Soil organic carbon change relating to the prevention and control of rocky desertification in Guizhou Province, SW China

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Abstract: This article reports on the relationship between the prevention and control of rocky desertification and potential change to soil organic carbon storage (SOC) in Guizhou Province, in Southwestern China. Three strategic measures including the return of cultivated land to forestlands (RCLF), construction of artificial pasture (CAP) and artificial afforestation (AA) will be employed and more than approximately 20,923.22 km^2 lands will be improved in Guizhou Province. The SOC density of these areas will change significantly at different calculated depths. At calculated depths of 0.00–0.10 m, 0.00–0.20 m, 0.00–0.0.30 m and 0.00–1.00 m, the total SOC sequestration will reach up to 1.99×10^{13} g, 3.37×10^{13} g, 4.45×10^{13} g and 6.29×10^{13} g, respectively, over the next several decades. In the 0.00–1.00 m soil horizon, the potential increase in SOC storage related to rocky desertification prevention and the control project would reach 3.19% of the total present SOC storage in Guizhou province.

Keywords: rocky desertification; soil organic carbon; carbon sequestration; land use; global warming; soil thickness; environmental policy; karst mountainous area; Guizhou Province; China.

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1 Introduction

Rocky desertification refers to the process that transforms a karst area covered by vegetation and soil into a rocky landscape almost devoid of soil and vegetation under severe natural conditions or improper management and intensive disturbance from human activities (Jiang et al., 2014). This is the most severe ecological issue threatening and constraining regional sustainable development in Southwestern China (Bai et al., 2013). Rocky desertification is a type of land degradation that has occurred globally, such as in the European Mediterranean, Dinaric karst regions of the Balkans and Southwestern China. There are many factors contributing to this process, such as climate change, hydrological and geographic conditions and human development (Zhou et al., 2007). Rocky desertification has had tremendously negative impacts on the environment and socio-economic conditions and it is a significant global ecological and environmental problem. Karst landforms cover approximately 3.44×10^6 km^2, comprising 36% of the total area in China and 15.6% of the total karst area in the world (Jiang et al., 2014; Xu and Zhang 2014). In the context of green agriculture and global warming, there is great interest in the prevention and control of rocky desertification when targeting carbon sequestration (Bellamy et al., 2005; Xiong et al., 2016).

Guizhou Province is a typical karst mountainous area and mountains and hills cover 92.50% of the total area (Xiong et al., 2007). This area has experienced a severe contradiction between human and environmental needs over eighty and ninety years of the last century. To solve the temporary starvation problem, a large amount of forestlands and grasslands (GL) were reclaimed for croplands to increase food production. Ecological deterioration occurred over time and rocky desertification became a focus. Many studies concerning this problem have been carried out during the past two decades and these studies cover a wide range of topics. Xu and Zhang (2014) have studied the characterisation and interaction of driving factors in karst rocky desertification at Changshun in Guizhou Province and they found that lithology, soil type and road influence are the leading factors in this desertification. Using principal components analysis, Xie et al. (2015) developed an evolution of soil fertility in the succession of karst rocky desertification and they claimed that the changing trend in total organic carbon, total nitrogen, available phosphorus, microbial biomass carbon and microbial biomass nitrogen was as follows: potential rocky desertification > light rocky desertification > moderate rocky desertification > intensive rocky desertification. Bai et al. (2013) studied the spatio-temporal karst rocky desertification evolution processes from 1986-2000 and they found that:

a no obvious change took place in the total area of karst rocky desertification, but the mutual transformation of different types of karst rocky desertification land was remarkable

b the total change rate of karst rocky desertification reached 398.31 km^2 per year. However, we can draw a conclusion based on these previous studies.

Rocky desertification is caused by many factors. Without proper management, regional ecosystems with rocky desertification areas may experience a vicious cycle. For instance, Huajiang is a town with a strong degree of rocky desertification in Guizhou Province. The ecological system was very weak due to a shortage of water resources. Instead of planting trees to improve the ecological system, local residents cut down the remaining small trees to expand their sloping cropland. Therefore, water shortage is a fatal factor that has been threatening and constraining the daily life of local peasants and development of a regional economy over the past several decades.

