Ken Renard 1118

中美陡坡土壤流失量推估技術研討會論文輯

Proceedings of Sino-American Workshop on Steepland Soil Erosion Estimation Technology

中華民國八十四年五月

目錄
Contents

1.通用土壤流失公式在臺灣地區應用之探討 1
范正成
Assessment of Implementation of USLE in Taiwan
J.-C. Fan

2.台灣容許土壤流失量之訂定 53
盧光輝
Soil Loss Tolerance in Taiwan
K.-F. Lo

3.台灣土壤沖蝕性因子之測定 71
萬鑫森、黃俊義
Determination of Soil Erodibility on Hillslopes of Taiwan
S.-S. Wann, and J.-I. Hwang

4.覆蓋管理因子（C值）之評定 109
林俐玲
Evaluation of Cropping and Management (C) Factor
L.-L. Lin

5.台灣水土保持因子之訂定與坡長坡度研究 117
吳嘉俊
Support Practice Factors and Current LS Factors' Study in Taiwan
C.-C. Wu

6.台灣降雨沖蝕指數與未來USLE公式研究之展望 135
黃俊德、吳嘉俊、王阿碧
Rainfall Erosivity Factor and Prospect of USLE Research in Taiwan
C.-T. Huang, C.-C. Wu, and A.-B. Wang

7.Introduction to the USLE and RUSLE 153
George R. Foster

8.Overview of RUSLE and its Factors 161
Kenneth G. Renard

9.The RUSLE Computer Program and its Databases: Maximizing Flexibility and Power 179
Daniel C. Yoder

10.Erosion Prediction - A User's Perspective 195
Glenn A. Weesies

11.Differences Between the USLE and RUSLE: Implications for Taiwan 215
George R. Foster

作者索引(Contributors) 225

Overview of RUSLE and its factors

Kenneth G. Renard[1]

The need for RUSLE (Revised Universal Soil Loss Equation) was one of the recommendations of a 1985 workshop in Lafayette, Indiana. Those in attendance, scientists and engineers from the Agricultural Research Service, Forest Service, Natural Resources Conservation Service (formerly the Soil Conservation Service), Universities, and other organizations involved in erosion prediction, recommended that 1) the USLE should be upgraded to reflect information available after the 1978 USLE publication, and 2) new technology was needed which would be more fundamentally based, and which would provide the capability to address future problems. These recommendations led to 1) RUSLE (Renard et al., 1991: Renard and Ferreira, 1993) and 2) WEPP, the Water Erosion Prediction Project (Lane and Nearing, 1989: Laflen et al., 1991).

Although RUSLE maintains the basic USLE regression equation (1), the evaluation of each factor value is appreciably different. The following information describes the procedures used to determine the individual factor values.

$$A = R \cdot K \cdot LS \cdot C \cdot P \qquad (1)$$

where A = soil loss, R = rainfall-runoff erosivity, K = soil erodibility, LS = slope length and steepness, C = cover-management, and P = support practice.

Figure 1 is a flow chart of the logic used for RUSLE soil loss estimation. The left side of the chart details user specified data on specific field-management and support-practice details. The right hand side contains information on the data bases used in the individual factor values. As noted, the CITY DATABASE provides input for the R factor, K factor, the cover-management C factor as well as the support practice P factor. The CROP and OPERATION data bases facilite the development of rotations needed for C factor evaluation. These data bases eliminate the repeated input of basic data needed for the calculation of soil loss.

R Factor

The data needed for the R factor calculations have been developed for the entire counterminious US using greatly expanded information not available in the USLE Agriculture Handbook (Wischmeier and Smith, 1978). The data associated with this factor are summarized in the CITY database. The CITY database information is included in RUSLE with other data

[1].Research Hydraulic Engineer (Retired), USDA-ARS Southwest Watershed Research Center, 2000 E. Allen Road, Tucson, AZ 85719. Voice 520-670-6381: FAX 520-670-5550.

