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"The universal soil loss equation (USLE) for predicting rainfall erosion losses"

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Ellison (1944) and Bisal (1960) showed that soil detachment and/or splash erosion are related to the mass and velocity of falling drops. Mihara (1959) and Free (1960) found that splash erosion is directly correlated with kinetic energy. Kinetic energy of a falling raindrop may be computed indirectly when the drop size and the terminal velocity are known. Kinetic energy may also be determined by converting the kinetic energy into another form of energy which may be more easily measured, such as with an acoustic recorder (Kinnell, 1968; Forrest, 1970; De Wulf and Gabriels, 1982). But studies on this line are still continuing.

Different authors found different relationships between kinetic energy (E) and intensity (I) of rainfall:

Mihara (1952): $E = 75.9 I^{1.2}$
with E: $erg/cm^2.minute$
I: $mg/cm^2.minute$

Wischmeier and Smith (1958):
$E = 916 + 331 \log I$
with E: foot ton/acre.inch
I: inch/hour
in metric units the expression is:
$E = 1.213 + 0.890 \log_{10} I$
with E: $kg\ m/m^2\ mm$
I: mm/hour

In Zimbabwe, Hudson (1965) found:
$$E = 758.52 - \frac{127.51}{I}$$
with E: ergs x $10^3/cm^2$
I: inch/hour

For the Miami area, Kinnell (1973) found:
$E = 8.37\ I - 45.9$
with E: $ergs/cm^2\ sec$
I: mm/hr

Carter et al. (1974) found in Louisiana and Mississippi:
$$E = 429.2 + 534.0\ I - 122.5\ I^2 + 78\ I^3$$
with E: foot ton/acre.inch
I: inch/hour

It is clear that there is a good correlation between kinetic energy and rainfall intensity, but the equation and regression coefficient expressing the relationship are different from one place to another, depending on the climatic condition.

Wischmeier and Smith (1958) found as a result of extensive statistical analysis that EI_{30}, the product of the total energy of a rainstorm (E) and the storm's maximum intensity for a 30-minute duration (I_{30}) gave the best correlation with soil loss.

The EI_{30} index has been widely used in America, and other countries such as: India (Bhatia and Singh, 1976), West and Central Africa (Roose, 1977), Indonesia (Bols, 1978), Belgium (Bollinne et al., 1980). However, the index has not been entirely satisfactory, particularly for the tropical rainstorms (Lal, 1976). This author indicated that EI_{30} may underestimate the kinetic energy of tropical storms. Hudson and Jackson (1959) found in Rhodesia that the EI_{30} index was not efficient as might be expected from Wischmeier's studies in U.S. Ahmad and Breckner (1974) found in Trinidad that the correlations of this index with soil loss were generally low.

Hudson (1971) proposed an alternative method for estimating the erosivity of rainfall. He defined the KE > 1 index as the sum of the kinetic energies in storms with intensities greater than 1 in/hr (25 mm/hr). It is based on the concept that there is a threshold value of intensity at which rain starts to become erosive. Such an index could be more adequate for describing rainfall erosion hazards for tropical soils, which are generally characterized by well-structured profiles and infiltration rates greater than 1 in/hr.

Lal (1976) proposed the AI_m index being the product of total rainfall (A) in cm and maximum intensity (Im) in cm/hour for a minimum duration of 7.5 minutes.

Fournier (1960) in his attempt to correlate climatic parameters to suspended sediment load in rivers defined a rainfall distribution coefficient C as p_m^2/P where p_m is the mean rainfall for the wettest month of the year and P the mean annual rainfall. Soil erosion can be estimated using this coefficient only insofar as the suspended sediment load of a river is related to the soil loss for the whole catchment. Arnoldus (1980) obtained poor correlations between the EI_{30} and Fournier's indices. He proposed the modification:

$$\sum_{1}^{12} p_i^{\,2}/P$$

in which p_i is the monthly precipitation and P is the annual precipitation.

