Erodibility of Agricultural Soils in the Loess Plateau of China

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Abstract: Soil erosion is more severe in China than that in other countries, and has resulted in a lot of environmental problems. For soil conservation planning and erosion impact assessment, erodibility values for the main soils in China are needed to predict soil loss. The purpose of this study was to choose an index reflecting the impact of soil properties on erosion for soil loss prediction in China, and to calculate a set of erodibility values for main soils on the loess plateau based on the data from several field stations. The standard unit in China was recommended as a plot which is 20 meters long and 5 meters wide with a slope of 15 degree in continuous fallow. The results showed that the soil-erodibility factor K defined as soil loss per rainfall erosion index unit as measured on a unit plot in the USLE more directly and accurately reflects the effect of loess properties on erosion than other available indices of soil erodibility even on the steep farmlands. Values of factor *k* for loessial soils range from 0.3 to 0.7, with the maximum appearing in Zizhou from where values of *k* decrease southward, northward, and eastward. The high value 0.61 appears in the tract of Zizhou and Suide from where *k* values gradually fall southward to 0.3278 in Ansai, eastward to 0.4372 in the region of Lishi, Shanxi, and northward to 0.531 in the watershed of Huangfuchuang river.
Keywords: erodibility, soil loss, the loess plateau

1 Introduction

Since the Universal Soil Loss Equation (USLE) was published by Wischmeier in 1965, it has been commonly used as a tool to predict the average soil loss rate from agricultural lands in many countries around the world. As an important factor of the equation, soil erodibility (*k*) was focused on and *k* values for many soils were determined. Since the soil-erodibility nomograph was published by the USDA in Agriculture Handbook No. 537 in 1978, it has become easy for farmers to predict soil loss using the USLE. Although new soil-loss prediction models have been studied, soil erodibility is still an essential index, to which great attention is being given. Soil erosion is more severe in China than that in other countries, and has resulted in a lot of environmental problems. For soil conservation planning and erosion impact assessment, erodibility values for the main soils in China are needed to predict soil loss.

Since studies of the effect of soil properties on erosion began in China several decades ago, a great many achievements have been made. Nevertheless, different methods and indexes have been used in previous research work, especially in the studies conducted on the loess plateau. Zhu (1962) related the dispersion ratio and the coefficient of expansion of soil to its resistance to scour and detachment by flow. Later, Tian *et al.* (1964) and Shi *et al.* (1983) evaluated the soil erodibility by relating the physical properties of soil to erosion. Jiang (1978), Zhu (1960) and Li *et al.* (1990) measured the relative anti-scouribility indexes of the loess soils by the experiments conducted in small flumes. Meanwhile, Zhou *et al.* (1993) attempted to analyze and compute soil erodibility based on data from field plots, and defined an erodibility index as the soil loss per unit runoff depth. In the early 1990's, the erodibility factor used in the USLE was approved of in China and, henceforth, erodibility values for the main soils in the provinces of Inner Mongolia, Heilongjiang, Guangdong, Fujian, Jiangxi, Liaoning, and Yunnan etc have been successively determined (Jin *et al.*,1992; Zhang *et al.*, 1992; Chen and Wang, 1992; Chen *et al.*, 1995; Shi, Yu, and Lu, 1995; Lin *et al.*, 1997; Yang, 1999; Bu and Li, 1994). But as a result of diverse perspectives and methods a number of problems still exist in soil-erodibility evaluation. The first problem is that a variety of indexes have been adopted to evaluate erodibility. Inconsistent indexes not only lead to differing knowledge about the relation of soil properties and erosion, but also impede the application of erodibility indexes. The second problem is that the definitions of unit plot are not uniform. It is difficult to compare the erodibility of different soil types when differing standards of unit plot are used. The third problem is that different methods are used to calculate *k* although factor *k* was applied in some studies. In this paper, the selection of soil erodibility indexes and their determination methods, as well as the scale of unit plot were discussed based on data from field plots scattered throughout the loess plateau. Meanwhile, *k* values for soils on the loess plateau were tested.