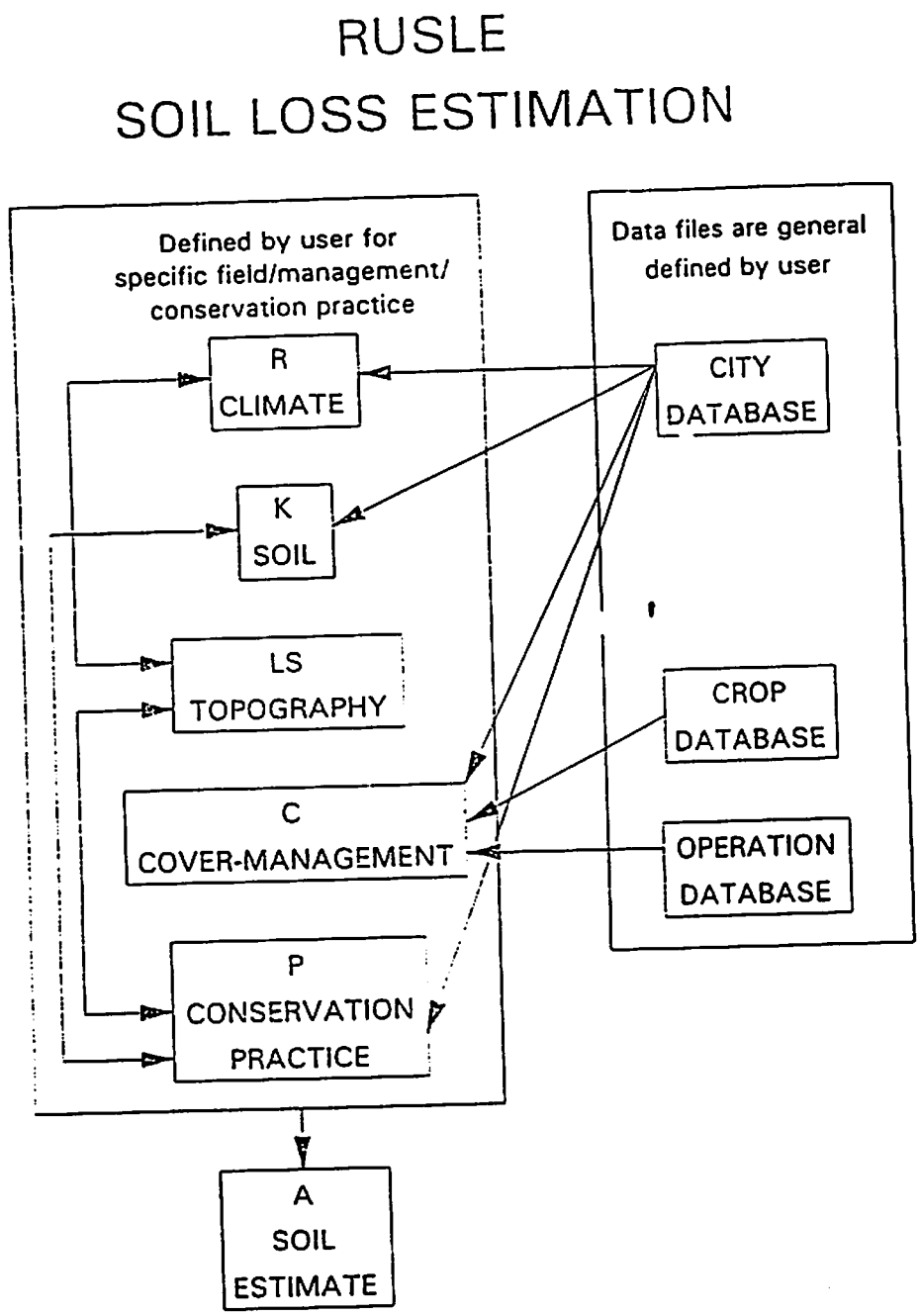

Figure 1. A general flow chart of the RUSLE software

needed to operate the RUSLE software.Several major changes are included in RUSLE R factor calculations as contrasted to the older USLE data of Agriculture Handbook #537. Brown and Foster (1987) recommended using a unit energy relationship of the form:

$$e_m = 0.29\,[1 - 0.72\,\exp(-0.05\,i_m)] \qquad (2)$$

where e_m is the unit energy having units of $MJ \cdot ha^{-1} \cdot mm^{-1}$ and i_m is rainfall intensity with units of $mm \cdot h^{-1}$. They stated that this equation has a superior analytical form by having a finite positive value at zero intensity. This equation was used to calculate R factors for the western

United States with US Weather Bureau 15- and 60-minute intensity data. Data for over 1000 stations in the western US provided isoerodent maps that are considerably different than that developed by the Wischmeier and Smith (1978) procedure.

In the eastern US, the data of Agric. Handbook 537 were used to construct a new isoerodent map. Wischmeier and Smith (1978) used an upper limit of 550 units of R (US units) in the area near New Orleans, LA to reflect, in a crude way, the effect of rain falling on ponded water and thereby the reduction in effective kinetic energy for conditions of flat slopes. When developing the new isoerodent maps for this portion of the country, the total kinetic energy was used. The software then estimates a corrected R value based on land slope and an estimate of the amount of ponded water. The calculations use a runoff index based on Soil Conservation Service Curve Numbers for different hydrologic soil groups.

In the Northwest Wheat and Range Region (NWRR) (Austin, 1981), an R_{eq} value is used to estimate the effect of frozen soils (or partly frozen) where rain on snow or snowmelt cause unusually large amounts of erosion; amounts greater than might be expected with the normally calculated EI product. Users of this procedure are referred to the draft RUSLE handbook #703 (Renard et al, 1995).

City data base. The CITY data file requires information such as annual and monthly precipitation (inches) as well as monthly average temperature (used to calculate residue decomposition, 24 15-day distribution amounts of the annual R factor, and the frost free period (days) which is used to calculate the erosion hazard weighted K and the cover-management, C factor values. The information is stored in the RUSLE software as a file of 5 digit length with the first two digits representing the numerical state index and the last three digits reflecting the city within each state. Details for the preparation to the data bases are included in the paper by Yoder.

K Factor

The K factor is a measure of the inherent erodibility of a given soil under standard condition of the unit USLE plot maintained in continuous fallow. Values for K typically range from about 0.10 to 0.45 (customary English units), with high-sand and high-clay content soils having the lower values and high-silt content soils having higher values. Users have little difficulty choosing a K-factor value because SCS (now called the NRCS) has identified K values for major soil mapping units. However, site-specific K values can be quite different from the value given in soil survey information.

The erodibility nomograph is the most commonly used tool for estimating K values, but it does not apply to some soils. The updating of the K factor for RUSLE involves developing guides so that the user can identify soils where the nomograph does not apply and then estimating K using alternative methods. For example, erodibility data from around the world have been reviewed and an equation developed that gives an estimate of K as a function of an "average" soil particle diameter. Use of this function is only recommended where the nomograph or another procedure does not apply. K values for the volcanic soils of Hawaii are estimated with an alternative algorithm (El-Swaify and Dangler, 1976).

RUSLE varies K seasonally in the eastern US. Experimental data show that K is not

constant throughout the year, but varies with season, being highest in the spring with soil fluffing from freeze-thaw actions. The data also indicates K is lowest in mid-fall and winter following rainfall compaction or frozen soil. The seasonal variability is addressed by weighting the instantaneous estimate of K in proportion to the EI (the percent of annual R) for 15-day intervals. Instantaneous estimates of K are made from equations relating K to the frost-free period and the annual R factor.

An additional change incorporated in RUSLE is to account for rock fragments on and in the soil. Rock fragments on the soil surface are treated like mulch in the C factor, while K is adjusted for rock in the soil profile to reflect rock effects on permeability, and, in turn, runoff.

