ESTIMATING THE USLE - SOIL ERODIBILITY FACTOR IN DEVELOPING TROPICAL COUNTRIES:A CASE STUDY IN TANZANIA

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Abstract

Developing countries in the tropics are facing more soil erosion problems than the developed temperate countries. These developing countries have no accurate locally applicable equation(s) for predicting soil erosion or for planning and implementation of soil conservation measures. Furthermore, these countries do not have the necessary resources to develop the soil loss prediction equation(s). Existing empirical equations like the Universal Soil Loss Equation (USLE) if modified to suit tropical conditions can be useful a tool in soil erosion control in the region for a foreseeable future.

In this paper equations for estimating the soil erodibility factor in the USLE for tropical soils are presented. The equations have been developed using tropical soils, ranging from sandy to clayey in texture. Statistically the equations explain about 84 to 90 percent of the variations in soil erodibilities. As determining the USLE erodibility factor for the tropical soils has been a problem, difficult to solve, these equations are useful for the countries in the tropics needing soundly based measures for controlling soil erosion.

Introduction

Soil erosion is more serious in developing tropical countries than it is in developed temperate countries[1,2]. This is mainly due to the erosive nature of tropical rains and inappropriate land use practices[3,4,5,6,7]. Soil erosion problems in these countries is compounded by lack of resources to undertake soundly based soil conservation planning and implementation which requires a soil loss prediction tool as one of the inputs. Experience has shown that however well implemented, conservation measures like contour banks when used without the aid of accurate soil loss prediction equation still result in serious erosion on the land between the contour banks[8,9,10]

Up to now no appropriate and accurate soil erosion prediction equation exists for use in the tropics, although the Soil Loss Estimation Model for Southern Africa (SLEMSA)[8] and the Universal Soil Loss Equation (USLE)[11] are used in different tropical countries. The SLEMSA (developed in Zimbabwe) still needs some modifications[8] and have shown to give unrealistic soil loss values[12,13]. The USLE (developed in the USA) and widely used throughout the world has been found to be inapplicable in the tropics, mainly due to the fact that the nomograph for estimating its soil erodibility factor gives unrealistic values for tropical soils [10,14,15,16]. Furthermore, the table values developed in the USA for estimating the crop and soil management factor of the equation are not applicable for farming practices and conditions found in the tropics.

Currently research efforts in the developed temperate countries are directed towards developing physically based soil erosion prediction equations[17,18,19]. The aim is to overcome the transferability problems of empirical equations like the USLE and SLEMSA and to develop equations able to predict event based soil erosion and deposition. These equations are not going to be of use in most of the tropical countries in the foreseeable future. These countries have limited resources to meet research needs for generating necessary data base, insufficiently trained personnel[8] and they do not have agricultural sophistication required for practical use of the equations.

Since the physically based models are not going to be useful in developing countries of the tropics in the near future and the countries have very limited resources to meet expensive research, the only option open to them is to adapt empirical models such as the USLE. Developing a method useful for estimating the USLE - erodibility values is critical for the adaption of the equation in the tropics.

Developing methods for estimating soil erodibility in the tropics has been a problem difficult to solve because many soil parameters can be related to erodibility. The parameters are also variable from soil to soil, though texture - related parameters have been found to be the most important[14,20,21,22]. Furthermore, developing soil erodibility prediction equations need long term field runoff plot research or use of rainfall simulators[14,20]. Both of them require financial and technical resources which cannot be met by most of the developing countries in the tropics[8]. The equations presented in this paper for estimating the USLE - soil erodibility factor result from a wider research programme initiated to identify a suitable soil loss prediction equation for use under Tanzanian conditions[23,24].

Materials and Methods

Data on tropical soil erodibility and soil characteristics known to affect soil erodibility were assembled from different literature sources. The data obtained in sufficient amount to warrant statistical analysis for developing soil erodibility predictive equations were those related to the soil characteristics used to develop the USLE nomograph[25].

The soils and some of their characteristics used in the analysis are shown in Table 1. Simple correlation analysis was conducted to identify all the characteristics related to soil erodibility. All the characteristics identified to be related to erodibility were then subjected to multiple regression analysis using the Statistical Package for Social Scientists (SPSS). Backwards, forwards and stepwise multiple regression analysis was undertaken to obtain equations useful in predicting soil erodibility.

