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The effects of *Herba Andrographitis* hedgerows on soil erodibility and fractal features on sloping cropland in the Three Gorges Reservoir Area

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Abstract To evaluate if hedgerows could improve the soil physicochemical properties and enhance the soil anti-scouring and anti-shearing capabilities, the effects of *Herba Andrographitis* hedgerows on soil erodibility and fractal features on sloping cropland in the Three Gorges Reservoir Area were investigated. Results showed that: (1) the clay particle accumulation around the hedgerows was significantly affected by the hedgerows; (2) the fractal dimension of soil particles was positively correlated with both silt and clay contents and had a negative linear correlation with sand content; (3) fine-grained content significantly influenced fractal dimension of the soil particles; (4) soil erodibility K was significantly and positively correlated with the sand content (correlation coefficient r=0.870), but significantly and negatively correlated with the silt content (r=−0.538), clay content (r=−0.739), organic carbon content (r=−0.603), the aggregation degree (r=−0.486), and soil fractal dimension (r=−0.538); and (5) the contents of organic matter and clay particles in the soil were found to be the effective indicators for soil erodibility at the Three Gorges Reservoir Area. The hedgerows may improve soil fractal features and decrease soil erodibility. The effective distance between hedgerows on a slope of 10° was less than 6 m.

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Introduction

Soil and water loss is a serious problem on slope cultivation in the purple soil areas of China due to fragile geology and ecology. The anti-erosion ability of soil is one of the important factors affecting soil erosion. Usually, soil erodibility factor K is used to describe the susceptibility of soil particles detached and transported by rainfall and runoff as a significant factor for the Universal Soil Loss Equation and could be estimated in other different approaches (Zhang et al. 2008). Soil erodibility factor K is not only an internal factor indicating the amount of soil loss, but also the basis for the quantitative study of soil erosion (Parysow et al. 2003; Wang et al. 2013a). Soil erodibility is closely related to the basic physicochemical characteristics of soils (Breshears et al. 2003; Kuhn and Bryan 2004; Van Pelt et al. 2004). The total aggregate content, 1–10 mm aggregate content, aggregation degree, aggregate dispersion coefficient, and erosion rate are of indexes for the analysis of soil anti-erosion capability. Not only may soil erosion be different for various types of soils, but also it is different for the same type of soil under different climate conditions or management modes (Giovannini et al. 2001). Wang et al. (2013b) studied soil erodibility of China and suggested that factor K was highest for purple soil and lowest for Quaternary red clay. The fractal dimension of soil particle size distribution not only depicts soil particle size, but also reflects the uniformity of texture and permeability of soils (Tyler and Wheatcraft 1992).

Contour hedgerow management can reduce soil erosion on slopes in mountainous areas. The planting of hedgerows has been considered to be an important technique to reduce soil erosion and improve soil structure and fertility (Baudry et al. 2000; Pattanayak and Mercer 1998) and one of the important approaches to protect soil resources on slopes (Lal 2000). It is conducive to a single farming system in controlling nonpoint pollution, in improving efficient use of agricultural resources, and in obtaining high yield. Fagerstrom et al. (2002) and Sudhishri et al. (2008) have found that hedgerows improved the control of soil nutrient cycling and reduced nutrient loss. In recent years, studies on hedgerows have been focused on type selection, soil erosion control, nonpoint pollution, eco-efficiency evaluation, and changes in soil nutrients (Cullum et al. 2007; Salvador-Blanes et al. 2006). In the Three Gorges Reservoir Area, studies on the use of hedgerows have been largely focused on the screening and testing of hedgerows and their effects on soil erosion control.

Soil fractal features and soil erodibility in various watersheds with different soil types have been studied intensively. However, few reports have focused on the influence of hedgerows on soil fractal features and soil erodibility factor K. Based on the determination of the soil particle composition and soil organic carbon pre- and post-hedgerow planting, we estimated the effects of *Herba Andrographitis* on fractal features and soil erodibility using fractal dimension of soil particle size distribution and Erosion Productivity Impact Calculator (EPIC) model and provided evidence for enhancing soil anti-erosion ability and managing soil and water loss on sloping farmlands in the Three Gorges Reservoir Area, southwest China.

