An Empirical Soil Loss Equation

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Abstract: A model was developed for estimating average annual soil loss by water on hillslope for cropland, which is called Chines Soil Loss Equation (CSLE). Six factors causing soil loss were evaluated based on soil loss data collected from experiment stations covering most regions of China and modified to the scale of Chinese unit plot defined. The model uses an empirical multiplicative equation, $A=RKLSBET$, for predicting interrill erosion from farmland under different soil conservation practices. Rainfall erosivity (R) was the product of rainfall amount and maximum intensity of 10min, and also was estimated by using daily rainfall data. The value of soil erodibility (K), the average soil loss of unit plot per rainfall erosivity, for 6 main soil types was calculated based on the data measured from unit plots and other data modified to the unit plot level. The method of calculating K from soil survey data for regions without measured data was given. The slope length and steepness factors was calculated by using the equations in USLE if slope steepness is less than 11 degree, otherwise the steepness factor was evaluated by using a new seep slope equation based on the analysis of measured soil loss data from steep slope plots within China. According to the soil and water conservation practices in China, the values of bio-control, engineering-control, and tillage factors were estimated.

Keywords: Chines soil loss equation, soil loss, unit plot

1 Introduction

Soil loss equation is to predict soil loss by using mathematical methods to evaluate factors causing soil erosion. It is an effective tool for assessing soil conservation measures and making land use plans. Universal soil loss equation is an empirical equation developed during 1950's that had been applied for natural resources inventory successfully in the US and revised in 1990's. From 1980's the process-based models for prediction of soil loss have been studied though the world, such as WEPP (Water Erosion Predict Project, Nearing *et al*., 1989), GUEST (Griffith University Erosion System Template, Misra and Rose, 1996), EUROSEM (the European Soil Erosion Model，Morgan *et al*., 1998) and LISEM (Limburg Soil Erosion Model, De Roo and Wesseling, 1996). There have been many studies on soil erosion models and related experiments since 1940's, but the models were limited in local levels and difficult to expand to broad regions due to data collected without universal standard. So far there is not any soil loss equations that could be applied through China with minor errors. The objective of this study is to develop a soil loss equation used within China based on measured data from Chinese unit plots and data from many plots modified to Chinese unit plot, which is called Chinese soil loss equation (CSLE).

2 Model description

Soil loss is a process of soil particle detachment by raindrops and then transported by runoff from the rainfall. Many factors like soil physical characteristics slope features, land surface cover etc. will influence soil loss amount, but they have interactions. It is necessary to distinct their effects on soil loss mathematically and to evaluate them on the same scale in order to improve the accuracy of the model. Unit plot is such a good method to solve the problem. The normalized data covering the China by modified to unit plot supported the development of Chines soil loss equation. In addition, two features of soil erosion in China are distinctive and should be considered in the equation. One is soil erosion with steep slope, and the other is the systematical practices for soil conservation during the long history of combating soil erosion, which could be classified as biological-control, engineering-control and tillage measures. So the Chinese soil loss equation was express as follows after the analysis of data collected from most regions of China

$$A = RKSLBET \tag{1}$$

where A is annual average soil loss (t/ha), R is rainfall erosivity (MJ • mm/(h • ha • y)), K is soil erosibility (t • ha • h/(ha • MJ • mm • y)), S and L are dimensionless slope steepness and slope length factors, B, E, and T are dimensionless factors of biological-control, engineering-control, and tillage practices respectively. The dimensionless factors of slope and soil conservation measures were defined as the ratio of soil loss from unit plot to actual plot with aimed factor changed but the same sizes of other factors as unit plot. Chinese soil loss equation is to predict annual average soil loss from slope cropland under different soil conservation practices.

To evaluated factors in the equation, about 1841 plot-year data were analyzed. Of these, 214 plot-year data from 12 plots and 1143 rainfall events from 14 weather stations were used to evaluate rainfall erosivity. The Chinese unit plot was determined by analyzing 384 plot size data, and about 200 plot-year data from 12 plots modified to unit plot were used to evaluate erodibility for 6 types of soil. About 30 plot-year data from steep plots modified to unit plot was used to establish the steep slope factor equation. Other plot data was used to calculate the values of biological-control, engineering-control and tillage factors.

