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Measurement of Erodibility for Soils in Subtropical China by Simulated and Natural Rainfall

Shi Xuezheng and Yu Dongsheng*

ABSTRACT

Erodibility factor K of seven different soil types in subtropical China was measured under both simulated and natural rainstorms. Soils included in the study were, eroded Acrisol, cultivated Acrisol and barren land Acrisol on Quaternary red clay; barren land Cambisol and cultivated Cambisol on red sandstone; calcaric Regosol from purple shale and Cambisol on granite. Results show that K measured by simulated rainfall varied widely, with the cultivated Cambisol derived from red sandstone being the highest (about 0.390) and the barren land Cambisol derived from the same parent material being the lowest (0.054). The erodibility K for these soils was also measured by using field plots without vegetation cover and under natural rainfall. The results showed that calcaric Regosol on purple shale had the highest K value of 0.451, while the eroded Acrisol on Quaternary red clay being the lowest, only 0.107. K measurement by simulated and natural rainfall are compared and discussed.

INTRODUCTION

Soil erosion is a major problem worldwide and among afflicted countries, China has some of the most serious soil erosion problem. Soil erosion is widely distributed in subtropical China, varying with local soil and rainfall. The amount of eroded sediment depends not only on external erosivity, but also on the soil's resistance to erosion, which is usually measured as the soil erodibility factor K. K can be used for predicting sediment transport and as such is a good land use planning tool. Wischmeier & Smith (1978) defined the soil erodibility factor K and its calculation. In 1980's and 1990's, the artificial rainfall simulator was widely used to determine soil erodibility (Meyer and Harm, 1979; Kramer and Alberts, 1986; Bui and Box, 1993), under the premise that the derived K values will be very similar to values that would be arrived at under natural rainfall conditions. A comparison of K values estimated from simulated and natural rainfall trials is detailed below to assess the reliability of soil erodibility measurements based on the two sources of precipitation

METHODOLOGY

The test plots (No.9-15) with seven different soil types (see Table 1) are located in the Ecological Station of Red Soil in Yingtan, Jiangxi Province, China. The site was formerly a tract of barren land with sparse masson pines and an average slope of 8%. Prior to the experiment, this barren land had only one dwarf masson pine for each 30 m^2. The soil is an Acrisol derived from Quaternary red clay, with an entirely eroded A horizon. All plots are 8.0 m in length and 1.5 m in width. The soils in plot 9, plot 10 and plot 11 were all derived from Quaternary red clay (Table 1), while the soils in plot 12 and plot 13 were on red sandstone. Plot 14 and plot 15 are calcaric Regosols on purple shale and Cambisols on granite, respectively. Every year at the end of March, all the plots were cultivated. Runoff and silt content of eroded sediment were determined after each rainfall.

A German-made rainfall simulator was used for all rainfall simulations. The simulator provides a predetermined intensity of rainfall to a 110 m^2 area, with dimensions of 5.5 m in width and 20 m in length. The intensity of simulated rainfall can be varied from 20 to 100 mm/hour. The average kinetic energy of rainfall simulator was 14.11 J m^{-2} mm^{-1} During the test simulated rainfall was applied at an intensity of approximately 70-80 mm hr^{-1} for 60 min. Vegetation was removed from all plots before all simulated rainfall tests. All plots were prepared by plowing, followed by raking the soil level soil.

The first rainfall application was made at the prevailing field moisture condition and is referred to as a "dry run". Two "wet runs" were applied to all plots at one-hour intervals after the "dry run" respectively. The second storm and third storms were of similar duration and intensity to the first. Runoff initiation times were recorded for each run (Table 2). Runoff samples for sediment content measurements were collected 10 minutes after runoff initiation. The sediment content of each sample was determined gravimetrically in the laboratory by oven drying.

RESULTS

Simulated rainfall experiment

From Table 2 it is evident that during “dry run” trials there were very big difference between the runoff initiation times comparing plot to plot. The runoff initiation time of all soils (plot 9-11) derived from Quaternary red clay exceeded 20 min and among them the eroded Acrisol (plot 9) had the longest runoff initiation time for 35 min. The cultivated Cambisol on red sandstone (plot 13) and calcaric Regosol on purple shale (plot 14) had the shortest runoff initiation time only for approximately 3 min. During “wet run” the runoff initiation time of all soils became very short and varied from 0.2 to 3.0 min. All soils had lower runoff coefficient during "dry run" than “wet run” trials. For example, the runoff coefficient of eroded Acrisol (plot 9) during “dry run” was only approximately 1/5 that found from the “wet run”. From first storm (“dry run”) to second storm, third storm (“wet runs”) the amount of eroded sediment varied from plot to plot. The amount of eroded sediment of soils (plot 9-11) derived from

*X.Z. Shi and D.S. Yu, Institute of Soil Science, Chinese Academy of Sciences, Nanjing, 210008. *Corresponding author: xzshi@ns.issas.ac.cn

Table 1. The soil types and land use.