L and S Factors

More questions and concerns are expressed for the L factor than any of the other RUSLE and USLE factors. One reason is that the choice of slope length involves judgment, and different users choose different slope lengths for similar situations. The RUSLE includes improved guides for choosing slope length values to give greater consistency among users.

The attention given to the L factor is not always warranted because soil loss is less sensitive to slope length than to any other RUSLE (and USLE) factor. For typical slope conditions, a 10 percent error in slope length results in a 5 percent error in computed soil loss. RUSLE uses three separate slope length relationships. They include (i) a function of slope steepness, as in the USLE, (ii) a function of the susceptibillity of the soil to rill erosion relative to interrill erosion, and (iii) a slope length relationship specifically for the frozen soil region of the Northwest Wheat and Range Region (NWRR). A guide assists the user to identify the appropriate relationship for the particular field conditions.

Soil loss is much more sensitive to changes in slope steepness than to changes in slope length. In the present USLE, a 10 percent error in slope steepness gives about a 20 percent error in computed soil loss. Thus, special attention should be given to obtaining good estimates of slope steepness.

RUSLE has a more nearly linear slope steepness relationship than the USLE. Computed soil loss for slopes less than 20 percent are similar in RUSLE and the USLE. However, on steep slopes, computed soil loss is reduced almost by half with RUSLE. Experimental data and field observations, especially on rangeland, do not support the USLE quadratic relationship. RUSLE also provides a slope steepness relationship for short slopes subject primarily to interrill erosion and a steepness relationship for the NWRR.

Slope length factor (L). Plot data used to derive the slope length (L) effect have shown that average erosion for the slope length λ (in ft) varies as:

$$L = (\lambda/72.6)^m \tag{3}$$

where 72.6 = the RUSLE unit plot length (ft) and m = a variable slope length exponent. The slope length λ is the horizontal projection. The slope-length exponent is related to the ratio β of rill erosion (caused by overland flow) to interrill erosion (principally caused by raindrop

impact

$$m = \beta/(1 + \beta) \tag{4}$$

Values for the ratio of rill to interrill erosion for conditions when the soil is moderately susceptible to both rill and interrill erosion are given as:

$$\beta = (\sin\theta/0.0896)/[3.0(\sin\theta)^{0.8} + 0.56] \tag{5}$$

where θ = slope angle. Given a value for β, a value for the slope-length exponent m is calculated from equation 4. When runoff, soil, cover, and management conditions indicate that the soil is highly susceptible to rill erosion, the exponent should be increased (See Agric. Handbook #703 draft). Such conditions might be expected on steep, freshly prepared construction slopes. The values can be obtained by doubling the value obtained from equation 5. Conversely, when conditions favor less rill erosion than interrill erosion, m should be decreased by halving the β values from equation 4. The low ratio of rill to interrill erosion are typical of conditions for rangelands. For thawing, cultivated soils dominated by surface flow, a constant value of 0.5 should be used (McCool et al. 1989).

<u>Slope steepness factor (S)</u>. Soil loss increases more rapidly with slope steepness than slope length. The slope steepness factor is evaluated with the following relationships from McCool et al, 1987.

$$S = 10.8 \sin\theta + 0.03 \qquad s < 9\% \tag{6}$$

$$S = 16.8 \sin\theta - 0\ 50 \qquad s \geq 9\% \tag{7}$$

Equation 7 is based on the assumption that runoff is not a function of slope steepness for slopes greater than about 9%. The effect of slope on runoff and erosion as a result of mechanical disturbance is considered in the support practice factor (P).

For slopes shorter than 15 ft, the following equation should be used to evaluate S (McCool et al. 1987):

$$S = 3.0\,(\sin\theta)^{0.8} + 0.56 \tag{8}$$

This equation applies to conditions where water drains freely from the end of the slope. For the slope steepness factor given by equation 8, it is assumed that rill erosion is insignificant on slopes shorter than 15 ft and that interrill erosion is independent of slope length.

When recently tilled soil is thawing, in a weakened state, and subjected primarily to surface flow, the following equations for S are used from the work of McCool et al. (1987).

$$S = 10.8 \sin\theta + 0.01 \qquad s < 9\% \tag{9}$$

$$S = (\sin\theta/0.0896)^{0.6} \qquad s \geq 9\% \tag{10}$$

In most practical applications, a slope segment previously estimated as a single plane or uniform slope can be a poor representation of the topography. In RUSLE complex slopes can be represented readily to provide a better approximation of the topographic effect. Users are cautioned and encouraged to use these complex slope calculations because they can be most significant when contrasted with a simple uniform plane.

C Factor

The cover-management factor, C, is perhaps the most important of the RUSLE (or USLE) factors because it represents conditions that can be managed most easily to reduce erosion. Values for C can vary from near zero for a very well protected soil, to nearly 1.5 for a finely tilled, ridged surface that produces much runoff and leaves the soil highly susceptible to rill erosion.

C values are weighted average soil loss ratios (SLR's) that represent the soil loss for a given condition at a given time to that for a unit plot. Thus, SLRs vary during the year as soil and cover conditions change. To compute C, SLRs are weighted according to the distribution of erosivity during a year.

In RUSLE, a subfactor method is used to compute SLRs as a function of five subfactors (Equation 3):

$$C = PLU \cdot CC \cdot SC \cdot SR \cdot SM \tag{11}$$

where C = cover-management factor, PLU = a prior land use subfactor, CC = a canopy subfactor, SC = the surface cover subfactor, SR = the surface roughness subfactor, and SM = a soil moisture subfactor (used only in the NWRR: otherwise assumed as unity).

Ground cover affects erosion the most. Too much attention can be given to ground cover without considering the within-soil effects, such as those associated with root mass and tillage. For example, 30 percent cover after planting is the criterion frequently used for conservation tillage. A 30 percent cover reduces soil loss about 72 percent according to the USLE. For comparison, the soil loss from a freshly plowed out of high production meadow is only 25 percent of that from the unit plot. Thus, within-soil effects can be substantial.

