

Original Research

Effects of Land Use Change of Sloping Farmland on Characteristic of Soil Erosion Resistance in Typical Karst Mountainous Areas of Southwestern China

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Abstract

With the implementation of ecological projects such as the Grain-for-Green Project, rocky desertification control and comprehensive control of soil and water loss for sloping farmland, ecological environment of karst mountainous areas in southwest China has been improved significantly, but soil and water loss of sloping farmland is still an important ecological and environmental problem in this region. In this paper we took a typical karst rocky desertification mountainous area, Jinlan Demonstration Area, as the study area located in Qianxi County, Guizhou Province. On the basis of a previous experimental demonstration of grass planting and afforestation on sloping farmland (planted in 2014), the sample plot method was used to obtain soil samples and soil shearing test piece in 2017, and soil shear strength and soil erodibility factor (K) were measured by direct shear method and hydrometer method in order to study the effect of sloping farmland converted to abandoned land, pastureland and agroforestry on soil erosion resistance. Results showed that the soil shear strength was no obvious change and soil erodibility was no significant difference ($P>0.05$) in sloping farmland with the level of rocky desertification becoming more serious; soil shear strength greatly increased after sloping farmland was abandoned, ultimate shear strength τ_{300} was increased by 65.5%, and K was significantly different ($P<0.05$) after 10 years; in the process of sloping farmland converted to pastureland, the soil ultimate shear strength τ_{300} was increased by 34.55% and K decreased significantly ($P<0.05$), which indicated that the effect of grass planting on improving soil erosion resistance of sloping farmland was obvious; in the process of sloping farmland converted to agroforestry, soil erosion resistance was also enhanced, soil shear strength was increased, and K was decreased (it did not reach the significant level, $P>0.05$). Based on the preliminary results of this paper, we think both grass (tree) planting and land abandonment could improve soil erosion resistance and reduce soil erosion risk, which

are feasible non-engineering measures for soil and water conservation in the karst area of southwestern China.

Keywords: karst, rocky desertification, sloping farmland, land use, soil erodibility factor, soil erosion resistance

Introduction

Rocky desertification is a severe ecological problem in the subtropical karst area of southern China, which leads to rapid infertility of karst-weathered residual soil [1], like desertification in northwestern China, it is a fundamental and regional environmental problem of ecological construction in the development of western China, and it has become one of the main obstacles to regional sustainable development [2]. The overexploitation and unreasonable tillage practices caused by rapid population growth is the main human factor to accelerate and aggravate rocky desertification [3]. Barren soil, heavy and concentrated rainfall, and unreasonable tillage practices lead to soil loss and rock exposure, which lead to rocky desertification eventually. Therefore, soil and water loss is one of fundamental reasons for the occurrence and development of regional rocky desertification [4]. Sloping farmland is an important original place for soil and water loss [5], and soil erosion control in China is also dominated by soil erosion control of sloping farmland, thus it is of great practical significance to carry out basic research on soil erosion of sloping farmland.

Soil is one of the most important natural resources for sustaining biological life, and it plays an important role in agricultural production. Soil erosion causes negative impacts on land productivity and environmental quality, and degrades the socioeconomic status of farmers, so it poses a threat to livelihoods of landowners and overall ecosystem health [6]. There are many indexes to characterize soil erosion resistance, including Smith and Wischmeier suggesting the use of soil erodibility factor K to characterize soil erosion resistance [7], and some scholars have suggested using soil aggression ratio, dispersion ratio and soil organic carbon to indicate soil erosion resistance [8-11], while Amezketa, Zhao Xiaoguang and others have used soil shear strength to characterize soil erosion resistance [12-13]. At present, soil erodibility factor is widely used, its connotation is the susceptibility of soil to erosion, and it is the key parameter for evaluating the sensitivity of soil erosion and an important basis for predicting soil erosion and evaluating its environmental effect [14]. When slope length and slope gradient (LS), coverage (C), rainfall characteristics (R) and management measures (M) are the same, soil erosion is only dependent on the inherent characteristics of soil [15]. Soil erosion is not only related to water, but also to land use/coverage change as they affect soil erodibility by changing the physical characteristics of soil [16].