2 Materials and Methods

2.1 Study Area

The loess plateau (Figure 1) in northwest China covers an area of 380 000 km^2. It is located in the middle reaches of the yellow river and bordered by Taihang Mountain in the east, extending westward to Wuqiaoling Mountain and Riyue Mountain, and by Qinling Mountain in the south, stretching northward to the Great Wall. The loess plateau with an altitude of 1 200 m—2 000 m becomes lower from the north to the south and from the west to the east. It is surrounded by mountains and crossed by the yellow river and its tributaries. The loess had been developed under arid climate in Early Pleistocene, and is characterized by yellow color, absence of beddings, silt structure, looseness, macroporousness and wetness-induced collapsibility. Particle-size distribution of loess follows the regularities of consistency and zonality. The consistency is demonstrated by the fact that soil particles ranging from 0.25 to 0.05 and from 0.05 mm to 0.01 mm in diameter predominate in the loess soils and account for 50%—75% of all soil particles with soil particles ranging from 0.05 mm to 0.01 mm in diameter occupying about 50%. The zonality is illustrated by the fact that soil particles generally become finer from the northwest to the southeast. The loess plateau is dissected by crisscross gullies such that the main landform types including Yuan (high flat loess tableland), Liang (elongated loess mound), Mao (round loess mound), and valley have been formed and the loess plateau is divided into a variety of geomorphic areas. On the loess plateau, annual average rainfall ranges from 200 mm to 650 mm and decreases northwest from 650mm to 200mm (Figure 2). The distribution of rain within a year is irregular with the flood period from June to September when more than 65 percent and at times up to 94 percent of annual precipitation falls. Rainstorms with high intensity and short duration tend to occur in the flood period. On the loess plateau, the activities of agricultural production have mainly been occurring on rainfed land, and the major crops are wheat,

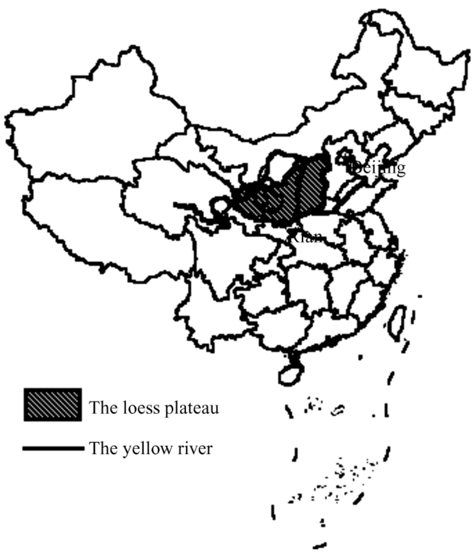

Fig. 1 Location of the loess plateau in China

corn, millet, sorghum, soybean, buckwheat and so on. One of the main irrational landuse types is steep farmland on which water is lost at the rate of 300 m^3/hm^2—600 m^3/hm^2 and surface soil at the rate of 15 t/hm^2—75 t/hm^2 with the maximum exceeding 150 t/hm^2 every year. On the loess plateau, soil erosion occurs on more than 500 000 km^2 of areas, of which the severe soil-loss areas with the erosion module beyond 5 000 ton/(km^2 •yr) occupy 145 000 km^2. The sediment in the yellow river mostly comes from the loess plateau from where average annual eroded soil is 0.63 cm deep. There is sixteen million tons of sediment being transported to the lower reaches of the yellow river every year, resulting in a lot of environmental problems for China.

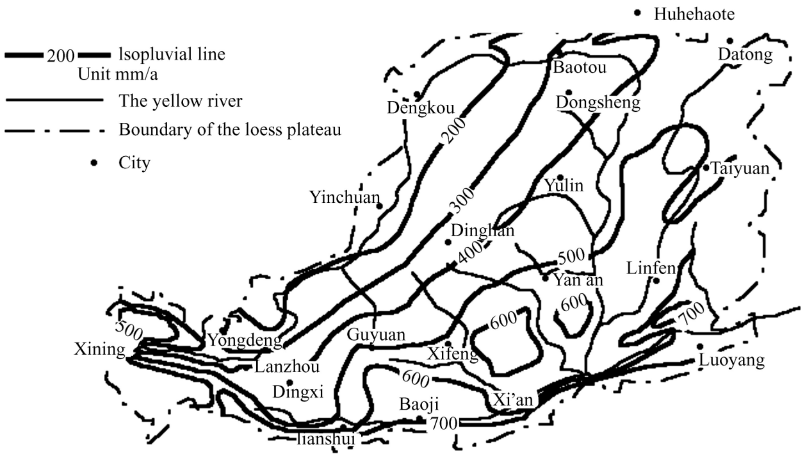

Fig. 2 Average annual isopluvial map on the loess plateau

2.2 Data Collection

According to soil texture, the loess plateau in China is divided into three zones: the sandy loess zone in the north, the typical loess zone in the middle, and the clayey loess zone in the south (Liu, 1966). The soil loss data used in this study were obtained from four field observation stations representing different soil zones, i.e. Huangfuchuan (39° 12′ N, 110° 18′ E), Lishi (37° 33′ N, 111° 09′ E), Zizhou (37° 31′ N, 109° 47′ E), and Ansai (36° 56′ N, 109° 16′ E) (Figure 3). Huangfuchuan station, established in 1982, is located in the sandy loess zone. The data collected from Huangfuchuan station were measured on a plot with the slope gradient of 10.5% from 1982 to 1989. Lishi station, in Shanxi province, is situated in the typical loess zone. The data collected from Lishi station were measured on five plots sloping 8.7%,