Runoff plot research sites at Sokoine University of Agriculture Farm, Morogoro (located at longitude 37^0 37' E and latitude 6^0 30' S) which had pairs of bare fallow plots, plots under semi-natural vegetation and plots under maize crop and at Hombolo Agricultural Research Institute, Dodoma (located at longitude 35^0 59' E and latitude 5^0 57' S) which had pairs of bare fallow plots and plots under sorghum[23] provided data to test the accuracy of the developed soil erodibility equations. The runoff plots were set up by the Agricultural Engineering Department, Sokoine University of Agriculture since the 1994/95 rainy season to provide data for testing and adaption of the SLEMSA and (R)USLE soil loss prediction equations under Tanzanian conditions.

Results and Discussion

The results of simple correlation of soil erodibility to some parameters used to develop erodibility equations are given in Table 2. The results show that soil erodibility (K) is strongly related to texture - related parameters as has been found in many studies[14,21,22,25].

Structure code and permeability class are as defined by Wischmeier et al.[25]

The multiple regression analysis involving all the parameters in Table 2 showed that only the Mn variable which equals percent silt (0.1 - 0.002 mm) plus percent

Table 1 Physical and chemical characteristics and soil erodibility values of some tropical soils

Soil type	Particle size distribution (%)			Permeability class*	Erodibility (SI - Units)	Reference
	clay	silt	sand			
1. Ferric Chromic Luvisol;sand clay loam	22.2	8.5	73.4	2.0	0.030	[2]
2. Fersiallitic (red) soil; clay loam	30.0	37.0	41.0	4.0	0.068	[27,22,27,10]**
3. Rhodic Ferrasol; clay	50.0	13.2	43.6	3.0	0.018	[18]
4. Rhodic Ferrasol; clay	43.8	10.8	54.2	2.0	0.020	[18]
5. Rhodic Ferralsol; clay	42.3	14.3	53.2	3.0	0.016	[18]
6. Haplorthox; clay	77.0	19.7	3.3	2.0	0.005	[28]
7. Tropohumult; clay	68.1	26.5	6.0	3.0	0.017	[28]
8. Tropuqualfs; clay	65.7	28.3	6.6	3.0	0.022	[28]
9. Arenosol/Luvisol; sand/loamy sand	4.1	11.0	92.5	1.0	0.024	[29]
10. Arenosol; sand/loamy sand	5.9	12.7	88.7	1.0	0.023	[29]
11. Cracking clay	62.0	34.0	7.1	3.0	0.032	[1]
12. Oxisol; loamy sand	20.0	1.5	83.4	1.0	0.007	[16,30]

* Permeability class as defined by Wischmeier et al. [13]

** The references provided data on soil characteristics for "K" computation

Table 2 Simple correlation coefficients between some soil parameters and erodibility for tropical soils listed in Table 1

Parameter*	Correlation coefficient
M	+0.920
Mn	+0.929
N	+0.636
Organic matter	-0.202
Structure code	+0.535
Permeability class	+0.425

* $M = (si + vfs)(si + vfs + sa > 0.1 mm)$; $Mn = si(si + sand)$; $N = si (sa)$

where si = silt (2 μm to 50 μm) (%); vfs = very fine sand (50 - 100 μm) (%);
sa = sand (> 100 μm) (%)

sand (> 0.1 mm) times percent silt was significant for predicting erodibility. As investigations have shown that the texture - related parameters were interrelated. further regression without the Mn parameter was performed. The regression showed that parameter M which equals percent silt (0.1 - 0.002 mm) plus percent very fine sand (0.05 - 0.1 mm) times the the quantity 100-minus-percent clay and permeability class (Pe) were significant in predicting soil erodibility, and the resulting equation had improved accuracy over the one involving only the Mn variable as shown in equations 1 and 3. Plots of observed soil erodibility versus predicted soil erodibility for equations 1 and 3 are shown in Figures 1 and 2.