Materials and methods

Study area

The experiment was conducted in the Xinzheng Village (30°24′53″N, 108°10′25″E), Zhong County, Chongqing City, southwest China. The study area is in the middle reaches of the Three Gorges Reservoir Area and in the parallel ridge-and-valley area of the eastern Sichuan Basin. The area has a humid subtropical southeast monsoon climate with four distinct seasons, abundant rainfall (1,150 mm/year), and sufficient sunlight. The average annual air temperature is 19.2 °C. The precipitation is distributed unevenly throughout the year, and most rainstorms occur during the rainy season from May to September, which accounts for more than 70 % of total annual precipitation.

The landform in this area is dominated by hills and valleys with a fragmented landscape, underlain by horizontally bedded Mesozoic mudstone, siltstone, and sandstone. These rocks, which are sedimentary material of purple color, consist of the dark purple shale of the Feixianguan Formation of the Triassic System, the brown purple sandy mudstone of the Penglai Formation, the red brown purple mudstone of the Suining Formation, and the gray brown purple sandy mudstone of the Shaximiao Formation of the Jurassic System. The main soils in the area are neutral purple soils which usually contain around 15 % clay with 1.7 % organic matter, 0.07 % total nitrogen, and 0.06 % total phosphorus (Ge et al. 2007; Yin 2005).

Experimental design

Four treatments (TI, TII, TIII, and TIV) on the same slope of 10° with three replications for each treatment (totally 12 runoff plots) were established in the study. Each plot was designed as a projection length of 8 m and a width of 4 m in the purple soil area. The concrete treatments are as follows: The plots of TII, TIII, and TIV were planted with *Herba Andrographitis* as hedgerows with a width of 0.5 m, which was combined with inter-band maize conventionally straight planted. TI without hedgerows was served as a control, and the cropping pattern of the maize planted was the same as TII, TIII, and TIV. The hedgerows were planted and transplanted in April 2010 with patterns as follows: two parallel bands of hedgerows were set up in plots of TII, one at the bottom of the slope and the other dividing each plot into two parts with a 4.5-m upslope belt and a 2.5-m downslope belt. For TIII, there were also two parallel bands in every plot, one at the bottom of the slope and the other one dividing the plot into a 5.5-m upslope belt and a 1.5-m downslope belt. In the plots of TIV, one band of hedgerow was planted at the bottom, which was 7.5 m from the top of the plot. Each band had two lines with 0.2 m row spacing, and 0.2 m plant spacing, and was isolated by a 0.5-m blank space from cropland (Table 1 and Fig. 1).

Collection and analysis of soil samples

Two batches of soil samples were collected from the four runoff plots in April 2010 before planting hedgerows for the soil background and in October 2010 after the hedgerows had grown for one rainy season (from May to September). The sampling protocol was as follows: samples from the surface soil (0–0.2 m) at 0.5 and 1.5 m in front of the upslope hedgerow bands and 0.5 and 1.0 m in front of the downslope hedgerow bands in plots of TII were collected

Table 1 Design of experimental plots

Plot number	Slope (°)	Land utilization pattern	Hedgerows
I	10	Cropland (maize)	No
II	10	Cropland (maize)	Yes
III	10	Cropland (maize)	Yes
IV	10	Cropland (maize)	Yes

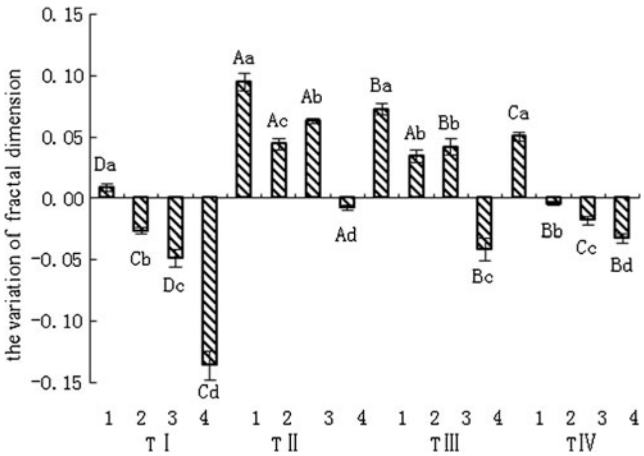


Fig. 1 Experimental plots and arrangement of sampling points

with a soil sampler. Surface soil in the other plots was sampled at similar spots as in the plots of TII. In each plot, four soil samples, each of which was a uniformly mixture of subsamples about 500 g weight from two randomly selected spots, were collected. Of each uniformly mixed sample, 500 g was used for laboratory analysis. Forty-eight mixed soil samples were collected each time, and a total of 96 samples were acquired for the study. All analyses were performed in the triplicate. The four sampling spots in each plot were distributed at downslope (1, 2) and upslope (3, 4), as shown in Fig. 1.

