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ESTRATEGIAS DE CLASIFICACION Y MANEJO DE VEGETACION SILVESTRE PARA LA PRODUCCION DE ALIMENTOS EN ZONAS ARIDAS

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Revised Universal Soil Loss Equation for Western Rangelands[1]

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Abstract.--The Universal Soil Loss Equation has been revised to accommodate field conditions found throughout the western United States. The revision uses a subfactor approach to evaluate the "C" factor and additional algorithms to describe the "LS" and "P" factors. The revised "C" factor is now the product of subfactors: PLU (prior land use), CC (vegetation canopy cover), SC (surface ground cover), and SR (surface roughness). Included in these subfactors are conditions for vegetation canopy height and root biomass. Algorithms for "LS" consider non-linear interactions between slope steepness and length. The algorithms for "P" are based on surface roughness, slope steepness, and runoff reduction.

A procedure is presented for estimating, from above ground biomass, the root biomass in the upper 100 mm of the soil profile of various rangeland vegetation types. A sensitivity analysis of the root biomass input to the subfactors PLU and SR is presented to illustrate the importance of root biomass to erosion from rangelands.

Rangeland soil loss estimates are made from a wide range of assumed factor values using the old and revised USLE. Also, each equation is used to estimate soil loss and the results are compared to actual soil loss measurements from simulated rainfall plots.

INTRODUCTION

Surface soils of much of the western rangeland areas of the U.S. have been badly eroded. From the viewpoint of a soil morphologist, such soils are only partly weathered parent geologic material. Climatic and agronomic conditions which might lead to soil formation like that encountered in cultivated agricultural areas are unfavorable or at best, soil building occurs at a reduced rate. When unprotected, the most fertile A-horizon is rapidly removed by erosion under the sparse vegetation found on such deteriorated areas. Thus, preservation of rangeland soil resources is a high priority need to the conservationist/environmentalist and, from the viewpoint of the rancher trying to maximize forage production, soil protection is critical if plants are to have a sufficient nutrient and soil moisture reservoir for growth.

The severity of rangeland erosion problems has been illustrated with published work from Langbein and Schumm (1958) and Marshall (1973). Figure 1 illustrates in a conceptual way the water and wind erosion problem as a function of annual precipitation.

Sediment yield and erosion are closely related phenomenon although yield reflects the transport efficiency of not only the upland erosion processes but also that occurring in the channels of a watershed. Sediment yield also includes deposition of eroded materials in natural and man-made features *such as terraces* and ponds/reservoirs. Curve A shows that, under natural vegetation cover, water erosion increases from the origin to a peak at 400 mm annual rainfall, such as that in semiarid conditions. Near

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the peak (approximately at the transition between brush and grasslands) the precipitation is insufficient to maintain a complete year long vegetation cover but does produce sufficient energy and rainfall excess to erode bare soils. With increasing precipitation, the natural vegetation cover increases (less bare soil would be expected) and water erosion decreases. Curve B indicates expected erosion under bare soil conditions. Comparison of curves A and B illustrates conceptually the difficulty of controlling water erosion in the arid and semiarid end of the precipitation spectrum, a phenomenon not extending into the more humid spectrum.

