, which are also represented in the USLE:

$$A = R\,K\,L\,S\,C\,P \qquad \textbf{(1)}$$

where: A = average annual soil loss, R= rainfall-runoff erosivity factor, K = soil erodibility factor, L = slope length factor, S = slope steepness factor, C = cover-management factor, and P= supporting practices factor. Soil loss (erosion rate) is computed by substituting values for each RUSLE factor to represent conditions at a specific site. Detailed discussions of the 6 components may be found in Renard et al. (1997).

Renard and Simanton (1990) evaluated the USLE and RUSLE predictions with measured soil loss from 17 rangeland sites in 7 western states. The simulation experiments consisted of natural vegetation and 2 altered treatments: 1) clipping vegetation only, and 2) removing all litter, vegetation, and soil surface erosion pavement (bare plots). On bare, clipped, and natural plots combined, coefficients of determination (r^2) between the RUSLE and measured soil loss (r^2 = 0.66) were higher compared to the USLE (^{2} = 0.62). On clipped and natural plots, r^2 between the RUSLE and measured soil loss (r^2 = 0.36) were higher compared to the USLE (r^2 = 0.08). When bare plots were included with the other 2 treatments, r^2 between the USLE and

RUSLE predicted and field measured soil loss improved; i.e., the bare plots produced more soil loss thus improving the "best fitted" prediction line. The bare plot treatment may represent the "worst case scenario" encountered; however, this situation is not a common occurrence on rangelands. Even after wildfire, root structures remain intact in the soil surface, which help stabilize the soil surface even when live surface cover is gone. Only after severe wind and water erosion and little plant regrowth over more than 1 growing season, would the bare treatment begin to become a reality.

Using Johnson and Gordon's (1988) sagebrush-grassland rainfall simulation and erosion data from the Reynold's Experimental Watershed, Benkobi et al. (1994) evaluated the RUSLE soil loss predictions using a refined RUSLE surface cover subfactor. The RUSLE soil loss was correlated with slope steepness and length (r = 0.90), vegetation cover (r = –0.88), random roughness (r = –0.68), root biomass (r = –0.50), and rock cover (r = –0.42). Coefficients of determination comparing field measured soil loss with the refined RUSLE model were 0.81 for dry and 0.50 for the wet simulation treatments. Using the unrefined RUSLE, $r^2 = 0.67$ for the dry treatment and $r^2 = 0.14$ for the moist treatment. Their conclusion was that use of the refined surface cover subfactor method increased accuracy; however, the RUSLE still underpredicted actual amounts of soil loss for the sagebrush/grassland sites. The objective of this study is to compare the USLE and RUSLE (version 1.06) soil loss estimates with observed soil loss from rainfall simulation studies conducted on a large and diverse set of rangeland community types.

Procedures and Methods

Field Methodology

In 1990, the NRCS established the National Range Study Team (NRST), which was a cooperative effort between the NRCS and the USDA-Agricultural Research Service (ARS). The purpose of the team was to collect field data that would expand the database for development and implementation of the WEPP and other rangeland models within the NRCS. The study was modeled (using same simulator design and field methodology) from the original ARS-Southwest Watershed Research Center rangeland simulation experiments conducted during 1987–1988 (Renard and Simanton 1990); however, additional sampling of vegetation and soils were included.

Twenty-two sites (6 plots per site), from 8 states in the NRST data set were used in this study (Table 1). Summaries of plant composition, soils, hydrology, erosion data, and management history are published in USDA (1998) and Pierson et al. (2002). This study data set represents a total of 396 rainfall simulation runs. The original NRST data set included 2 sites each from Utah and California, but were not used in this analysis because the very-wet run simulations were not conducted. Only natural vegetated plots were used in this study (no artificial soil altering treatments such as rototilling; scalping; or removing vegetation, litter, organic layer, or the O horizon). Site selection by the NRST was based on benchmark soils and rangeland community types. Each site was selected because it represented a major soil type within the selected Major Land Resource Area (MLRA). To insure soil uniformity at each study site, 22 pedons were examined and described morphologically at 7.6 m intervals around the perimeter of the study site to a depth of 0.5 m. Study sites were located on slopes between 3–12%. Five soil pedon descriptions and samples were taken on each site. These plots were chosen to represent dominant and minor soil conditions occurring at the plot level.

The rainfall simulation technology used by the NRST was developed by Swanson (1965). The NRST simulator was trailer-mounted and has ten, 7.6 m booms radiating from a central stem. The arms support 30 V-jet 80100 nozzles positioned at various distances from the stem. Half of the nozzles can be opened or closed by solenoid valves to attain target simulated rainfall intensities of 65 mm/hr (15 nozzles open) or 130 mm/hr (30 nozzles open). Rainfall was simulated uniformly over a 15 m diameter area where two (3.05 x 10.7 m) steel walled plots (long axis parallel to the slope) were located on each side of the simulator. Three rainfall simulation treatment rates were sequentially applied during the growing season: 1) dry antecedent moisture, at an application rate of 65 mm/hr until runoff equilibrium (denoted the dry run); 2) wet antecedent moisture, 24 hours later, at 65 mm/hr until runoff equilibrium (wet run); and 3) very-wet antecedent moisture, 30-min after the end of the wet application at 65 mm/hr (phase 1) until runoff equilibrium, 130 mm/hr (phase 2) until runoff equilibrium, and 65 mm/hr (phase 3) until final runoff equilibrium (very-wet run). Simulator rainfall energy is 77% of natural rainfall when the simulator pressure and rainfall application rate using the V-jet 80100 nozzles are held constant at 65 mm/hr (Simanton et al. 1991). The same pressure in the V-jet 80100 nozzles is used for the very-wet treatment; however, 30 nozzles are used instead of 15. The coefficient of variation of rainfall spatial distribution over the plots is < 10% (Simanton et al. 1987, Weltz et al. 1997). One recording raingage was placed between the paired plots to measure rainfall intensity. Six stationary gauges were also located in each plot to measure total applied rainfall.

Runoff troughs attached to the plot cutoff wall drained into drop-box weirs (Bonta 1998). Runoff water depths through small super critical flumes was measured using a pressure transducer bubbler gauge on each plot. Calibration curves allowed conversion of instantaneous depth to flow rate. Sediment sampling intervals were dependent on hydrograph curve dynamics, with 1–2 minute intervals between samples on the rising and falling portions of the hydrograph. Sediment concentrations were determined by adding a flocculating agent to each sample, and then decanting as much water as possible from the pre-weighed sample bottle, oven dried at 105° and reweighed to the nearest 0.01 g. Observed soil loss (kg/m^2) from the dry, wet, and very-wet rainfall simulation treatments were used in this study. The total sum of these 3 rainfall simulation treatments is denoted as the pooled data set.

