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Assessment of the Resistance of land to Erosion for Land Evaluation

Jamaica Physical Land Evaluation System

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Assessment of the Resistance of Land to Erosion for Land Evaluation

Abstract

The presented method for determining the resistance to erosion of land was designed for a computerized land evaluation system that is being developed in the Rural Physical Planning Division of the Ministry of Agriculture of Jamaica.

It considers the environmental factors that influence soil erosion (rainfall erosivity, soil erodibility, slope gradient and slope length) and also incorporates the land use and soil management in the determination of the grade of resistance to erosion.
All these factors are calculated with a modified version of the Universal Soil Loss Equation (USLE). The resulting soil loss is calculated for a number of pre-specified combinations of soil conservation practices including zero soil conservation and is compared with the tolerable soil loss.
The final rating of the resistance to erosion is expressed as a range in values of the land use or crop factor.
The data required for the described method are available in most developing countries. The series of calculations involved have proved to be rather complex. Therefore, a flow-chart has been developed to facilitate the adaptation of the formulas to a computer. For those lacking a computer a "manual" method has also been worked out.

1. Introduction

The complexity of the erosion process can best be understood by analyzing the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978):

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

where: A = Soil loss (tonnes/ha yr);
R = Rainfall erosivity (index);
K = Soil erodibility (tonnes/ha);
L = Slope length factor (no dimension);
S = Slope gradient factor (no dimension);
C = Crop factor (no dimension);
P = Soil management factor (soil conservation factor) (no dimension).

With equation (1) the soil loss can be calculated under different conditions of climate, topography, management and soils. USLE has been developed for use in the United States, and its validity for tropical countries is sometimes doubted. However, no other formulas are available as yet.
USLE is used in this article to calculate the soil loss of a hectare of land with a certain land use, and to compare this calculated soil loss with the tolerable soil loss. By adapting the land use and the soil conservation practices, it is possible to arrive at a land-land use system, that adequately protects the soil against erosion.
In the following pages each factor of USLE will be discussed. For the manual method classes of all factors are proposed and used for the determination of the final rating of the land quality ' resistance to erosion'. A flow chart of the computerized calculation procedure is presented in Annex 4. A computer program in Basic can be obtained from the author.

2. Environmental factors

2.1 The Rainfall Erosivity Index (R)

The rainfall erosivity index is calculated using equation (9) of Annex 1. Alternative formulas to calculate R are discussed in annex 1. In equation (9) the total annual rainfall plays no direct role. A numerical example of this phenomenon is the comparison of Turrialba, Costa Rica and Smithfield, Jamaica: Turrialba has an annual rainfall of 2,680 mm and a value of R of 122; Smithfield has an annual rainfall of 2,500 mm and a value of R of 2,600.

The classes of the rainfall erosivity index are presented in table 1. The computerized calculation requires the exact value of R as one of its inputs.

Table 1. Classes of the Rainfall Erosivity Index R

Class	Range of R
R1	500 - 1,000
R2	1,000 - 1,500
R3	1,500 - 2,000
R4	2,000 - 2,500
R5	> 2,500

2.2 The Soil Erodibility Factor (K)

Soils with a high content of silt and very fine sand and a low content of clay and organic matter are generally highly susceptible to erosion, i.e, have a high erodibility. This susceptibility generally decreases with increasing contents of clay and organic matter.

The nomograph of figure 1 allows the determination of the soil erodibility factor if no pocket calculator is available. The formula, on which this nomograph was based, is presented in Annex 2. The data required for the nomograph are: %silt and very fine sand (0.002-0.1 mm fraction), %sand (0.1-2.0 mm fraction), % organic matter, a soil structure parameter for the topsoil and a permeability parameter.
The calculation procedure for the computer is shown in annex 2.

The K-values of a number of temperate and tropical soils are presented in table 2. In some cases soils of the same taxonomic subgroup can greatly differ in terms of their susceptibility to erosion (K-factor).

Table 2. Soil Erodibility Factor K in Selected Tropical and Temperate Locations

Location	Soil Type	K(tonnes/ha)
USA (Hawaii)	Humoxic Tropohumults	0.13
	Typic Torrox	0.31
	Tropeptic Eutrustox	0.22
USA (Puerto Rico)	Typic Tropohumults	0.01
	Vertic Eutropepts	0.02
	Typic Dystropepts	0.12
Trinidad	Orthoxic Tropudults	0.12
	Orthoxic Tropudults	0.08
Costa Rica (Turrialba)	Alluvial	0.16
	Typic Dystropepts	0.10
Ecuador (Quito)	Entic Dystrandepts	0.18
USA (New York)	Dunkirk siltloam	0.89
USA (Ohio)	Keene siltloam	0.62
USA (Texas)	Boswell fine sandy loam	0.32

Source: Posner (1982)

Some remarks about the determination of the soil erodibility as presented in figure 1 and Annex 2, must be made here:

(a) Tropical soils generally have lower K-values than soils of the temperate regions, which is most likely due to a higher aggregate stability in the former.

(b) The K-values are determined for soils with dry topsoils. This may not be realistic in soils with an impermeable or slowly permeable layer near the surface. These soils will be saturated with water shortly after the onset of a rainstorm. Subterranean water flows can occur, thereby decreasing aggregate stability and increasing the possibility for erosion (unpublished data of Forestry and Soil Conservation Department, Ministry of Agriculture, Kingston, Jamaica).

(c) The initial moisture content of the topsoil is of great importance when assessing K-values especially when two rainstorms occur within a short period of time. The moisture content of the topsoil just before the second rainstorm probably is of greater importance than the K-factor when predicting soil loss.