The effect of surface ground cover on erosion has been observed to vary greatly in research studies. In some studies, a 50 percent cover reduced soil loss by 95 percent. To address this varied effectiveness, the following equation is used in RUSLE:

$$SC = \exp(-b \cdot M) \tag{12}$$

where SC is the mulch or ground cover subfactor and M is the percentage of ground cover. The b coefficient is assigned values between 0.025 and 0.050 for conditions that reflect the tendency for rill erosion to dominate over interrill erosion increases. Guidelines are provided in the software and in the RUSLE Ag. Handbook 703 (Renard et al., 1995) on choosing the b value.

Subfactor values (PLU and SR) for the within-soil effect are calculated from the amount of

biomass in the soil that accumulates from roots and the incorporation of crop residue. RUSLE computes biomass decomposition on and in the soil using a residue decomposition model. Characteristics of tillage operations are important in computing estimates of subfactor values for SLRs. Values for SLRs in RUSLE for conservation tillage are less than those of the USLE because RUSLE assumes greater effectiveness for ground cover.

One reason for the subfactor approach in RUSLE is for applications where SLR values are not available. For example, no experimental data exist for many vegetable and fruit crops. Developing SLR values using the subfactor method in RUSLE is easier and more accurate than making comparisons with values for other crops in Agric. Handbook 537.

RUSLE has computer routines for many tillage operations and crops. In still other instances, the user must input new data reflecting the amount of residue incorporated by a soil disturbing operation and the roughness residual following tillage. For crops not available in the software, data are needed to reflect canopy characteristics and root mass in the upper four inches of the soil profile. Thus, the user specifies the crops in a rotation, crop yield, and the dates of the soil disturbing operations. The software then calculates SLRs and an average annual C-factor.

Prior Land Use Subfactor. The PLU subfactor is calculated in RUSLE from the relationship:

exp

$$PLU = C_f \cdot C_b \cdot \exp[(-c_{ur} \cdot B_{ur}) \div (c_{us} \cdot B_{us} / C_{f}c_{uf})] \qquad (13)$$

where PLU is the prior-land-use subfactor (which ranges from 0 to 1), C_f is a surface-soil-consolidation factor, C_b represents the relative effectiveness of subsurface residue in consolidation, B_{ur} is mass density of live and dead roots found in the upper inch of soil (lb·acre^{-1}·in^{-1}), B_{us} is mass density of incorporated surface residue in the upper inch of soil (lb·acre^{-1}·in^{-1}), C_{uf} represents the impact of soil consolidation on the effectiveness of incorporated residue, and C_{ur} and C_{us} are calibration coefficients indicating the impacts of the subsurface residues.

The variable C_f expresses the effect of tillage-induced surface density changes on soil erosion. Tillage operations tend to break soil aggregate bonds, increasing the potential for erosion. This factor then reflects lower erosion rates associated with undisturbed soils of rangeland or no-till systems. Based on other work, the value of C_f for freshly tilled conditions is 1.0. If the soil is left undisturbed, the value decays exponentially to 0.45 over 7 yr, or some other length of time specified by the user.

The B_u variables are used to calculate the impact of erosion rates of live and dead roots and incorporated residue. The effectiveness of such materials can take two forms. First, roots and residue can control erosion directly by physically binding soil particles together and by acting as mechanical barriers to soil and water movement. Second, roots and residue exude binding agents and serve as a food source for microorganisms that produce other organic binding agents. These serve to increase soil aggregation and thereby reduce its susceptibility to erosion. The RUSLE program keeps track of the biomass in each soil layer, continuously adjusting the rootmass and subsurface residue to account for additions and decomposition.

Canopy-Cover Subfactor. The canopy-cover subfactor expresses the effectiveness of

vegetative canopy in reducing the energy of rainfall striking the soil surface. Although most rainfall intercepted by crop canopy eventually reaches the soil surface, it usually does so with much less energy than does rainfall that strikes the ground without having been intercepted. The intercepted raindrops fracture into smaller drops with less energy, or drip from leaf edges, or travel down crop stems to the ground. The canopy-cover effect is given as:

$$CC = 1 - F_c \cdot \exp(-0.1 \cdot H) \tag{14}$$

where CC is the canopy-cover subfactor ranging from 0 to 1, F_c is the fraction of land surface covered by canopy, and H (ft) is the distance that raindrops fall after striking the canopy.

Surface-Cover Subfactor. Surface cover affects erosion by reducing the transport capacity of runoff water by causing deposition in ponded areas, and by decreasing the surface area susceptible to raindrop impact. It is perhaps the single most important factor in determining SLR values. Surface cover includes crop residue, rocks, cryptogams, and other nonerodible material that is in direct contact with the soil surface. The effect of surface cover on soil erosion is given by:

$$SC = \exp[-b \cdot S_p (0.24/R_u)^{0.08}] \tag{15}$$

where SC is the surface-cover subfactor, b is a coefficient, S_p is the percentage of land area covered by surface cover, and R_u is the surface roughness (in) as will be defined later.

The percentage of land area covered by residue can be estimated from residue weight with the relationship of Gregory (1982):

$$S_p = [1 - \exp(-\alpha \cdot B_s)] \cdot 100 \tag{16}$$

where S_b is percent residue cover, α is the ratio of the area covered by a piece of residue to the mass (acre·lb^{-1}), and B_s is the dry weight of crop residue on the surface (lb·are^{-1}). If more than one type of residue is present, the resulting total surface cover is calculated as:

$$S_p = \{1 - \exp[-\Sigma (\alpha_i B_{si})]\} \cdot 100 \tag{17}$$

where α_i is the ratio of the area covered to the mass of that residue for each type encountered. The summation then is for each type of residue.