USLE and RUSLE Components

Predicted soil loss was calculated via SAS (SAS 1999), by individual plot, from the 6 component factors in USLE and RUSLE. Both models were programmed in SAS to facilitate calculation of soil loss and to perform the analysis in 1 package. The SAS program outputs for the RUSLE component factors were verified using the RUSLE. The energy-times-intensity factor (EI) (Renard et al. 1997) was calculated using the Brown and Foster (1987) unit energy equation for the dry, wet, very-wet rainfall simulation treatments and pooled data. Since the simulator rainfall energy is 77% of natural rainfall, the EI value was adjusted for all simulation runs. The LS for the USLE was determined from Wischmeier and Smith (1978); whereas, the RUSLE was used to calculate LS using percent slope and length of the plot for 1 overland flow element. A support practice value (P) of 1.0 was used throughout this study. Two K factors were alternately

Table 1. Summary of descriptive information for the National Range Study Team sites.

Site, State	Rangeland formation, Cover type, Range site	Soil series, Avg. surface texture for the site, Avg. slope, Soil taxonomic classification	Major Land Resource Area (MLRA)	Annual precip. (cm)	Dominant species % comp. (By wt. descending order)
B1-Nebr.	Tallgrass prairie, Bluestem prairie, Loamy	Burchard, loam, 10% Fine-loamy, mixed, mesic Typic Argiudolls	106, Nebraska and Kansas Loess-Drift Hills	64-86	1-Kentucky bluegrass (*Poa pratensis* L.) 2-Dandelion (*Taraxacum officinale* G.H. Weber ex Wiggers) 3-Alsike clover (*Trifolium hybridum* L.)
B2-Nebr.	Tallgrass prairie, Bluestem prairie, Loamy	Burchard, loam, 11% Fine-loamy, mixed, mesic Typic Argiudolls	106, Nebraska and Kansas Loess-Drift Hills	64-86	1-Primrose (*Primula* spp.) 2-Porcupinegrass [*Hesperostipa spartea* (Trin.) Barkworth] 3-Big bluestem (*Andropogon gerardii* Vitman)
C1-Tex.	Shortgrass prairie, Blue grama-buffalograss, Deep Hardland (25-34)	Olton, loam, 3% Fine, mixed, thermic, Aridic Paleustolls	77, Southern High Plains	41-53	1-Blue grama [*Bouteloua gracilis* (Willd. ex Kunth) Lag. Ex Griffiths] 2-Buffalograss [*Buchloe dactyloides* (Nutt.) Engelm] 3-Prickly pear cactus (*Opuntia polyacantha* Haw.)
C2-Tex.	Shortgrass prairie, Blue grama-buffalograss, Deep Hardland (25-34)	Olton, loam, 2% Fine, mixed, thermic, Aridic Paleustolls	77, Southern High Plains	41-53	1-Blue grama 2-Buffalograss 3-Prickly pear cactus
E1-. Kans.	Tallgrass prairie, Bluestem prairie, Loamy Upland	Martin, silty clay loam, 5% Fine, smectic, mesic, Typic Hapuderts	76, Bluestem Hills	86	1-Annual broomweed [*Amphiachyris dracunculoides* (DC.) Nutt.] 2-Missouri goldenrod (*Solidago missouriensis* Nutt.) 3-Tall dropseed [*Sporobolus compositus* (Poir.) Merr.]
E2-Kans.	Tallgrass prairie, Bluestem prairie, Loamy Upland	Martin, silty clay loam, 5% Fine, smectic, mesic, Typic Hapuderts	76, Bluestem Hills	86	1-Little bluestem [*Schizachyrium scoparium* (Michx.) Nash] 2-Big bluestem 3-Indiangrass [*Sorghastrum nutans* (L.) Nash]
E3-Kans.	Tallgrass prairie, Bluestem prairie, Loamy Upland	Martin, silty clay loam, 3% Fine, smectic, mesic, Typic Hapuderts	76, Bluestem Hills	86	1-Buffalograss 2-Sideoats grama [*Bouteloua curtipendula* (Michx.) Torr.] 3-Little bluestem
F1 Colo.	Northern mixed prairie, Blue grama-buffalograss Loamy Plains	Stoneham, loam, 7% fine-loamy, mixed, mesic, Aridic Haplustalfs	67, Central High Plains	28-39	1-Blue grama-buffalograss, 2-Western wheatgrass [*Pascopyrum smithii* (Rydb.) A. Löve] 3-Buffalograss
F2-Colo.	Northern mixed prairie, Blue grama-buffalograss, Loamy Plains	Stoneham, fine sandy loam, 8% fine-loamy, mixed, mesic, Aridic Haplustalfs	67, Central High Plains	28-39	1-Blue grama 2-Sun sedge [*Carex inops* Bailey ssp. *heliophila* (Mackenzie) Crins] 3-Bottlebrush squirreltail [*Elymus elymoides* (Raf.) Swezey]
F3-Colo.	Northern mixed prairie, Blue grama-buffalograss, Loamy Plains	Stoneham, loam, 7% fine-loamy, mixed, mesic, Aridic Haplustalfs	67, Central High Plains	28-39	1-Buffalograss 2-Blue grama 3-Prickly pear cactus
G1-Wyo.	Northern mixed prairie, Wheatgrass-grama-needlegrass, Loamy	Kishona, vf sandy loam, 7% Fine-loamy, mixed (calcareous), mesic Ustic Torriorthents	60A, Pierre Shale Plains and Badlands	25-36	1-Prickly pear cactus 2-Needle-and-thread [*Hesperostipa comata* (Trin. & Rupr.) Barkworth] 3-Threadleaf sedge (*Carex filifolia* Nutt.)
G2-Wyo.	Northern mixed prairie, Wheatgrass-grama-needlegrass, Loamy	Kishona, clay loam, 8% Fine-loamy, mixed (calcareous), mesic Ustic Torriorthents	60A, Pierre Shale Plains and Badlands	25-36	1-Cheatgrass (*Bromus tectorum* L.) 2-Needle-and-thread 3-Blue grama

Table 1 continued on page xxx.

Table 1. Continued.