Since the implementation of the Grain-for-Green Project in China in 1999, especially in the past 10 years, with the implementation of ecological control projects such as the special fund of rocky desertification control and comprehensive control of soil and water loss for sloping farmland, the rural land structure in the karst area has been continuously optimized and adjusted, and regional ecological environment and soil environments have been significantly improved [17-19]. In the process of ecological restoration, the land-use pattern changed, with farmland mainly converted to abandoned land, grassland and woodland. During the process of land use change in farmland, soil characteristics and soil erodibility both change to a different extent, and soil erosion resistance of surface soil is enhanced [20-22].

Compared with the Loess Plateau of northwestern China and the black soil region of northeastern China, there are few studies on soil erosion in the karst region of southwestern China, with the effects of the farmland converted to other land-use types on soil erosion resistance that is not reported. Taking the typical karst rocky desertification area in southwestern China as the study object, this paper discusses the effects of sloping farmland converted to other land-use patterns on soil shear strength and soil erodibility, which demonstrates the feasibility of non-engineering measures (planting trees and grass, abandoned land – natural restoration) for soil and water conservation, accumulate data for the subsequent basic research on soil erosion in the karst area and provide a theoretical reference for regional soil and water loss prevention, especially the comprehensive control of soil and water loss for sloping farmland.

Materials and Methods

General Situation of the Study Area

This study selected Jinlan Demonstration Area (located in Jinlan Town, Qianxi County, Guizhou Province of China) as the study area. The core demonstration area mainly consists of Houchang and Shuangqing administrative village in Jinlan Town, its longitude is $106^{\circ}1'51.28''\text{E}\sim 106^{\circ}5'37.63''\text{E}$ and its latitude is $26^{\circ}51'71''\text{N}\sim 26^{\circ}52'58.98''\text{N}$, the altitude is 1361-1563 m. Different rocky desertification degrees, potential, slight, moderate and severe rocky desertification land are widely distributed in this region, which is a typical karst rocky desertification area. The total land-use area of the core demonstration region is 560 hm^2 , in which rocky desertification land accounts for 86%. The annual

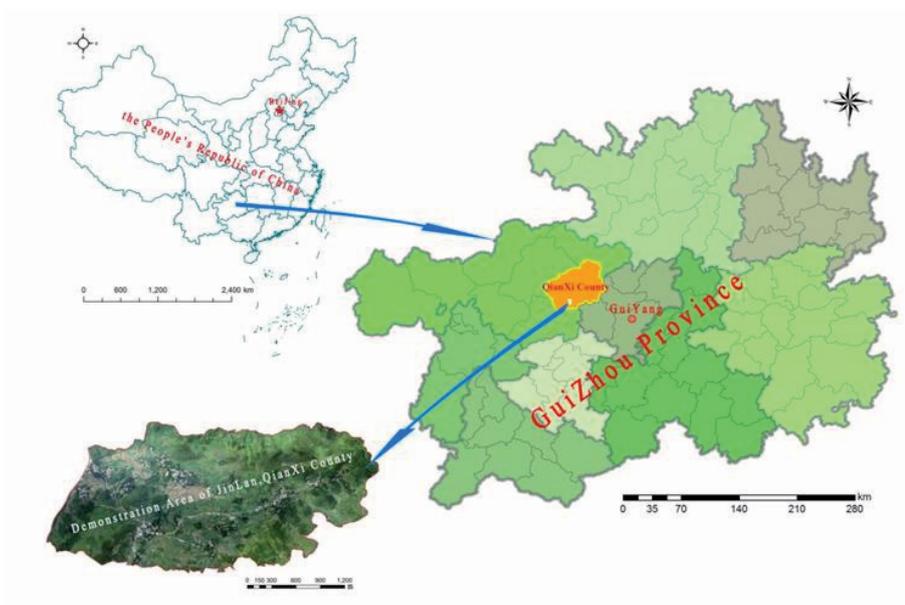


Fig. 1. Geographical location of the study area.

average temperature is 13.2°C and annual average rainfall is 980 mm. The soil is dominated by yellow soil and yellow lime soil, yellow soil is zonal soil, and yellow lime soil is staggered. The geographical location of the study area is shown in Fig. 1.