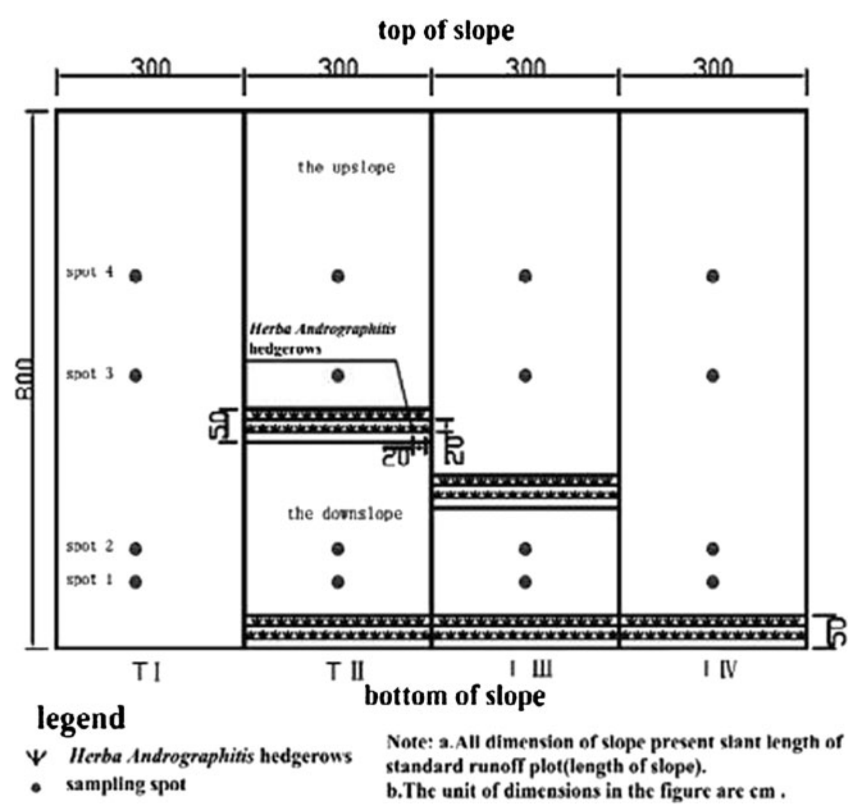
Before analysis, the soil samples were air dried and sieved with sundries (e.g., gravel and roots) eliminated. Mechanical composition of the soils and the micro-aggregates was determined using the pipette and sieve analysis (Kilmer and Alexander 1949), and the soil organic matter (SOM) and soil organic carbon (SOC) were determined using the potassium dichromate titrimetric method. The degree of aggregation (Shen et al. 2000) was calculated as follows:

$$\text{degree of aggregation}\,(\%) = [\text{aggregate content}\,(>0.05\text{ mm}) - \text{particle constituent}\,(>0.05\text{ mm})] \times 100\,\%/\text{aggregate content}\,(>0.05\text{ mm})$$

The fractal dimensions of the soil particles were calculated using the computational model developed by Liu et al. (2009) as follows:

$$D = 3 - \frac{\log M\left(r < \overline{R}_i\right)/M_{\mathrm{T}}}{\log\left(\overline{R}_i/R_{\max}\right)}$$

Fig. 2 Soil fractal dimension feature variation. Variation within a pair of columns followed by *different case letters* indicates significant differences among four spots under each treatment ($P<0.05$, Duncan). *Capital letters* on the columns indicate significant differences among four treatments in each sampling spot ($P<0.05$, Duncan)



M_T The total mass of all soil particles
M The mass of soil particles with an average size greater than the given $\overline{R}_i$
$\overline{R}_i$ The mechanical composition level of particles between the R_i and R_{i+1} soil particles
R_{max} The maximum soil particle size
D The fractal dimension of the soil particles