Site, State	Rangeland formation, Cover type, Range site	Soil series, Avg. surface texture for the site, Avg. slope, Soil taxonomic classification	Major Land Resource Area (MLRA)	Annual precip.	Dominant species % comp. (By wt. descending order)
				(cm)	
G3-Wyo.	Northern mixed prairie, Wheatgrass-grama-needlegrass, Loamy	Kishona, vf sandy loam, 7% Fine-loamy, mixed (calcareous), mesic Ustic Torriorthents	60A, Pierre Shale Plains and Badlands	25-36	1-Needle-and-thread 2-Threadleaf sedge 3-Blue grama
H1-N.Dak.	Northern mixed prairie, Prairie sandreed-needlegrass, Sandy	Parshall, sandy loam, 12% Coarse-loamy, mixed, Pachic Haploborolls	54, Rolling Soft Shale Plain	38	1-Needle-and-thread 2-Prairie sandreed [*Calamovilfa longifolia* (Hook.) Scribn.] 3-Sedge (*Carex* spp.)
H2-N.Dak.	Northern mixed prairie, Prairie sandreed-needlegrass, Sandy	Parshall, fine sandy loam, 11% Coarse-loamy, mixed, Pachic Haploborolls	54, Rolling Soft Shale Plain	38	1-Clubmoss (*Lycopodium dendroideum* Michx.) 2-Sedge 3-Crocus (*Anemone patens* L.)
H3-N.Dak.	Northern mixed prairie, Prairie sandreed-needlegrass, Sandy	Parshall, sandy loam, 10% Coarse-loamy, mixed, Pachic Haploborolls	54, Rolling Soft Shale Plain	38	1-Sedge 2-Blue grama 3-Clubmoss
I1-Wyo.	Sagebrush steppe, Sagebrush-grass, Loamy	Forkwood, loam, 10% Fine-loamy, mixed mesic Aridic Argiustolls	58B, Northern Rolling High Plains, Southern Part	25-36	1-Wyoming big sagebrush (*Artemisia tridentata* Nutt. ssp.*wyomingensis* Beetle & Young) 2- Prairie junegrass [*Koeleria macrantha* (Ledeb.) J.A. Schultes] 3- Western wheatgrass
I2-Wyo.	Sagebrush steppe, Sagebrush-grass, Loamy	Forkwood, loamy, 7% Fine-loamy, mixed mesic Aridic Argiustolls	58B, Northern Rolling High Plains, Southern Part	25-36	1-Western wheatgrass 2-Bluebunch wheatgrass [*Pseudoroegneria spicata* (Pursh) A. Löve] 3-Prairie junegrass
J1-Id.	Sagebrush steppe, Mountain big sagebrush, Loamy (16-22)	Robin, silt loam, 8% Fine-silty, mixed, Cryic Pachic Paleborolls	13, Eastern Idaho Plateaus	41-56	1-Mountain big sagebrush [*Artemisia tridentata* Nutt. var.*vaseyana* (Rydb.) Boivin] 2-Letterman needlegrass [*Achnatherum lettermanii* (Vasey) Barkworth] 3- Sandberg bluegrass (*Poa secunda* J. Presl)
J2-Id.	Sagebrush steppe, Mountain big sagebrush, Loamy (16-22)	Robin, silt loam, 8% Fine-silty, mixed, Cryic Pachic Paleborolls	13, Eastern Idaho Plateaus	41-56	1-Letterman needlegrass 2-Sandberg bluegrass 3-Prairie junegrass
K1-Ariz.	Shrub steppe-shortgrass Blue grama-galleta, Loamy Upland	Lonti, sandy loam, 5% Fine, mixed, mesic Ustic Haplargids	35, Colorado and Green River Plateaus	30-41	1-Blue grama 2-Goldenweed (*Haploppaus* spp.) 3-Ring muhly [*Muhlenbergia torreyi* (Kunth) A.S. Hitchc. ex Bush]
K2-Ariz.	Shrub steppe, shortgrass Blue grama-galleta, Loamy Upland	Lonti, sandy loam, 4% Fine, mixed, mesic Ustic Haplargids	35, Colorado and Green River Plateaus	30-41	1-Rubber rabbitbrush [*Ericameria nauseosa* (Pallas ex Pursh) Nesom & Baird] 2- Blue grama 3-Threeawn (*Aristida* spp.)

used: the NRCS assigned K value for the soil type (K_{NRCS}), and nomograph K (K_{NOMO}) calculated from the soil-erodibility nomograph equation (Wischmeier and Smith 1978). Data for the nomograph (percent silt, very fine sand, clay, organic matter, soil structure, and profile permeability class) were determined from soil profile descriptions and samples collected at each plot. Complete soil characterization (physical and chemical) was performed by the NRCS National Soil Survey Laboratory in Lincoln, Nebr. Laboratory procedures are given in detail in the Soil Survey Laboratory Methods Manual (USDA-SCS 1992).

The study plot USLE cover management factors (C) were obtained from Table 10 of USDA-Agriculture Handbook No. 537 (Wischmeier and Smith 1978). The RUSLE C factor was calculated using 2 strategies (C_{table} and C_{field}). The RUSLE C_{table} value was obtained by "best fitting" the study plot vegetation type with values given in Tables 5-4 (ratio of effective root mass to annual site production potential, n_i) and 5–6 (soil surface roughness, Ru)(Renard et al. 1997). For example, site B1, plot 1 (tall grass prairie ecotype) is dominated by Kentucky bluegrass (*Poa pratensis* L.), dandelion (*Taraxacum officinale* G.H. Weber ex Wiggers), and alsike clover (*Trifolium hybridum* L.)(Table 1).

The site now represents short sod forming species (the vegetation type most closely represented in RUSLE is the "pasture" designation, since Kentucky bluegrass is an introduced cool season species. Field plot data was used for the other C parameters: percent vegetation canopy cover, rock cover, ground cover, and effective raindrop fall height. The RUSLE C_{field} value is based on using actual field measured values to calculate n_i and R_u. Field plot data (as was C_{table}) was used to parameterize percent vegetation canopy cover, rock cover, ground cover, and effective raindrop fall height.

The RUSLE cover management factors were calculated using the 4 C subfactor equations in Renard et al. (1997). The RUSLE C subfactor calculations were programmed in SAS using the equations cited in Renard et al. (1997) and verified using RUSLE. The 4 subfactors are:1) canopy cover subfactor (CC); 2) surface cover subfactor (SC); 3) surface roughness subfactor (SR); and 4) the prior use subfactor (PLU).

Calculation of the CC subfactor requires the fraction of land surface covered by canopy and the distance that raindrops fall after interception by the plant canopy. Plot canopy cover was determined from 49 pinpoints on 10 separate transects (490 points) horizontally traversing each plot. Canopy cover was determined as the first aerial contact point by plant life form (shrub, half-shrub, forb, grass, cactus, or standing dead). In the RUSLE, effective raindrop fall height is defined as the average fall height of a raindrop which has been intercepted by the canopy. Effective fall height was determined from the dominant plant in each plot.

The SC subfactor was calculated from the percentage ground surface cover, surface roughness, and the empirical coefficient (b), which is the effectiveness of surface cover (rock and residue) in controlling erosion. Renard et al. (1997) gives recommendations for "b" which is dependent on soil type, slope steepness, and land use. A "b" value of 0.035 was used for medium and coarse textured soils with slope ranges of 3–8%. A "b" value of 0.045 was used for shrub communities and for relatively coarse rangeland soils with low annual rainfall. Study plot ground surface measurements were recorded directly after the canopy cover measurement–as the pin was lowered to the surface of the ground, ground surface cover characteristics were recorded (bare soil, litter, vegetative residue, plant basal cover, cryptogams, gravel and rocks). At each pinpoint, R_u was determined by measuring ground surface height above an arbitrary reference line on the point frame. The standard deviation of heights were calculated for each of the 10 transects across the plot, then averaged to determine plot random roughness. Calculation of the SR subfactor also requires the R_u.