Rocky desertification problems in Guizhou Province have received great attention from central and local governments as well as researchers. Billions of Chinese yuan (￥RMB) have been invested to solve this problem over the past decade. A report was developed titled the ‘Atlas for integrated protection of karst rocky desertification in Guizhou Province, (2006 ~ 2050)’ (Xiong et al., 2007). This report presents information about the rocky desertification status and a plan for the prevention and control of rocky desertification in Guizhou Province for the period from 2006 to 2050. This is a declaration that prevention and control of rocky desertification has been listed on the development agenda in Guizhou Province. What will happen during and after implementation of this enormous project? It is necessary to conduct some studies on the environmental and ecological outcomes of this project. Soil organic carbon (SOC) is a vital part of the terrestrial carbon pool (Batjes, 1996; Post and Kwon, 2000; Swift, 2001; Kristen et al., 2011; Martin et al., 2014; Taghizadeh-Toosi and Olesen, 2016). The importance of the SOC pool in the global carbon cycle has been widely recognised in recent decades (Trumbore, 1997; Hobley et al., 2016; Wang et al., 2010a). It is necessary to have a clear picture of SOC change for carbon management in a region, a country and the word. Most previous studies have emphasised factors affecting SOC, SOC spatial distribution and SOC storage assessment at different scales (Yu et al., 2010; Zhang et al., 2014). Increasing numbers of scientists recognise that great attention should be paid to potential SOC changes (Yan et al., 2007; Vanguelova et al., 2010; Chuai et al., 2013; Silveira et al., 2013; Camilli et al., 2016). Large projects have been undertaken to improve the environmental quality at the regional or national scale. It is necessary to undertake some studies on the potential SOC change coupled with these projects. The present research attempts to study the following:

1. the characteristics of rock exposure, soil thickness, SOC concentration and SOCD of different land uses in Guizhou Province
2. the relationship between the SOC characteristics and land use
3. the potential change in SOC in the near future caused by the prevention and control of rocky desertification in Guizhou Province.

2 Materials and methods

2.1 Study region

Guizhou Province (103°3’–109°35’, 24°37’–29°13’) is located on the eastern end of the Yunnan-Guizhou Plateau, which is one of the three main karst distribution regions on earth. It covers an area of 176,155 km^2 and has a population of 34.75 million. It is also a typical karst mountainous area that is experiencing environmental degradation. Guizhou Province has undergone the most severe contradiction between humans and the environment during the eighty and ninety years of the last century. At present, this region is still experiencing some severe environmental problems, such as karst rocky desertification and persistent water shortages. Guizhou Province has a subtropical humid monsoon climate. The mean annual temperature (MAT) and mean annual precipitation (MAP) range from 18 to 26°C and between 1,100 and 1,300 mm, respectively. The main ecosystem types include evergreen broad-leaved forest, coniferous and broad-leaved mixed forest and montane elfin forest. The problem of rocky desertification in Guizhou Province is severe and detailed information about the status of rocky desertification in Guizhou Province is present in Table 1 (Xiong et al., 2007).

Table 1 Status of rocky desertification in Guizhou Province (km^2)

Districts	*Total area*	*NRSD*	*LRSD*	*RDLD*	*RDMD*	*RDSD*	*RDESD*	*Non-karst area*
Guiyang	8,034.00	2761.11	2,192.05	1,307.25	487.54	80.01	2.29	1,203.64
Qiannan	26,193.00	662.08	7,015.02	4,576.18	2,098.91	847.92	194.48	4,838.81
Anshun	9,267.00	2475.85	1,182.27	1,243.53	954.51	601.06	170.61	2,639.57
Qianxinan	16,804.00	2,985.97	2,114.12	2,111.54	1,757.17	870.56	290.15	6,674.49
Liupanshui	9,914.00	1,468.00	1,529.49	1,574.20	921.71	635.18	134.51	3,650.71
Bijie	26,853.00	6,086.72	6,597.99	4,577.18	2,066.50	312.94	51.76	7,160.01
Zunyi	30,762.00	8,452.08	7,109.84	3,222.53	1,275.83	173.81	1.59	10,526.05
Qiandongnan	30,337.00	2,906.35	2,345.66	1,253.23	493.43	36.94	0.00	23,301.39
Tongren	18,003.00	3,701.88	3,940.14	2,290.12	813.35	156.99	11.85	7,088.67

Notes: NRSD = area with no risk of rocky desertification; LRSD = area with latent risk of rocky desertification; RDLD = area with rocky desertification to a light degree; RDMD = area with rocky desertification to a moderate degree; RDSD = area with rocky desertification to a strong degree; RDESD = area with rocky desertification to an extremely strong degree.

2.2 Soil sampling and general information collection

From March 2013 to June 2015, 2,340 soil profiles, consisting of 17,511 soil samples, were obtained from different districts in Guizhou Province in southwestern China (shown in Figure 1). Each profile was divided into 12 soil layers (0.00–0.05 m, 0.05–0.10 m, 0.10–0.15 m, 0.15–0.20 m, 0.20–0.30 m, 0.30–0.40 m, 0.40–0.50 m, 0.50–0.60 m, 0.60–0.70 m, 0.70–0.80 m, 0.80–0.90 m and 0.90–1.00 m) if the soil thickness was equal to or greater than 0.95 m. Otherwise, sampling was conducted at the actual depth. Concurrently, the rock exposures (coverage proportion of rocks) around the sampling sites were assessed using a tape measure. The oil bulk density (SBD) was determined in the field according to the cylindrical core method. The slope gradient and slope position of each sampling site was simultaneously recorded. The soil samples were stored in self-sealing plastic bags and returned to the laboratory, where the soil samples were air-dried, weighed and sieved to remove the gravel fraction (> 2 mm). The resulting samples were saved in zip-lock bags for an analysis of the SOC content. The total SOC was determined by $K_2Cr_2O_7$ oxidation at 170–180°C followed by titration with $FeSO_4$ (Wang et al., 2010b). The information reported about SOC content in the Qiandongnan and Zunyi Districts was applied in this study as well (Huang et al., 2014; Hui et al., 2014).