Soil erodibility factor K was calculated using the EPIC method (Williams and Arnold 1997):

$$K = \{0.2 + 0.3\exp[-0.0256\,SAN(1-SIL)/100]\}\cdot\left[\frac{SIL}{CLA+SIL}\right]^{0.3}\cdot\left[1.0-\frac{0.25C}{C+\exp(3.72-2.95C)}\right]\cdot\left[1.0-\frac{0.7\,SN_1}{SN_1+\exp(-5.51+22.9\,SN_1)}\right]$$

Where SAN stands for the sand content (2–0.05 mm), SIL stands for the silt content (0.05–0.002 mm), CLA stands for the clay content (<0.002 mm), and C stands for the content of SOC. C=0.583×the content of SOM. $SN_1=1-SAN/100$. K is the habitual unit of USA, multiplied by 0.1317 to the standard international unit of t·ha·h/(MJ·mm·ha), showing in English as: in tons, in hectares, in hour per megajoule, per millimeter, and per hectare. Data were subjected to ANOVA and mean values separated using Duncan's multiple range test at $P<0.05$. Relationships among variables were conducted by bivariate and partial correlation analysis using Pearson correlations. All statistical analyses were performed by Excel 2010 software and SPSS 18.0 software.

Results and discussion

Effects of hedgerows on soil fractal features

Variation in fractal dimension of soil particle

According to the Soil Taxonomy of USA, the soil mechanical composition in this experiment was determined as three fractions: sand (2–0.05 mm), silt (0.05–0.002 mm), and clay (<0.002 mm). Soil particle size plays a decisive role in the combination of soil particles and pore characteristics (such as size, number, and geometry) (Ersahin et al. 2006). With increasing content of clay, soil texture become finer and fractal dimensions become larger. Compared to the background value, the fractal dimensions of soil particles in spot 1 of the four treatments were increased by 0.0083, 0.0947, 0.0724, and 0.0502 (Fig. 2), respectively. Meanwhile, the fractal dimensions in spot 4 of the four treatments were reduced by 0.1364, 0.0081, 0.0418, and 0.0329. The changes in the fractal dimensions of each treatment indicated that fine particles were more likely to migrate from top of the slope to the bottom; thus, clay was enriched at the downslope while it was largely absent at the upslope.