Layout of Sample Plots

The types of field sample plot in this study area include the land use of sloping farmland, abandoned land, agroforestry and pastureland. Sloping farmland

includes nil rocky desertification sloping farmland (NF), potential rocky desertification sloping farmland (PF) and slight-moderate rocky desertification sloping farmland (MF). Abandoned land includes 3-year abandoned land (A3) and more than 10-year abandoned land (A10), with A10 basically having been restored to natural shrub-grass land. Agroforestry just includes silvopasture (SP), in which the tree species includes Sichuan plum (*Prunus salicina* L.), Mauhong pomegranate (*Punica granatum* L.), etc., and the grass species mainly includes alfalfa (*Medicago sativa* L.) and Perennial Ryegrass



Fig. 2. Sketch map of sample plot layout.

Table 1. Basic information of sample plots.

Type of Land use	Name of sample plot	Identifier	Rocky desertification degree	Center point coordinates	Planting status
Farmland	Nil rocky desertification farmland (NF)	NF1	Nil	E106°2.67' N26°52.04'	<i>Zea mays, Brassica napus</i>
		NF2	Nil	E106°2.79' N26°52.06'	<i>Zea mays, Brassica napus</i>
	Potential rocky desertification sloping farmland (PF)	PF1	Potential	E106°2.79' N26°51.97'	<i>Zea mays, Brassica napus</i>
		PF2	Potential	E106°2.94' N26°51.98'	<i>Zea mays, Brassica napus</i>
	Slight-moderate rocky desertification sloping farmland (MF)	MF1	Light-moderate	E106°2.73' N26°51.87'	<i>Zea mays</i>
		MF2	Light -moderate	E106°2.74' N26°51.88'	<i>Zea mays</i>
Abandoned land	3-years abandoned land (A3)	A3-1	Light-moderate	E106°2.85' N26°51.79'	Abandoned
		A3-2	Light-moderate	E106°2.93' N26°51.74'	Abandoned
	10-years abandoned land (A10)	A10-1	Light-moderate	E106°2.78' N26°52.17'	Abandoned
		A10-2	Light-moderate	E106°2.89' N26°52.16'	Abandoned
Agroforestry	Silvopasture (SP)	SP1	Potential	E106°2.86' N26°52.07'	Forest-grass compound planting
		SP2	Potential	E106°2.84' N26°52.12'	Forest-grass compound planting
Pastureland	Cultivated pastures (CP)	CP1	Potential	E106°2.95' N26°52.05'	<i>Medicago sativa, Lolium perenne</i>
		CP2	Potential	E106°2.93' N26°52.13'	<i>Medicago sativa, Lolium perenne</i>

(*Lolium perenne* L.); the silvopasture had been planted for 4 years till field survey, and it was sloping farmland before planting. Planting varieties of cultivated pastures (CP, type of land-use was farmland before planted) mainly include perennial ryegrass, alfalfa and chicory (*Cichorium intybus* L.), and it also had been planted 4 years before the field survey. Each type of land-use set up 2 field sample plots, amounting to 14 sample plots. The location of sample plots is shown in Fig. 2, and basic information of the sample plots is shown in Table 1.

Sampling and Analytical Test Method of Soil Samples

Three soil sampling points were randomly assigned to each field sample plot, amounting to 42 sampling points. Test and analysis content of soil physical and chemical properties includes soil organic carbon, soil bulk density, soil particle size distribution and others. Because soil erosion often occurs in the topsoil layer, sampling depth of soil in this study was 0-20 cm, and sampling time was February 2017.

Soil organic carbon was tested by potassium dichromate oxidation, soil particle size distribution was tested by hydrometer method, and soil bulk density was tested by metal cylinder method.