(d) The K-factor is generally underestimated in soils rich in amorphous oxides of aluminium or iron and in soils that have allophane, halloysite or immogolite as the predominant clay mineral because of the soils' low bulk density. For these volcanic ash soils, that show thixotropic characteristics, the initial moisture content is even more important for the above mentioned soils.

The classes of K for the "manual" method are shown in table 3. The computer uses the calculation procedure of K of annex 2.

Table 3. Classes of the Soil Erodibility factor K

Classes	Range of K-values (Tonnes/ha)
K1	0.05-0.10
K2	0.10-0.15
K3	0.15-0.20
K4	0.20-0.25
K5	0.25-0.30
K6	0.30-0.35

2.3 The slope length factor (L) and slope gradient factor (S)
Equation (2) yields the slope length factor L:

$$L = \left[\frac{l}{22.1} \right]^m$$

Where: l = slope length (m);
m = exponent (m = 0.3 for 0-0.5% slopes; m = 0 for slopes 0.5-10%; for slopes >10% m = 0.6);
L = slope length factor (no dimension).

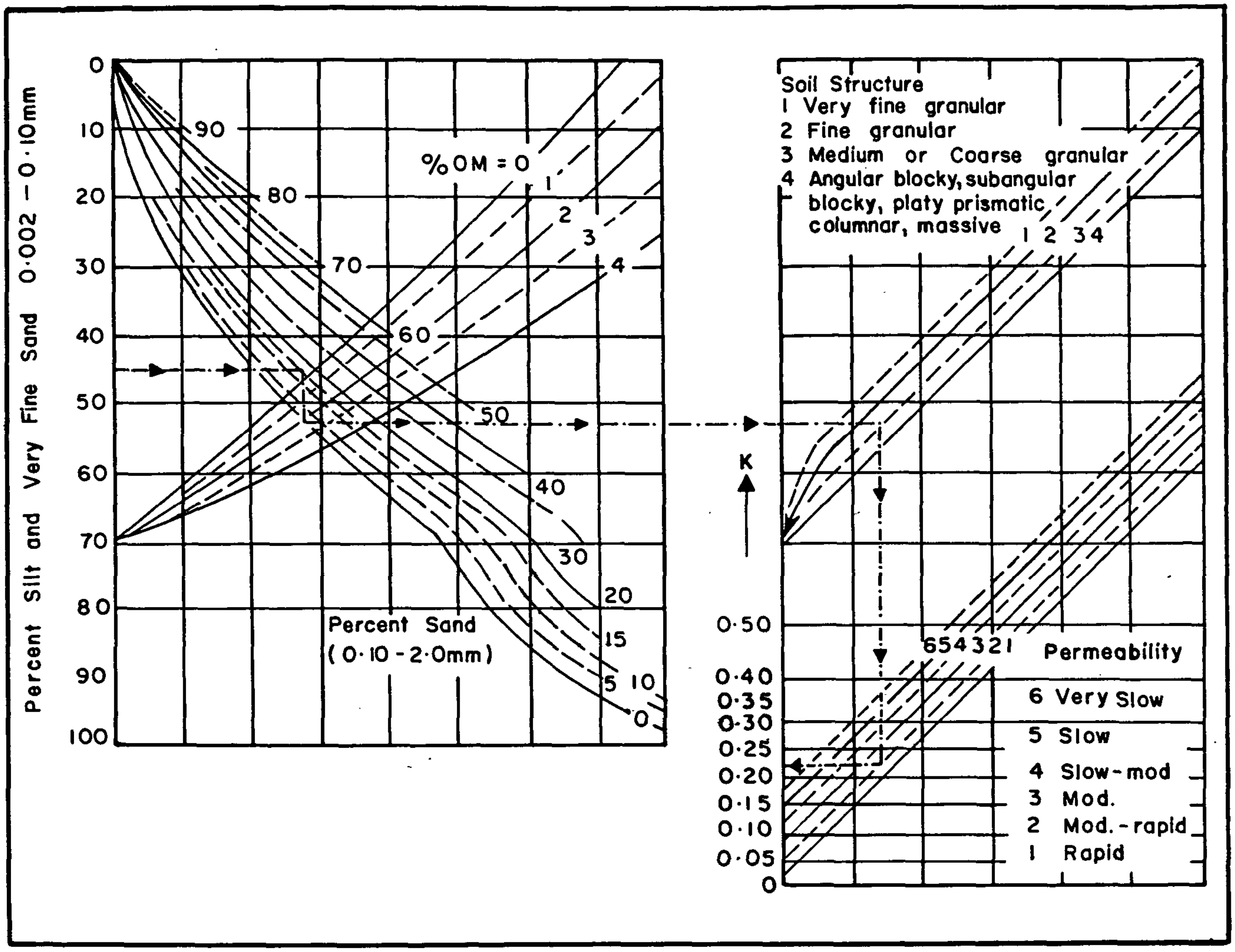


Figure 1. The soil erodibility nomograph. (K in tonnes/ha)
Source: Wischmeier and Smith (1978).

The slope gradient factor S is calculated with equation (3) or (4) depending on the slope gradient:

(a) For slopes < 20%: $S = 0.0065s^2 + 0.004545 + 0.065$ (3)

(b) For slopes > 20% $S = (s/9)^{1.35}$ (4)

Where : S = slope factor (no dimension);
s = slope gradient (in%).

Other formulas (see Wood, 1983) give approximately the same results as equations (3) and (4).
The classes of the slope gradient factor (S) is normally derived from the slope categories as found on a soil map or slope map.
The topography factor T can be calculated with equation (5).

$$T = L \times S \tag{5}$$

Using the topography factor T, the number of variables in USLE is reduced, thereby simplifying the final rating of the land quality 'resistance to erosion.' The classes of T can be determined using the slope gradient classes and slope length classes from in table 4. The slope gradient classes in table 4 are adapted from the FAO concept for topography (see FAO, 1977c).