3. THE SOIL ERODIBILITY FACTOR K

The soil erodibility factor K in the universal soil loss equation describes the susceptibility of the soil to erosion and reflects the fact that different soils erode at different rates when the other factors that affect erosion are the same. As intended by the USLE, the experimental determination of K must be based on unit values for other factors in the equation (see further).

The inherent susceptibility of a soil to erosion by water is collectively determined by its structural and hydrological properties. Aggregate breakdown and particle detachment depend on aggregate stability and particle size distribution characterisitcs. The particle-transporting runoff depends not only on rainfall characteristics but also on water transmission and rillability properties of the soil, particularly infiltration rates at the prevailing antecedent water contents.

The dependence of soil susceptibility to water erosion on textural, structural, and hydrological properties has been established by several investigators (Wischmeier and Mannering, 1969; Wischmeier et al., 1971; Roth et al., 1974). They developed equations and nomographs which were recommended for estimating K-values whenever experimental values are not available (figure 2 and figure 3). These nomographs were widely used in the U.S. and in many other countries, including tropical. El-Swaify (1977) and El-Swaify and Dangler (1977) however criticized the use of the nomographs to predict the erodibility of tropical soils.

4. THE TOPOGRAPHIC FACTOR LS

It has been observed that soil loss per unit area increases with increasing slope length and slope steepness. The slope steepness in percent (s) and the slope length in meters (λ) are quantitatively incorporated in the USLE by the dimensionless factors S and L respectively.

The exponential dependence of soil loss on slope steepness (or gradient) is generally accepted. Mathematically the relation is:

$$E = c\ s^a$$

where E is the erosion, s the slope in percent and a is an exponent.

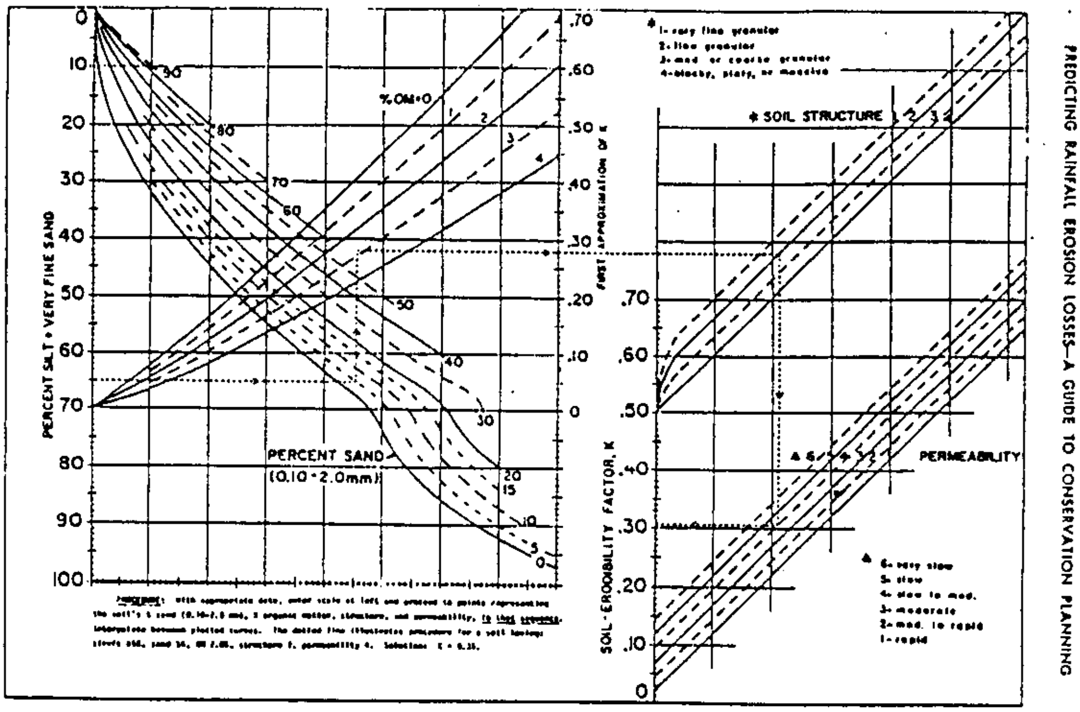

Figure 2 : Soil erodibility nomograph (Wischmeier et al., 1971)