3 Factor calculations for the equation

3.1 Rainfall erosivity (*R*)

A threshold for erosive rainfall of 12mm was estimated, close to that suggested by Wischmeier and Smith (1978), 12.7mm. After comprehensive considering the accuracy of rainfall erosivity, the data availability and calculation simplicity, the rainfall index of a rainfall event for Chinese soil loss erosion was defined. It is the product of rainfall amount (P) and its maximum 10-min intensity (I_{10}), and the relationship between PI_{10} and the universal rainfall index EI_{30} was also estimated as follows:

$$(EI_{30}) = 0.1773\ (PI_{10}) \qquad R^2 = 0.902 \tag{2}$$

where E is the total energy for a rainfall event (MJ/ha), I_{30} and I_{10} are the rainfall maximum 30min and 10min intensities respectively (mm/hr), P is the rainfall amount (mm). The annual rainfall erosivity is the sum of PI_{10} for total rainfalls through the year. Actually, it is also difficult to get the rainfall event data. To apply the weather data from weather stations covering the China, an equation function for estimating half-month rainfall erosivity by using daily rainfall data was developed.

$$R_{hm} = 0.184\sum_{i=1}^{n}\left(P_d I_{10d} \right)_i \qquad R^2 = 0.973 \tag{3}$$

where R_{hm} is the rainfall erosivity for half-month (MJ •mm/h •ha), P_d is the daily rainfall amount (mm) and I_{10d} is the daily maximum 10min rainfall intensivity (mm/h). I=1, …, n is the rainfall days within a half-month. If there is no I_{10d} available, R_{hm} was also calculated by using only daily rainfall amount.

$$R_{hm} = \alpha\sum_{i=1}^{n}(P_d)_i^{\beta} \tag{4}$$

where α and β are fitted coefficients and other variables had the same meaning as above.

Seasonal rainfall erosivity distribution could be estimated by the sum of R_{hm}. To plot Chinese isoerodent map for estimation or interpolation of local values of average annual rainfall erosivity in any place, the empirical relationships by using different rainfall available data were estimated (not listed). Users can choose different equations to calculate average annual rainfall erosivity according to the data availability.

3.2 Soil erodibility (*K*)

Soil erodibility is defined as soil loss from unit plot with 22.1m long and 9% slope degree per rainfall erosion index unit (Olson and Wischmeier, 1963). Different from the US, much of soil loss was from steep slope in China. So the Chinese unit plot was defined as a 20m long, 5m wide and 15° degree slope plot with continuously in a clean-tilled fallow condition and tillage performed upslope and downslope. The suggestion of Chinese unit plot made data measured be used to evaluate *K* values as much as possible without large errors. Because 15° is the middle values for most plots in China. Modified data measured from both plots of less than 15° and larger than 15° to a unit plot had the relative minimum errors.

Based on the *K* defination and Chines unit plot, soil erodibility for 6 main soil types in China was estimated. For example, the values of *K* for loess were 0.61, 0.33, and 0.44 t •ha •h/(ha •MJ •mm) in Zizhou, Ansai, and Lishi in Loess Plateau of China.

3.3 Slope length (*L*) and slope steepness (*S*) factors

Topography is an important factor affecting soil erosion. It is significant to quantitatively evaluate the effects of topography on erosion for predicting soil loss. The effects of topography on erosion includes slope length and steepness in terms of soil-loss estimation. In soil loss equation, factors of slope length and steepenss were cited with dimensionless values. They are values of the ratio of the soil loss from the plot with actual slope steepness or slope length to that from the unit plot.

The relationship between slope length and soil loss has been studied from field or lab data for a long time. Many studies showed that the soil loss per area is proportional to some power of slope length except that the values of the exponent are slightly different. For example, Zingg (1940) derived a value of 0.6 for the slope-length exponent. Musgrave (1947) used 0.35. USLE (Universal Soil Loss Equation) published in 1965 suggested the values of 0.6 and 0.3 respectively for slopes steeper than 10% and very long slopes, and 0.5 for other conditions. In 1978, the USLE (Wischmeier and Smith, 1978) adjusted the exponent values for different cases, 0.5 for 5% slope or more, 0.4 for slopes between 3.5% and 4.5%, 0.3 for slopes between 1% and 3%, and 0.2 for slopes less than 1%. Revised USLE (RUSLE) published in 1997 used a continuous function of slope gradient for calculating slope-length exponent.

