AN EQUATION FOR ESTIMATING THE (R) USLE SLOPE STEEPNESS FACTOR, S

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ABSTRACT

Currently three equations are used for calculating slope steepness factor for the revised universal soil loss equation (RUSLE); one for slopes less than nine percent, the second for slopes equal or greater than nine percent, and the third equation that has been proposed for use in China for slopes equal or greater than 17 %. The three equations have linear relationships between slope steepness factor, S and the sine of the slope angle, q. The three equations under predict the factor, S when used on slope steepness beyond the data sets used to develop them. In addressing this problem several alternative forms of equations (linear, power, and polynomial) were tested using field plot soil loss data gathered by several researchers in different countries for slopes ranging from three percent to 55 %. A single power function relating the sine of the slope angle, q to the slope steepness factor, S has been identified to be more suitable and accurate for estimating the RUSLE slope steepness factor, S.

Key words: Slope steepness factor; Soil loss prediction; Statistical regression.

INTRODUCTION

The slope steepness factor, S for the Revised Universal Soil Loss Equation is the ration of soil loss from a field with given slope gradient to that from a field with slope gradient of nine percent under otherwise identical conditions (slope length, soils, soil moisture regimes, rainfall, and management) (Wischmeier and Smith, 1978). The slope steepness (gradient) affects soil erosion because it affects soil detachment and transport by rainfall splash (Brian, 1979; Savat, 1981) and runoff (Wischmeir and Smith, 1978). The relationship of slope steepness to soil loss is influenced by its interactions with soil properties, vegetation types, surface roughness, and residue management (Wischmeier and Smith, 1978; Liu et al,1994), and rainfall characteristics (Liu et al, 1994).

Different researchers have found varying relationships between slope steepness and soil loss. Zingg (1940), using simulated rainfall on slopes up to 20%, and Musgrave (1947), using composite data from slopes up to 16% found the slope steepness factor, S equation of the form:

$$S = \left(\frac{s}{9}\right)^n \qquad (1)$$

Where, s is the tangent of the slope angle and n is 1.4 or 1.35 respectively.

Smith and Wischmeier (1957) using data from runoff plot with gradients varying from three percent to 18% developed the slope steepness factor equation of the form:

$$S = 0.0065s^2 + 0.0453s + 0.065 \qquad (2)$$

Wischmeier and Smith (1978), realising that shear stress of the surface flow is related to the sine of the slope angle (Chow, 1959), used same data for equation 2 to develop the slope steepness factor of the form:

$$S = 65.4\sin^2\theta + 0.0453\sin\theta + 0.0654 \qquad (3)$$

McCool et al. (1987) using data from simulated rainfall for slopes of 0.1% to three percent and data from natural rainfall for slopes of three percent to 18 % and Liu *et al*. (1994) using data from natural rainfall for slopes of nine percent to 55 %, developed equations of the form:

$$S = A\sin\theta + B \qquad (4)$$

Where, A equals to 10.8, 16.8, or 21.91 and B equals to 0.03, -0.5, and –0.96, respectively.

Although for the slope steepness ranges used the linear relationship between soil loss to the sine of the slope angle was statistically more accurate the increasing gradients of the equations with increasing slope steepness suggest that using the equations for land slopes beyond that used to develop them results in under prediction of soil loss. This poses problems in planning soil conservation in mountainous regions where cultivation of steeper slopes is common. In this study an equation which can be used for all land slopes, giving accurate predictions is presented.

MATERIALS AND METHODS

Data on slope steepness and soil loss for slopes ranging from three percent to 55 % were assembled from different literature sources (Wendelaar, 1978; Liu *et al*., 1994; Vogel, 1994; Mulengera; 1996). All the data came from natural runoff plot research. All soil loss data not normalized to nine percent slope as required for use in the RUSLE were normalized (Murphree and Mutchler, 1981).

The Microsoft Excel soft ware was used for statistical regression analysis. Tangent values of slope angles and sine values of the slope angles were used to test the three different functional forms, (i.e. linear, polynomial, and power) to identify the most consistently accurate equation(s) for estimating the slope steepness factor, S.