Shear Samples Sampling Method and Soil Shear Strength Test Method

The sampling point of soil shear samples was the same as the sampling point of soil samples as above, and four shear samples (shear tests were performed on 4 normal compressive stresses of 50 kPa, 100 kPa, 200 kPa and 300 kPa respectively) taken around each sampling point accounted for 4×42 shear samples, sampling depth was also 0-20 cm, and sampling time was May 2017. The basic method of sample preparation was found in the literature [23]. After samples were prepared completely in the field, the samples were packaged in sealed plastic bags and sent to the laboratory for natural air drying (reducing effect of water content on the shear results), then shear test was carried out. In this study, the rapid shear test was carried out with ZJ-2 strain-controlled direct shear apparatus.

Data Statistical Analysis Method

Index of Soil Shear Strength

Indexes reflected soil shear strength include shear strain, shear stress and shear strength. The index of soil shear strength refers to the ultimate strength of soil against shear failure when it is subjected to external forces (rainfall scour, gravity and mechanical impact, etc.) [24]. According to Coulomb theory, the shear strength (τ_f) was composed of cohesive force (c) and frictional resistance ($\sigma \tan \phi$). The specific formula is as follows:

$$\tau = \sigma \tan \phi + c \tag{1}$$

In this formula, τ_f is the soil shear strength (kPa), σ is the normal compressive stress on the shear plane (kPa), ϕ is soil internal friction angle ($^\circ$) and c is soil cohesion.

The Calculation Method of Soil Erodibility

There are many calculation models of soil erodibility, such as the universal soil loss equation (USLE), the revised universal soil loss equation (RUSLE), erosion productivity impact calculator (EPIC) and Dg model. After comprehensive comparison, the EPIC was used to calculate soil erodibility factor K as following formula:

$$K = \{0.2 + 0.3 \exp[0.0256SAN(1 - SIL/100)]\} \left[\frac{SIL}{CLA+SIL} \right]^{0.3} \left[1.0 - \frac{0.25C}{C + \exp(3.72 - 2.95C)} \right] \left[1.0 - \frac{0.7SN1}{SN1 + \exp(-5.51 + 22.9SN1)} \right] \tag{2}$$

In this formula, SAN, SIL and CLA are sand, silt and clay content, respectively, C is the content of soil organic carbon, $SN1 = 1 - SAN/100$. The result above uses the American soil particle size classification system, which is multiplied by 0.1317 and converted into the international soil particle classification system.

Statistical Analysis and Mapping Tools

Excel, SPSS 22.0 and Origin 8.5 were used for data collation, analysis, statistics and cartography.

Results and Analysis

Effects of Land Use Change on Soil Shear Strength

Table 2 was the experimental test value of soil internal friction angle and soil cohesion for different types of land use in the study area. According to the Coulomb theory, the ultimate shear strength of soil

Table 2. Soil internal friction angle and soil cohesion in the study area.

Number	Name of sample plot	Soil internal friction angle ϕ ($^\circ$)	Soil cohesion c (kPa)
1	NF	22.40	42.7
2	PF	24.76	31.2
3	MF	25.55	38.9
4	A3	31.47	52.5
5	A10	38.50	46.0
6	SP	31.93	44.0
7	CP	32.54	39.2

was determined by soil internal friction angle and soil cohesion.

Fig. 3 shows the ultimate shear strength of different land use patterns in the study area. The results showed that there was no obvious difference in the ultimate shear strength under four normal compressive stress

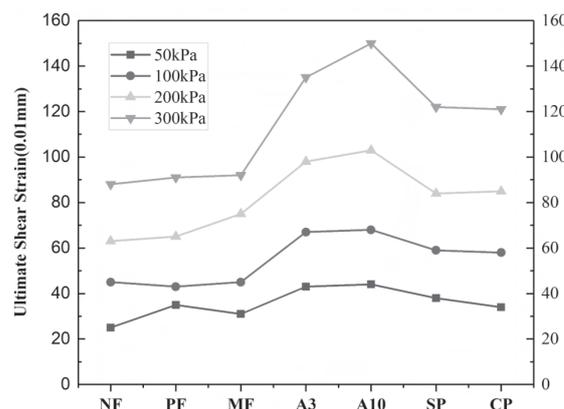


Fig. 3. Ultimate shear strength under different normal stresses (kPa).