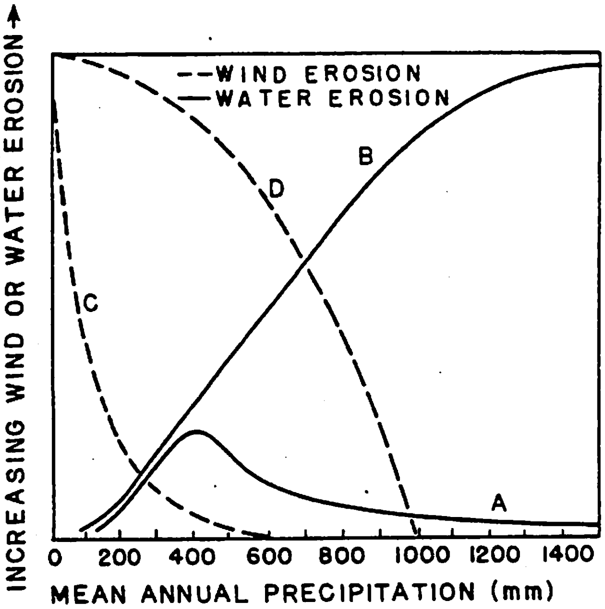

Figure 1. Relationships of water erosion (continuous lines) and wind erosion (broken lines) with increasing mean annual precipitation. The curves for water erosion indicate the relationships with mean annual precipitation for (A) areas of natural vegetation cover and (B) bare ground. The curves for wind erosion indicate the relationships with mean annual precipitation for (C) areas of natural vegetation cover and (D) bare ground. These curves are based on what would be expected from the relationship of wind erosion to vegetation cover and to moist soil (from Marshall 1973).

The schematic curves for wind erosion, curves C and D, differ appreciably from those for water erosion. Curve C depicts a rapid decrease in the normal wind erosion with increasing precipitation because the presence of even a moderately sparse vegetation cover would be expected to reduce the wind erosion shear at the ground surface. With the absence of vegetation (curve D), wind erosion would be expected to remain high until the precipitation increases sufficiently to keep the soil surface moist most of the time. The shape of curve D depends upon the amount of precipitation and its distribution and the curve would be expected to drop most steeply for a uniform distribution or a distribution where the moist soil coincides with periods of greatest wind. In contrast with water erosion, the greatest potential reduction of wind erosion (contrasting curves C and D) occurs in the drier precipitation areas.

In this paper, we intend to (1) present a proposed revised form for the Universal Soil Loss Equation (USLE, Wischmeier and Smith, 1978); (2) illustrate how the revised form agrees with observed data in southeastern Arizona; and (3) illustrate with sensitivity analysis, the magnitude of erosion estimates by sequentially varying values of parameter terms in the subfactor approach for estimating the cover-management term.

REVISED USLE

Technology to assess erosion from rangelands is not as widely available as for cultivated agriculture. The technology generally involves the use of the USLE which was developed for more humid areas and then extrapolated to rangeland conditions. Developed from extensive field experiments, the USLE involves six terms, the product of which furnishes an estimate of the average annual erosion from a field area. The expression is

$$A = R * K * L * S * C * P \quad (1)$$

where A = computed soil loss per unit area; R = a rainfall and runoff factor; K = soil erodibility factor; L & S = topographic terms representing slope length and steepness; C = cover-management factor; and P = support practice factor.

Unfortunately, this technology was developed from experiments performed on cultivated areas; although the technology has been extended to most other land use conditions (Renard and Foster, 1985). In the current revision of the USLE, perhaps the most significant change occurs in the method used to determine a value of the cover-management factor, C. A subfactor approach is used, as proposed by Wischmeier, 1975, Mutchler et al., 1982 and Laflen et al., 1985. The factor C is expressed as

$$C = PLU * CC * SC * SR \quad (2)$$

where PLU is a prior land use subfactor, CC is a canopy subfactor, SC is a surface cover subfactor and SR is a surface roughness subfactor. Each of these subfactors in turn is also expressed by an equation so that a value can be computed for any specific situation. The equations contain the variables recognized to greatly influence erosion and vary according to land use and management practices.

The individual subfactor values presently proposed for rangeland are as follows:

$$PLU = (1-DY) * \exp(-0.012 * RS) \quad (3)$$

where $D = \frac{0.55}{T}$ and T is the total years over which a soil disturbance diminishes, Y is the years since disturbance, exp is an expression for the base of the natural logarithm (2.718) raised to the power of the number following, and RS is the live roots and buried residue in the upper 100 mm of soil (kg per ha per mm of depth). When Y = T, the coefficient decreases to 0.45 which is the value of the soil loss ratio observed for a well consolidated soil. RS is not easily measured without destructive sampling and considerable manpower. Therefore, Equation 4 was developed so that RS could be estimated from above-ground biomass estimates.

$$RS = BIO * \eta_i * \alpha_i/100 \quad (4)$$

where BIO is the annual above ground biomass estimate (kg per ha), α_i is the ratio of below ground biomass to above ground biomass and η_i is the ratio of biomass in the upper 100 mm of soil to the total below ground biomass. Table 1 has been prepared for reported typical values of η_i and α_i by vegetation type (e.g. grass, brush, tree, etc.) which more or less corresponds to climatic region.