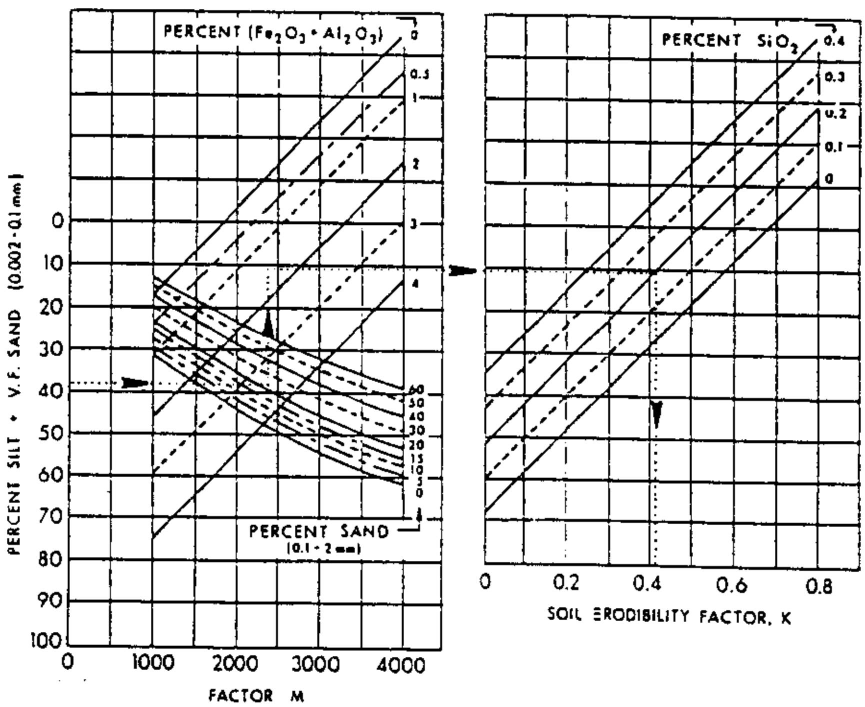

Figure 3 : Roth, Nelson, and Romkens' (1974) nomograph for soil erodibility estimation

Zingg (1940) analyzed the results of laboratory and field plot experiments and found a value for a of 1.49. Musgrave (1947) used a = 1.35. Wischmeier and Smith (1965, 1978) calculated the dimensionless S factor for the USLE as:

$$S = \frac{0.43 + 0.30\ s + 0.043\ s^2}{6.613}$$

in which the figure 6.613 is the value of the numerator for a standard soil plot (s = 9%).

Hudson and Jackson (1959) found that in the more extreme erosion conditions of the tropics the slope effect is more exaggerated and that a figure of about 2 is more appropriate for the exponent a.

It is agreed that the dependence of soil loss E on slope length l is of the form:

$$E = b\ l^m$$

in which b and m are empirical constants. For slopes of 3 percent or less the exponent becomes 0.3, for 4 percent slopes it is 0.4, and for 5 percent or steeper the exponent is 0.5 (Wischmeier and Smith, 1958). For the USLE the slope length factor L, a dimensionless factor has been calculated as:

$$L = \left(\frac{l}{22.13}\right)^m$$

where l is the slope length in meters and 22.13 m the length for standard plots for which L = 1, and m is the exponent as explained above.

In the USLE a combined LS factor is used as shown in figure 4. This figure is intended for use on uniform slopes.