2.3 Calculations and statistical analysis

On the basis of field record information and laboratory analysis data, we calculated the SOC density (SOCD) for each sample site using the following equation:

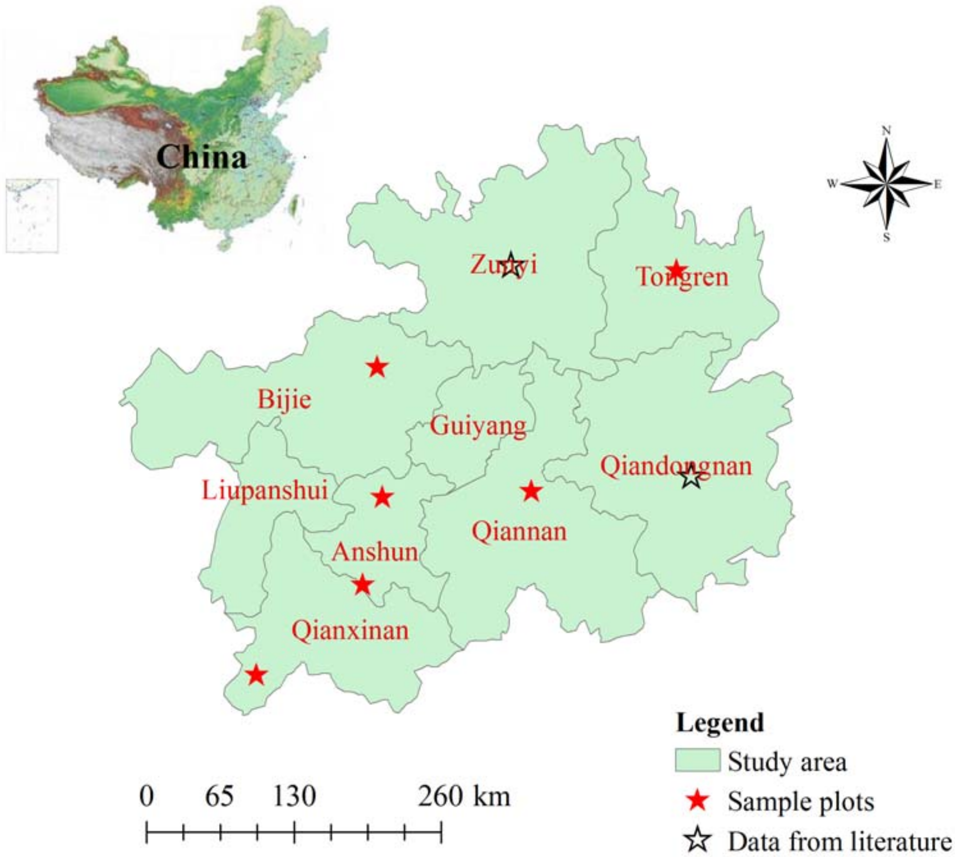
$$SOCD = \sum_{m=1}^{n+1} C_m \times SBD_m \times T_m \times (1-\theta_m) \times (1-A_r) \div (1-M_m) \tag{1}$$

where

SOCD	SOC density for the sample site (g m^2)
n	the number of soil samples collected from the sample site
C_m	SOC concentration (g kg^{-1}) of layer m
SBD_m	soil bulk density (kg m^{-3}) of layer m
T_m	soil thickness (m)
θ_m	gravel fraction size larger than 2 mm (%) of layer m
A_T	rock exposure around the sample site
M_m	moisture in the tested soil samples

Since a soil horizon (< 0.05 m) always remained that could not be sampled as an independent layer, our calculation continued to the $n + 1$ layer and we calculated this layer with the data for its upper layers, except the soil thickness.

Figure 1 Distribution of the sample plots (see online version for colours)



2.4 Potential changes in SOC storage resulting from the rocky desertification restoration project

According to the project description (Xiong et al., 2007), three key measures were employed in the prevention and control of rocky desertification in Guizhou Province:

a To return cultivated land to forest (RCLF), the core approach in this measure is planting trees on arid lands and on sloping croplands (AL-SCL), which have a poor soil quality, including shallow soil thickness, high rock exposure, large slope degree and so on.

b To construct artificial pasture (CAP), wherein the core approach of this measure is reclaiming abandoned lands and uncultivated lands (AbL-UL) for GL.

c To undertake artificial afforestation (AA), wherein the core approach of this measure is planting trees on AbL-UL lands.