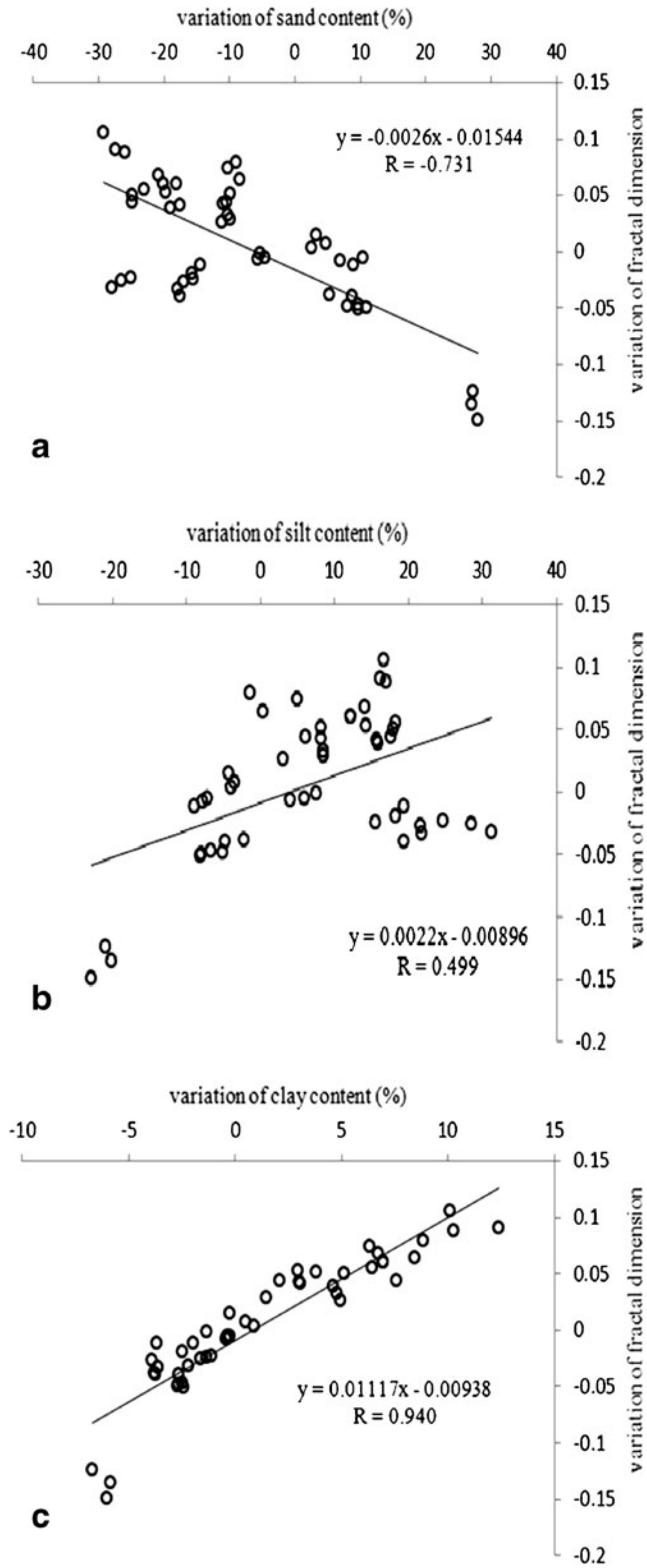


Fig. 3 The relationship between variation of soil fractal dimension and variation of soil particle content for **a** sand, **b** silt, and **c** clay

In addition, the fractal dimensions of soil particles significantly increased in the plots of TII and TIII, indicating that

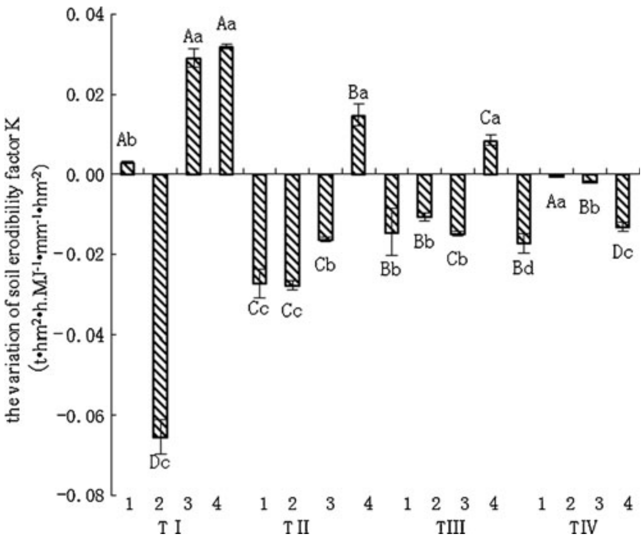


Fig. 4 The variation of soil erodibility factor K. Variation within a pair of columns followed by *different case letters* indicates significant differences among four spots under each treatment ($P<0.05$, Duncan). *Capital letters* on the columns indicate significant differences among four treatments in each sampling spot ($P<0.05$, Duncan)

hedgerows had remarkable effects on runoff interception of clay, which accumulated around the hedgerows. Compared to the background, the variable quantity of the fractal dimension under the four treatments was −0.2041, 0.1936, 0.1062, and −0.0055, respectively. The fractal dimensions under the hedgerows changed significantly compared to the control. The influence of *Herba Andrographitis* on the fractal dimensions of soil particles on sloping land showed a general order as follows: TII > TIII > TIV, which implied that the effectiveness of hedgerows on controlling soil erosion on sloping land was of dependent on the distance between hedgerows. When the distance was less than 5.5 m, hedgerows could reduce soil loss significantly. These results could be attributed to the following reason: the threshold value of distance for rill erosion occurring was 6.13 m on slope land with 10° in the same study area (Yan et al. 2010). A continuously increasing eroding force by slope flow led to increase rill erosion and eroding force sharply, which significantly promoted soil particle loss (Roemer 2008). Rill erosion is the key factor in soil granular matter transportation and erosion. In order to improve soil fractal features and decrease soil erodibility on slopes, the distance between hedgerows should be less than 6 m on a slope of 10° in the Three Gorges Reservoir Area.