Table 4. Classes of the Topography factor T and Corresponding T-values

Class	Range of T-values	Average Value of T	Slope Length (M)	Slope Class (%)
T1	0-0.50	0.25	all 0-30	0-2 2-8
T2	0.50-1.0	0.75	30-100 0-20	2-8 8-16
T3	1.0-2.5	1.75	100 20-50 0-20	2-8 8-16 16-30
T4	2.5-5.0	3.75	50-100 0-20	16-30 30-60
T5	5.0-7.5	6.25	50-100 0-20	16-30 30-60
T6	7.5-15.0	11.25	20-50 0-30	30-60 > 60
T7	> 15.0	15.0	> 50 > 30	30-60 > 60

In the computerized calculation procedure the slope gradient classes and slope length classes as shown in table 4 are both direct inputs of USLE (see annex 4).

3. Agronomical Factors

3.1 The Crop Factor C

Crops providing good protection of the soil surface, have a value of the crop factor C close to 0. For crops with poor soil coverage C is close to 1.0 (see Annex 3 for a list of crops with the corresponding c-values).
For annual and bi-annual crops, the value of C is an average of the C-values that are typical for the various stages of growth and development of the crop. The C-factor is close to 1 directly after land preparation and harvesting and close to 0 when the plants develop. At maturity, the value of C depends, amongst others, on weeding practices and row distance.

The C-value of treecrops depends on the type of undergrowth and soil cover. For pasture under coconuts the combined C-value is 0.01, i.e., the lowest C of the two crops (see Annex 3). The C-factor does not account for the large volume of earth movement that takes place on slopes during the planting and harvesting of tuberous crops.

The classes of C are in table 5. The classes of the C-factor are typical for certain groups of crops: C1 for (nearly) unprotected soil; C2 for crops with a low to moderate cover %; C3 for crops with moderate to high cover %; C4 for pasture and densely sown cereals; C5 for forest. The class ranges are taken wide to account for the variability of C during the growing season.
The computerized calculation procedure (Annex 4) yields as output feasible combinations of C and the soil management factor (P).

Table 5. Classes of the Crop Factor C

Class	Range of C-values
C1	0.8 - 1.0
C2	0.4 - 0.8
C3	0.1 - 0.4
C4	0.01 - 0.4
C5	less than 0.01

3.2 The Soil Management Factor P

The classes and the corresponding ranges of P-values that are used in the "Manual" method of determination of the resistance to erosion are shown in table 6. The soil conservation practices have been divided into 4 groups, according to the level of required inputs. Each input level corresponds to a specific combination of cultural and mechanical soil conservation practices. Each of these is indicated by a specific value of K (conservation option number, see Annex 5). Each combination of conservation practices has its corresponding P-values as shown in table 6 and TAB P (k, j) in Annex 4.

From table 6 and TAB P (k, j) in Annex 4 follows that the P_factor is related to topography, because the effect of soil conservation practices generally decreases with increasing slope gradient.
The soil conservation practices have been grouped according to their level of required inputs, because any form of conservation must be economically and socially viable. This is meant to facilitate the economic evaluation of the proposed conservation practices.

Table 6. Values of the Soil Management Factor (P) at Four Input Levels for 6 Slope Classes and the Corresponding Soil Conservation Option Number (K).

Input level	Corr. Value of K (annex 5)	Slope Class (%) 0-2	2-8	8-16	16-30	30-50	>50
A low	3	0.6	0.5*	0.6	0.7	0.8	0.9
B medium	6	0.3	0.25*	0.3	0.4	0.55	0.7
C high	8	0.15	0.10*	0.15	0.2	0.25	0.35
D very high	13	0.01	0.01	0.02	0.03	0.04	0.05

* Contouring is most effective on 2-7% slopes (Hudson, 1981)

The computerized calculation procedure (see Annex 4) is based on a more complex table for P. It considers 13 conservation options that are described in Annex 5. The P-values are in TAB P (k.j) in Annex 4 where k expresses the soil conservation option number and j the slope gradient class. The computer programme yields the feasible combinations of C and P (k, j) (crop and required soil conservation practices) and the total variable and fixed cost of the required conservation measures. Therefore no grouping according the the required inputs has been added. Some routines have been included in the computer programme that prevent the calculation of unfeasible combinations of soil conservation practices and crops/land use (e.g. forest on bench terraces) or soil depth (bench terraces on shallow soils are not recommended).

4. The Tolerable Soil Loss

All the factors that influence the erosion process and the protection of the soil surface have been discussed in the previous chapters.With USLE it is now possible to calculate the (hypothetical) soil loss from a hectare of land with specified environmental and soil management conditions.

The tolerable or acceptable soil loss needs to be quantified at this stage of the discussion. The FAO (1977b) uses a tolerable soil loss of 11.2 tonnes/ha/yr for soils over 150 cm deep and 6.7 to 4.5 tonnes/ha/yr for 50 to 100 cm deep soils. For shallower soils, the tolerable soil loss is set at 2.2 to 4.5 tonnes/ha/yr.

Wood (1983) uses a rate of soil formation of 6 tonnes/ha.yr as the basis for calculation. For adequate soil conservation, soil loss should be less than or equal to the rate of soil formation.

A tolerable soil loss of 10 tonnes/ha/yr and of 5 tonnes/ha/yr has been used for deep resp. moderately deep soils (100 cm, resp. 50-100 cm) when rating the resistance to erosion. It has been assumed that net soil loss (total soil loss minus soil formation) is 0.