The PLU subfactor was calculated using total average annual site production potential, and ni. The PLU factor was calculated using root biomass at 10 cm soil depth from each simulation plot. Root samples were taken as follows: In each plot, after the very-wet run, 6 perpendicular transects were established at 1.5 m intervals starting from the bottom of the plot. Along each of these transects, a point was selected and a single 9.84 cm diameter, 10 cm deep soil core was collected. The above ground biomass was clipped from the core and discarded. The soil core was then divided into a 0-2.5 cm layer and a 2.5-10 cm layer. In shrub communities this sampling procedure was repeated for shrub interspace and shrub coppice areas 25 cm from the base of the shrub. The soil and below ground biomass samples were washed in mesh containers for 40–90 minutes until all mineral soil material was removed, then oven dried at 60° C for 24 hours and weighed. Average annual production was determined by clipping all vegetation by species from five 0.18 m^2 quadrats per simulation plot on grassland sites and five, 0.45 m^2 quadrats in shrub communities. In shrub communities, current years growth was separated from total shrub weight. Vegetation samples were oven-dried at 60° C for 48 hours, then weighed to determine dry weight percentage. Average annual production was calculated via the methodology outlined in the National Range and Pastureland Handbook (USDA-NRCS 1997). When actual production values are not available, Renard et al. (1997) suggest that average annual production estimates can be obtained from NRCS rangeland ecological site descriptions.

Statistical Analysis

Model efficiency R^2eff (Nash and Sutcliffe 1970) was used to evaluate USLE and RUSLE estimated soil loss with field measured soil loss for all study plot simulation runs. Model efficiency was calculated as follows:

$$R^2\text{eff} = \cdot \frac{\sum_{i=1}^{n}(Q_{mi} - Q_{ci})^2}{\sum_{i=1}^{n}(Q_{mi} - Q_m)^2} \quad (2)$$

where R^2eff = the efficiency of the model, Q_{mi} = measured value of event i, Q_{ci} = the RUSLE computed value of event i, and Qm = the mean of the measured values. The R^2eff is the proportion of the initial variance in the measured values which is explained by the model. Initial variance is relative to the mean value of all the measured values. The R^2eff is different than the coefficient of determination (r^2) in that it compares the measured values to a 1:1 line (measured = predicted) rather than to a best-fitted regression line. The R^2eff is always lower than the coefficient of determination (r^2) and a R^2eff value of 1 indicates that the model provided perfect prediction, and R^2eff = 0 indicates that the sum of squares of the difference between the measured and computed values is equal to the sum of squares difference between the measured values and the mean of the measured values. Therefore, the mean value of the measured plot erosion from the data set would be as good a predictor of plot erosion as the RUSLE model. A negative value (can go to -(∞) indicates that Q_m is a better predictor of Q_{mi} than Q_{ci}. The SAS (SAS 1999) system was used to compute the R^2eff. Residual values (measured soil loss $\bar{n}$ USLE or RUSLE predicted soil loss) were calculated and plotted to evaluate systematic patterns and variances of the error terms.

Results

USLE Predicted Soil Loss

Nash-Sutcliffe model efficiencies (R^2eff) were calculated on 132 plots for the dry, wet, very wet rainfall simulation treatments and the pooled data (Table 2). Model efficiency of the USLE (w/K_{NRCS} and K_{NOMO}) was negative for the dry, wet, and very-wet simulation treatments, and the pooled data (Table 2). The negative R^2eff statistic implies that mean measured soil loss for the respective runs is a better representation of soil loss than estimated USLE values. Using the K_{NOMO} value in the USLE calculation did not result in better predictions: the respective R^2eff values were more negative with K_{NOMO} compared to using K_{NRCS}.

Figure 1a plots measured and USLE estimated values of soil loss for the dry, wet, and very wet runs combined (the pooled set). About 61% of the USLE predicted soil loss was higher than the field measured soil loss. Figures 2a,b,c and 3a represent plots of the residual values and predicted USLE (w/K_{NRCS}) for the dry, wet,

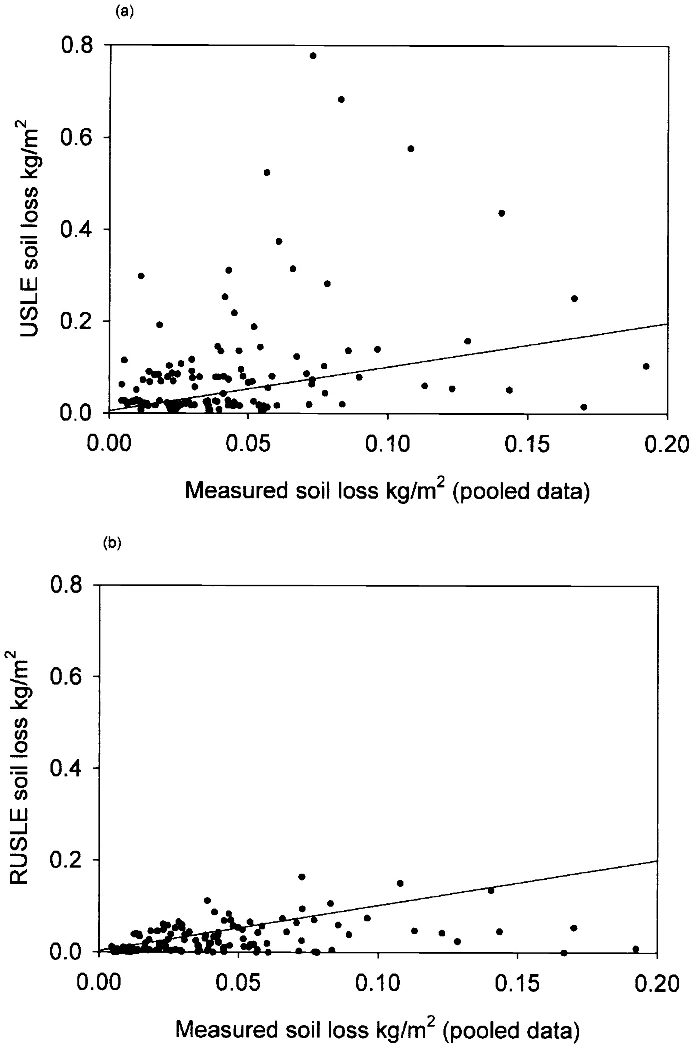


Fig. 1a. Measured soil loss (pooled from dry, wet, and very-wet rainfall simulation treatment runs) and USLE predicted soil loss. 1b) Measured soil loss (pooled) and RUSLE predicted soil loss.

very-wet, and pooled data. The trend of residuals for the 3 simulation treatment runs and the pooled data are consistent: more than half of the error variance is negative (predicted USLE soil loss is higher than measured). Percent negative error variance for the respective simulation treatments were: dry run = 70.5%, wet run = 69%, very-wet run = 55%), and the error becomes increasingly negative as USLE predicted values increase (Figs. 2a,b,c, 3a).