RESULTS AND DISCUSSION

Figures one to three show some of the statistical regression analysis results. The three expressions shown are the best results from the regression analysis. The slope steepness factor equation of the polynomial form (Fig. 2) shows that soil erosion stops when gradient equals 1.3 % and below this value the equation predicts deposition. Thus, the equation is not good for land slopes below the lowest value of runoff plots data used for its development (i.e. three percent). Although the coefficient of determination for the linear function relationship is the highest, the slope angle does not show to follow the scatter well. As a result it shows that soil erosion stops when land slope is 3.25 % and the equation predicts deposition for lower slope gradients. The scatter plot points below about four percent slope gradient show that the linear slope steepness factor equation under predicts soil erosion. Therefore, this equation is also not suitable for such low slope gradients.

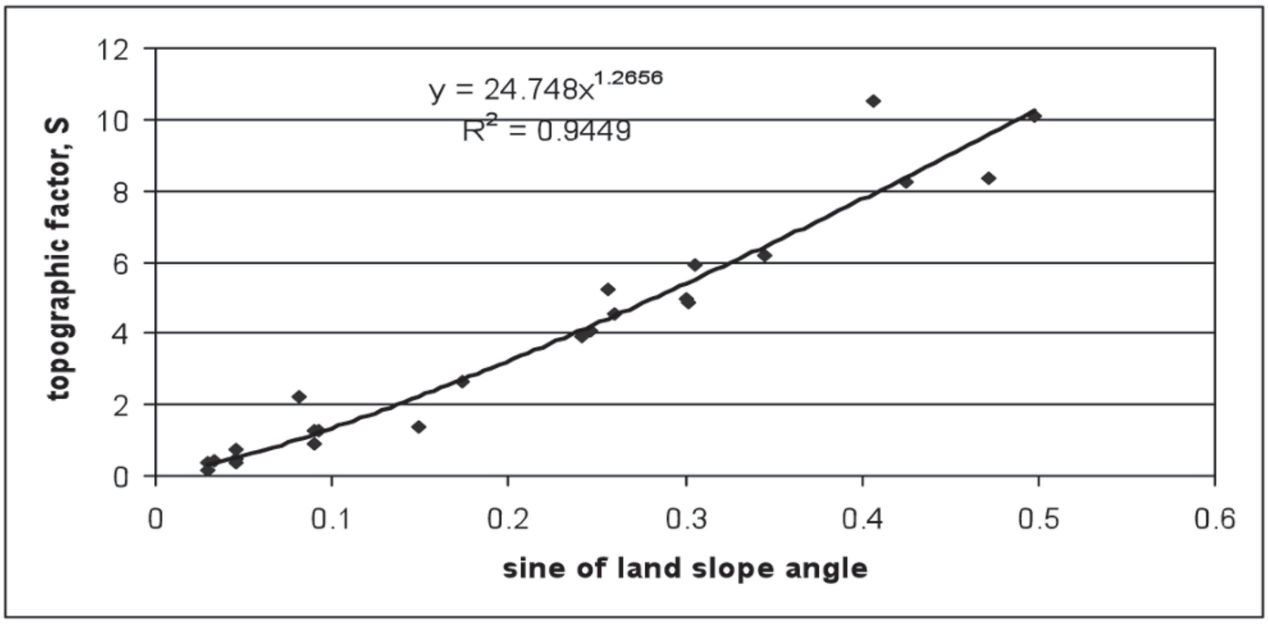


Fig. 1: Power function relating topographic factor, S to sine of slope angle, θ

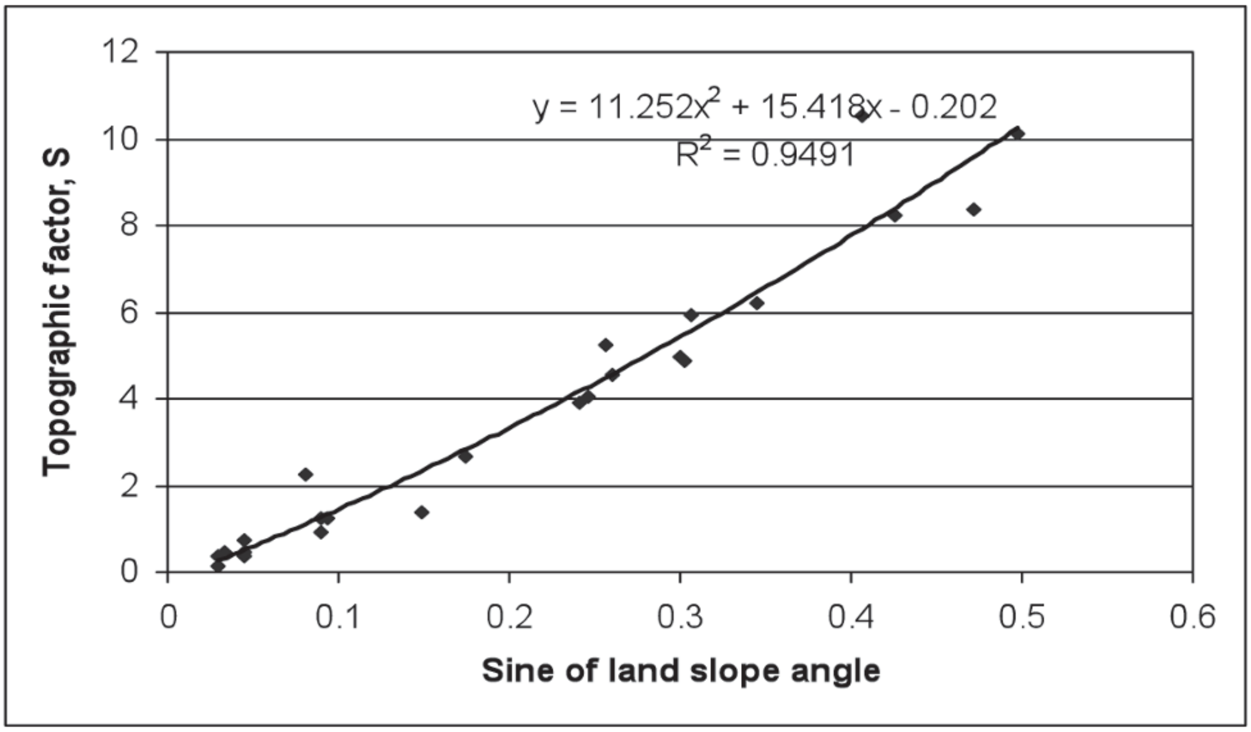


Fig. 2: Polynomial function relating topographic factor, S to sine of slope angle θ