5. Rating of the Landquality Resistance to Erosion

5.1 "Manual" Method

The correct combination of crops and soil conservation techniques that result in a reduction of the erosion to a tolerable level, has to be assessed. At this level of erosion, a high productivity can be maintained for long periods.

For a specific land (mapping) unit, the potential soil loss PL can be calculated. The tolerable soil loss (TL) is 5 or 10 tonnes/ha.yr (for deep and moderately deep soils respectively). The relation between TL and PL is a function of the type of crop (with specific crop factor C) and soil conservation practice (determining the value of the P-factor). Schematically, the procedure is as follows:

$$\boxed{PL = R \times K \times T} \qquad (6)$$

$$\boxed{TL/PL = C_x} \qquad (7)$$

: for the current resistance to erosion (without soil conservation)

$$\boxed{TL/(PL \times P_y) = C_x} \qquad (8)$$

: for the potential resistance to erosion (with soil conservation)

Where: TL = Tolerable soil loss (5 or 10 tonnes/ha/yr);

PL = Potential soil loss

C_x = Crop factor

P_y = Soil management factor.

Table 8. Final rating of the Resistance to Erosion. T = topography factor, R = rainfall erosivity index, K = soil erodibility. The rating is expressed as a code that corresponds to the class number of the crop factor C (e.g. 2 = C2);

For moderately deep soils (50-100 cm):

		T1		T2		T3		T4		T5		T6		T7	
R1(500-1000)															
K1	2/1	3	1 3/1 1	3	2 4/1 3	4	3 4/1 3	4	4 4/2 4	4	4 5/3 4	5	4 5/3 4	5	5/3
K2	2/1	3	1 3/1 2	4	3 4/1 3	4	3 4/1 4	4	4 4/2 4	4	4 5/3 4	5	5 5/3 4	5	5/4
K3	3/1	3	2 3/1 2	4	3 4/1 3	4	4 4/1 4	4	4 5/2 4	5	4 5/3 4	5	5 5/4 5	5	5/4
K4	3/1	3	2 4/1 3	4	3 4/1 3	4	4 4/1 4	5	4 5/3 4	5	5 5/3 5	5	5 5/4 5	5	5/4
K5	3/2	4	2 4/1 3	4	3 4/1 4	4	4 4/2 4	5	4 5/3 4	5	5 5/3 5	5	5 5/4 5	5	5/4
K6	3/2	4	3 4/1 3	4	3 4/1 4	4	4 5/2 4	5	4 5/3 4	5	5 5/4 5	5	5 5/4 5	5	5/4
R2(1000-1500)															
K1	2/1	3	1 3/1 2	4	3 4/1 3	4	3 4/1 4	4	4 4/2 4	5	4 5/3 4	5	5 5/3 4	5	5/4
K2	3/1	3	2 4/1 3	4	3 4/1 3	4	4 4/1 4	5	4 5/3 4	5	4 5/3 5	5	5 5/4 5	5	5/4
K3	3/2	4	3 4/1 3	4	3 4/1 4	4	4 5/2 4	5	4 5/3 4	5	5 5/3 5	5	5 5/4 5	5	5/4
K4	3/2	4	3 4/1 3	4	4 4/1 4	4	4 5/2 4	5	4 5/3 4	5	5 5/4 5	5	5 5/4 5	5	5/4
K5	3/2	4	3 4/1 3	4	4 4/1 4	5	4 5/2 4	5	4 5/3 4	5	5 5/4 5	5	5 5/4 5	5	5/4
K6	3/2	4	3 4/1 3	4	4 4/1 4	5	4 5/3 4	5	5 5/3 5	5	5 5/4 5	5	5 5/4 5	5	5/4
R3(1500-2000)															
K1	3/1	3	2 3/1 2	4	3 4/1 3	4	4 4/1 4	4	4 4/2 4	5	4 5/3 4	5	5 5/4 5	5	5/4
K2	3/2	4	3 4/1 3	4	3 4/1 4	4	4 5/2 4	5	4 5/3 4	5	5 5/3 5	5	5 5/4 5	5	5/4
K3	3/2	4	3 4/1 3	4	4 4/1 4	5	4 5/2 4	5	4 5/3 4	5	5 5/4 5	5	5 5/4 5	5	5/4
K4	3/2	4	3 4/1 3	4	4 4/1 4	5	4 5/3 4	5	5 5/3 5	5	5 5/4 5	5	5 5/4 5	5	5/4
K5	4/3	4	3 4/1 3	4	4 5/1 4	5	4 5/3 4	5	5 5/3 5	5	5 5/4 5	5	5 5/4 5	5	5/4
K6	4/3	4	3 4/1 4	4	4 5/1 4	5	4 5/3 4	5	5 5/4 5	5	5 5/4 5	5	5 5/4 5	5	5/4
R4(2000-2500)															
K1	3/1	3	2 4/1 3	4	3 4/1 3	4	4 4/1 4	5	4 5/3 4	5	5 5/3 4	5	5 5/4 5	5	5/4
K2	3/2	4	3 4/1 3	4	4 4/1 4	4	4 5/2 4	5	4 5/3 4	5	5 5/4 5	5	5 5/4 5	5	5/4
K3	3/2	4	3 4/1 3	4	4 4/1 4	5	4 5/3 4	5	5 5/3 5	5	5 5/4 5	5	5 5/4 5	5	5/4
K4	4/3	4	3 4/1 3	4	4 5/1 4	5	4 5/3 4	5	5 5/3 5	5	5 5/4 5	5	5 5/4 5	5	5/4
K5	4/3	4	3 4/1 4	4	4 5/1 4	5	4 5/3 4	5	5 5/4 5	5	5 5/4 5	5	5 5/4 5	5	5/4
K6	4/3	4	3 4/1 4	5	4 5/1 4	5	4 5/3 4	5	5 5/4 5	5	5 5/4 5	5	5 5/4 5	5	5/5
R5(> 2500)															
K1	3/1	3	2 4/1 3	4	3 4/1 3	4	4 4/2 4	5	4 5/3 4	5	5 5/3 5	5	5 5/4 5	5	5/4
K2	3/2	4	3 4/1 3	4	4 4/1 4	5	4 5/2 4	5	4 5/3 5	5	5 5/4 5	5	5 5/4 5	5	5/4
K3	4/3	4	3 4/1 3	4	4 4/1 4	5	4 5/3 4	5	5 5/3 5	5	5 5/4 5	5	5 5/4 5	5	5/4
K4	4/3	4	3 4/1 4	4	4 5/1 4	5	4 5/3 4	5	5 5/3 5	5	5 5/4 5	5	5 5/4 5	5	5/4
K5	4/3	4	3 4/1 4	5	4 5/1 4	5	4 5/3 4	5	5 5/4 5	5	5 5/4 5	5	5 5/4 5	5	5/5
K6	4/3	4	3 4/1 4	5	4 5/1 4	5	4 5/3 5	5	5 5/4 5	5	5 5/4 5	5	5 5/4 5	5	5/5