$$CC = 1 - FC * \exp(-0.34 * H) \quad (5)$$

where FC is the fraction of the land surface beneath canopy and H is the height (m) that raindrops fall after impacting the canopy.

$$SC = \exp(-4.0 * M) \quad (6)$$

where M is the fraction of the surface covered by nonerodible material (e.g. living and dead plant material, rock and large gravel). This factor is extremely important, especially where erosion pavement, cryptogams, or other nonerodible material protects bare soil from the erosive forces of raindrops or flowing water or both.

$$SR = \exp(-.026(RB-6)(1-\exp[-.035 * RS])) \quad (7)$$

where RB is a random roughness (mm) expressed as the standard deviation of surface elevations from a plane and is intended to reflect any tillage consequence or other roughness forms. These solutions for the equations presented herein as well as those for the other factors have been programmed for speedy solution in a user friendly way on a personal computer.

The soil erodibility value, K, as presented in the nomograph in Agriculture Handbook 537 will be left unchanged.

Other factors in the USLE have also been changed. For example, the R-factor data base which in Agriculture Handbook 537 (Wischmeier and Smith, 1978), was so inadequate for the western U.S., will be expanded to include about 1000 hourly precipitation stations. The R-factor analysis includes using site specific and

Table 1.--Mean values of η_i and α_i for use in calculating the root subfactor (RS) in the universal soil loss equation.

	η_i		α_i	
Vegetation type	Best Estimate	Range	Best Estimate	Range
Northern mixed prairie	0.34	0.219-0.770	1.12	0.636-119.610
Tallgrass prairie	0.74	0.730-0.753	2.08	0.230- 2.080
Shortgrass prairie	0.41	0.244-0.645	3.18	1.12- 10.465
Desert grasslands	0.38	0.364-0.394	2.28	1.976- 2.804
Lehmann lovegrass	0.63	0.320-0.626	2.73	2.500- 3.126
Annual grasslands	NA[1]	NA	NA	NA
Southeastern grasses and forbs	0.40	0.228-0.667	0.69	0.402- 1.520
Pinyon-Juniper	0.20	0.039-0.276	NA	NA
Sagebrush-bunchgrass	0.38	0.353-0.413	28.8	27.270- 29.600
Herbaceous interspaces	0.45	0.413-0.451	27.3	7.850- 27.266
Cold desert shrubs	0.46	NA	5.87	4.090- 11.000
Chaparral	0.13[2]	0.085-0.300	1.37	0.300- 1.900
Sandy shinnery oak	0.38	0.205-0.697	18.6	3.445- 18.589
Herbaceous interspaces	0.70	NA	5.48	NA
Southern desert shrubs	0.56	0.200-1.720	1.23	0.200- 18.35

[1]Data are not available.
[2]Root crowns and burls were excluded from root biomass calculations.

regionally developed correction factors. This approach adjusts hourly precipitation values to the EI_{30} that would be obtained from a recording gage with an expanded time scale similar to that used by Wischmeier and Smith in their original work (also called variable time digitization). The new isoerodent map for the western U.S. will have greater detail than that used heretofore. The correction for the approach on the Walnut Gulch Experimental Watershed in southeastern Arizona is:

$$EI_{30}(BP) = 0.215 + 1.956\ EI_{30}(60) \qquad (8)$$

$$r^2 = 0.95,\ S.E.E. = 2.42$$

where $EI_{30}(BP)$ = kinetic energy x 30 min. maximum depth of rainfall based on a breakpoint hyetograph and $EI_{30}(60)$ = kinetic energy x 30 min. maximum depth of rainfall based on the record from an hourly recording.

Slope length and steepness (LS) for rangeland has been investigated extensively by McCool and Foster (personal communication) using research models and new field data. The nonlinear LS versus erosion relationship presented in Agriculture Handbook 537 (Equation 9) will be replaced with tables/algorithms (Equations 10, 11, and 12) for rangelands (and other land uses) reflecting the estimated intensity of rill to interrill erosion and the presence of erosion associated with thawing soil. Slope length and steepness were given in the original Handbook 537 as:

$$LS = \left(\frac{\lambda}{72.6}\right)^m (65.41 \sin^2\theta + 4.56 \sin\theta + 0.065) \qquad (9)$$

where λ = slope length in feet;

θ = angle of slope; and

m = 0.5 if percent slope is 5 or more, 0.4 slopes of 3.5 to 4.5 percent, 0.3 on slopes of 1 to 3 percent, and 0.2 on uniform slopes of less than 1 percent.