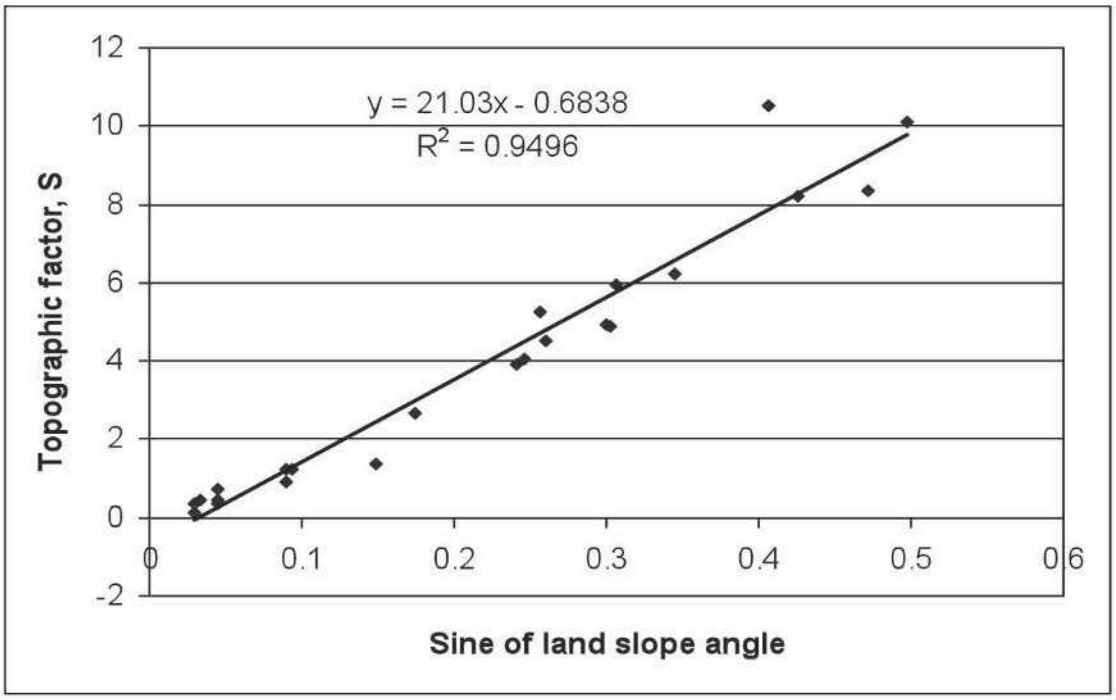


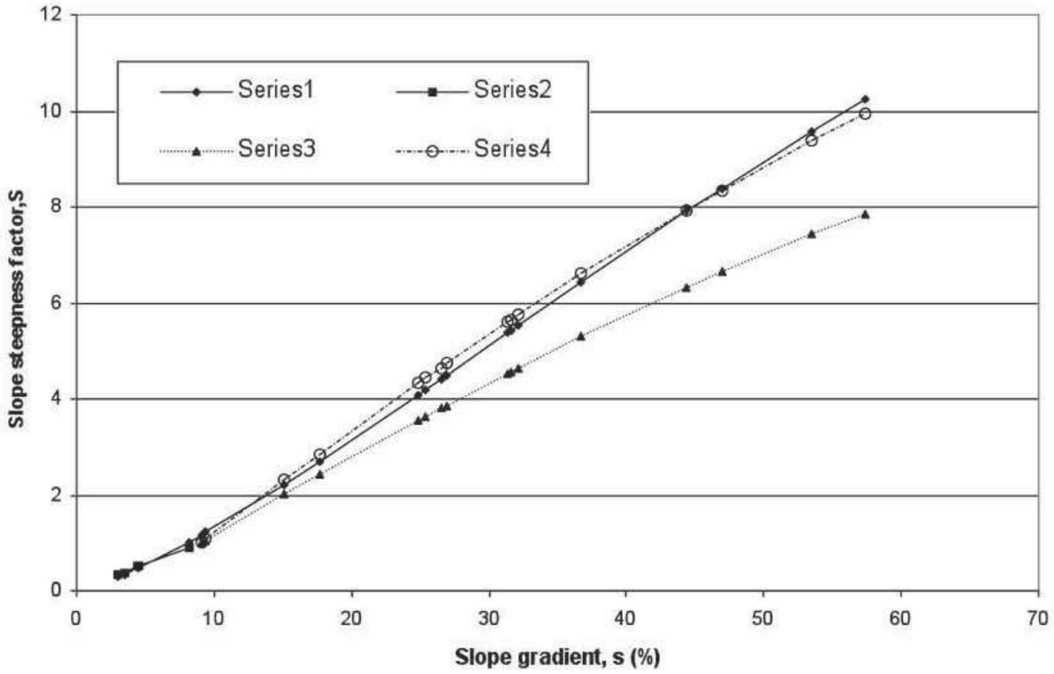
Fig. 3: Linear function relating topographic factor, S to sine of slope angle, θ

Figure four shows that the currently used slope steepness factor, S equations and the new power function equation give close values for the data ranges that were used during their development. However, they give different prediction values when not so. For example, the series three equation gives low values when compared to the series one and four, and its under prediction increases with increasing slope steepness. Thus, the new power function equation (series 1) can be used to give good estimates of slope steepness factor, S, the RUSLE for all slope gradients.