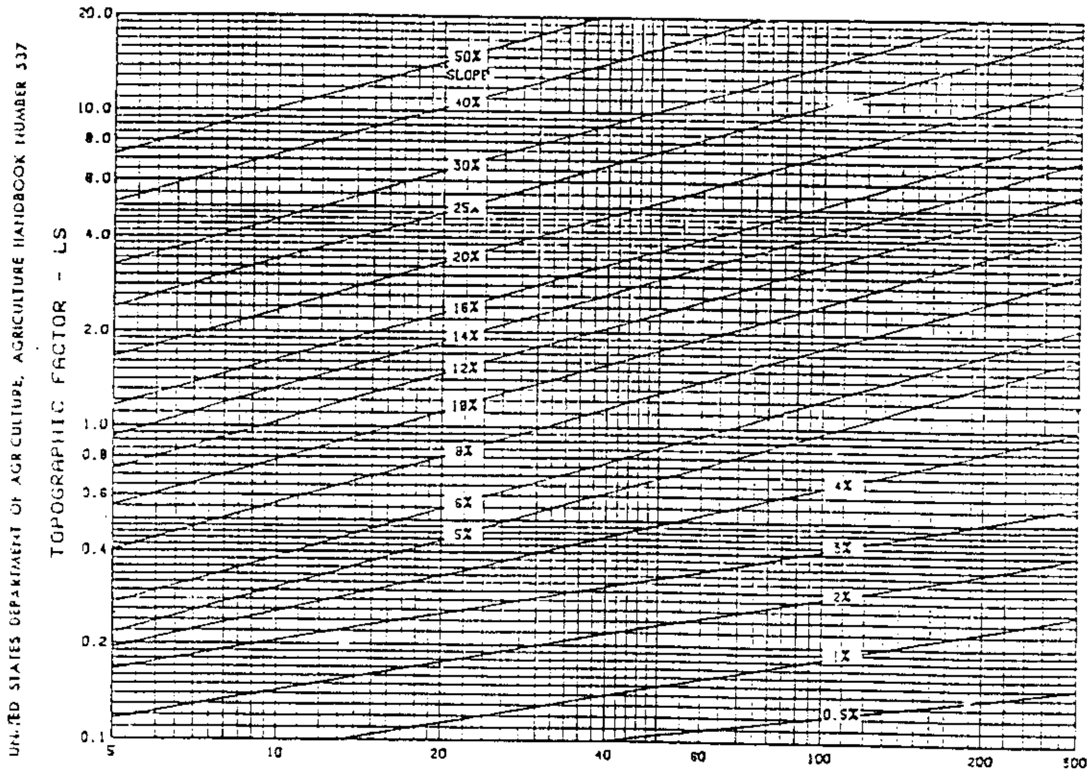

Figure 4 : Slope steepness - slope length chart

Foster and Wischmeier (1974) developed an equation to derive the LS factor for irregular slopes by breaking them up into a series of segments each with an uniform regular slope but having different gradients. Table 1 derived by this procedure shows the amounts of soil loss for successive equal-length segments of a uniform slope. Segment No. 1 is always at the top of the slope. For example, three equal length segments of a uniform 10 percent slope would be expected to produce 19, 35 and 46 percent of the loss from the entire slope.

Table 1 : Estimated relative soil losses from successive equal-length segments of a uniform slope

Number of segments	Sequence number of segment	Fraction of soil loss		
		m = 0.5	m = 0.4	m = 0.3
2	1	0.35	0.38	0.41
	2	.65	.62	.59
3	1	.19	.22	.24
	2	.35	.35	.35
	3	.46	.43	.41
4	1	.12	.14	.17
	2	.23	.24	.24
	3	.30	.29	.28
	4	.35	.33	.31
5	1	.09	.11	.12
	2	.16	.17	.18
	3	.21	.21	.21
	4	.25	.24	.23
	5	.28	.27	.25

[1] Derived by the formula:

$$\text{Soil loss fraction} = \frac{j^{m+1} - (j-1)^{m+1}}{N^{m+1}}$$

where j = segment sequence number; m = slope-length exponent (0.5 for slopes $\geq$ 5 percent, 0.4 for 4 percent slopes, and 0.3 for 3 percent or less); and N = number of equal-length segments into which the slope was divided.