Soil loss was greatest during the very-wet run (0.035 kgm^2), followed by the dry (0.011 kg/m^2) and wet (0.007 kg/m^2) rainfall treatment simulation runs (Table 3). Soil loss from the very-wet simulation run was the most variable (coefficient of variation, CV = 20.0%) compared to the dry (CV = 9.0%) and wet runs (CV = 10.0%). The average of measured soil loss for the pooled data was 0.045 kg/m^2 (Table 3).

The average ratios of measured soil loss to USLE predicted (w/K_{NRCS}) soil loss were 0.38:1, 0.46:1, 0.60:1, 0.48:1 for the dry, wet, very-wet rainfall simulation treatments and pooled data, respectively. These ratios were consistent with the Johnson et al. (1984) sagebrush and shadscale studies and Simanton's et al. (1980) findings on grass-covered watersheds and some brush covered watersheds where runoff events were more numerous and of greater magnitude. In Simanton's study, USLE overpredicted soil loss on grass-covered watersheds [measured (0.015 kg/m^2/yr) vs. USLE predicted (0.033 kg/m^2/yr), a 0.45:1 ratio]. On brush covered watersheds, USLE overpredicted soil loss in years with small runoff events and underpredicted soil loss in years with large runoff events. Wilcox et al. (1989) evaluated the Modified Universal Soil Loss Equation (MUSLE) on Wyoming big sagebrush (*Artemisia tridentata* Nutt. ssp.*wyomingensis* Beetle & Young) sites at the Reynolds Creek Experimental Watershed and observed predicted rates to be 12 and 6 times higher on 2 sites. They attributed the poor predictive capability to the fact that the slope range of the 2 sites were well beyond the range of the data base from which the USLE was designed. However, in this study, slope ranges were within the designated range for USLE (see Table 1).

RUSLE Predicted Soil Loss

Nash-Sutcliffe model efficiency of the RUSLE was negative for the wet, very-wet, and pooled data (Table 2). This implies that mean measured soil loss for the respective runs are a better representation of soil loss than estimated RUSLE

Table 2. Nash Sutcliffe coefficient of model efficiency (R^2eff) for USLE and RUSLE 1.06 estimated soil loss with field measured erosion from 3 rainfall simulation treatments (dry run, wet run, very-wet run, and pooled data).

Model Estimated Erosion	Dry Run	Wet Run	V-wet Run	Pooled[1]
USLE w/ K_{NRCS} [2]	– 8.29	–7.28	–1.06	–12.34
USLE w/ K_{NOMO} [3]	–11.66	–15.43	–1.67	–20.49
RUSLE 1.06 w/ C_{table}, K_{NRCS} [4]	0.16	–0.05	–0.12	–0.33
RUSLE 1.06 w/ C_{table}, K_{NOMO} [5]	0.17	–0.22	–0.14	–0.41
RUSLE 1.06 w/ C_{field}, K_{NRCS} [6]	–0.74	–0.71	–0.07	–1.32
RUSLE 1.06 w/ C_{field}, K_{NOMO} [7]	–1.12	–1.53	–0.16	–2.18

[1]Pooled data is the composite of all three rainfall simulation runs (dry, wet, and very-wet)
[2]Universal soil loss equation with NRCS soil erodibility (K)
[3]Universal soil loss equation with nomograph soil erodibility (K)
[4]RUSLE 1.06 with C subfactor values from Renard et al. 1997 tables (best fit to plot), and NRCS K
[5]RUSLE 1.06 with C subfactor values from Renard et al. 1997 tables (best fit to plot), and nomograph K
[6]RUSLE 1.06 with C subfactor values from field measurements, and NRCS K
[7]RUSLE 1.06 with C subfactor values from field measurements, and nomograph K