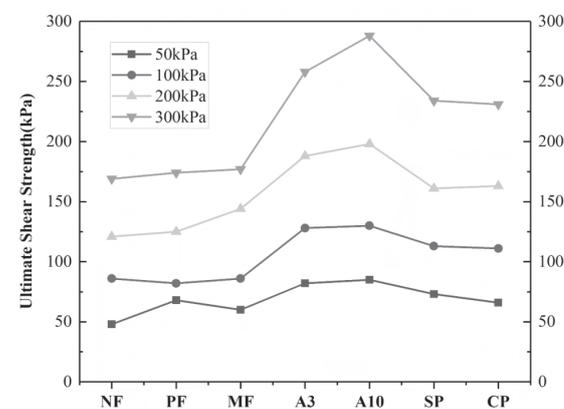


Fig. 4. Ultimate shear strain under different normal stresses (0.01mm).

Table 3. Soil erodibility factor *K*.

Type of land use	Name of sample plot	Plot number	Sample number	Range of variation	Mean value
Sloping farmland	Nil rocky desertification farmland (NF)	2	6	0.0208-0.0237	0.0221 ^{ab}
	Potential rocky desertification sloping farmland (PF)	2	6	0.0180-0.0239	0.0227 ^{ab}
	Sight-moderate rocky desertification sloping farmland (MF)	2	6	0.0218-0.0335	0.0260 ^a
Abandoned land	3-years abandoned land (A3)	2	6	0.0220-0.0267	0.0244 ^{ab}
	10-years abandoned land (A10)	2	6	0.0133-0.0173	0.0152 ^c
Agroforestry	Silvopasture (SP)	2	6	0.0186-0.0237	0.0217 ^{ab}
Pastureland	Cultivated pastures (CP)	2	6	0.0168-0.0225	0.0205 ^b

Note: There was no significant difference in the same letter, there was significant difference in the different letter, and the significance level was 0.05.

in sloping farmland with different degrees of rocky desertification. Taking soil ultimate shear strength under normal compressive stress of 300kPa (τ_{300}) as an example, NF was 169 kPa, PF was 174 kPa and MF was 177 kPa, with the difference between them not being obvious. Results above showed that with the intensification of rocky desertification, the ultimate shear strength of sloping farmland has not changed much. The ultimate shear strength of soil changed greatly after the sloping farmland was converted to abandoned land, during the change process of PF→A3→A10, τ_{300} increased from 174 kPa to 258 kPa and 288 kPa respectively, the rates of increase were 48.3% and 65.5% respectively, indicating that the soil shear strength increased continuously with the prolongation of abandoned time of sloping farmland, which was closely related to vegetation restoration and soil root increasing. From the change process of PF→SP, the soil shear strength was also increased, τ_{300} was increased from 174 kPa to 234 kPa with an increase rate of 34.5%. The soil shear strength also increased obviously during the change process of PF→CP, τ_{300} increased from 174 kPa to 231 kPa with an increase rate of 32.8%.

The results of ultimate shear strain under different types of land use are shown in Fig. 4, where the effect of land use change on soil shear strain was the same as soil shear strength.

Effects of Land Use Change on Soil Erodibility

The effect of land use change in sloping farmland on soil erodibility in the study area was shown in Table 3. The *K*-values of 3 different degrees of rocky desertification sloping farmland were NF 0.0221, PF 0.0227 and MF 0.0260, respectively. It can be seen that with the intensification of rocky desertification, the soil erodibility change of sloping farmland was not

obvious, that is, soil erosion resistance did not change significantly with the increase of rocky desertification degree and there was no significant difference in soil erosion resistance among them ($P>0.05$), which was basically consistent with the results of soil shear strength mentioned above.