The following calculation illustrates the procedure for a 150 meter convex slope on which the upper third has a gradient of 5 percent; the middle third 10 percent and the lower third 15 percent.

Segment	% slope	Figure	Table	Product
1	5	1.2	0.19	0.228
2	10	3.0	0.35	1.050
3	15	5.5	0.46	2.530
			LS =	3.808

5. CROP MANAGEMENT FACTOR C

The factor C in the universal soil loss equation is the ratio of soil loss from land cropped under specific conditions to the corresponding loss from clean-tilled, continuous fallow (Wischmeier and Smith, 1978). This factor measures the combined effect of all the interrelated cover and management variables, crop sequence, productivity level, growing season length, cultural practices, residue management, rainfall distribution.

The magnitude of the C factor may be derived experimentally from research plots designed to measure soil loss. To calculate its numerical value, cropstage periods must be defined and their duration as well as cover effectiveness estimated. Each segment of the cropping and management sequence must be evaluated in combination with the rainfall erosivity distribution for the region.

To calculate the C factor, the year is divided into a series of cropstage periods defined so that cover and management effects may be considered approximately uniform within each period. Six cropstage periods were defined by Wischmeier et al. (1978):

1. Rough fallow,
2. seedbed: 10% canopy cover,
3. establishment: 50% canopy cover (35% for cotton),
4. development: 75% canopy cover (60% for cotton),
5. maturing crop,
6. residue or stubble.

Elwell and Stocking (1976) considered the time distributions of crops cover and rainfall throughout the season, and developed a percent cover-soil loss relationship as an alternative to the USLE cropping-management factor.

Table 2 reports the C factor identified by Roose (1977) for cultivated crops on Alfisols and Oxisols in West Africa.

Table 2 : Estimated value of the C factor in West Africa (Roose, 1977)

Practice	Annual average C factor
Bare soil	1
Forest or dense shrub, high mulch crops	0.001
Savannah, prairie in good condition	0.01
Over-grazed savannah or prairie	0.1
Crop cover of slow development or late planting (first year)	0.3-0.8
Crop cover of rapid development or early planting (first year)	0.01-0.1
Crop cover of slow development or late planting (second year)	0.01-0.1
Corn, sorghum, millet (as a function of yield)	0.4-0.9
Rice (intensive fertilization)	0.1-0.2
Cotton, tobacco (second cycle)	0.5-0.7
Peanuts (as a function of yield and date of planting)	0.4-0.8
First year cassava and yam (as a function of date of planting)	0.2-0.8
Palm tree, coffee, cocoa with crop cover	0.1-0.3
Pineapple on contour (as a function of slope)	
(burned residue)	0.2-0.5
(buried residue)	0.1-0.3
(surface residue)	0.01
Pineapple and tied-ridging (slope 7%)	0.1

6. CONSERVATION PRACTICE FACTOR P

The conservation practice factor or support practice factor or erosion control practice factor P in the USLE is the ratio of soil loss with a specific control practice to the soil loss with up-and-down slope culture. The erosion control practices to be considered are contouring, contour strip-cropping and terracing.

The practice factors for the three major mechanical practices as recommended by Wischmeier and Smith (1978) are shown in table 3.