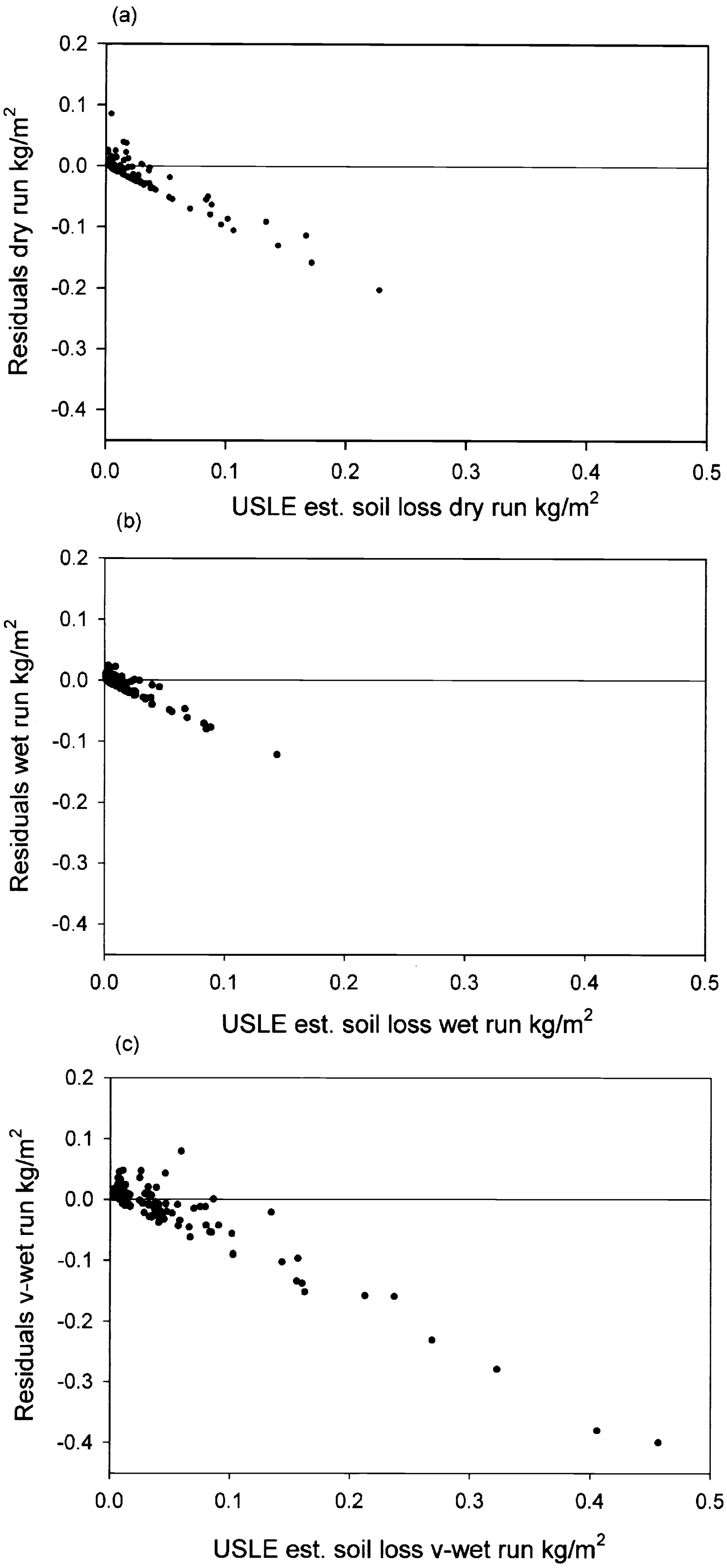


Fig. 2a,b,c. USLE predicted soil loss for the dry, wet, and very-wet rainfall simulation treatments plotted against residual values (measured-predicted soil loss).

soil loss. However, 2, R^2eff values were positive for the dry simulation data. The Nash-Sutcliffe model efficiency of the RUSLE for the dry simulation treatment was 0.16 and 0.17 using the C_{table}, K_{NRCS} and C_{table}, K_{NOMO} factors, respectively (Table 2). The C_{table} calculation used the Renard et al. (1997) table values (5-4, 5-6) for n_i and R_u. The R^2eff inference is that the RUSLE was a marginally better predictor of soil loss; however, when actual field measured values for ni and R_u were used to calculate C_{field}, the dry simulation treatment R^2eff's were negative (Table 2). Similarly, R^2eff for the wet, very-wet, and pooled runs were negative (Table 2).

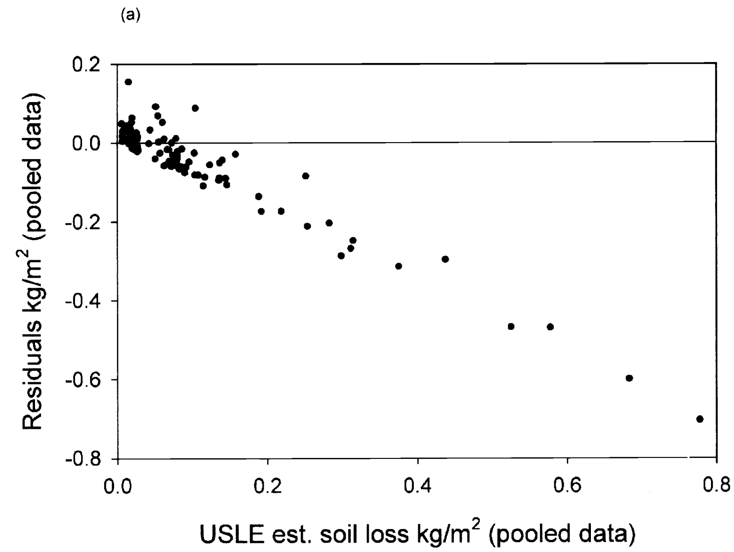
In contrast to the USLE, the RUSLE trend was toward underprediction. The average ratio of measured soil loss to RUSLE (w/C_{table}, K_{NRCS}) predicted soil loss was 1.57:1,1.75:1, and 2.69:1 for the dry, wet, and very-wet run rainfall simulation treatments, respectively. The average ratio of measured vs. RUSLE predicted soil loss for the pooled data was 1.8:1. In Figure 1b (pooled field measured and RUSLE predicted soil loss), about 70% of the points fall below the 1:1 line. In comparing figure 1a and 1b, the USLE had extreme outliers above the 1:1 line; whereas, the RUSLE did not. Figures 3b and 4,a,b,c show a trend of increasing positive residuals for the dry (58.2%), wet (55.7%), very-wet (71.4%) rainfall simulation treatments and the pooled data (69.7%). As soil moisture and rainfall intensity increased (the very-wet simulation treatment), the RUSLE predictions become more erratic. Although the RUSLE tended to underpredict soil loss on more plots than the USLE, the maximum magnitude of positive error variance was about the same for both models (Figs 2a,b,c, and 4a,b,c). For both the USLE and RUSLE, positive error variances never exceeded 0.13 kg/m^2 for the dry, wet, and very-wet rainfall simulation treatments. For the pooled data, positive error variance did not exceed 0.20 kg/m^2 for both models (Figs. 3a,b).

On plots where the RULSE overpredicted soil loss, the trend, much like the USLE, showed increasing negative error variance (Figs. 3b, 4a,b,c). As soil moisture and rainfall intensity increased (the very-wet simulation treatment), the RUSLE negative error variance was the greatest. Although the USLE and RULSE displayed similar linear patterns of negative error variance, the magnitude of error was less for the RUSLE. On the very-wet simulation plots, the USLE negative error variance reached –0.40 kg/m^2; whereas, the RUSLE error never exceeded –0.06 kg/m^2.

Discussion and Conclusions

In this study we evaluated the USLE and RUSLE soil loss predictive capability with a rangeland data set that included a diverse cross section of rangeland plant communities. The overall R^2eff of the USLE and RUSLE using the 3 rainfall simulation treatments was negative, except for the RUSLE prediction with the dry run data (Table 2). The negative R^2eff indicates that the use of model predictions is worse than using mean measured soil loss from the field. Distribution of error variances (measured soil loss-USLE predicted soil loss) for the 3 rainfall simulation treatments showed a consistent trend of overprediction by USLE. Conversely, the RUSLE error variances showed a consistent trend of underpredicted soil loss among the 3 rainfall simulation treatments. As the soils on the rangeland sites became more saturated, the propensity for underprediction increased. In comparison to the USLE, the RUSLE had less error variance between field measured soil loss and RUSLE predicted soil loss.

Nearing (1998) states that an inherent phenomenon of erosion models is that they "tend to overpredict soil erosion for small measured values, and underpredict soil erosion for larger measured values. This trend appears to be consistent regardless of whether the soil erosion value of interest is for individual storms, annual totals, or average annual soil losses, and regardless of whether the model is empirical or physically based." Nearing's hypothesis is related to the inherent random components from field measurements that are not accounted for in erosion models. In studying the overall predictive nature of the USLE on rangeland using the NRST rangeland data, it appears that the USLE overestimated plots with low erosion rates. This trend was consistent for the dry, wet, and very-wet rainfall simulation treatments. On plots with higher intense rainfall (130 mm/hr very-wet run) and higher soil loss rates, the USLE also tended to overpredict soil loss. In summary, the prediction capability of the USLE on rangeland fit Nearing' s premise for the small measured values and for the 2 highest measured values (Fig. 1a.). The RUSLE results also tended to fit Nearing's premise on rangeland: overprediction of soil loss for the lowest measured values (dry, wet, and very-wet simulation treatments) and underprediction as observed soil loss rates increased.