Plot No.	Parent material	Soil type	Soil and land use
9	Quaternary red clay	Eroded Acrisol	The soils of original A- and B-horizon were washed away. It contains only plinthitic horizon and no vegetation grows on the surface.
10	Quaternary red clay	Cultivated Acrisol	The land was a mature forest approximately 40 years ago. At that time, the soil was very deep and was converted to production agriculture, with a crop rotation of rape and peanut. This is a representative Quaternary red clay soil that presents in upland throughout the region.
11	Quaternary red clay	Acrisol	The land was put into barren land with both sparse masson pine and grasses. The soils were eroded, depleting the fertility. This soil is representative soil type in the Quaternary red clay region.
12	Red sandstone	Cambisol	This is barren land with sparse grasses. The soils of original A- and a partly B-horizon were washed away. This is representative soil type in barren land of red sandstone.
13	Red sandstone	Cultivated Cambisol	40 years ago the land was converted into cropland. Local representative crop system is a rotation of rape and peanut in the upland.
14	Purple shale	Calcaric Regosol	These soils are subject to very serious soil erosion exists in such soil. In the study area the A- and B-horizon of these soils were washed away. This is very young soil derived from purple shale.
15	Granite	Cambisol	Like the previously mentioned soils, this one was formerly covered by forest. After forest was cut, the land was only able to support sparse growth of shrub and grasses.

Table 2. Runoff and sediments measured by simulated rainfall.

Plot No.	Soil type	Rainfall order	Runoff initiation times	Rainfall intensity (mm/hr)	Runoff (mm)	Runoff coefficient	Sediment (metric t / ha.hr)
9	Eroded Acrisol	1 (dry)	35.0	69.1	9.4	0.14	1.77
		2 (wet)	2.0	72.9	46.6	0.64	6.07
		3 (wet)	1.2	64.8	48.5	0.75	8.96
10	Cultivated Acrisol	1 (dry)	24.0	65.0	11.5	0.18	4.03
		2 (wet)	2.5	62.8	35.4	0.56	8.04
		3 (wet)	1.5	68.7	43.6	0.63	13.1
11	Acrisol	1 (dry)	22.5	65.0	20.3	0.31	1.84
		2 (wet)	3.0	62.8	43.1	0.69	4.61
		3 (wet)	1.9	68.7	49.5	0.72	4.71
12	Cambisol	1 (dry)	11.6	82.3	27.3	0.33	3.34
		2 (wet)	1.7	76.6	48.8	0.64	3.21
		3 (wet)	0.7	80.1	51.4	0.64	1.35
13	Cultivated Cambisol	1 (dry)	3.0	82.3	53.0	0.64	24.1
		2 (wet)	0.6	76.6	64.2	0.83	16.8
		3 (wet)	0.3	80.1	61.5	0.77	15.9
14	Calcaric Regosol	1 (dry)	3.3	83.6	50.9	0.61	21.4
		2 (wet)	1.3	73.4	60.9	0.83	18.5
		3 (wet)	0.8	81.0	58.6	0.72	16.5
15	Cambisol	1 (dry)	13.5	83.6	37.3	0.45	4.68
		2 (wet)	1.8	73.4	54.2	0.74	9.10
		3 (wet)	1.0	81.0	63.9	0.79	12.1

Table 3. Monthly precipitation distribution from 1993-1995 in Yingtan of Jiangxi Province (mm).

Year	J	F	M	A	M	J	J	A	S	O	N	D	Total
1993	74	118	127	187	490	372	300	76	86	69	48	38	1909
1994	72	137	156	288	209	546	29	151	58	47	7	230	1930
1995	74	89	207	419	275	593	129	95	91	15	0	0	1987

Table 4. Soil erodibility factor K measured by simulated rainfall.

Plot No.	9	10	11	12	13	14	15
LS	0.47	0.45	0.39	0.44	0.43	0.49	0.43
R	9.75	9.17	9.17	11.61	11.60	11.80	11.8
Kd	0.042	0.114	0.060	0.060	0.445	0.336	0.084

Unit: R factor:17MJ·mm/ha·hr; K factor:0.132t·hr/MJ·mm; Kd: the factor K measured by simulated rainfall at the first storm.