For deep soils (100 cm):

		T1		T2		T3		T4		T5		T6		T7	
R1(500-1000)															
K1	1/1	2	1 2/1 1	3	1 3/1 2	3	3 4/1 3	4	3 4/1 3	4	4 4/2 4	4	4 4/3 4	4	4/3
K2	1/1	2	1 3/1 1	3	2 3/1 2	4	3 4/1 3	4	4 4/1 4	4	4 4/2 4	5	4 5/3 4	5	4/4
K3	2/1	3	1 3/1 2	3	2 4/1 3	4	3 4/1 3	4	4 4/2 4	4	4 5/3 4	5	4 5/4 4	5	5/4
K4	2/1	3	1 3/1 2	4	3 4/1 3	4	3 4/1 4	4	4 4/2 4	5	4 5/3 4	5	5 5/4 4	5	5/4
K5	3/1	3	2 3/1 2	4	3 4/1 3	4	4 4/1 4	4	4 4/2 4	5	4 5/3 4	5	5 5/4 5	5	5/4
K6	3/1	3	2 3/1 2	4	3 4/1 3	4	4 4/1 4	4	4 5/2 4	5	4 5/3 4	5	5 5/4 5	5	5/4
R2(1000-1500)															
K1	1/1	2	1 2/1 1	3	2 4/1 2	4	3 4/1 3	4	4 4/1 4	4	4 4/2 4	5	4 5/3 4	5	4/4
K2	1/1	3	1 3/1 2	4	3 4/1 3	4	3 4/1 3	4	4 4/2 4	4	4 5/3 4	5	4 5/4 4	5	5/4
K3	2/1	3	2 3/1 2	4	3 4/1 3	4	4 4/1 4	4	4 5/2 4	5	4 5/3 4	5	5 5/4 5	5	5/4
K4	2/1	3	2 3/1 3	4	3 4/1 3	4	4 4/1 4	5	4 5/3 4	5	4 5/3 4	5	5 5/4 5	5	5/4
K5	2/1	3	2 3/1 3	4	3 4/1 3	4	4 4/1 4	5	4 5/3 4	5	5 5/3 5	5	5 5/4 5	5	5/4
K6	3/2	4	2 3/1 3	4	3 4/1 4	4	4 5/2 4	5	4 5/3 4	5	5 5/3 5	5	5 5/4 5	5	5/4
R3(1500-2000)															
K1	2/1	3	1 3/1 2	3	2 4/1 3	4	3 4/1 3	4	4 4/2 4	4	4 5/3 4	5	4 5/3 4	5	5/4
K2	3/1	3	2 3/1 2	4	3 4/1 3	4	4 4/1 4	4	4 5/2 4	5	4 5/3 4	5	5 5/3 5	5	5/4
K3	3/1	3	2 4/1 3	4	3 4/1 3	4	4 4/1 4	5	4 5/3 4	5	4 5/3 4	5	5 5/4 5	5	5/4
K4	3/1	3	2 4/1 3	4	3 4/1 4	4	4 4/2 4	5	4 5/3 4	5	5 5/3 5	5	5 5/4 5	5	5/4
K5	3/2	4	3 4/1 3	4	3 4/1 4	4	4 5/2 4	5	4 5/3 4	5	5 5/4 5	5	5 5/4 5	5	5/4
K6	3/2	4	3 4/1 3	4	4 4/1 4	4	4 5/2 4	5	4 5/3 4	5	5 5/4 5	5	5 5/4 5	5	5/4
R4(2000-2500)															
K1	2/1	3	1 3/1 2	4	3 4/1 3	4	3 4/1 4	5	4 4/2 4	5	4 5/3 4	5	5 5/4 4	5	5/4
K2	3/1	3	2 4/1 3	4	3 4/1 3	4	4 4/1 4	5	4 5/3 4	5	4 5/4 4	5	5 5/4 5	5	5/4
K3	3/2	3	2 4/1 3	4	3 4/1 4	4	4 4/2 4	5	4 5/3 4	5	5 5/4 5	5	5 5/4 5	5	5/4
K4	3/2	4	3 4/1 3	4	3 4/1 4	4	4 5/2 4	5	4 5/3 4	5	5 5/4 5	5	5 5/4 5	5	5/4
K5	3/2	4	3 4/1 3	4	4 4/1 4	5	4 5/2 4	5	4 5/3 4	5	5 5/4 5	5	5 5/4 5	5	5/4
K6	3/2	4	3 4/1 3	4	4 4/1 4	5	4 5/3 4	5	4 5/3 5	5	5 5/4 5	5	5 5/4 5	5	5/4
R5(> 2500)															
K1	2/1	3	1 3/1 2	4	3 4/1 3	4	3 4/1 4	4	4 4/2 4	5	4 5/3 4	5	5 5/4 4	5	5/4
K2	3/1	3	2 4/1 3	4	3 4/1 3	4	4 4/1 4	5	4 5/3 4	5	4 5/3 5	5	5 5/4 5	5	5/4
K3	3/2	4	3 4/1 3	4	3 4/1 4	4	4 5/2 4	5	4 5/3 4	5	5 5/3 5	5	5 5/4 5	5	5/4
K4	3/2	4	3 4/1 3	4	4 4/1 4	4	4 5/2 4	5	4 5/3 4	5	5 5/4 5	5	5 5/4 5	5	5/4
K5	3/2	4	3 4/1 3	4	4 4/1 4	5	4 5/2 4	5	4 5/3 4	5	5 5/4 5	5	5 5/4 5	5	5/4
K6	3/3	4	3 4/1 3	4	4 4/1 4	5	4 5/3 4	5	5 5/3 5	5	5 5/4 5	5	5 5/4 5	5	5/4