The term of Equation 9 is now replaced with:

$$LS_R = \left(\frac{\lambda}{72.6}\right)^m (10.0 \sin\theta + 0.027) \quad S \le 8\% \qquad (10)$$

$$LS_R = \left(\frac{\lambda}{72.6}\right)^m (17.2 \sin\theta - 0.55) \quad S \ge 8\% \qquad (11)$$

where LS_R = revised topographic factor, and

λ = horizontal projection of a slope

s = slope in percent

The slope lengths exponent m is related to the ratio β of rill erosion (caused by shear of flow) to interrill erosion (caused primarily by raindrop impact), by the equation (Foster, et al., 1977):

$$m = \beta/(1+\beta)$$

Values of the ratio β are obtained from (McCool et al., 1985; unpublished material):

$$\beta = \left[\frac{E(r/i)(\sin\theta/0.0896)}{(2.96 \sin^{0.79}\theta + 0.56)}\right] \qquad (12)$$

where $\sin\theta$ = slope angle

E(r/i) = ratio of rill to interrill erosion; use 1 when the soil is moderately susceptible to rill erosion relative to interrill erosion; use 0.5 when the rill erosion is slight relative to interrill erosion; and use 2 when rill erosion is high relative to interrill erosion.

Finally, the supporting practices factor, P, has never been adapted specifically to mechanical rangeland conservation practices like ripping, root plowing, contouring and chaining. These practices affect wind and water erosion in several ways, most importantly by removal (usually temporarily) of surface cover. That effect is and should be considered in the cover-management factor. The mechanical practice effects on the P-factor involve the rate, amount and direction of runoff as well as the hydraulic forces that the flowing water exerts on soil. A table of P-factor values for five common mechanical practices used on rangelands, was developed by incorporating an estimate of the surface disturbance, duration of effectiveness of the disturbance and the runoff reduction into a physically based simulation model, CREAMS (Knisel, 1980). Simulations were performed for different slope steepness with the result that the table 2 values were adjusted internally in the computer program to reflect the slope steepness differences used in the program. Furthermore, 15 different scenarios for mechanical practices which alter roughness and runoff and are dependent on slope steepness are included in the computer program. This work was not used in the subsequent testing reported in this paper.

Table 2. Erosion Control Practice Values for Rangeland

Practice	P-Factor
Contour (1-16% slope)	0.60
Contour (17-25% slope)	0.85
Terraces (sod channel outlets)	0.14
Terraces (underground outlets)	0.05
Rootplow on countours	0.13
No practice	1.00

DATA BASE

The Agricultural Research Service of the U.S. Department of Agriculture maintains the 150 square kilometer Walnut Gulch Experimental Watershed in and around Tombstone, Arizona (fig. 2). The watershed is representative of millions of hectares of brush and grass rangeland found throughout the semiarid Southwest. Major vegetation on the watershed includes creosote bush (Larrea divaricata), whitethorn (Acacia constricta, tarbush (Flourensia cernua), black grama (Bouteloua eriopoda), blue grama (Bouteloua gracillas), tobosagrass (Hilaria mutica), and bush muhly (Muhlenbergia porteri). Typically, plant canopy averages 50 percent and plant basal area averages 2 percent. Average annual precipitation on the watershed is about 300 mm, and is bimodally distributed, with approximately 70 percent occurring during the summer thunderstorm season of July through September when essentially all of the runoff occurs. General watershed characteristics and results of the research programs were described by Renard (1970, 1977).

Erosion data have been collected on the Walnut Gulch Watershed using a rotating boom (Swanson, 1965) rainfall simulator (Simanton and Renard, 1982 and 1986).