Table 5. Soil erodibility factor K measured by simulated rainfall in "wet run".

Plot No.	9	10	11	12	13	14	15
Kw1	0.131	0.244	0.162	0.067	0.358	0.377	0.211
Kw2	0.245	0.332	0.138	0.026	0.311	0.276	0.232
Kw	0.188	0.288	0.150	0.047	0.335	0.327	0.222
Kd	0.042	0.144	0.060	0.060	0.445	0.336	0.084
Kw- Kd	0.146	0.144	0.090	-0.013	-0.110	-0.009	0.138

Unit: K factor:0.132t·hr/MJ·mm; Kw1 and Kw2: the factor K measured by simulated rainfall at the second storm and at the third storm, respectively; Kw: the average value of the K factor at the second and the third storm.

Table 6. Comparison of soil erodibility factor K measured by simulated rainfall and natural rainfall.

Plot No.	9	10	11	12	13	14	15
Kd	0.042	0.114	0.060	0.060	0.445	0.336	0.084
Kw	0.188	0.288	0.150	0.047	0.335	0.327	0.222
Kdw	0.115	0.201	0.105	0.054	0.390	0.332	0.153
Kn	0.107	0.263	0.245	0.231	0.422	0.451	0.259
Kn- Kd	0.065	0.149	0.185	0.171	-0.023	0.115	0.175
Error(%)	60.7	56.6	75.5	74.0	-5.5	25.5	67.6
Kn- Kw	-0.081	-0.025	0.095	0.184	0.087	0.124	0.037
Error(%)	-75.7	-9.5	38.8	79.7	20.6	27.5	14.3
Kn- Kdw	-0.008	0.062	0.140	0.177	0.032	0.119	0.106
Error(%)	-7.5	23.6	57.1	76.6	7.6	26.4	40.9

Kdw: the average value of K factor in "dry run" and "wet run"; Kn: the K factor measured by natural rainfall.

Quaternary red clay increased from the first storm to the third storm, while the eroded sediment of soils (plot 12-14) decreased.

Precipitation and runoff under natural condition

The precipitation (Table 3) in the Yingtan of Jiangxi Province in subtropical China is unevenly distributed throughout the year. The years from 1993 to 1995 were basically normal and had their rainfalls concentrated mainly in the period April to June. In 1995, rainfall fell mainly between March to June. June 1995 had the greatest cumulative rainfall, approximately 593 mm, which is 30% of the annual total. The mean annual runoff coefficient from 1993 to 1995 of different soil types varied from plot to plot (Fig. 1). The seven plots could roughly be classified into 3 groups.

The first group with the highest runoff coefficient being greater than 0.40, included plot 13 (cultivated Cambisol derived from red sandstone), plot 14 (calcaric Regosol) and plot 15 (Cambisol derived from granite). The group with the lowest runoff coefficient being only 0.16,
included only plot 9 of eroded Acrisol from Quaternary red clay; and the other group consisted of plots 10, 11 and 12 were characterized by runoff coefficients lying in between groups one and two.

Sediment under natural condition

Amount of eroded sediment from these plots also varied greatly, showing roughly the same trend as with the runoff coefficient. The highest was with plot 14 of calcaric Regosol on purple shale and plot 13 of cultivated Cambisol derived from red sandstone (Fig 1.). Their mean annual sediment (1993 and 1994) reached 122.6 ton and 108.1 tons per hectare, respectively. The lowest was plot 9 of eroded Acrisol from Quaternary red clay, being only 28.6 tons per hectare, even less than 1/4 of that from calcaric Regosol derived from purple shale (Shi et al., 1998 and Yu et al., 1997).

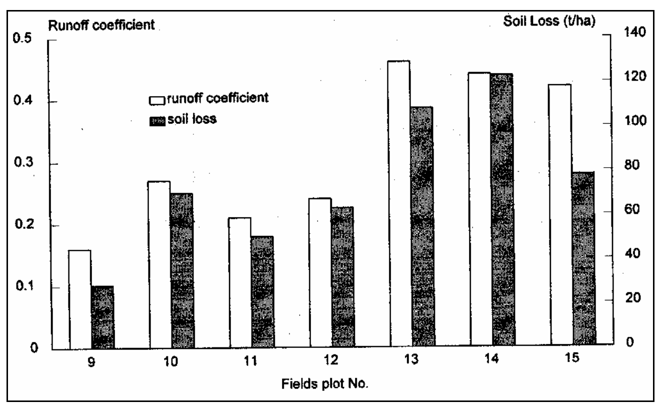

Figure 1. Mean annual runoff coefficient and soil loss for different soil types.