$$K = 1.333 \times 10^{-4} + 2.459 \times 10^{-5} \text{ Mn} \qquad (r^2 = 0.864) \qquad (1)$$

$$K = 2.0114 \times 10^{-5} \text{ M} - 0.00155 \qquad (r^2 = 0.843) \qquad (2)$$

$$K = 1.8247 \times 10^{-5} \text{ M} + 0.0045 \text{ Pe} - 0.0097 \qquad (r^2 = 0.911) \qquad (3)$$

where K is soil erodibility (t - ha - h/ha - MJ - mm)
Mn = si(si + sa) (see Table 2)
M = a (a + sa) (see Table 2)
a = si + vfs (see Table 2)
Pe = 1 for rapid permeability ($\geq$ 127 mm/hr)
= 2 for moderate to rapid permeability (63.5 to 127 mm/hr)
= 3 for moderate permeability (20 to 63.5 mm/hr)
= 4 for slow to moderate permeability (5 to 20 mm/hr)
= 5 for slow permeability (1 to 5 mm/hr)
= 6 for very slow permeability (< 1 mm/hr)

The results explain why the USLE nomograph gives unrealistic erodibility values for tropical soils, although the results by Wischmeier et al.[25] and these results show that erodibility is strongly related to the parameter M (equation 2). The results by Wischmeier et al.[25] showed that the M parameter could explain about 85 % of the erodibility variations while the results in this paper show that it can explain about 84 % of the variations. It is however, important to note that for the erodibility range of 0.007 to 0.055 (t - ha - h/ha - MJ - mm) the M parameter of the soils used by Wischmeier et al.[25] (given in Roth et al.[22]) varied from 1615 to

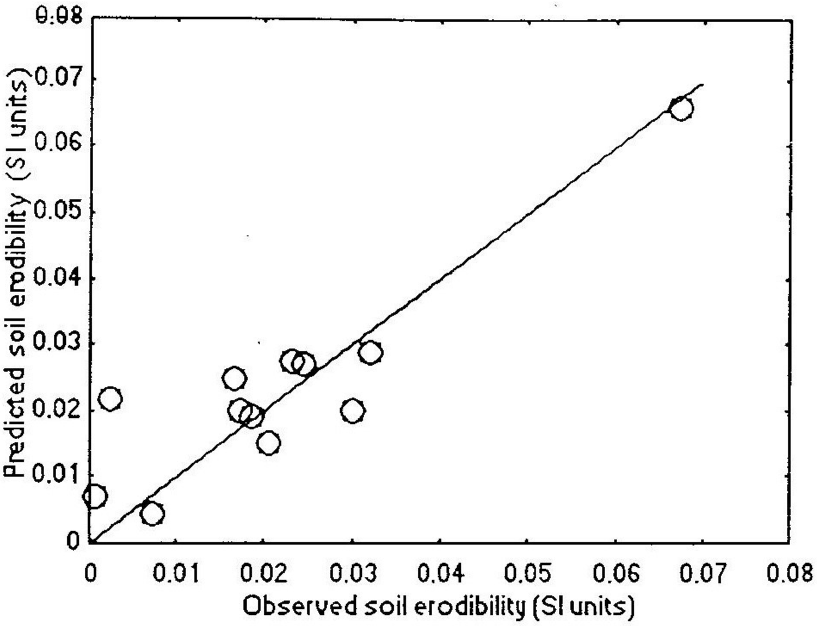

Fig. 2 Observed versus predicted soil erodibility using the equation involving parameter M and permeability class as defined by Wischmeier et al , 1971

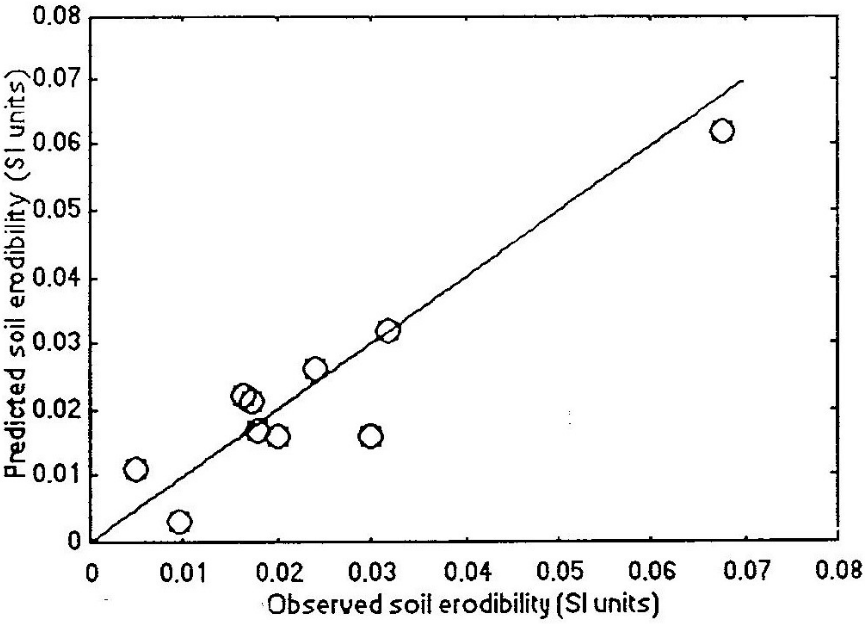

Fig. 1 Observed versus predicted soil erodibility using an equation involving parameter Mn: silt(silt+sand)