Soil erosion from the steep slope is serious in China. How slope length influences soil loss on steep slopes needs further studies. For this end, the relationship between slope length and soil loss on steep slopes was examined based on the plot data obtained at Suide, Ansai, and Zizhou on the loess plateau of China and modified to the unit plot. The results indicated that the slope-length equation in the RUSLE could not be used for soil loss prediction under the steep slope conditions. The equation for calculating soil length factor in the USLE published in 1978 could be applied into China:

$$L = \left(\frac{\lambda}{22.13} \right)^m \tag{5}$$

where λ is slope-length (m), m is the slope length exponent.

Slope gradient is another topographical factor affecting soil erosion. Most studies have shown that the relation of soil loss to gradient may be expressed as some exponential function or quadratic polynomial. Zingg (1940) concluded that soil loss varies as the 1.4 power of percent slope, and Musgrave (1947) recommended the use of 1.35. Based on a substantial number of field data, Wischmeier and Smith (1965) derived a slope-gradient equation expressed as quadratic polynomial function of gradient percent. Having analyzed the data assembled from plots under natural and simulated rainfall, McCool *et al*., (1987) found that soil loss increased more rapidly from the slopes steeper than 5° than that from slopes less than 5°, and he recommended two different slope steepness factor equations for different ranges of slopes:

$$S=10.8\sin\theta + 0.03 \qquad \theta \leqslant 5° \tag{6-1}$$

$$S=16.8 \sin\theta - 0.5 \qquad \theta > 5° \tag{6-2}$$

These equations were established based on soil loss data from gentle slopes, and have not been tested for steep slope conditions. We used soil loss plot data from Suide, Ansai, and Tianshui on the loess plateau of China to test the equations. The results showed that great errors were produced when using equations suggested by McCool *et al*., (1987) for predict soil loss from slopes steeper than 10°. After the slope degree was larger than 10°, soil loss from steep slopes increased ripedly. Based the regression analysis of our data, am equation to calculate slope steepness factor for seep slopes was developed:

$$S=21.91 \sin\theta - 0.96 \qquad \theta \geqslant 10° \tag{6-3}$$

So in Chinese soil loss equation, slope steepness factor could be estimated by using equation (6-1) to (6-3) under different slope conditions

3.4 Bilogical-control (*B*), engineering-control (*E*), and tillage (*T*) factors

During the development of the historical agriculture traditions in China, the systematical practices for soil and water conservation formed. They could be divided into three categories: biological-control, Engineering-control and tillage measures. Biological-control practices include the forest or grass plantation for reducing runoff and soil loss. Engineering-control practices refer to the changes of topography to reduce runoff and soil loss by engineering construction like terrace, check-dams. Tillage practices are the measures taken by farmland equipment. The difference between engineering and tillage is that the latter does not change the topography and is only applied on the farmland.

Table 1 Estimated values of biological-control factor for crops

	Seedbed	Establishment	Development	Maturing crop	Growing season	Annual average
Buckwheat	0.71	0.54	0.19	0.21	0.74	0.74
Potato	1.00	0.53	0.47	0.30	0.47	0.50
Millet	1.00	0.57	0.52	0.52	0.53	0.55
Soybean	1.00	0.92	0.56	0.46	0.51	0.53
Winter wheat	1.00			0.17		0.23
Maize intercropping with soybean	1.00	0.40	0.26	0.03		0.28
Hyacinth Dolichos	1.00	0.70	0.46			0.57

Table 2 Estimated values for factors of woodland and grassland vegetation

Sophora	Korshinsk Peashrub	Seabuckthorn	Seabuckthorn & Poplar	Seabuckthorn & Chinese Pine	Erect Milkvetch	Sainfoin	Alfalfa	First year Sweetclover	Second year Sweetclover
0.004	0.054	0.083	0.144	0.164	0.067	0.160	0.256	0.377	0.083

Many studies gave the B values for different biologic measures in China, but they were not from the universal calculated methods and could not be used directly in soil loss equation. Based on the defination of B values, the ratio of soil loss from plots with some biological-control practice to that from unit plot, we calculated B values for some types of biological-control practices (Table 1). Some values for typical engineering-control and tillage measures in China were summarized (not listed).

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