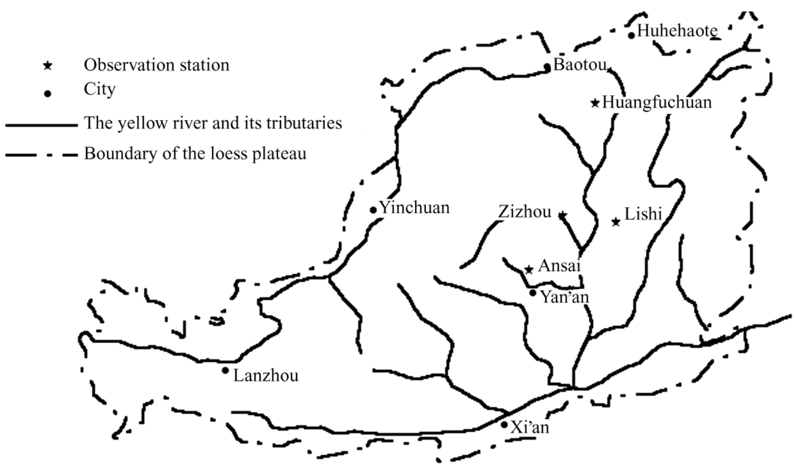

Fig. 3 Location of observation stations on the loess plateau

17.6%, 26.79%, 36.39%, 46.63% and 57.74% respectively. These plots were cropped to a 3-yr rotation of millet, sorghum and potato. Zizhou station, in Shanxi province, lies in the sandy loess zone. The data collected from Zizhou station from 1963 to 1967 were measured on four plots, of which one plot is at 60%, others kept at 40.4%. The data collected from the Ansai station from 1985 to 1989 were measured on five plots in 5-year continuous fallow condition. The slope gradients of these plots are 8.7%, 17.6%, 26.79%, 36.39%, 46.63% and 53.17% respectively. The data of Huanfuchuang station were obtained from literature 9. These data were adjusted to the unit plot with the slope gradient of 15 degree according to the slope equation and were then used to calculate erodibility factor *k*.

3 Results and Discussions

3.1 Selection of erodibility indexes for China

To date, there are mainly three different types of methods applied in soil erodibility determination in China. As a result, different indexes have been used in soil erodibility studies. The first one is based on determinations of physical and chemical properties of soil. But the result cannot be used to predict soil loss because how to quantitatively relate soil erodibility to soil loss has not been established. The second one is based on the results from flume experiments, which determines soil erodibility directly by measuring soil loss as a result of scouring by water. Compared to the former method, this one shows but little progress. In 40s, however, Gussak noted that when this method was applied to measure the erodibility of two different soils, opposite orders appeared when inflow rates were different. It is impossible to exactly describe the effect of soil properties on erosion by applying this method. The third is field measurement from unit plots. Although soil erodibility can be directly computed by use of observation data from field plots, the erodibility of the same soil alters with the slope gradient if improper indexes are being used. For example, soil erodibility was regarded as a dynamic index being a function of natural properties of soil, topography, precipitation, and soil conservation in previous studies on loess erodibility in China. It is evident that erodibility of different soils is impossible to be compared because this type of indexes fails to directly reflect the influence of soil properties.