To study the potential changes in SOC storage (SSOC) resulting from the rocky desertification prevention and control project, the sampling sites were divided into different groups, first according to land use. A profile of the distribution characteristics of average SOC concentrations under different land uses was calculated based on our field record information and results from the laboratory. Then, we calculated the average potential changes in SOCD by replacing the SOC profile concentrations of all sampling sits on original lands with the average SOC profile concentrations of intent land uses. For instance, RCLF refers to AL-SCL land conversion into forestlands. In the first few years, these lands would be converted into shrub-grasslands (SGL) since there are only a few planted trees during this time. Then, these lands will become shrublands (SL), arbor-shrub mixed forestland (ASFL) and finally arbor forestland (AFL); finally, ecological succession occurs. We calculated the SOCD of these lands using equation (1) by gradually replacing the SOC profile concentrations with the average SOC profile concentrations of SGL, SL, ASFL and AFL. The potential changes in SOC storage were obtained by the following equation:

$$SSOC_{change} = SOCD_{variation} \times A_{plan} \quad (2)$$

where

$SSOC_{change}$ change in SOC storage (g)

$SOCD_{variation}$ change in SOCD (g m^{-2})

A_{plan} prevention and control area under the project (m^2).

Statistical analysis was carried out using Microsoft excel 2003, SPSS 13.0 for Windows, Origin 6.1 and Arc Map 10.3.

3 Results

3.1 *The spatial inhomogeneity of soil thickness and rock exposure of different land uses in Guizhou Province*

A karst landscape has high spatial inhomogeneity in geographical characteristics, including soil thickness and rock exposure. These characteristics lead to complexity in land uses and spatial variation of vegetation and soil nutrients. In Guizhou Province, flat lands comprise little of the total area and these lands have a deep soil thickness (> 1.00 m) and low rock exposure (< 5%). Almost all of these lands have been used for planting rice. Since the present study did not refer to paddy lands, information about paddy lands is not referenced in the present study. As shown in Table 2, the other lands have a high variance in soil thickness and rock exposure. Obviously, land use in Guizhou Province was determined based on many factors, including soil thickness, rock exposure, slope position, slope degree, micro-circumstance and so on.

Table 2 Statistical information on soil thickness (cm) and rock exposure (%)

Land uses	*Items*	*n*	*Minimum*	*Maximum*	*Mean*	*Standard deviation*	*Variance*	*Skewness*	*Kurtosis*
AL-SCL	Soil thickness	1,153	6.00	100.00	43.92	27.97	927.91	0.85	–0.44
	Rock exposure	1,153	0.00	91.00	10.55	18.49	341.83	1.85	2.73
AFL	Soil thickness	209	5.00	100.00	44.11	28.82	830.76	0.82	–0.54
	Rock exposure	209	0.00	83.00	30.43	26.47	700.41	0.32	–1.24
ASFL	Soil thickness	64	7.00	100.00	40.21	30.41	925.05	1.16	–0.02
	Rock exposure	64	0.00	85.00	28.05	29.70	882.11	0.74	–0.78
SL	Soil thickness	172	5.00	100.00	31.75	20.94	438.57	1.57	2.55
	Rock exposure	172	0.00	90.00	27.54	21.42	458.70	0.93	0.30
SGL	Soil thickness	71	7.00	100.00	30.07	16.96	287.56	1.21	2.83
	Rock exposure	71	0.00	91.00	35.30	22.51	506.73	0.31	–0.43
GL	Soil thickness	142	7.00	100.00	58.05	30.93	956.69	0.20	–1.40
	Rock exposure	142	0.00	92.00	22.04	24.55	602.65	1.00	–0.05
AbL-UL	Soil thickness	529	6.00	100.00	43.92	27.97	782.43	0.85	–0.44
	Rock exposure	529	0.00	95.00	36.44	22.63	511.94	0.54	–0.65

Table 3 Means and standard errors of the SOC content of different land uses (g kg^{-1})

Land uses	*Soil horizons (m)*					
	0.00–.05	*0.05–0.10*	*0.10–0.15*	*0.15–0.20*	*0.20–0.30*	*0.30–0.40*
AL-SCL	23.24 ± 0.27Ak	20.69 ± 0.24Aj	18.30 ± 0.24Ai	15.44 ± 0.24Ah	12.55 ± 0.23Ag	9.99 ± 0.20Af
AFL	39.42 ± 1.37Dh	33.51 ± 1.19Dg	29.27 ± 1.11Df	25.73 ± 1.09De	21.23 ± 1.07Dd	14.84 ± 0.91BCc
ASFL	44.17 ± 2.80Ee	38.44 ± 2.61Ee	32.10 ± 2.67DEd	30.19 ± 2.72Ed	22.54 ± 2.20DEc	14.30 ± 1.92BCb
SL	47.41 ± 1.48Eg	40.44 ± 1.23Ef	36.94 ± 1.35Fe	32.08 ± 1.36Ed	25.23 ± 1.36Ec	19.24 ± 1.24Dbc
SGL	43.67 ± 2.12Ee	38.32 ± 2.10Ed	34.00 ± 1.99EFcd	29.92 ± 1.91Ebc	25.46 ± 1.96Eb	17.48 ± 1.09CDa
GL	29.91 ± 1.28Bh	25.47 ± 1.13Bg	21.64 ± 1.04Bf	18.98 ± 0.98Be	17.07 ± 1.02Bd	13.94 ± 0.98Bc
AbL-UL	35.97 ± 0.82Cj	30.39 ± 0.72Ci	26.84 ± 0.70Ch	23.33 ± 0.62Cg	19.34 ± 0.61Cf	15.23 ± 0.62BCe