SUMMARY AND CONCLUSIONS

Several equations have been proposed for calculating slope steepness factor of the revised USLE. Currently three equations are used, one for slopes less than nine percent, the second for slopes equal or greater than nine percent, and the third equation that has been proposed for use in China for slopes equal or greater than 17 %. The three equations have linear relationships between slope steepness factor, S and the sine of the slope angle, Ð. The three equations under predict the factor, S when used Ð\son slope steepness beyond the data sets used to develop them.

Several alternative forms of equations (linear, power, and polynomial) were tested using field plot soil loss data gathered by several researchers in different countries for slopes ranging from three percent to 55 %. A single power function relating the sine of the slope angle, Ð to the slope steepness factor, S has been identified to be more suitable and accurate for estimating the RUSLE slope steepness factor, S.



Equations for

$$Series\ 1: S = 24.748\ (\sin\theta)^{1.2656} \qquad Series\ 2: S = 10.8 \sin\theta + 0.03$$

$$Series\ 3: S = 16.8 \sin\theta - 0.5 \qquad Series\ 4: S = 21.91 \sin\theta - 0.96$$

Fig. 4: Plots of slope steepness factor values obtainable using equations by McCool *et al*. (1987):, Liu *et al*. (1994). and equation in Fig.1

References

Chow V. T., 1959. Open channel hydraulics. McGraw Hill, New York.

Brian, R. B., 1979. The influence of slope angle on soil entrainment by sheetwash and rainsplash. Earth Surface Processes 4:43 – 58.

Chow, Ven Te, 1959. Open channel hydraulics McGraw Hill ,New York.

Liu, B. Y.; Nearing, M. A.; and Risse, L. M. 1994. Slope gradient effects on soil loss for steep slopes. Trans. of the ASAE. Vol. 37(6):1835 – 1840.

McCool, D. K.; Brown, L. C.; Foster, G. R.; Mutchler, C. K., and Meyer, L. D.1987. Revised steepness factor for the Universal Soil Loss Equation. Trans. Of the ASAE 30(5):1387 – 1396.

Mulengera, M. K., 1996. Soil loss prediction in the semi-arid tropical savanna zone: A tool for soil conservation planning in Tanzania, *PhD thesis,* Univ. of Newcastle upon Tyne, U. K., 232 pp.

Murphree, C. E. and Mutchler, C. K., 1981. Verification of the slope factor in the Universal Soiln Loss Equation for low slopes. J. of Soil and Water Conserv. Vol. 36(5): 300 – 302.

Musgrave, G. G., 1947. The quantitative evaluation of factors in water erosion – Afirst approximation. J. Soil and Water Conserv., 2(3): 133 – 138, 170.

Savat, J., 1981. Workdone by splash: Laboratory Experiments. Earth Surface Processes, 6: 275 – 283.

Smith, D. D. and Wischmeier, W. H., 1957. Factors affecting sheet and rill erosion. Trans. Am. Geophys. Union, 36 (6): 889 – 896.

Vogel H., 1994. Conservation tillage in Zimbabwe: Evaluation of several techniques for development of sustainable crop production systems in small holder farming, *PhD thesis,* Univ. of Berne, Switzerland.Geographica, Bernensia, African Studies Series, No. A11, 150 pp.

Wendelaar, F. E., 1987. Applying the Universal Soil Loss Equation in Rhodesia, Unrefenced Report, Inst. Agric. Eng., Harare, Zimbabwe.

Wischmeier, W. H. and Smith. D. D., 1978. Predicting rainfall erosion losses – Aguide to conservation planning. U. S. Dept. of Agric., Agric. Handb., No. 537, 58 pp.

Zingg, A. W., 1940. Degree and length of land slope as it affects soil loss in runoff. Agric. Eng. 21(2):59 – 64.