The soils at the three simulator sites have been reclassified and new series descriptions are being prepared by the USDA Soil Conservation Service. The old Cave, Hathaway, and Bernardino soil series (Gelderman, 1970) have been proposed in the new soil survey as the Bactor (loamy-skeletal, mixed, thermic Ustollic Calciorthid), Stronghold (coarse-loamy, mixed, thermic Ustollic Calciorthid), and Abrigo (fine-loamy, mixed, thermic Ustollic Hapargid) series, respectively. Slopes on the rainfall simulation plots ranged from 9-11%, 10-12%, and 10-12% for the Bactor gravelly loam, Stronghold gravelly sandy clay loam, and the Abrigo very gravelly sandy loam series, respectively. The ground surface cover of all three sites is dominated by erosion pavement (rock and gravel typically occupy 40-60% of the soil surface).

At each simulator site, three surface conditions were evaluated: natural plots; plots wherein the vegetation was clipped at the plot surface and removed; and bare plots where the vegetation was clipped and the erosion pavement along with all litter removed. Furthermore, the simulation sequence involved an application of one hour at a rate of approximately 60 mm on day one followed by a 1/2 hour application 24 hours after the first run and a second 1/2 hour 60 mm/hr application about a half hour after the second run. Thus, the three simulation periods are called dry, wet and very wet runs indicative of antecedent soil moisture conditions. The simulations were also continued in the spring and fall over a four-year period (Simanton and Renard 1986). Differences in the temporal characteristics of erosion and runoff were appreciable for the treatments of clipping, bare and natural plots for all three soil sites although the trends were not consistent across the soil types (Simanton and Renard, 1986).

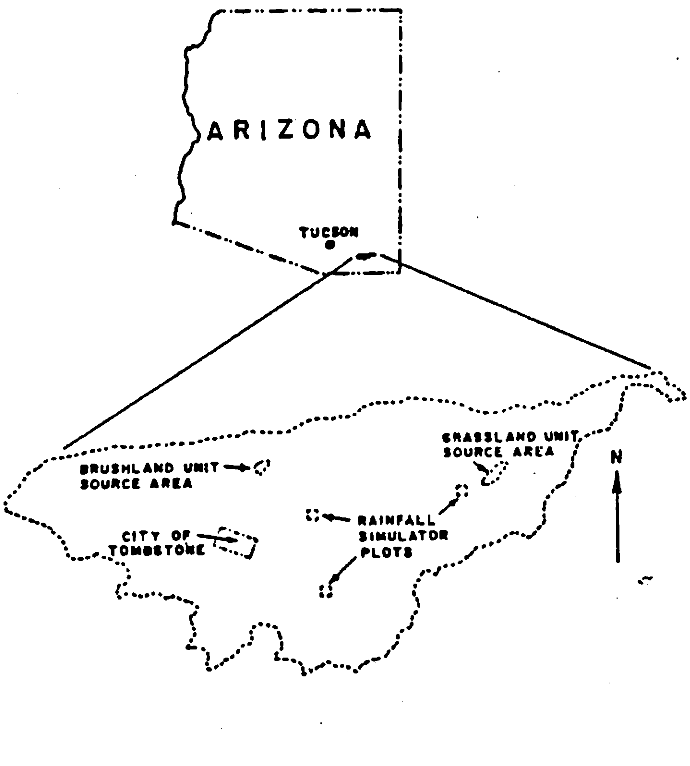

Figure 2. Location map showing the rainfall simulator plots in the Walnut Gulch Experimental Watershed.

CORRELATION OF PREDICTED AND OBSERVED SOIL LOSS

Some of the data from Walnut Gulch contained in Appendix A (Simanton et al., 1986) of the Proceedings of the Rainfall Simulator Workshop, January 1985, Tucson, Arizona, were used as input to predict erosion with the proposed revision of the USLE as well as with the procedure outlined in Agriculture Handbook 537. To facilitate the computations, a computer program was written which permitted easy computations for the algorithms expressed in Equations 1 to 7 and Equations 10 to 12. The program is available upon request to the authors.