Notes: Within rows, values followed by the same lowercase letter (a-d) are not significantly different ($p < 0.05$) among soil horizons of the same land use; within columns, values followed by the same capital letter (A-D) are not significantly different ($p < 0.05$) among one soil horizon under different land uses.

Table 3 Means and standard errors of the SOC content of different land uses (g kg^{-1}) (continued)

Land uses	*Soil horizons (m)*					
	0.40–0.50	*0.50–0.60*	*0.60–0.70*	*0.70–0.80*	*0.80–0.90*	*0.90–1.00*
AL-SCL	8.59 ± 0.20Ae	7.50 ± 0.19Ad	6.79 ± 0.18Acd	6.25 ± 0.1A8bc	5.59 ± 0.16Aab	5.24 ± 0.18Aa
AFL	12.17 ± 0.96Bbc	9.76 ± 1.03Bab	8.85 ± 1.00Bab	7.96 ± 0.95Bab	8.09 ± 1.04Bab	6.61 ± 0.91Aa
ASFL	8.42 ± 0.98Aa	7.72 ± 1.38ABa	5.73 ± 1.03Aa	5.30 ± 1.05Aa	6.16 ± 1.38ABa	6.22 ± 1.53Aa
SL	17.38 ± 1.82Cbc	14.83 ± 2.28Cb	9.44 ± 2.35Bab	5.69 ± 0.91Aa	4.96 ± 1.03Aa	4.92 ± 1.00Aa
SGL	16.06 ± 1.59Ca	10.25 ± 1.57BCa	11.36 ± 4.40Ba	6.27(n = 1)	5.68(n = 1)	5.98(n = 1)
GL	11.14 ± 0.82Bbc	8.98 ± 0.71Bab	8.15 ± 0.68ABab	7.07 ± 0.72ABa	6.85 ± 0.75ABa	6.22 ± 0.77Aa
AbL-UL	12.38 ± 0.57Bde	9.84 ± 0.61Bcd	7.96 ± 0.43ABbc	7.12 ± 0.40ABab	6.39 ± 0.43ABab	5.63 ± 0.41Aa

Notes: Within rows, values followed by the same lowercase letter (a-d) are not significantly different ($p < 0.05$) among soil horizons of the same land use; within columns, values followed by the same capital letter (A-D) are not significantly different ($p < 0.05$) among one soil horizon under different land uses.

3.2 Profile SOC concentrations of different land uses in Guizhou Province

A measure of RCLF is converting AL-SCL lands under severe condition (shallow soils, high rock exposure, large slope degree and so on) into forestlands and a measure of CAP and AA is transforming AbL-UL lands into GL and forest lands, respectively. Therefore, AL and SCL lands were divided into one group in the study area based on the profile SOC concentrations and abandoned lands (AbL) and uncultivated lands (UL) lands were divided into one group as well. The average SOC profile concentrations of different uses are listed in Table 3. Obviously, SOC content differences exist among different land uses in the same soil horizon and among different soil horizons of the same land use. However, the variation in SOC content on different land uses mainly occurred in the top several soil horizons (0.00–0.05 m, 0.05–0.10 m, 0.10–0.15 m, 0.15–0.20 m, 0.20–0.30 m, 0.30–0.40 m and 0.40–0.50 m) and the difference in the SOC content was gradually eliminated with increasing soil depth. The SOC content of the same soil horizon under different land uses under study decreased, generally, on the order of SL > ASFL > SGL > AFL > AbL-UL > GL > AL-SCL.

3.3 SOCD of different land uses in Guizhou Province

The SOC densities of different land uses and different calculating thicknesses are listed in Table 4. In the 0.00–0.10 m soil horizon, the average SOC densities for different land uses follow the order of SL > AFL > SGL > ASFL > AbL-UL > GL > AL-ACL. In the 0.00–0.20 m soil horizon, the average SOC densities have the following decreasing order: SL > AFL > ASFL > AbL-UL > SGL > AL-ACL > GL. In the 0.00-0.30 m soil horizon, the average SOC densities exhibit a different decreasing order: AFL > SL > ASFL > AbL-UL > AL-ACL > GL >SGL. In the 0.00-1.00 m soil horizon, the average SOC densities have the following order: AL-ACL > GL > AFL > AbL-UL > SL > ASFL > SGL. Obviously, these orders vary with increases in the calculated soil depth. It is believed that this results from many factors, such as cover vegetation, soil thickness, rock exposure and so on.