Surface-Roughness Subfactor. Surface roughness has been shown to directly affect soil erosion and to indirectly affect it through the impact of residue effectiveness in equation 15. In either case, this is a function of the surface's random rougness, which is defined as the standard deviation of surface elevations when changes due to land slope or nonrandom tillage marks (such as dead furrows, traffic marks, and disk marks) are removed from consideration. A rough surface has many depressions and barriers. During a rainfall event, these trap water and

sediment, causing rough surfaces to erode at lower rates than do smooth surfaces under similar conditions. Increasing the surface roughness decreases the transport capacity and runoff detachment by reducing the flow velocity.

Roughness and cloddiness of soils also affect the degree and rate of soil sealing by raindrop impact. Soils that are left rough and cloddy typically have higher infiltration rates. Soils that are finely pulverized are usually smooth, seal rapidly, and have low infiltration rates.

$$D_r = \exp[1/2(-0.14P_t) + 1/2(-0.012 \cdot EI_t)] \tag{18}$$

where D_r is the dimensionless roughness decay coefficient, and P_t is the total inches of rainfall since the most recent operation that disturbed the entire surface, and EI_t is the total EI amount since that same operation.

If the initial roughness is defined as R_i, surface roughness just before the current tillage operation (R_u) can be defined as:

$$R_u = 0.24 + [D_r (R_i - 0.24)] \tag{19}$$

where R_u is in inches. Since many field operations affect only a portion of the surface, R_u is also the roughness of the portion of the field that is undisturbed by the current field operation.

For that portion of the surface that is affected by the field operation, the resulting roughness has been found to be a function of subsurface biomass present in the top 4 in of soil. The relationship is described by:

$$R_a = 0.24 + (R_t - 0.24)\{0.8\,[1 - \exp[(-0.0012\,B_u)] - 0.2\} \tag{20}$$

where R_a is the roughness after biomass adjustment (in), R_t is the original tillage roughness based on the assumption of ample subsurface biomass such as that found with high-yielding midwestern US corn (in), and B_u is total subsurface biomass density in the top inch of soil (lb·acre^{-1}·in^{-1}). $B_u = B_{ur} + B_{us}$ given in equation 13.

The adjusted tillage roughness is then combined with that of the undisturbed portion of the surface as:

$$R_n = R_a F_d + R_u F_u \tag{21}$$

where R_n is the net roughness following the field operation (in) and F_d and F_u are the fractions of the surface disturbed and undisturbed, so their sum equals one.

Similarly, the decay coefficient must be adjusted to reflect that only a portion of the field is disturbed. This is done using:

$$D_e = D_r F_u + 1.0 F_d \tag{22}$$

where D_e is the equivalent roughness decay coefficient. Under the assumption that the ratio

EI_t/P_t before the operation equals that after, the P_t and EI_t values corresponding to the equivalent roughness decay coefficients are:

$$P_t = -2 \cdot \ln(D_e)/\{0.14 + 0.012[EI_{t,b}/P_{t,b}]\} \tag{23}$$

$$EI_t = EI_{t,b} \cdot P_t/P_{t,b} \tag{23}$$

where the subscript b indicates the value before the operation.

These values for the decay coefficent and corresponding precipitation and EI describe a point on a new roughness decay curve, asymptotic to zero at infinite amounts of precipitation, and with a new initial roughness at $P_t = 0$. This new initial roughness R_t (in) is calculated from the following relationship which describes the decay curve.

$$R_t = 0.24 + (R_n - 0.24)/D_e \tag{24}$$

If a site is clean-tilled and left without human interventions, two things will happen: (1) the tillage roughness will decrease as defined previously, and (2) as the years go by, the vegetation will trend towards its climax community, with attendant roughness caused by protruding roots, soil pushed up around old basal areas, rocks, and so on.

RUSLE assumes that the formation of this vegetative roughness follows a typical sigmoidal growth curve increasing from the minimum roughness (r_{min}, with a default of 0.24 in) to be total roughness when the soil is consolidated (r_{max}) over the time required for consolidation (t_{con}).

The surface roughness subfactor for this time period is then:

$$SR = \exp[-0.66(R_u - 0.24)] \tag{25}$$

Soil-Moisture Subfactor. In the nonirrigated portions of the Northwest Wheat and Range Region (Austin, 1981), soil moisture during crtical crop periods depends on crop rotation and management. Addition of a soil-moisture subfactor (SM) is suggested for this region. SM reflects dry fall conditions and the increase in soil moisture over the winter. The soil moisture decrease over the summer depends on the crop rooting depth and soil depth, and the soil moisture replenishment depends on the precipitation amount and soil depth. If such a practice is required in Taiwan, research will be required to make such a correction. In most instances, this factor is assumed to be 1.0 in the US.

Crop Data Base. Crop data bases are needed for any crop (including varying yields) for which a soil loss simulation is needed. Many crops are included in the computer data base. Information required for these data bases include a senescence code (whether falling canopy is to be added to the ground cover), residue at harvest, surface and subsurface residue decomposition constant, surface residue at 30-, 60- and 90-percent cover, as well as root biomass, canopy cover and fall height at 15 day intervals following planting. These values are

sometimes difficult to evaluate but Agriculture Handbook #703 (Renard et al., 1995) suggest values for many crops. In addition, a procedure is provided for making parameter adjustments in response to varying yields.

Operation Data Base. Soil disturbing operations have large impacts on soil loss estimation. To facilitate the evaluation, many operation data bases have been included in the RUSLE software. They require information on the percentage of the area disturbed, the random roughness left after an operation (given as the standard deviation of a plane across a field), the percentage of cover left on the surface, and the depth to which the disturbance is made. Up to five different effects can occur including: 1) no effect; 2) soil surface disturbed; 3) current crop residue added to the surface; 4) other residue added to the surface; 5) residue removed from the field; 6) current crop is harvested; 7) crop growth begins; 8) current crop is killed; and 9) call in a new crop growth set.