Because the erosion was much larger from the bare plots and because the vegetation and erosion pavement removal disturbed the soil surface of these plots, special care was made to account for differences between the predicted and observed bare plot soil loss. The effort involved evaluation of the coefficient of the exponential decay in the PLU (prior land use) term in the subfactor approach (equation 3). Observation of the data previously reported by Simanton and Renard (1986) showed that the disturbance lasted about 2 1/2 years. Thus the D term was assigned a value of 0.22 and the predictions made accordingly. The plot was kept free of vegetation by chemical control and only minimal disturbance occurred subsequently with rock removal.

Total root biomass measured near the site was 15,000 lbs/ac (Cox et al. 1986). The near surface fibrous root mass was 2,800 lbs/ac. Root crowns and deeper (> 4 in) large lateral roots comprised 81% of the total root mass. These deep roots contribute little to the stability of the soil surface and have no effect on surface erosion from raindrop impact and overland flow. Therefore, the near surface fibrous root mass value of 2,800 lbs/ac was used to initialize the RS subfactor for the first rainfall simulation runs on all three treatments. On the bare plots RS was reduced to 1,400 lbs/ac after 6 mo., 700 lbs/ac at the end of 1 year, and to 0 lbs/ac for the remainder of the study. On the clipped plots, the root mass was assumed to be 1,400 lbs/ac after the first year.

Table 3 lists regressions of predicted versus observed erosion for six different groupings of the simulator plot data. Data groupings #2 and 5 were made because of some questionable data on plot 4 in the spring of 1982.

In each instance, the slope of the line was less than unity indicating that the predicted values of soil loss (Handbook 537 procedure and proposed revised USLE) were less than the measured values. Comparison of data groups 3 and 6 showed that the new USLE which includes the subfactor approach to determining C and the new algorithms for the LS-factor give better estimates of soil loss than does Handbook 537. The new method also did not overpredict as often as did the Handbook 537 procedure for smaller soil loss conditions such as were obtained for the natural and clipped plots.

Table 3. Regression Analysis $Y = a(OBS_{SL})$ for Predicted vs. Observed Soil Loss

Group No.	Data	N	a	r^2
		Prediction with Handbook 537		
1	bare plots 1981, 82, 83, 84	96	0.586	0.389
2	#1 w/o spring 1982 on plot 4	94	0.643	0.529
3	#2 plus clipped & natural 1982 & 84	190	0.659	0.699
		Prediction with Revised USLE		
4	bare plots 1981, 82, 83, 84	96	0.712	0.348
5	#4 w/o spring 82 on plot 4	94	0.772	0.517
6	#5 plus clipped & natural, 1982 & 1984	190	0.768	0.766

SENSITIVITY ANALYSIS

To illustrate the sensitivity of the subfactor values, the individual parameter values RS, FC, H, M and RB contained in equations (3) to (7) were varied about the mean values used in the Bactor soil simulator plots. The results of the sensitivity analysis on the cover-management factor in the USLE are presented in figures 3a, b, c, d and e. Care must be used in interpreting these figures because of the differing scale used for the ordinate values.

The single most sensitive term is probably that associated with ground cover, figure 3d. This sensitivity might also be expected intuitively because the intensity of bare soil exposed to either the splash erosion of impacting raindrops or the shear of water moving over the soil surface or both are the major elements permitting erosion to occur. Although the amount of roots present in the upper 100 mm of the soil profile are also quite sensitive (fig. 3a), much of this change occurs near the origin, i.e., most of the change occurs when the root mass changes from about 0 to 4000 lbs/ac and might, therefore, be expected in connection with decomposition of annual roots within a fallow field rotation and/or tillage activity, factors not encountered in normal range practices. The other factors, shown in figures 3b, c, and e, are not specially sensitive on an annual basis or at a specific site associated with land use or management.

CONCLUSIONS

A new procedure has been presented to estimate soil loss resulting from water erosion on rangelands. The procedure involves a more realistic approach for estimating the cover-management factor in the USLE involving