Table 4 Means and standard errors of the SOC density of different land uses

Land use	*0.00–0.10 m*	*0.00–0.20 m*	*0.00–0.30 m*	*0.00–1.00 m*
AL-ACL	2.16 ± 0.03a	3.95 ± 0.05a	5.22 ± 0.07a	8.99 ± 0.15d
AbL-UL	2.42 ± 0.06b	4.21 ± 0.10a	5.33 ± 0.14a	7.12 ± 0.21b
AFL	2.74 ± 0.12cd	4.74 ± 0.22b	5.96 ± 0.27b	7.91 ± 0.37bc
ASFL	2.46 ± 0.16bc	4.31 ± 0.31ab	5.39 ± 0.41ab	6.75 ± 0.53ab
SL	2.90 ± 0.11d	4.80 ± 0.18b	5.78 ± 0.24ab	6.87 ± 0.34ab
SGL	2.48 ± 0.15bc	4.09 ± 0.26a	5.04 ± 0.35a	5.89 ± 0.47a
GL	2.17 ± 0.09a	3.85 ± 0.17a	5.08 ± 0.23a	8.07 ± 0.42c

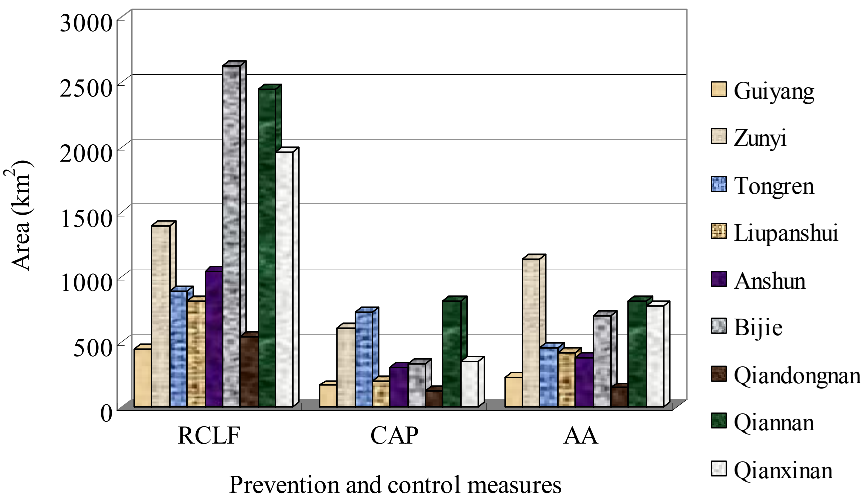
Note: Within columns, values followed by the same letter (a-d) are not significantly different ($p < 0.05$).

4 Discussion

4.1 Prevention and control area of different approaches in the plan

As mentioned above, the main prevention and control measures of rocky desertification in Guizhou Province include RCLF, CAP and AA. Information about areas with different prevention and control measures in different districts are listed in Figure 2. According to the 'Atlas for integrated protection of karst rocky desertification in Guizhou Province (2006 ~ 2050)', the total area of RCLF, CAP and AA in Guizhou Province would be 12,178.51 km^2, 3,655.55 km^2 and 5,089.16 km^2, respectively. The area change of land at certain rocky desertification degree is unclear. However, one thing is certain, approximately 20,923.22 km^2 of land, which accounts for 11.88% and 16.09% of the total land area and the total karst area of rocky desertification area in Guizhou Province, will be converted into potential rocky desertification lands (covered with vegetation).

Figure 2 Information about areas with different prevention and control measures in different districts (see online version for colours)



4.2 Variation in SOCD and SOC storage related to rocky desertification prevention and control

Once the measure of RCLF is carried out, the SOCD of converted lands will increase in all soil horizons (0.00–0.10 m, 0.00–0.20 m, 0.00–0.30 m and 0.00–1.00 m). However, over time, the SOCD of these lands will experience some initial increases and then a small decrease. In the first few years after afforestation, planted trees will still be short and the SOC contents in converted lands will be close to those on SGL lands. During this period, the SOCD variation will reach 1.69 kg $C.m^2$, 2.94 kg $C.m^2$, 4.03 kg $C.m^2$ and 5.84 kg $C.m^2$ at a calculation depth of 0.00–0.10 m, 0.00–0.20 m, 0.00–0.30 m and 0.00–1.00 m, respectively. The SOC storage change will reach 2.06×10^{13} g, 3.58×10^{13} g, 4.91×10^{13} g and 7.11×10^{13} g at a depth of 0.00–0.10 m, 0.00–0.20 m, 0.00–0.30 m and 0.00–1.00 m, respectively. With elapsed time, this land will become SL, AFSL and finally AFL through ecological succession. Then, the final SOCD change will be