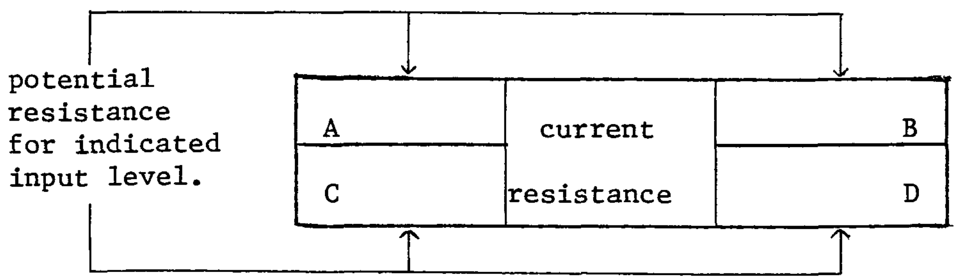
The "manual method is summarized in table 8. The classes of R, K and T are as presented in tables 1, 3 and 4. The final rating of the resistance to erosion is expressed as the ranges of values of the crop factor that correspond to the previously defined classes of C (see table 7 and table 5).

Table 7. <u>Classes of the Resistance to Erosion and the Corresponding Subrating of C and Acceptable Range of Values of C</u>

Rating	Class of C	Range of C
1. Very high resistance to erosion	C1	0.8 - 1.0
2. High resistance to erosion	C2	0.4 - 0.8
3. Medium resistance to erosion	C3	0.1 - 0.4
4. Low resistance to erosion	C4	0.01-0.1
5. Very low resistance to erosion	C5	< 0.01

Thus, the current and potential resistance to erosion for the 4 different combinations of soil conservation practices can be determined for a specific land unit.

Table 8 shows for each combination of R, K and T a set of 5 numbers, that are grouped as follows:



The following example illustrates the use of table 8:

example

Data: R = 1250; Soil: 45% silt and very fine sand and 15% sand, 2% organic matter in topsoil; (top)-soil structure is coarse granular; the permeability is 175 mm/h (mod. to rapid); slope class 2-8%, slope length 0-30m. Soil depth 120 cm. The input level of soil conservation is low (level A).

Procedure: The classes of P, K and F follow table 1, figure 1 and table 4. respectively: R2, K4 and T1. Table 8 shows for this deep soil a high resistance to erosion (rating 2) with an acceptable range of the crop factor C of 0.4-0.8 at input level A. In annex 3 the crop (s) that correspond to this range of crop factor C may be found.
If the crop is the starting point instead of the input level of soil conservation then the required soil conservation practices can be determined (with given R, K and T).

Combinations of input level D of soil conservation (soil conversation option number 13) with acceptable values of C of less than 0.1 (C4 and C5 for pasture resp. forest) may occur in table 8. However, it is beyond the scope of this article to judge the economic viability of soil conservation practices.

5.2 Computerized Calculation Procedure

A flow chart of the model is shown in Annex 4. the outputs of the model are the feasible combinations of P and C (soil conservation practices and crops) and the costs of the involved soil conservation practices.

6. Discussion

The method as presented can easily be computerized as follows from the computer flow chart of Annex 4. The advantage of the discussed method is, that it takes the environmental factors such as rainfall intensity, soil and slope, as well as crop and managament factors into consideration.
A recognized disadvantage is, that the calcualtions are based on factors that vary widely from one site to another and that are not easily determined. The rainfall erosivity can only be determined if the maximum 30-minute rainfall intensity is known. Otherwise, R has to be estimated or another index has to be used.

Exact values of the crop factor are lacking. The value of C varies greatly during the growing season and depends on crop management (control of pests and diseases, etc.). The method of determining the soils' erodibility K has been tested on a number of soil types in the USA and can only with great caution be used in tropical countries.

The calculations as presented in this paper cannot yield the exact soil loss, because the basic formula is far from universal. The method, however, is highly suitable to assess which type of land use and of soil management practice are best suited for a specific land (mapping) unit, considering factors such as climate, soil and topography.

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Annex 1

Determination of the Rainfall Erosivity Factor R

1. $R = \frac{E \times I_{30}}{1000}$ (9)

Where: R = Rainfall erosivity (index);
E = Total storm kinetic energy (Joules/m^2/mm of rainfall);
I_{30}= Maximum 30-minute intensity (that occurs during that particular rainstorm) in mm/h.