More details regarding C-factor calculations and the CROP and OPERATION data bases are included in the material prepared by Daniel C. Yoder and Glenn A. Weesies.

P FACTOR

Of all of the RUSLE factors, values for the P factor are the least reliable. The factor represents how surface conditions affect flow paths and flow hydraulics. For example, with contouring, tillage marks are credited with directing runoff around the slope at reduced grades. Slight changes in grade can change runoff erosivity greatly. In experimental field studies, small changes in such features as row grade and their effect on erosion are difficult to document, leading to appreciable measured data scatter. Identifying subtle characteristics in the field are difficult when applying RUSLE. Thus, P-factor values represent broad, general effects of such practices as contouring.

P factor credit in RUSLE is treated as subfactors with Equation 26.

$$P = \text{contouring} \cdot \text{stripcropping} \cdot \text{terracing} \cdot \text{drainage} \qquad (26)$$

Subroutines are included in the software to permit credit in the support-practice factor P. The current version of RUSLE does not have a subroutine for drainage but the user is permitted to enter a value based on an external evaluation.

Contouring. In RUSLE, extensive data have been analyzed to reevaluate the effect of contouring. The results have been interpreted to give factor values for contouring as a function of ridge height, furrow grade, and climatic erosivity. Agriculture Handbook 703 (Renard et al. 1995) recommends values for the RUSLE contour P-factor based on erosion theory and analyses of experimental data. Data used came from three sources: plots; small watersheds; and solutions of equations derived from erosion theory, namely the CREAMS model (Foster et al. 1981).

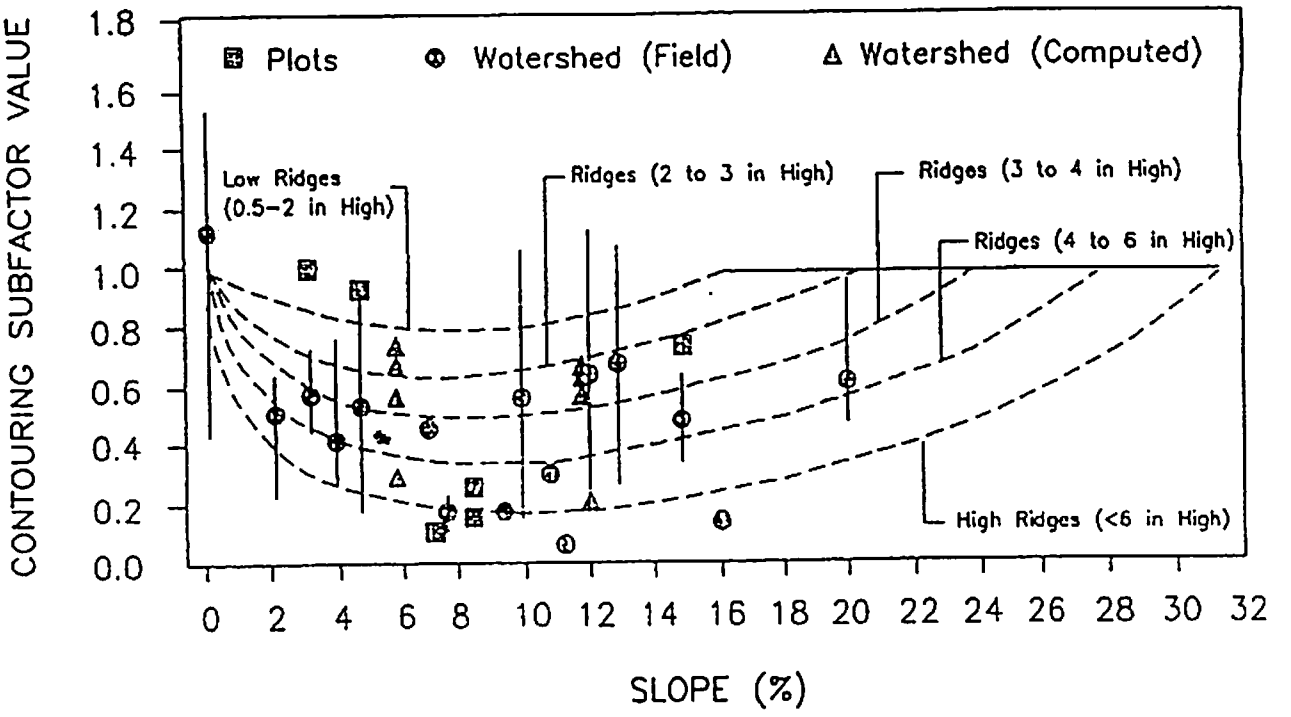

Figure 2. Effect of contouring on soil loss

Five curves, drawn by inspection through the data shown in figure 2 represent the effectiveness of contouring where ridge heights are very low, low, moderate, high, and very high and where ridges follow the contour so closely that runoff spills over the ridges uniformly along their length. Data showing the greatest effectiveness of contouring were generally from plots having high ridges. Data in figure 2 are assumed to be for the base condition of a 10-yr-frequency storm of EI of 100 ft·tonf·in(ac·hr)$^{-1}$ and for a row crop with clean tillage on a soil classified as being in hydrologic soil group C (USDA-SCS, 1972).

Data from field studies indicate that contouring is less effective for large storms than for small storms (Moldenhauer and Wischmeier, 1960). The reduced effectiveness depends on both amount and peak rate of runoff. These runoff variables are directly related to rainfall amount and intensity, which are the principal variables that determine EI, the erosivity factor in RUSLE. Therefore, values for the contouring subfactor should be near 1 (little effectiveness) when EI is high and infiltration into the soil is low, and should be small (greater effectiveness) when EI is low and infiltration is high. Loss of contouring effectiveness is likely to occur from a few major storms. Therefore, erosivity of a single storm, such as the storm having a 10-yr return frequency should be a better indicator of loss of contouring effectiveness than average annual erosivity.