What method and what index can actually represent the essential effect of soil on soil loss? We recommend that a good index used to describe soil erodibility should follow the principles of uniqueness and applicability. So-called uniqueness denotes that a type of soil must correspond to a certain erodibility value reflecting impact of soil properties on erosion. Even though soil erodibility may interact with some factors such as slope, rainfall, and land use etc in measurement, soil erodibility clearly should not vary with these factors. Conversely, the erodibility of a soil would have a myriad of values and would lost its meaning in soil loss prediction because the variations in rainfall, landuse and topography are infinite. So-called applicability denotes that soil erodibility must be a quantitative numeric index and be easy to be measured. In 1963, Olson and Wischmeier (1963) proposed a practical index of soil erodibility as soil loss per rainfall erosion index unit as measured on a unit plot. This index has definite physical meaning and allows for convenient measuring-methods. When measured on unit plots its values can be determined by a formula expressed as

$$k = \frac{\sum_{e=1}^{N} A_e}{\sum_{e=1}^{N} (EI_{30})_e}$$

where k is the soil-erodibility factor, A is the rainfall-induced soil loss, EI_{30} is the rainfall-erosivity factor among which E and I_{30} represent the total storm energy and the maximum 30-min intensity for a given storm respectively, and e designates the times of rainfall. Given the erodibility index values of different soils, it is possible to predict soil loss in the light of the factors such as topography and rainfall.

3.2 Scale of unit plot for China

A unit plot is thought of as a benchmark used to analyze and compare the data directly measured at field plots. If the unit plot is defined, all data from different areas can be adjusted to the unit plot when field data are being analyzed, after which the regularities can be uniformly drawn. In addition, it's only after the unit plot is defined that to consistently evaluate and compare erodibility of different soils is possible. In the USLE, a unit plot is 72.6 feet long, with a slope of 9 percent, in continuous fallow, tilled up and down the slope. This definition deviates from the cropping practice and the natural conditions of China to such an extent that it renders impossible any attempts at generalizing in China. And the gradient and scale of a unit plot suitable to China has not yet been determined. It was proposed that a unit plot be established on slopes of 10 degrees or 15 degrees in previous studies (Jiang and Li, 1988; Guo and Wang, 1995), but it has neither been tested nor verified. After comprehensive consideration of practices of reclamation and cropping on steep slopes as well as scale and slope range of available plots, we suggest that the unit plot in China be 20 m long and 5 m wide with a slope of 15 degree and in continuous fallow. The plot is prepared in local conventional seedbed conditions each year and is tilled according to the needs of local farming systems, such as to prevent marked growth of weeds. The values of erodibility determined at unit plots for the main soils in China may make up a basic data set serving as criteria to compare erodibility characteristics of soils and predict soil loss in China.

Though a unit plot only serves as a man-established benchmark as data are analyzed, a certain number of principles should be complied with. First of all defining a unit plot is contingent on particular natural conditions in addition to landform characters and land use in the investigated area. Secondly a unit plot should favor making the most of available data, which means making data use easy after scale and slope range of available plots have been fully considered. Thirdly error from data modification should be minimal. A unit plot is intended to facilitate the comparison and analysis of data, and great errors would be introduced in data modification as well as the final soil loss prediction if the improper criterions were to be used to define a unit plot.

3.3 Soil erodibility value in the loess plateau

In China, a variety of indexes were adopted in previous studies on erodibility. But only a few can be applied directly to soil loss prediction. In order to select the better index for soil erodibility for soil loss prediction in China, the suitability of the soil erodibility index defined in the USLE and another index (Zhou, 1993) was examined based on selected observation data from the unit plots in Ansai County, Shanxi province (Zhang, 1991). It indicates that values of k for the loess soils measured on the plots of different gradients are rather constant and do not vary with plot gradients. Meanwhile, values of the index defined by Zhou *et al*. (1993) as soil loss per unit depth from unit area alter greatly. This result shows that the soil erodibility factor k in the USLE more literally represents the effect of soil properties on erosion than the index defined by Zhou *et al*. (1993) do on the loess plateau. So it is justified to use k factor in soil loss prediction as an index reflecting soil properties on the loess plateau.

Values of the soil erodibility factor k on the vast loess plateau vary greatly due to regional variations in the properties of loess soils. Values of k factor in different regions of the loess plateau were computed as listed in Table 1 by use of plot data collected from the selected sites, i.e. Huangfuchuan, Zizhou, Lishi and Ansai. At Huangfuchuan site, the data from literature 9 were adjusted to unit plot according to the slope equation and were used to compute k factor. At Zizhou site, the soil loss data were adjusted by means of C factor and were used to compute factor k. At Lishi and Ansai sites, the data measured on plots with different gradients were used.