6641, while for the tropical soils used to derive equations 1 to 3 the erodibility varied from 0.005 to 0.068 (t - ha - h/ha - MJ - mm) and the M parameter varied from 447 to 3150.

As has been shown by other researchers in the USA [14,21,22], organic matter and structure code are not significant predictors of erodibility on soils other than the silt loams used to derive the nomograph. The results from simple correlation analysis (Table 2) show that the correlation of organic matter to erodibility is low while on the other hand structure code is much more related to erodibility than is permeability. The exclusion of structure code from the erodibility equation(s) while permeability is included is most likely due to its correlation with the parameters derived from soil texture and the general structural behaviour of tropical soils. Thus, the fact that the results from the multiple regression analysis show structure code to be insignificant in predicting soil erodibility does not mean that structure does not affect erodibility of tropical soils. Dispersion ratio and suspension percentage which are related to soil structure have shown to be related to soil erodibility in the tropics[14,23,16]. The structure related parameter like these if included in a an equation for estimating erodibility of some tropical soils have shown to improve its accuracy[14].

There are some tropical soils whose physical and chemical properties are not represented by the soils used to derive the equations above. For example the equations may be inaccurate when used to estimate erodibility of volcanic soils (called Andosols according to FAO soil classification system[26]) which have unique chemical and physical properties. Equation 1 which heavily depends on silt content (and probably the other two) may not be accurate for estimating erodibility of soils with very low contents of silt and sand as these soils are not represented by the soils used to derive them (see Table 1).

The results of soil erodibility from the ongoing runoff plot research[23,24] and the values calculated using the equations above are given in Table 3. The measured soil erodibility values are comparable with the predicted values. This indicates that the equations give good estimates although the measured values are from limited periods of research. The measured soil erodibility at Morogoro site which had been under semi-natural vegetation for about 8 years and runoff plots were not under bare fallow conditions for at least two years before data collection started is lower than the values predicted using equations two and three.

Table 3 Measured and predicted soil erodibility values at Morogoro and Hombolo (Dodoma), Tanzania

Site	Soil Type	Measured K (t - ha / ha - MJ - mm)	Estimated K (t - ha - / ha - MJ - mm) Eq.1	Eq. 2	Eq. 3
Hombolo	Haplic Alisol	0.018	0.019	0.020	0.019
Morogoro	Ferric Lixisol	0.011	0.010	0.018	0.021

Summary and Conclusion

Although derivation of the erodibility equations for the tropical soils have shown that soil erodibility is strongly related to texture-related soil characteristics as has been shown for soils in temperate regions, there are differences in the magnitudes of the characteristics for soils with relatively similar erodibility values in both regions. This is due to differences in clay, silt and sand fractions of the soils and possibly rainfall characteristics found in the two regions. While soils in the temperate region have all the three fractions well distributed, soils in the tropics are mainly composed of clay and/or sand fractions with relatively small fraction of silt content. The results have also shown that it is impossible to develop one universal soil erodibility equation.

The prediction of soil erosion in the tropics using the USLE or its revised version (RUSLE), widely used throughout the world had been hampered by the inapplicability of the soil erodibility nomograph for tropical soils. This paper has presented equations derived based on soil texture - related parameters and/or soil permeability that are technically accurate (i.e. explaining about 84 % to about 91 % of the erodibility variations) for estimating the erodibility factor of the (R)USLE in the tropics for soils whose physical and chemical characteristics are similar to the soils used in the derivation. The equations are useful for conservation planning in these areas currently suffering from severe soil erosion.

ACKNOWLEDGEMENT

The authors acknowledge with thanks the financial support obtained from the

Overseas Development Administration (ODA), now called Department For International Development (DFID), UK, and the Sokoine University of Agriculture, Morogoro, Tanzania.

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