1.35 kg m^{-2}, 2.30 kg m^{-2}, 3.06 kg m^{-2} and 4.43 kg m^{-2} at a depth of 0.00–0.10 m, 0.00–0.20 m, 0.00–0.30 m and 0.00–1.00 m, respectively. The SOC storage change will reach 1.64 × 10^{13} g, 2.80 × 10^{13} g, 3.73 × 10^{13} g and 5.40 × 10^{13} g at a depth of 0.00–0.10 m, 0.00–0.20 m, 0.00–0.30 m and 0.00–1.00 m, respectively. Once the CAP measure is carried out, the SOCD of converted lands will experience a small decrease, in theory and will then gradually experience a small increase and a weak decrease. However, this decrease will not actually happen or the decrease intensity will not reach these values (Table 5). For one thing, the prevention and control activity will not lead to a decrease in the SOC contents or a change in the SOCD and storage directly. Furthermore, the resulting GL will convert into SGL quickly under ecological succession since Guizhou Province has a subtropical humid monsoon climate. Once the AA measure is carried out, the change in SOCD of converted lands will be very similar to that land treated by the RCLF measure. The potential changes in SOC storage in relation to rocky desertification prevention and control are provided in Table 6. Based on the present study, the final total potential change in SOC storage will be up to 1.99 × 10^{13}, 3.37 × 10^{13}, 4.45 × 10^{13} and 6.29 × 10^{13} g in the top 0.10 m, 0.20 m, 0.30 m and 1.00 m soil horizons, respectively. Detailed information regarding the change in SOCD and SOC storage of converted lands during different ecological succession periods can be found in Tables 5 and 6. The total SOC storage (0.00–1.00 m) is 1.97 pg (Li et al., 2007) in Guizhou Province. Therefore, the potential increase in SOC storage from the prevention and control projects would reach 3.19% of the total SOC storage in Guizhou Province.

Table 5 Variation in SOC density at different soil depths after the remediation of rocky desertification (kg m^{-2})

Land type	*0.10 m*		*0.20 m*		*0.30 m*		*1.00 m*	
	SOC density	*Difference*	*SOC density*	*Difference*	*SOC density*	*Difference*	*SOC density*	*Difference*
				RCLF				
AL-SCL	2.16	——	3.95	——	5.22	——	8.99	——
SGL	3.85	1.69	6.89	2.94	9.25	4.03	14.83	5.84
SL	3.96	1.80	7.19	3.24	9.51	4.29	15.35	6.36
ASFL	3.59	1.43	6.43	2.48	8.49	3.27	12.42	3.43
AFL	3.51	1.35	6.25	2.30	8.28	3.06	13.42	4.43
				CAP				
AbL-UL	2.42	——	4.21	——	5.33	——	7.12	——
GL	2.26	–0.16	3.91	–0.30	5.03	–0.30	6.92	–0.20
SGL	3.08	0.66	5.36	1.15	6.87	1.54	9.08	1.96
SL	3.17	0.75	5.59	1.38	7.08	1.75	9.41	2.29
ASFL	2.87	0.45	5.00	0.79	6.32	0.99	7.86	0.74
AFL	2.81	0.39	4.86	0.65	6.16	0.83	8.14	1.02
				AA				
AbL-UL	2.42	——	4.21	——	5.33	——	7.12	——
SGL	3.08	0.66	5.36	1.15	6.87	1.54	9.08	1.96
SL	3.17	0.75	5.59	1.38	7.08	1.75	9.41	2.29
ASFL	2.87	0.45	5.00	0.79	6.32	0.99	7.86	0.74
AFL	2.81	0.39	4.86	0.65	6.16	0.83	8.14	1.02

Table 6 Potential change in SOC storage correlated with different restoration measures

Land type	*0.10 m*	*0.20 m*	*0.30 m*	*1.00 m*
		RCLF		
Original lands (AL-SCL)				
SGL	2.06×10^{13}	3.58×10^{13}	4.91×10^{13}	7.11×10^{13}
SL	2.19×10^{13}	3.95×10^{13}	5.22×10^{13}	7.75×10^{13}
ASFL	1.74×10^{13}	3.02×10^{13}	3.98×10^{13}	4.18×10^{13}
AFL	1.64×10^{13}	2.80×10^{13}	3.73×10^{13}	5.40×10^{13}
		CAP		
Original lands (AbL-UL)				
GL	-5.85×10^{11}	-1.10×10^{12}	-1.10×10^{12}	-7.31×10^{11}
SGL	2.41×10^{12}	4.20×10^{12}	5.63×10^{12}	7.16×10^{12}
SL	2.74×10^{12}	5.04×10^{12}	6.40×10^{12}	8.37×10^{12}
ASFL	1.65×10^{12}	2.89×10^{12}	3.62×10^{12}	2.71×10^{12}
AFL	1.43×10^{12}	2.38×10^{12}	3.03×10^{12}	3.73×10^{12}
		AA		
Original lands (AbL-UL)				
SGL	3.36×10^{12}	5.85×10^{12}	7.84×10^{12}	9.97×10^{12}
SL	3.82×10^{12}	7.02×10^{12}	8.91×10^{12}	1.17×10^{13}
ASFL	2.29×10^{12}	4.02×10^{12}	5.04×10^{12}	3.77×10^{12}
AFL	1.98×10^{12}	3.31×10^{12}	4.22×10^{12}	5.19×10^{12}
Total variation of Guizhou Province	1.99×10^{13}	3.37×10^{13}	4.45×10^{13}	6.29×10^{13}