The *K*-value of 3-year abandoned land was 0.0244, which decreased by 6% compared with MF, which indicated that the soil erodibility did not change obviously after having been abandoned for 3 years, and comparing with NF, PF and MF, soil erodibility was no significant difference ($P>0.05$); the *K*-value of A10 was 0.0152, and it had an obvious change compared with NF, PF and MF. A significant test showed that it was significantly lower than NF, PF and MF ($P<0.05$), but there was no significant difference between A3 and A10. The results above showed that the soil erosion resistance of sloping farmland did not change much after 3 years of abandonment; however, after more than 10 years of abandonment it increased significantly.

The *K*-values of SP and CP were 0.0217 and 0.0205, respectively (Table 3). Soil erodibility of SP and CP decreased to a certain extent, that is, soil erosion resistance for SP and CP was improved. Further significant tests indicated that it had no significant difference between SP and the three degrees of rocky desertification sloping farmland mentioned above ($P>0.05$). However, there was a significant difference between CP and MF ($P<0.05$), that is, soil erosion resistance had been improved significantly after planting grass for 3 years in sloping farmland (the grass was planted in 2014). Although sloping farmland to silvopasture for 3 years, soil erosion resistance improved to some extent, but it had not reached a significant level ($P>0.05$); it was not known whether soil erosion resistance of silvopasture would be significantly improved with the extension of planting time, but we will continue to study it in the future.

Table 4. Pearson correlation between soil erodibility and related soil indicators.

Statistical quantity	Organic carbon	Soil bulk density	Clay content	Silt content	Sand content
Pearson correlation	-0.644**	0.510**	0.425**	0.902**	-0.712**
Significant (bilateral)	0.000	0.001	0.005	0.000	0.000
Covariance	-0.002	0.000	0.010	0.021	-0.026
N	42	42	42	42	42

** indicates significant correlation at level 0.01 (bilateral)

Conclusion and Discussion

Conclusion

- 1) During the transition process of NF→PF→MF, soil ultimate shear strength (strain) and soil erodibility did not change significantly, which showed that soil erosion resistance of sloping farmland did not change significantly with increased rocky desertification grade.
- 2) In the process of sloping farmland converted to abandoned land, soil erosion resistance was improved and soil erodibility of 10-year abandoned land was significantly decreased; at the same time, soil ultimate shear strength and ultimate shear strain increased greatly in the process of sloping farmland abandonment. This showed that soil erosion resistance was greatly improved with the prolonged abandonment time.
- 3) In the process of sloping farmland converted to cultivated pastures and silvopasture, ultimate shear strength (strain) was increased and soil erodibility factor was decreased, which showed that soil erosion resistance was enhanced when sloping farmland converted to cultivated pastures and silvopasture.

Discussion

The Main Influencing Factors of Soil Erodibility

The Pearson correlation relationships between soil erodibility and soil properties (soil organic carbon, soil bulk density and clay content) are shown in Table 4. It can be seen from the table that there was a significant negative correlation between soil erodibility and soil organic carbon in the study area ($P < 0.01$), indicating that soil erodibility decreased with an increase in soil organic carbon, which was consistent with research conclusions of other scholars in the Loess Plateau region of China [25], the purple soil region of Southern China [26] and red soil region of Southern China [27], but the similar reports have not yet been seen in the karst region of southwestern China. Therefore, increasing soil organic carbon content will not only increase soil fertility, but also increase soil erosion resistance. Sand content and soil erodibility have a significant negative

correlation, meaning that soil erosion resistance improved with the increase of sand content [28]. As we know, under the raindrop splash (splash erosion) and sheet flow scouring (sheet erosion), soil with smaller particle size is the first to be stripped and transported, while the sand is larger in size and it is often difficult to be stripped and transported, therefore, the increase of sand content can strengthen soil erosion resistance. However, some studies have shown that erodibility is positively correlated with soil sand content [27], soil erosion resistance decreased with the increase of sand content, which may be related to different methods used and soil conditions in the study area. Soil erodibility showed significant positive correlation with soil bulk density, clay content and silt content ($P < 0.01$), which indicated that with the increase of soil bulk density, clay content and silt content, soil erodibility in the study area showed an increasing trend, that is, soil erosion resistance decreased.

Limited by the purposes of this study, this paper has not studied other indexes of soil properties that may affect soil erodibility, such as soil aggregates, so we will carry out research in the future and continue to observe the above-mentioned factors.