Table 3 : Erosion control practice factor P (Wischmeier and Smith, 1978)

Land Slope, percentage	Contouring	Contour Strip cropping and Irrigated Furrows	Terracing (1)
1-2	0.60	0.30	0.12
3-8	0.50	0.25	0.10
9-12	0.60	0.30	0.12
13-16	0.70	0.35	0.14
17-20	0.80	0.40	0.16
21-25	0.90	0.45	0.18

(1) For prediction of contribution to off-field sediment load

The factor for terracing is for the prediction of the total off-the-field soil loss when the terrace and ridge are cropped the same as the inter-terrace area. If within terrace interval soil loss is desired, the terrace interval distance should be used for the slope length factor L.

REFERENCES

AHMAD, N. and E. BRECKNER. 1974.
Soil erosion on three Tobago soils.
Trop. Agric. (Trinidad) 51 (2): 313-324.

ARNOLDUS, H.M. 1980.
An approximation of the rainfall factor in the universal soil loss equation. In De Boodt M. and Gabriels, D. (eds.): Assessment of Erosion.
Wiley and Sons, London, pp. 127-132.

BEST, A.C. 1950.
The size distribution of raindrops.
Quaterly Journal of the Royal Meteorological Society 76, 16.

BHATIA, K.S. and R.S. SINGH. 1976.
Evaluation of rainfall intensities and erosion index values for soil conservation.
Indian For. 102 (10): 726-734.

BISAL, F. 1960.
The effect of raindrop size and impact velocity on sand splash.
Canadian Journal of Soil Science 40, 242-245.

BOLLINNE, A.; A. LAURENT; P. ROSSEAU; J.M. PAUWELS; D. GABRIELS and J. AELTERMAN 1980.
Provisional rain erosivity map of Belgium. In De Boodt, M. and D. Gabriels (eds.): Assessment of Erosion.
Wiley and Sons, Chichester, pp. 441-453.

BOLS, P.L. 1978.
The iso-erodent map of Java and Madura.
Report of the Belgian Assistance Project ATA 105, Soil Research Institute, Bogor, Indonesia.

CARTER, C.E.; J.D. GREER; H.J. BRAUD and J.M. FLOYD. 1974.
Raindrop characteristics in South Central United States.
Trans. Am. Soc. Agric. Engrs., 17, 1033-1037.

DE WULF, F. and D. GABRIELS.
A device for analyzing the energy load of raindrops. In: De Boodt, M. and D. Gabriels (eds.): Assessment of erosion.
Wiley and Sons, London, 165-169.

ELLISON, W.D. 1944.
Studies of raindrop erosion.
Agricultural Engineering, 25: 131-136, 181-182.

EL-SWAIFY, S.A. 1977.
Susceptibilities of certain tropical soils to erosion by water. In: Greenland D. and R. Lal (eds.): Soil Conservation and Management in the Humid Tropics.
Chichester, pp. 71-77.

EL-SWAIFY, S.A.; E.W. DANGLER and C.L. ARMSTRONG. 1982.
Soil erosion by water in the tropics.
Research Extension Series 024, HITAHR, College of Tropical Agriculture and Human Resources.
University of Hawaii, pp. 173.

ELWELL, H.A. and M.A. STOCKING. 1976.
Vegetal cover to estimate soil erosion hazard in Rhodesia.
Geoderma 15: 61-70.

EVANS, R. 1980.
Mechanics of water erosion. In: Kirkby M.J. and R.P. Morgan (eds.):
Soil Erosion. pp. 111.
Wiley and Sons, Chichester.

FORREST, P.M. 1970.
The development of two field instruments to measure erosivity: A simple rainfall intensity meter, and an acoustic rainfall recorder tested with a rotating disk simulator.
B. Sc. (Hons) dissertation, National College of Agricultural Engineering, Silsoc, England.

FOSTER, G.R. and W.M. WISCHMEIER. 1974.
Evaluating irregular slopes for soil loss prediction.
Trans. Amer. Soc. Agric. Eng. 17 (2): 305-309.

FOURNIER, F. 1960.
Climat et érosion.
Presses Universitaires de France, Paris.