1.1 The kinetic energy of rainfall is calculated for the various classes of rainfall intensity (0-25, 25-50, 50-75, 75-100, etc.) with the following equations:

$E = 11.9 = 8.7 \log (1)$ I in mm/h, E in J/m^2/mm (Wischmeier, 1978) (10)

$E = 30 - \frac{125}{(I)}$ I in mm/h, E in J/m^2/mm (Hudson, 1981) (11)

1.2 The total amount of rainfall in each class of rainfall intensity and the total kinetic energy (=E x total rainfall in intensity class) are calculated for each month and rainfall intensity class.

Intensity Class (mm/h)	E° (J/m^2/mm)	Total Rainfall					E x Total Rainfall				
		Jan	Feb	Mar		Dec	Jan	Feb	Mar		Dec
0-25	24.1										
25-50	26.7										
50-75	28.2										
75-100	29.3										
100-125	30.1										
125-150	30.8										
etc.											

Monthly Sum

I_{30}

$\frac{I_{30} \times \text{monthly sum}}{1000}$

Yearly Total

° calculated with equation (10)

2. If No I_{30} data are available from autographic raingauge charts there are different alternatives to the above described method. Two of these alternative methods will be briefly described.

2.1 KE >25 index: Rainfall intensities of less than 25 mm/h are considered to be non-erosive. KE >25 is calculated by multiplying E (calculated with equation (10) or (11) with the total amount of rainfall in each rainfall-intensity class (KE >25 is expressed in J/M^2).

2.2 Bols rainfall agressivity index (see Wood et al, 1983):

$$E \times I_{30} = 6.119\ (RAIN)^{1.21}\ (DAYS)^{-0.47}\ (MAXP)^{0.53}$$

Where: ExI_{30} = Bols agressivity index;
RAIN = Total monthly rainfall (mm);
DAYS = Number of raindays per month;
MAXP = Maximum 24 h rainfall in month.

The Bols agressivity index is used in Indonesia; it has not been tested elsewhere yet.

Annex 2

Determination of the Soil Erodibility factor K
(The presented formula is the basis of the nomograph of fig. 1)

$$K = 2.730t^{1.14} (10^{-6}) (12-o) + 0.0325 (s-2) = 0.025 (h-3) \quad (12)$$

Where: t = particle size parameter (t = (%silt + very fine sand) x (100-%clay); silt 0.002-0.05 mm; very fine sand 0.05-0.10 mm; clay 0.002 mm (see also below);
h = permeability parameter (see table below);
s = soil structure parameter (see table below);
o = parameter for the organic matter content of the topsoil; 0=1 for org. matter % 0-1; o=2 for org. matter content of 1-2%; o=3 for 2-3% and 0=4 for topsoils with more than 3% organic matter.

h	USDA Permeability Class (mm/h)
6	< 1.5
5	1.5-15
4	15-50
3	50-150
2	150-500
1	> 500

s	(top-) soil structure type
1	very fine granular
2	fine granular
3	medium or coarse granular
4	blocky, platy, or massive

If no sieve analyses data are available, an approximation to t can be obtained from the following table, using the textural class of the topsoil.

Textural Class	Approximation to t
heavy clay	210
medium clay	750
sandy clay	1215
light clay	1685
sandy clay loam	2160
silty clay	2510
clay loam	2830
sand	3035
loamy sand	3245
silty clay loam	3770
sandy loam	4005
loam	4390
silt loam	6330
silty	8245

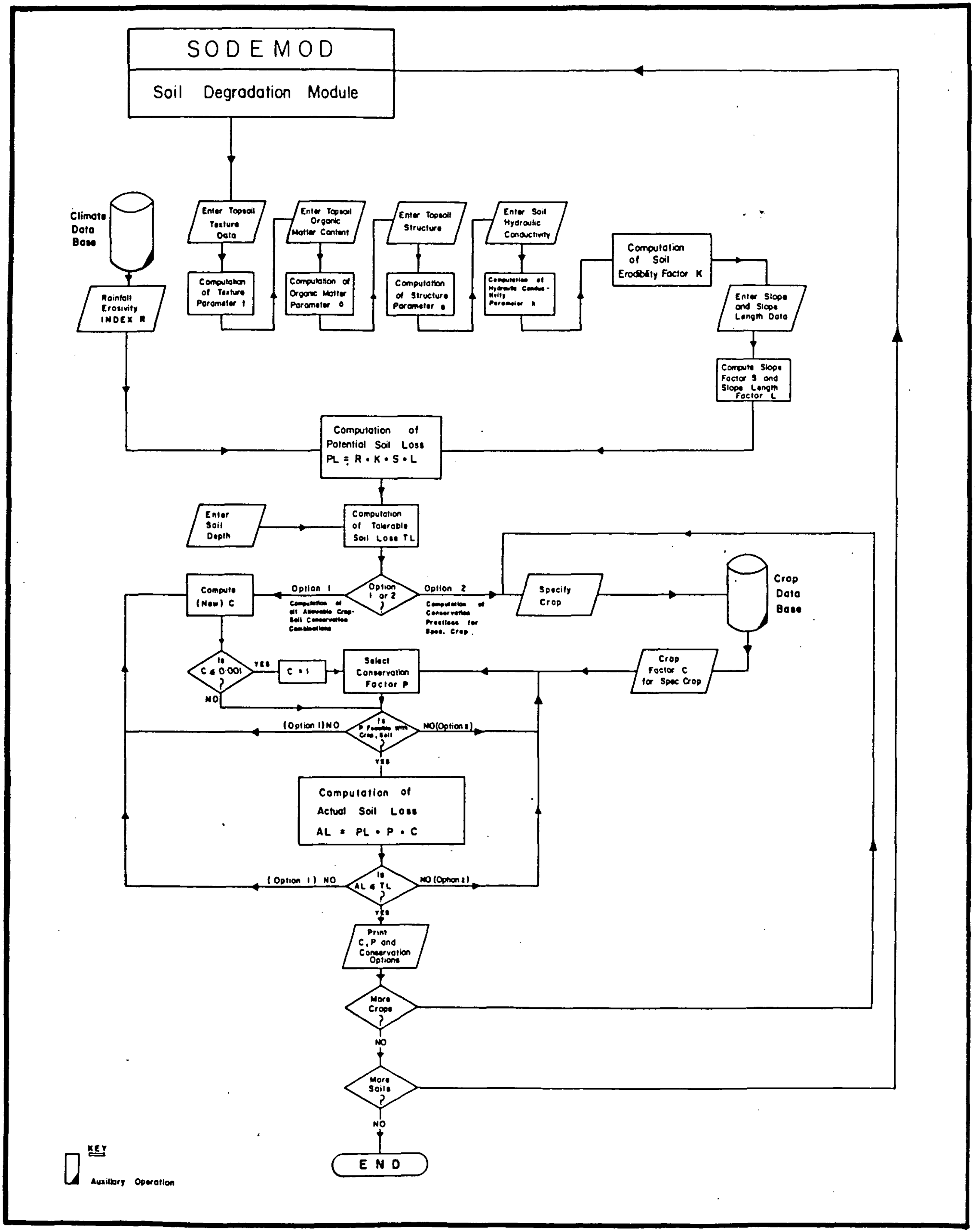
Source: Wood (1983)