Study of Soil Mechanics Mechanism

Soil mechanics mechanism is an important research content of soil erosion and soil and water conservation, and researchers mainly elucidate the vegetation regulating role through shear strength of the soil-root composite system [29-31]. Compared with the regulation mechanism of ground vegetation on soil and water loss, the study of underground root systems on soil and water conservation is much less, which is mainly caused by the study of an underground root system being relatively difficult [32]. However, studies in the past two decades have shown that plant roots play a leading role in reducing soil erosion rate on slope, so they can effectively regulate soil erosion [33]. Because of the existence of a root system, soil shear strength is greatly enhanced [34], which is often used to protect surface soil from human disturbance [35-36]. Related studies show that enhancement of soil shear resistance by plant roots depends on root characteristics and it is endemic to plants, such as root structure and root tensile strength [37]. The shear strength of the root-soil composite system

is negatively related to the diameter of root, that is, the finer the root system, the greater shear strength of root-soil composite system [38]. When we predicate slope erosion rate, soil shear strength is an important factor to be considered, because soil shear strength is positively correlated with critical runoff shear stress (τ_{cr}), and it is negatively correlated with soil erodibility factor (K) [39-40]. It can be seen that shear strength of the root-soil composite system plays an important role in resisting runoff erosion on the slope, so shear characteristics of the root-soil composite system should be considered in the study of the soil erosion mechanism.

The purpose of this paper is to study soil ultimate shear strength in different land use, so the effect of soil root characteristics and distribution on soil shear strength was not carried out. However, from the preliminary conclusions of this paper, it can be seen that soil shear strength increased to a different extent, whether slope farmland was converted into abandoned land, pastureland or agroforestry land. In fact, farmland converted into abandoned land, pastureland and agroforestry land reduces human activity and increases soil root number, thus affecting ultimate shear strength of soil. However, we know that there are great differences in characteristics of different plant root systems in soil, such as distribution and interweaving, so the shear strength of soil-root composite system composed of root system and soil is also different. At present, just a few studies on the mechanics mechanism of soil erosion in the karst area of southwestern China [41-42] and the related mechanical experiments of root-soil composite system have not been reported. In our next research stage we will carry out a soil mechanics test of soil-root composite system on different planting measurements of soil and water conservation to provide reference for plant selection on soil and water loss prevention in the karst area.

*Soil and Water Loss Control of Sloping Farmland
in the Karst Rocky Desertification Area
of Southwestern China*

Sloping farmland is the main original place for soil and water loss [5], which is a reason for the Chinese government to set up a special fund for comprehensive control of soil and water loss of sloping farmland. At present, the main measurements for the project are engineering measures, such as transforming sloping farmland to terraces, intercepting drain, reservoir, and drain ditch and so on; however, because of the investment limit of the special fund, fragile terrain and difficulty for transforming sloping farmland to terraces by machine, the scope of harness is still relatively limited. Compared with engineering measures, planting measures have characteristics of investment saving, good benefit (ecological benefit and economic benefit), and it is suitable for karst area with characteristics of topography in pieces. However, for poor karst mountainous areas, people are more concerned about

economic benefits than ecological benefits. The practice of soil and water loss control of sloping farmland in the karst area has shown that most planting measures with poor economic benefits ended in failure, for example *Lonicera hypoglauca* planting was organized by the government of Southwestern Guizhou Autonomous Prefecture many years ago, and the effect of soil and water conservation on sloping farmland was not bad; however, because of poor economic benefit, farmers cut *Lonicera hypoglauca* down and replanted *Zea mays*, and soil erosion was further aggravated. Therefore, planting measures on soil and water loss control should be adapted to local conditions, meet regional natural and socio-economic characteristics and market demand, and the selected plant species should have good ecological and economic benefits. In short, soil and water loss control of sloping farmland in the karst area should be carried out closely around the aim of poverty-alleviation in order to realize coordinated and sustained development of ecological and economic benefits.

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Conflict of Interest

The authors declare no conflict of interest.

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