FREE, G.R. 1960.
Erosion characteristics of rainfall.
Agr. Engr. 41: 447-449.

GUNN, R. and G.D. KINZER. 1949.
Terminal velocity of water droplets in stagnant air.
Jour. of Meteorology 6: 243-248.

HUDSON, N. and D.C. JACKSON. 1959.
Results achieved in the measurement of erosion and runoff in southern Rhodesia.
Proc. Inter. African Soils Conference Compte Rendus 3: 575-583.

HUDSON, N.W. 1963.
Raindrop size distribution in high intensity storms.
Rhodesian Journal of Agricultural Research 1, 1, 6-11.

HUDSON, N.W. 1964.
The flour pellet method for measuring the size of raindrops.
Res. Bull. No. 4, Salisbury, Rhodesia: Dept. of Conserv. and Extension.

HUDSON, N.W. 1965.
The influence of rainfall on the mechanics of soil erosion with particular reference to Southern Rhodesia.
Unpublished M.S. thesis, University of Capetown.

HUDSON, N.W. 1971.
Soil Conservation.
Ithaca, N.Y., Cornell Univ. Press.

KINNELL, P.I.A. 1968.
An acoustic impact rainfall recorder.
Postgraduate certificate dissertation, National College of Agricultural Engineering, Silsoe, England.

LAL, R. 1976.
Soil erosion on Alfisols in Western Nigeria, III: Effects of rainfall characteristics.
Geoderma 16: 389-401.

LAWS, J.O. 1941.
Measurements of fall-velocity of waterdrops and raindrops.
Trans. Amer. Geophys. Union 22: 709-712.

LAWS, J.O. and D.A. PARSONS. 1943.
The relation of raindrop size to intensity.
Trans. Amer. Geophys. Un. 24: 452-459.

MIHARA, J. 1952.
Raindrops and soil erosion.
Nation. Inst. Agric. Sci., Tokyo, Japan.

MIHARA, H. 1959.
Raindrops and soil erosion.
Bulletin of the National Institute of Agricultural Science, Series A, 1.

MUSGRAVE, G.W. 1947.
The quantitative evaluation of factors in water erosion, a first approximation.
Jour. Soil and Water Conservation 2: 133-138.

ROOSE, E. 1977.
Application of the universal soil loss equation of Wischmeier and Smith in West Africa. In Greenland and Lal (eds.): Soil conservation and management in the humid tropics.
Wiley and Sons, London, pp. 177-187.

ROTH, C.B.; D.W. NELSON and M.J. ROMKENS. 1974.
Prediction of subsoil erodibility using chemical, mineralogical, and physical parameters.
EPA-660/2-74-043, Washington, D.C., U.S. Environmental Protection Agency, Office of Research and Development.

WISCHMEIER, W.H. and D.D. SMITH. 1958.
Rainfall energy and its relationship to soil loss.
Trans. Amer. Geophys. Union 39 (2): 285-291.

WISCHMEIER, W.H. and D.D. SMITH. 1965.
Predicting rainfall-erosion losses from cropland east of the Rocky Mountains.
Agric. Handbook No. 282, Washington, D.C., USDA.

WISCHMEIER, W.H. and J.V. MANNERING. 1969.
Relation of soil properties to its erodibility.
Proc. Soil Sci. Soc. Amer. 33 (1): 131-137.

WISCHMEIER, W.H.; C.B. JOHNSON and B.V. CROSS. 1971.
A soil erodibility nomograph for farmland and construction sites.
Jour. of Soil and Water Conservation 26 (5): 189-193.

WISCHMEIER, W.H. and D.D. SMITH. 1978.
Predicting rainfall-erosion losses. A guide to conservation planning.
Agric. Handbook No. 537. Washington, D.C., USDA.

ZINGG, A.W. 1940.
Degree and length of land slope as it affects soil loss in run-off.
Agric. Eng. 21: 59-64.