The relationship between fractal dimension and soil particles

The fractal dimension of soil particles was fitted with the soil particle content including sand, silt, and clay. The variation of sand, silt, and clay on the slope in each plot was set as *X*-axis, and the variation of the fractal dimension was set as *Y*-axis. It showed that the variation of the fractal dimension was negatively and linearly correlated with the variation of sand content (correlation coefficient −0.713, Fig 3a), and the variation of fractal dimension had positive correlations with silt and clay (correlation coefficients 0.499, Fig 3b, and 0.940, Fig 3c). A higher clay or silt content on sloping land would lead to a higher fractal dimension, while a higher sand content on sloping land would lead to a lower fractal dimension. These observations were consistent with previous study reported by Ersahin et al. (2006). According to the fitting equation, the order of influence of soil particles on fractal dimension was as follows: clay > sand > silt, indicating that the fine particle content had significant effects on the fractal dimension of soil particle distribution, which was also affected by the grain with maximal size. The uniformity of soil texture can be characterized by the fractal dimension of soil particle distribution to some extent (Su et al. 2004). In order to improve soil fractal feature, it is critical to reduce soil erosion and to control soil loss on sloping land in the Three Gorges Reservoir Area, especially to reduce the loss of clay.

Effects of hedgerows on soil erodibility factor K

Soil erodibility factor K variation

Soil erodibility factor K decreased in plots with hedgerows than in plots without hedgerow. As shown in Fig. 4, the variation of soil erodibility factor K between the background

Table 2 Basic soil properties in the study area

Soil layer	pH	Samples	Natural moisture content (%)	Soil bulk density (g cm^{-3})	Crop coverage (%)	Water coefficient (%)	Mechanical composition mass fraction (%)		
							Sand	Silt	Clay
0–20 cm	7.02	Background	20.05	1.44	56	0.971	43.52Aa	33.12Bb	23.36Ca
	7.05	Under hedgerows	17.41	1.4	75	0.975	35.53Bb	47.01Aa	17.46Cb

Values with different case letters in columns indicate significant differences between background samples and samples under hedgerows in each group of mechanical composition mass fraction ($P<0.05$, Duncan). Capital letters in columns indicate significant differences among different group of mechanical composition mass fraction in each sample ($P<0.05$, Duncan).

Table 3 Correlation analysis of soil erodibility and factors

	Soil erodibility	Sand content	Silt content	Clay content	Organic carbon content	Degree of aggregation	Fractal dimension
Soil erodibility	1						
Sand content	0.870**	1					
Silt content	−0.538*	−0.730**	1				
Clay content	−0.739*	0.118	−0.765**	1			
Organic carbon content	−0.603*	−0.655**	0.436	−0.017	1		
Degree of aggregation	−0.486	−0.609*	0.286	0.157	0.651**	1	
Fractal dimension	−0.538*	−0.713**	0.322	0.204	0.833**	0.872**	1

*P=0.05, **P=0.01, level of significance

value and the value of under hedgerow under the four treatments was −0.0014, −0.0576, −0.0314, and −0.0308, respectively. Compared to the control treatment (TI), the K of the other three treatments with hedgerows was reduced by 39.60, 21.43, and 21.00 %, respectively. Moreover, the soil erodibility factor K in the control (TI) was reduced after one rainy season. This could be attributed to the increase in crop coverage (Table 2) which provided more protective canopy of vegetation that made less soil exposed to the erosion of raindrops and intercepted certain amounts of rain. Hence, it reduced soil erosion and could improve the soil structure (Xiao et al. 2012) which enhanced the anti-erosion capability of the soil on the sloping land: the soil erodibility factor K was lower, the anti-erosion capability was higher, or the erosion of the soil was milder.