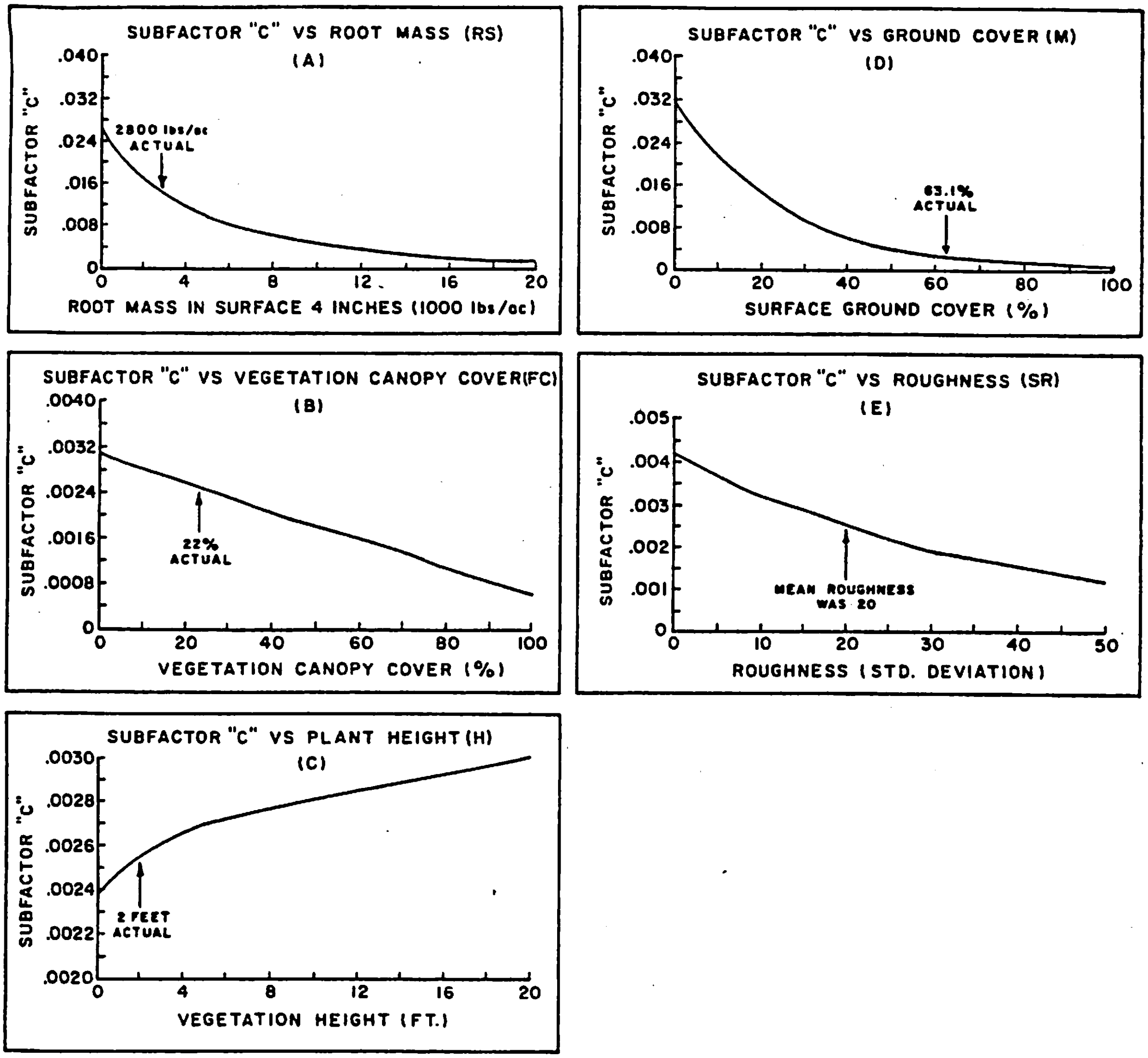

Figure 3. Sensitivity analysis for the cover-management subfactor.

consideration of prior land use, crop canopy, surface cover (including erosion pavement and cryptogams) and surface roughness. The prior land use and the surface roughness terms require information on the root mass in the upper 4 inches (100 mm) of the soil profile, a value not easily obtained without destructive sampling and extensive labor efforts. Root biomass can be estimated from above-ground biomass data using previously published data to relate above- to below-ground biomass. The table can be used in the absence of actual measurements.

The slope of a line through the origin for observed and predicted soil loss indicates that the predicted values (both with Handbook 537 and the revised USLE) underpredicted measured erosion on a series of plots in southeastern Arizona on three different soils. However, the predictions were substantially improved using the revised USLE method.

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