DISCUSSION

Soil erodibility factor K measured by simulated rainfall in a "dry run"

For the purposes of the experiment, the USLE C and P factors were set equal to 1 inch the experiment. Therefore, K could be calculated from K= A/(R·LS) K values measured from "dry run" and "wet runs" under conditions of simulated rainfall are listed in Tables 4 and 5 respectively. The results demonstrate that in subtropical China soil erodibility varies widely between soil types according to measurements by simulated rainfall in "dry run". The plot 13 of cultivated Cambisol and the plot 14 of calcaric Regosol had the highest

K factor and they were 0.445 and 0.336 respectively. While the lowest soil erodibility factor K was plot 9 of eroded Acrisol, only 0.042. It was approximately 11 times as much as the soil erodibility of the plot 13 of cultivated Cambisol (Yu, 1997).

Soil erodibility factor K measured by simulated rainfall in "wet run"

Results depicted in Table 5 are from the average soil erodibility factor K measured by simulated rainfall for the "wet run". Similar to the "dry run" there are wide differences in the K values between soils, similar to the "dry run" results. The highest soil erodibility factor K was again found to be plot 13, cultivated Cambisol, and the plot 14, calcaric Regosol. The lowest K value was measured from plot 12, Cambisol, only 0.067. Interestingly, it was found that the K "wet run1" was not always higher than the K "wet run2", as seen in the results for plots 9, 10, and 15. As is to be expected a greater difference was found when comparing "dry run" and the average "wet run" K values. The difference was approximately 0.14. For plots 12, 13 and 14 the "dry run" K values were greater than the K "wet run" values.

Comparison of soil erodibilities measured by simulated rainfall and by natural rainfall

The soil erodibility factor K of the seven different types of soils measured by simulated rainfall and by natural rainfall is listed in Table 6. After erosivity index R was estimated using EI_{30} method (Lal, 1990), K value under natural rainfall was calculated. We believe that the K measured by natural rainfall should be taken as a benchmark as it is erodibility under conditions of natural rainfall that are interest to USLE users. Therefore, in order to evaluate the reliability of simulated rainfall, a comparison was carried out of the factor K (Table 6) measured by simulated rainfall and by natural rainfall. From the results, it showed that the K measured by simulated rainfall was very close to the K measured by natural rainfall for some soil types and there was a greater difference between the K measured by simulated rainfall and by natural rainfall for other soil types. Except for plot 13 of cultivated Cambisol, the Kd measured by simulated rainfall in "dry run" at first storm differed greatly from the Kn measured by natural rainfall. The Kw measured by simulated rainfall in "wet run" and the average K (Kdw) measured by simulated rainfall both in "dry run" and "wet run" are close to the Kn measured by natural rainfall (Shi, 1998). The difference between Kn and K measured by simulated rainfall at different conditions depended on the soil type. Plot 12 of Cambisol and Plot 14 of calcaric Regosol had almost the same difference between Kd, Kw, Kdw and Kn. However, the plot 12 had a greater difference with 74-80%, while the plot 14 had a smaller difference with 25-28%. The K for plot 10 of cultivated Acrisol, plot 11 of Acrisol and plot 15 of Cambisol, measured by simulated rainfall at "wet run" was more close to the Kn measured by natural rainfall than other soils. The Kdw for plot 9 of eroded Acrisol was much more close to the Kn, while the Kd for plot 13 of cultivated Cambisol was much more close to the Kn measured by natural rainfall than other soils.

CONCLUSION

The highest soil erodibility factor K, measured by simulated rainfall for both "dry runs" and "wet runs' were found in plot 13 of cultivated Cambisol from red sandstone and in plot 14 of calcaric Regosol on purple shale. The plot 9 of eroded Acrisol, plot 11 of Acrisol, plot 12 of Cambisol and plot 15 of Cambisol had the lower factor K measured by simulated rainfall in "dry run". Though the soil erodibility K value measured by simulated rainfall at different condition may not be very close to the erodibility measured under conditions natural rainfall for all soil types the use of a simulator appears to be valid when determining K values under the "wet run" type of trial. The soil erodibility K value measured by simulated rainfall at "wet run" were closer to the K value by natural rainfall, than K values found for "dry run" trials. Overall the differences between K values measured under conditions of simulated and natural rainfall were wide. Based on these results we believe that the rainfall simulator needs to be rigorously compared with natural rainfall for measuring K values on a range of soils in subtropical China and in any new region in which it is to be applied. A rigorous comparison will permit a more definitive statement concerning the limits of the rainfall simulator as a tool for estimating K factor for USLE applications.

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