Values of the 10-yr storm EI are obtained from the Citycode files in the RUSLE computer program. These EI values are converted to storm rainfall amounts using the equation:

$$V_r = 0.255\ [(EI)_{10}]^{0.662} \tag{27}$$

where V_r = rainfall amount in inches. Values for rainfall amount, V_r, are used in the SCS runoff curve method to compute a runoff amount. Cover-management conditions for cropland are grouped in seven categories as described in table 6-4 of Agriculture Handbook #703 (Renard, et al. 1995).

As grade along furrows increases from tillage being off contour, the effectiveness of contouring decreases. The equation used in RUSLE to compute P-factor values for off-grade contouring is:

$$P_g = P_o + (1 - P_o)\{S_f/S_l\}^{1/2} \tag{28}$$

where P_g is the P-factor for off-grade contouring, P_o is the P-factor for on-grade contouring, s_f is the grade (expressed as the sine of the slope angle) along the furrows, and s_l is steepness (expressed as sine of the slope angle) of the land. Other values are also provided in the same reference for other land use conditions and storm types.

Estimating Soil Loss with Contouring When Slope Length Exceeds Critical Slope Length. At long slope lengths, contouring loses its effectiveness. The critical slope-length limits given by Wischmeier and Smith (1978) were given only as a function of slope steepness, but they suggested that critical slope length increased if residue cover exceeded 50%. Critical slope-length limits in RUSLE are computed with a simplification of the Foster et al. (1982) equation for mulch stability. The equation is:

$$\lambda_c = 20182\ n_t 1.5/\ s^{1.1667} Q \tag{29}$$

where λ_c = critical slope length, n_t = Manning's roughness, s = slope (expressed as sine of the slope angle),and Q = the runoff amount from the 10-yr storm EI.

Soil loss expressed in units of mass per unit area is obtained by dividing sediment yield from the slope by slope length λ. The equation for soil loss A is obtained from a series of equations and calculations as:

$$A = RKLSC[1 - x_c(1 - P)] \tag{30}$$

where

$$P_{eff} = [1 - x_c(1 - P)] \tag{31}$$

is the effective P-factor used to compute average soil loss for the slope length λ. Values of P_{eff} is computed using an equation and tables of slope-length exponent values for slope ranges and rill-to-interrill erosion classes found in Agriculture Handbook #703.

Cross-slope, Stripcropping, Buffer Strips, and Filter Strips. Stripcropping for the control of water erision is variously described as contour stripcropping, and field stripcropping. Each of these practices has the common characteristic of crops in a rotation forming strips of nearly equal width. The difference between the practices is the degree of deviation from the contour. All of them, including contour stripcropping, involve some degree of off-grade contouring The effectiveness of all of them can be determined with the same equations in the RUSLE computer code.

Buffer strips, located at intervals up the slope, are resident strips of perennial vegetation laid out across the slope. Like the strips in cross-slope stripcropping, they may or may not be on contour. Such strips, predominantly composed of grass species, are not in the crop rotation, are usually much narrower than the adjacent strips of clean-tilled crops, and may be left in place for several years or permanently. The effectiveness of buffer strips in trapping sediment and reducing erosion can be evaluated with the algorithms in the RUSLE software.

Vegetated filter strips are bands of vegetation at the base of a slope. Riparian filter strips are located along stream channels or bodies of water. These conservation practices are designed to reduce the amount of sediment reaching offsite water bodies. Neither practice traps eroded sediment on the hillslope and therefore is assumed to have minimal benefit as a P-factor.

Experimental data available in the literature are inadequate alone for developing the necessary P-factor values for the wide range of current practices. Thus, a conceptual approach was developed based on fundamental erosion concepts (Renard and Foster 1983, Flanagan et al. 1989) that uses RUSLE to estimate P-factor values for strips.

A value for the P-factor for strips is computed from:

$$P_s = (g_p - B)/g_p \tag{32}$$

where P_s = the value for P-factor for strips, g_p = sediment load at the end of a slope that would ocur if the strips caused no deposition, and B = credit for deposition. The model computes erosion, sediment transport, and deposition on a strip-by-strip basis, routing the sediment from the top to the bottom of the slope. One of four conditioins exists on each strip:

1) Net erosion occurs everywhere along the strip,
2) Net deposition occurs everywhere along the strip,
3) Net deposition occurs on an upper area of the strip and net erosion occurs on a lower area of the strip, or
4) Runoff ends within a strip and no runoff or sediment leaves the strip.

The objective in each case is to compute the amount of deposition on each strip and the sediment leaving each strip. Details of the computations and equations involved are not presented herein but users may refer to Agriculture Handbook #703 (Renard, et al. 1995)

Terracing. Terraces reduce sheet and ril erosion on the terrace interval by breaking the slope into shorter slope lengths. Also, deposition along the terrace may trap much of the sediment eroded from the interterrace interval, particularly if the terraces are level and include closed outlets, have underground outlets, or have a very low grade. So deposited sediment remains on the field and is redistributed over a significant portion of the field, reducing soil deterioration

caused by erosion. In this way, terraces help to maintain the soil resource much as contour stripcropping does. Without the terraces and outlet channels, runoff in natural waterways or unterraced fields can cause significant erosion.

Analysis of terrace data from the 1930's and 1940's showed that deposition varies greatly with terrace grade (Foster and Ferreira 1981; Foster and Highfill 1983). Sediment yield from single-terraced watersheds with a range of grades was measured for about 8 yrs at several locations. Results of this analysis show that the uniform-grade terraces increases according to the following exponential relationship:

$$Py = 0.1e^{2.4s} \qquad s<0.9\% \tag{33}$$

$$Py = 1.0 \qquad s>0.9\% \tag{34}$$

where Py = sediment delivery factor and s = the terrace-slope grade (%). The P-factor for conservation planning is computed as:

$$P = 1 - B(1 - Py) \tag{35}$$

where B is the benefit assigned to deposition and the quantity (1 - Py) is the amount of deposition. Values of B are given in Agriculture Handbook #703.