The extent of hedgerows influencing on soil erodibility factor K was in the order of TII > TIII > TIV. The inhibitory effects of hedgerows on slope soil erosion could be attributed to the mechanical arresting function by which hedgerows could effectively reduce runoff and prevent soil erosion (Salvador-Blanes et al. 2006). The fine grain components of the soil moved to downslope more easily than the coarse grain components by runoffs. However, interception, the primary ecological function of hedgerows, caused an enrichment and sedimentation of the soil clay around the hedgerows and increased the soil's clay content. The interception and dispersing effects of the compacted hedgerows could effectively prevent slope flow from further converging (Cullum et al. 2007) and could decrease the flow velocity. The duration of infiltration could increase when the distance between hedgerow bands was less than the critical slope length of rill erosion. This implied that mechanical arresting function was the main reason for the reduction of slope surface runoff and silt loss by hedgerows. The *Herba Andrographitis* with a strong stem and leaves could develop a fibrous root system which could be up to 2.5 m in vertical length and 1.5 m surrounded the plant which is intensively distributed in the layer of 0–0.3 m (Xiao et al. 2011). Besides, it is not only a high quality and high yield perennial grass, but it is also an excellent plant for soil conservation by improving the soil physical properties and increase its capacity for preserving and holding water (Xiao et al. 2010). *Herba Andrographitis* hedgerows on sloping land would have significant effects of mechanical arresting function on the fine particle (<0.02 mm).

Influential factors of soil erodibility

Pearson correlation analyses between soil erodibility and factors including variation of sand, silt, clay, organic carbon content, degree of aggregation, and the fractal dimension of the soil particles were performed with SPSS 18.0 software. Soil erodibility factor K was significantly and positively correlated with the sand content (correlation coefficient 0.870) and was negatively correlated with the contents of silt (−0.538), clay (−0.739), organic carbon (−0.603), degree of aggregation (−0.486), and the fractal dimension of the soil particles (−0.538). All the factors, except for degree of aggregation, were significantly correlated to soil erodibility factor K. The results implied that increasing the content of

Table 4 Partial correlation analysis between soil erodibility and factors

Erodibility	The content of sand	The content of silt	The content of organic carbon	The content of organic matter	The content of clay	The degree of aggregate
Correlation coefficient	0.822	−0.457	−0.331	−0.333	−0.09	−0.04
Significant probability level	0.01	0.09	0.23	0.23	0.76	0.89

The factors include the content of sand, silt, clay, organic matter, organic carbon, and the degree of aggregate silt and clay could improve soil structure and sustainable productivity, decrease soil dispersion and erodibility, and increase agglomeration degree (Table 3).

In order to determine the most basic factors and most effective indicators of erodibility in the Three Gorges Reservoir Area, partial correlation analyses were conducted (Table 4) between soil erodibility and various factors, including the content of sand, silt, and clay, the organic carbon, and the organic matter, revealed that K was most closely related with sand (correlation coefficients 0.822), silt (−0.457), clay (−0.09), organic carbon (−0.331), and organic matter (−0.333). As a cementing substance, soil organic carbon is an important chemical property of soils. Loss of organic matter caused by particle migration and runoff flushing plays a vital role on the stability of soil aggregate, which has remarkable effects on the anti-erosion capability of soils. The intensity of soil erodibility depends on the content of organic matter (Eynard et al. 2005), while soil aggregation is affected by both aggregate content and clay content. Barthes and Roose (2002) have found that soil erodibility was affected by the physicochemical properties of soil. Because of the dynamic change in soil physicochemical properties, the value of soil erodibility would be changed within a certain range but may change little in a long period. Furthermore, soil erodibility factor K and the fractal features of soil particles are constrained by many factors such as soil humus content, aggregate content, and cultivation. Therefore, further long-term research with the increasing planting period of hedgerows is required to elucidate the effects of hedgerows on soil erodibility factor K and the fractal features of soil particles.

Conclusions

The impact of hedgerows on fractal features and soil erodibility indicated that hedgerows exhibited important effects on fractal dimensions of soil particles and soil erodibility factor K and remarkable effects on interception of clay particles. Fine particles were migrated from top of the slope to the bottom by runoffs. Hedgerows could accumulate clay particles around them hence to increase clay content of the soil. The fractal dimension of soil particle distribution was negatively correlated with sand content, but had positive correlation with silt and clay contents, being more influenced by fine grain components. In addition, soil erodibility factor K was significantly and positively correlated with the sand content, and the contents of soil organic matter and clay were effective predictors of soil erodibility on slopes in the Three Gorges Reservoir Area. *Herba Andrographitis* hedgerows had significant effects on the control of soil erosion on sloping land by controlling the soil fine particle content. To exert the function of hedgerows on controlling soil erosion, the distance between hedgerows on a slope of 10° should be less than 6 m.

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