A karst landform has a high diversity of geographic characteristics and its land use and management are very complex. However, vegetation coverage has high variation that leads to a distinctive spatial inhomogeneity of soil nutrients, including SOC. As shown in Tables 5 and 6, significant differences could be found among the SOC contents and SOC densities of different land uses. Differences in SOC contents in the same horizon of different land uses mainly resulted from the divergence of vegetation coverage and human disturbance. Land use leads to a discrepancy in SOC input, including SOC total amounts and SOC quality. Most of the aboveground biomass on croplands is removed by peasants after harvesting (Hansen et al., 2004; Lal, 2009) and the removal of these residues diminishes the carbon flow into soils, thereby decreasing SOC stocks. However, most of the aboveground biomass of GL, SL, ASFL and AFL will remain in the field and a large proportion of this biomass will be input into soils after decomposition by microorganisms. In addition to land use, the input of root litter is an important factor influencing the ecosystem processes related to carbon and nutrient cycling (Persson and Stadenberg, 2010). The profile distribution of root systems is another key factor leading to discrepancies in SOC under different land uses. Canadell et al. (1996) found that the average maximum rooting depth for trees and shrubs is considerably deeper than for grasses and herbs. The root depths of Eucalyptus marginata in southern Australia could be up to 40 m and 25 m for Quercus fusiformis on the Edwards Plateau in central Texas (Jackson et al., 1999, 2000; Lorenz and Lal, 2005). Furthermore, the SOC input quality, which is linked to the bioavailability of SOC, varies with changes in planting resulting from different land uses (Baldock and Skjemstad, 2014; Hobley et al., 2016). Consequently, the resulting aggregate content and fraction of organic carbon are significantly different. Some studies suggest that mineral-association aggregation and physio-chemical transformation can reduce the biological accessibility of organic matter and convert it into more stable forms that are resistant to degradation processes (Tisdall and Oades, 1982; Oades, 1988; Skjemstad et al., 1996). Hence, land use strongly affects the amount of biomass input into the soil and occurrence of aggregates. It has been suggested that aggregate SOC and aggregates of easily oxidisable organic carbon (EOC) under GL and forestlands are normally higher than under farmlands (Liu et al., 2014). Apart from land use, variations in soil thickness and rock exposure are also important factors in the discrepancy of the SOCD in Guizhou Province. In the present study, the average SOC contents in the same soil horizon of different land uses generally follow this order: SL > ASFL > SGL >AFL AbL-UL > GL > AL-SCL (Table 3). However, the order of the average SOCD under different land uses changes under certain calculations of soil thickness (Table 4). This is mainly believed to be a result of the discrepancy in soil thickness and rock exposure.

With the implementation of different restoration measures, many changes continuously occur above and underground through ecological succession. Aboveground, intuitionistic changes include increases in vegetation coverage, improvement of the regional landscape and so on. Non-intuitive changes are mainly related to ecological systems, including increases in biodiversity and the balance of ecological systems and many ecological problems will be gradually alleviated, such as the shortage of water resources. Underground, changes refer to the abundance and structure of soil animals and soil microbes and to the abundance and geochemical processes of elements. Consequently, ecological system becomes more complex and ecological balance becomes increasingly strong.

5 Conclusions

In the present study, the final total increase in SOC storage is estimated to reach up to 1.99×10^{13} g, 3.37×10^{13} g, 4.45×10^{13} g and 6.29×10^{13} g in the top 0.10 m, 0.20 m, 0.30 m and 1.00 m soil horizons, respectively, in the near future (the next several decades). If the rocky desertification prevention and control project is implemented efficiently, the potential increase in SOC storage would be up to 3.19% of the total SOC storage in Guizhou Province in the 0.00–1.00 m soil horizon. Certainly, carbon sequestration in Guizhou Province would be much greater than these values since a considerable amount of carbon will be sequestrated in Guizhou Province as biomass, such as arbor trees, shrub trees, grass and so on. In the context of green agriculture and global warming, it is believed that rocky desertification will be alleviated and gradually eliminated. Therefore, further research should be conducted to develop an explicit picture of the carbon sink potential in karst mountainous areas.

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