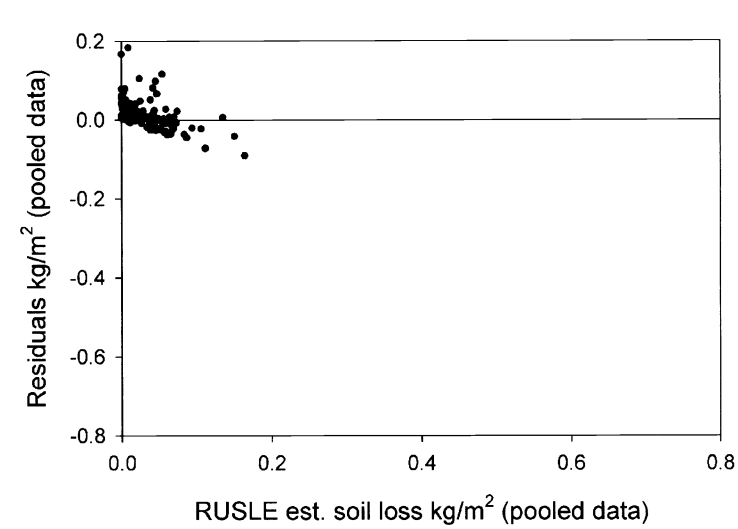


Fig. 3a. USLE predicted soil loss (pooled from the dry, wet, and very-wet rainfall simulation treatments) plotted against residual values (measured-predicted soil loss). Figure 3b. RUSLE predicted soil loss (pooled from the dry, wet, and very-wet rainfall simulation treatments) plotted against residual values (measured-predicted soil loss).

We realize that there is uncertainty associated with hydrologic and erosion predictions (Beven 1987) on rangeland because the interacting plant and soil variables affecting hydrology and erosion on rangeland are very complex (Gifford 1985, Thurow 1991). In addition, we recognize the difficulty of predicting relatively low amounts soil loss on relatively undisturbed rangeland sites (< 0.5 t/ha). In Renard and Simanton's (1990) study, their correlations of observed and RUSLE predicted soil loss only improved when the highly disturbed plots were added to the data set. Other rangeland hydrology studies have measured low soil loss rates on rangeland—even with substantial rainfall application rates. Hawkins (1985) states that rainstorm runoff and erosion on western rangelands and forestlands is rare, even with substantial overall precipitation input. Rangeland soil loss on natural plots (Blackburn and Skau 1974, Hart 1984, Buckhouse and Mattison 1980, Blackburn et al. 1990, Spaeth 1990); grazed plots (Gamougoun et al. 1984, McGinty et al.

Table 3. Summary of average measured soil loss, USLE, and RUSLE predicted soil loss with residual values.

Model Estimated Erosion	Dry Run	Wet Run	V-wet Run	Pooled[1]
	------------------- (kg/m^2) -------------------			
Avg. measured soil loss	0.011	0.007	0.035	0.045
USLE w/w/ K_{NRCS} [2]	0.029	0.015	0.056	0.093
Residual [3]	-0.018	-0.008	-0.021	-0.048
USLE w/K_{NOMO} [4]	0.030	0.016	0.058	0.10
Residual	-0.019	-0.009	-0.023	-0.055
RUSLE w/Ctable, K_{NRCS} [5]	0.007	0.004	0.013	0.025
Residual	0.004	0.003	0.02	0.02
RUSLE w/Ctable, K_{NOMO} [6]	0.007	0.007	0.013	0.024
Residual	0.004	0.0	0.02	0.021
RUSLE w/Cfield, K_{NRCS} [7]	0.003	0.003	0.007	0.005
Residual	0.008	0.004	0.028	0.04
RUSLE w/Cfield, K_{NOMO} [8]	0.005	0.005	0.009	0.012
Residual	0.006	0.002	0.026	0.03

[1]Pooled data is the composite of all 3 rainfall simulation runs (dry, wet, and very-wet)
[2]Universal soil loss equation with NRCS soil erodibility (K)
[3]Residual = averaged measured soil loss—model predicted soil loss.
[4]Universal soil loss equation with nomograph soil erodibility (K)
[5]RUSLE 1.06 with C subfactor values from Renard et al. 1997 tables (best fit to plot), and NRCS K
[6]RUSLE 1.06 with C subfactor values from Renard et al. 1997 tables (best fit to plot), and nomograph K
[7]RUSLE 1.06 with C subfactor values from field measurements, and NRCS K
[8]RUSLE 1.06 with C subfactor values from field measurements, and nomograph K

1979, Wood and Blackburn 1981, Warren et al. 1986); burned plots (Pierson et al. 2001); and on the watershed scale (Simanton et al. 1977, Wilcox et al. 1989) are relatively low compared to cropland (Risse et al.1993).

An important philosophical issue regarding the practical use of erosion models needs to be clarified: e.g., why attempt to model long-term average soil loss rates on rangeland (the literature shows relatively low rates on rangeland) and what is the value of this information to programs, monitoring, and resource assessments. In reality, it is the rare or unexpected storm event(s) that may cause instability in rangeland ecosystem functionality, which can compromise soil stability and hydrologic function. Resource managers should consider the probability or frequency of these types of events in conjunction with current rangeland conditions and various combinations of management. Improper management often exacerbates the destructive capacity of these rare events. In many cases, as rangeland deterioration progresses and some critical threshold has been crossed, rangeland ecosystem function can be acutely compromised (Satterlund 1972, Heede 1979, National Research Council 1994, de Soyza et al. 2000a, 2000b, Pellant et al. 2000).

There are technical and philosophical issues that relate to hydrology and erosion prediction models on rangeland. One important technical issue is the identification and integration of inherent component variables that relate to erosion and hydrology and how these variables are treated and modeled mathematically (Hanson et al. 1999). It is important that efforts be made to explore and include variables in models that help minimize the random components (the latent variables) of measured erosion that Nearing (1998) speaks about. This will require a different paradigm in modeling (Spaeth et al. 1996 a, 1996b, Pierson et al. 2002). The answer may lie in using exogenous variables which may account for latent variables that are difficult or cannot be readily identified. For example, many hydrology and erosion models commonly utilize readily measurable plant related variables such as plant cover, biomass, litter cover and amount, plant height, root biomass, and soil related variables such as bulk density, aggregate stability, porosity, organic carbon, and particle size. Spaeth et al. (1996 a,b) used ordination and gradient analysis (Gauch 1982) procedures to identify multivariate relationships between individual plants, groups of plants, soil variables and hydrologic data. A more ecological approach in recognizing plant community and soil components, both on the quantitative and qualitative level can significantly improve infiltration equations on rangeland (Spaeth et al 1996a,1996b). Individual plant species also have a profound affect on hydrology (Thomas and Young 1954, Mazurak and Conrad 1959, Dee et al. 1966, Spaeth 1990, Gutierrez-Castillo 1994); the presence of a particular plant species may represent unidentifiable latent variables (Spaeth et al. 1996a, 1996b).