Annex 3

Examples of C-values for various crops

Type/Group	Name	C-value
Cereals	maize	0.29-0.64
	rice	0.01
	sorghum	0.24
Legumes	phaseolus bean	0.35
	groundnut	0.45
	soybean	0.40
Sugar cane		0.30
Tuberous crops	sweet potato	0.40
	irish potato	0.45
	cassava	0.65
	yam	0.70
	taro	0.70
Treecrops	coffee	0.60
	coffee with ground-cover	0.20
	cocoa	0.80
	cashew	0.50
	coconut	0.70
Fruits	pineapple	0.40
	banana	0.55
Others	chilly peppers	0.80
	cotton	0.85
	tobacco	0.16
Intercropped	maize and	
	-sweet pepper	0.45
	-beans	0.45
	-groundnut	0.35
	-soybean	0.45
	-cassava	0.55
	groundnut-cassava	0.20
	soybean-cassava	0.18
Mixed Garden		0.10-0.30
Pasture		0.01
Forest		0.003

Sources: Wood (1983), Hudson (1981), FAO (1977 b).


SODEMOD
Soil Degradation Module
Climate Data Base
Rainfall Erosivity INDEX R
Enter Topsoil Texture Data
Computation of Texture Parameter t
Enter Topsoil Organic Matter Content
Computation of Organic Matter Parameter o
Enter Topsoil Structure
Computation of Structure Parameter s
Enter Soil Hydraulic Conductivity
Computation of Soil Erodibility Factor K
Enter Slope and Slope Length Data
Compute Slope Factor S and Slope Length Factor L
Computation of Potential Soil Loss PL = R • K • S • L
Enter Soil Depth
Computation of Tolerable Soil Loss TL
Option 1 or 2 ?
Option 1
Computation of all Allowable Crop-Soil Conservation Combinations
Option 2
Computation of Conservation Practices for Spec. Crop.
Compute (New) C
Specify Crop
Crop Data Base
Is C ≤ 0.001 ?
YES
NO
C = 1
Select Conservation Factor P
Crop Factor C for Spec Crop
Is P Feasible with Crop, Soil ?
(Option 1) NO
NO (Option 2)
YES
Computation of Actual Soil Loss AL = PL • P • C
Is AL ≤ TL ?
(Option 1) NO
NO (Option 2)
YES
Print C, P and Conservation Options
More Crops ?
NO
More Soils ?
NO
END
KEY
Auxiliary Operation

Annex 5

Specification of the Level of Cultural and Mechanical Practices of the Soil Conservation Options (k).

K	Level of Cultural Practices	Level of Mechanical Practices
1	very low	none
2	very low	low
3	low	none
4	low	low
5	low	moderate
6	moderate	none
7	moderate	low
8	moderate	moderate
9	moderate	high
10	high	none
11	high	low
12	high	moderate
13	high	high

Description of the Levels of Cultural Practices:

Very low: Zero mulch; crop residues removed; no application of manure; no mineral fertilizers; no farm plan; no crop rotation; bare fallow; monocropping; no living barriers.

Low: Low mulch applications; (less than 0.5 tonnes/ha); crop residues burnt on site; no application of manure; low gifts of mineral fertilizers; no farmplan; some crop rotation; contour cropping; intercropping; living barriers are grown at contours.

Medium: Surface mulch application (1-3 tonnes/ha); application of manure and/or composts; suboptimal use of mineral fertilizers; crop rotation; farmplan; intercropping; contour-strip cropping; if perennials: use of annual intercrops.

High: Surface mulch application (more than 3 tonnes/ha); application of mineral fertilizers combined with manure or composts; farmplan; crop rotation with legumes; intercropping or monocropping with good rotation; if perennials: use of intercrops and cover crops (legumes); contour stripcropping with grass strips.

Description of Mechanical Practices:

None: No soil conservation practices; field boundary effects only.

Low: Colluvial terraces (stone/bamboo/wood/living barriers).

Medium: For annual crops: hillside ditches and grassed waterways; for perennials: graded orchard terraces with reverse slope and with grassed waterways.

High: Graded bench terraces with reverse slope and stabilized risers; water disposal system.