Table 1 demonstrates that values of factor k for loess soils range from 0.3 to 0.6 in the American system, and from 0.04 to 0.008 in the metric system. The distribution of k values in investigated area follows a regular pattern displaying high values in the central region and decreasing the southward, northward, and eastward respectively. The high value 0.61 appears in the tract of Zizhou and Suide counties, Shanxi province, from where k values falls off northward to 0.531 in the watershed of Huangfuchuan river, southward to 0.3278 in Ansai, and eastward to 0.4372 in the region of Lishi, Shanxi province. The regionally differing k values described above may primarily be attributed to the regional variations in the physical properties of loessial soils. A soil's erodibility may be closely related to its particle-size distribution, permeability, organic matter content and structure. For loessial soils, organic matter content is generally low and structure alters slightly, so differences in soil erodibility are mainly attributed to variations in particle-size distribution among which silt and clay contents are the most important factors. On the loess plateau, from the northwest to the southeast soil particles generally become finer, the sand fraction decreasing, the clay fraction increasing, and the silt fraction firstly increasing then decreasing with its maximum appearing in the central regions of Zizhou and Suide (Tian, Huang, and Yong, 1987). With clay content increasing, soils become more resistant to erosion and, consequently, there is a corresponding decrease in erodibility. With silt content increasing, soils are more sensitive to erosion, which results in greater erodibility. The results listed in Table 1 may therefore be coupled rationally with the fundamental change pattern of particle-size distribution of loessial soils in the investigated region, which further corroborates it is reasonable to apply factor *k* in the USLE as the index of soil erodibility on the loess plateau. Although how to quantitatively relate particle-size distribution to erodibility of loess soils is pending, these results will be useful in soil loss prediction and soil conservation planning on the loess plateau.

4 Conclusions

(1) We suggest that the standard unit plot is 20 meters long and 5 meters wide with a slope of 15 degree in continuous fallow. The plot is placed in local conventional seedbed conditions each year and is tilled according to the needs of local farming systems, such as to prevent marked growth of weeds (coverage no more than 5%).

Table 1 Computed *k* values for loess soils on plots at Zizhou, Ansai and Lishi stations[1, 2, 3,4]

Location	Slope[5]	Slope length[6]	Soil loss[7]	Rainfall erosivity[8]	*k*[9]	Average *k*[10]
Zizhou	22	40	340.255	282.916	0.553	
	22	60	458.063	392.879	0.438	
	22	20	147.628	262.329	0.366	0.610
	31	20	302.95	257.183	0.536	
Ansai	5	20	34.174	511.548	0.331	
	10	20	98.634	511.548	0.319	
	15	20	173.027	511.548	0.338	
	20	20	230.379	511.548	0.325	0.3278
	25	20	309.244	511.548	0.343	
	28	20	313.983	511.548	0.310	
Lishi	5	20	3.676	77.786	0.2345	
	10	20	6.195	110.682	0.0927	
	15	20	28.531	108.653	0.2626	
	20	20	58.853	106.137	0.3998	0.4372
	25	20	56.501	109.388	0.2932	
	30	20	83.663	109.154	0.3612	
Huangfuchuan	6	20	11.913	80.347	0.525	0.525

[1]Type of landuse: bareland in Ansai and Huangfuchuan; farmland in Zizhou and Lishi.
[2]Data of Zizhou, from 1961 to 1969, quoted from Hydrological Data From The Experimental Runoff Station Of Zizhou In The Yellow River Watershed.
[3]Data of Lishi, from 1957 to 1964, quoted from Experimental Runoff Data From Soil And Water Conservation Science Institute Of Shanxi.
[4]At Ansai and Huangfuchuan, the plots were in bare condition; at Huangfuchuan, the *k* values were normalized to unit plot according to Jin *et al*. (1992); at Zizhou, the *k* values measured from cropped plots were adjusted to unit plot for C=0.753.
[5]In unit of degree.
[6]In unit of m.
[7]In units of $t \cdot km^{-2}$.
[8]In units of $MJ \cdot mm \cdot hm^{-2} \cdot h^{-1}$.
[9,10]In units of $t \cdot hm^{2} \cdot h \cdot hm^{-2} \cdot MJ^{-1} \cdot mm^{-1}$.

(2) When tested against the plot data, the soil-erodibility factor *k* defined as soil loss per rainfall erosion index unit as measured on a unit plot in the USLE more directly and accurately reflects the effect of loess properties on erosion than other available indexes of soil erodibility do.

(3) Values of factor *k* for loessial soils range from 0.3 to 0.7, with the maximum appearing in Zizhou from where values of *k* decrease southward, northward, and eastward. The high value 0.61 appears in the tract of Zizhou and Suide from where *k* values gradually fall southward to 0.3278 in Ansai, eastward to 0.4372 in the region of Lishi, Shanxi, and northward to 0.531 in the watershed of Huangfuchuan river.

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