Categorical or qualitative variables such as soil diagnostic features (argillic, salic, mollic . . . slickensides, duripans, fragipans); soil structural grades (weak . . . strong); structure size (coarse . . . very thin); dry and wet consistence (hard . . . very friable); soil boundary distinctness (abrupt . . . gradual); boundary topography (broken . . . wavy); structure size classes (angular blocky . . . single grain); rupture resistance concepts; cementation and agents; stickiness; soil plasticity; ped surface features (black stains . . . oxide coats); pore shape and size classes; concentration kind, (clay bodies, worm casts . . . carbonate nodules); concentration shape, size, location, hardiness, and origin; soil mottles (size, class, contrast, shape, location); soil texture modifiers; soil particle coatings (organic coats . . . clay films); rock fragments (kind, roundness, size); root pans; type of biological soil crusts (lichen, moss, algae etc); soil mineral crusts; root morphology (size, class, depth, location); plant life forms (grasses . . . shrubs); plant growth forms (sod forming, caespitose); plant distribution and patterns; plant and leaf architecture; and individual plant species or combinations of certain species should be considered in rangeland erosion and hydrology models. These variables can help explicate the soil-plant interactive environment and reduce unidentifiable error in empirical, statistical, and process bases models.

On rangeland, no uniform set of management guidelines fits all rangeland plant community types (Hanson et al. 1999). Resource managers are faced with synthesizing an overwhelming amount of ecological, soils, hydrology, and range management information (Spaeth et al. 2001). For this reason, rangeland resource tools that can model hydrology (infiltration, runoff, evaporation, transpiration, deep percolation, and water storage), soil loss, and soil deposition changes in response to management alternatives are greatly needed (Hanson et al. 1999). Rangeland managers would benefit greatly if a "user friendly" WEBB based rangeland hydrology and erosion decision support tool were avail-

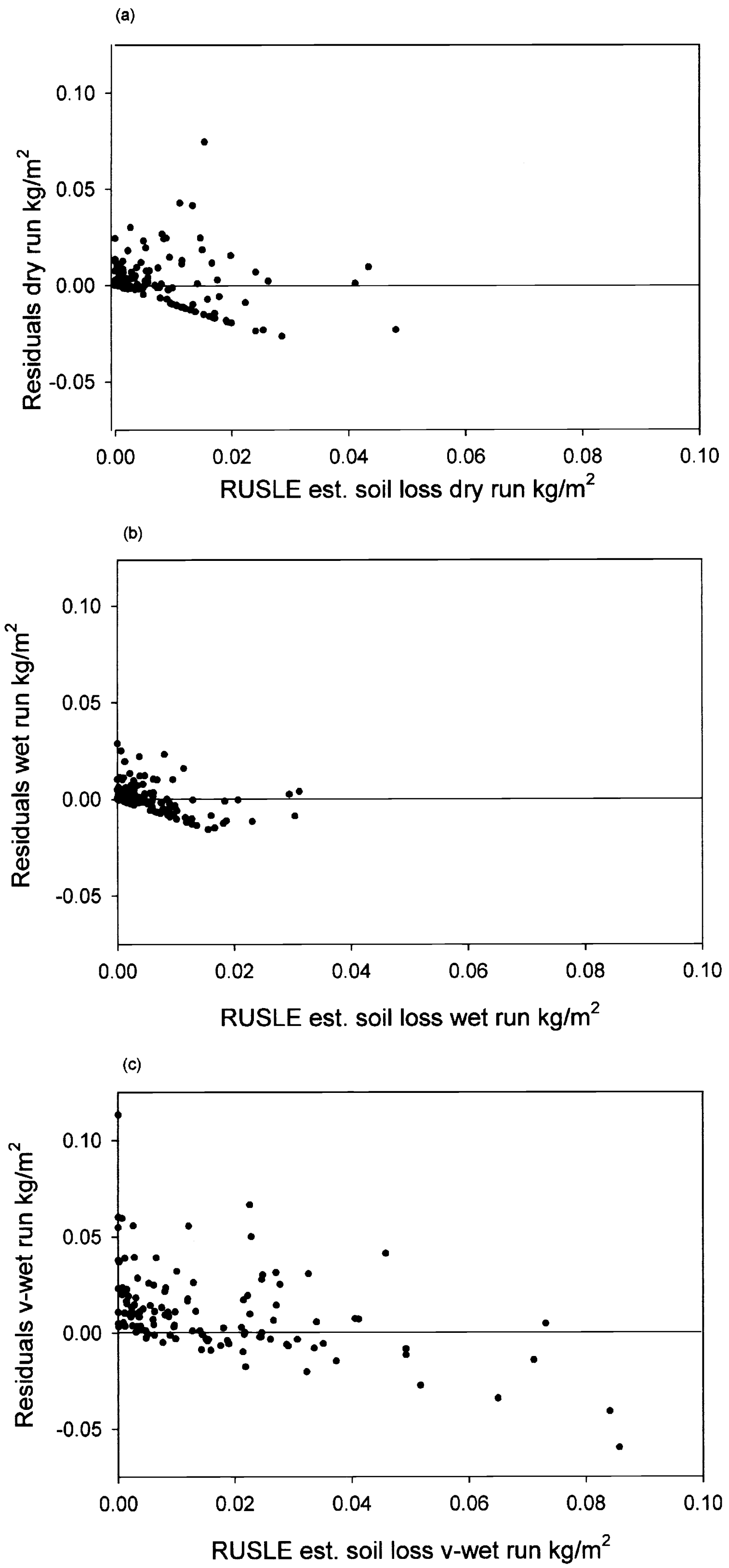


Fig. 4a,b,c. RUSLE predicted soil loss for the dry, wet, and very-wet rainfall simulation treatments plotted against residual values (measured-predicted soil loss).

able that overcomes the limitations of USLE and RUSLE 1.06 and is more plant species sensitive, rather than the only option being, identifying the site on a vegetation type basis. Such a tool should include outputs about the entire water budget or for selected parameters, individual storms, long-term climate (monthly-yearly), rare climatic events, and hydrologic responses to management alternatives. Meanwhile, several U.S. land management and resource agencies have begun training and use the Rangeland Health Model to qualitatively assess 3 attributes: hydrologic function, soil surface stability, and biotic integrity. Through proper training and use of the Rangeland Health tool, the 3 attributes can help identify change in rangeland ecosystems. This tool will most likely be used until an ecological based quantitative hydrologic and erosion model is available.

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