Subsurface Drained Areas. Limited field data indicate that subsurface drainage is effective in reducing overland flow and erosion. Because of limited information and differences in procedures among studies reported in the literature, further research is needed to develop a range of P-factor values for subsurface drained areas that are applicable across many condition of climate, soil, crop, and slope. The current RUSLE software does not contain a specific routine for such calculations although we recognize the effects.

SUMMARY

The USLE is a powerful tool that has been widely used for almost three decades for planning of soil conservation practices, inventorying and assessing the impacts of erosion, and developing and implementing policy related to soil conservation. Recent cooperative efforts have resulted in updating the USLE technology in new technology called RUSLE. Some of the improvements in RUSLE include:

- A greatly expanded erosivity map for the western United States
- Minor changes in R factors in the eastern United States
- Corrections to R which reflect rainfall on ponded water
- Use of an R_{eq} in areas of frozen soil and melting snow
- Expaned information on soil erodibility
- A time varing consideration of soil erodibility
- A slope length factor that varies with soil susceptibility to rill erosion

- A nearly linear slope steepness relationship that reduces computed soil loss values for very steep slopes
- A routine has been developed to make rapid determinations of slope length and steepness effect for complex topography
- A subfactor method for computing values for the cover-management factor
- Improved factor values for the effects of contouring, terracing, stripcropping, and drainage
- RUSLE has been computerized to facilitate the ease of making soil losscalculations

It has been recommended (Renard, et al., 1994) that RUSLE be used to replace the USLE whenever possible because of the improved technology embedded in RUSLE.

REFERENCES

1. Austin, M.E. 1981. Land resource regions and major land resource areas of the United States. USDA Agric. Handbook No. 296. 156 pgs.

2. Flanagan,D.C., G.R. Foster, W. H. Neibling, and J.P. Burt. 1989. Simplified equations for filter strip design. *Trans. ASAE* 32:2001-2007.

3. Foster, G.R. and V.A. Ferreira. 1981. Deposition in uniform grade terrace channels. IN: Crop Production with Conservation in the 80's. pp. 185-197, ASAE, St. Joseph, Michigan.

4. Foster, G.R. and R.E. Highfill. 1983. Effect of terraces on soil loss: USLE P-factor values for terraces. *J. Soil and Water Cons.* 38(1):48-51.

5. Foster, G.R., L.J. Lane, J.D. Nowlin, J.M. Laflen, and R.A. Young. 1981. Estimating erosion and sediment yield on field sized areas. *Trans. ASAE* 24:1253-1262.

6. Foster, G.R., C.B. Johnson, and W.C. Moldenhauer. 1982. Hydraulic failure of unanchored cornstalk and wheat straw mulches for erosion control. *Trans. ASAE* 25(4):940-947.

7. El-Swaify, S.A. and E.W. Dangler. 1976. Erodibilities of selected tropical soils in relation to structural and hydrologic parameters. IN: Soil Erosion: Prediction and Control. Soil Cons. Soc. Am., Ankeny, Iowa. pp. 105-114.

8. Laflen, J.M., L.J. Lane, and G.R. Foster. 1991. WEPP: A new generation of erosion prediction technology. *J. Soil & Water Cons.* 46(1):34-38.

9. Lane, L.J. and M.A. Nearing. 1989. USDA-Water Erosion Prediction Project: Hillslope profile model documentation. USDA-ARS-NSERL Report No. 2. West Lafayette, IN, 47907.

10. McCool, D.K., L.C. Brown, G.R. Foster, C.K. Mutchler, and L.D. Meyer. 1987. Revised slope steepness factor for the Universal Soil Loss Equation. *Trans. ASAE.* 30(5):1387-

1396.

11. McCool, D.K., G.R. Foster, C.K. Mutchler, and L.D. Meyer. 1989. Revised slope length factor for the Universal Soil Loss Equation. *Trans. ASAE* 32(5):1571-1576.

12. Moldenhauer, E.C. and W.H. Wischmeier. 1060. Soil and water losses and infiltration rates on Ida silt loam as influenced by cropping systems, tillage practices and rainfall characteristics. *Soil Sci. Soc. Am.* 24(5):409-413.

13. Renard, K.G. and V.A. Ferreira. 1993. RUSLE model description and database sensitivity. *J. Environ. Qual.* 22:458-466.

14. Renard, K.G. and G.R. Foster. 1083. Soil conservation: Principlse of erosion by water. IN: H.E. Dregne and W.O. Willis, eds., Dryland Agriculture, Agronomy No. 23, pp. 155-176. Am. Soc. Agron., Crop Sci. Soc. Am., and Soil Sci. Soc. Am., Madison, Wisconsin

15. Renard, K.G., G.R. Foster, G.A. Weesies, and J.P. Porter. 1991. RUSLE: Revised universal soil loss equation. *J. Soil & Water Cons.* 46(1):30-33.

16. Renard, K.G., G.R. Foster, D.C. Yoder, and D. K. McCool. 1994. RUSLE revisited: Status, questions, answers, and the future. *J. Soil and Water Cons.*, 49(3):213-220.

17. Renard, K.G., G.R. Foster, G.A. Weesies, D.K. McCool, and D.C. Yoder. 1995. Predicting soil erosion by water: A guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). US Department of Agriculture, Agriculture Handbook #703. Pending.

18. U.S. Department of Agriculture, Soil Conserv. Service. 1972. National Engineering Handbook, Sec. 4, Hydrology. Washington, DC.

19. Wischmeier, W.H. and D.D. Smith. 1978. Predicting rainfall erosion losses - A guide to conservation planning. US Dept. of Agric. Agric. Handbook No 537, 85 pp.