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Soil Organic Carbon Distribution Under Different Land Uses and Landscape Positions in Two Typical Watersheds of the Loess Plateau, China

Zhijing Xue*, Xuan Fang, Wanzhong Wang* and Shaoshan An***
*Northwest A&F University, State Key Laboratory of Soil Erosion and Dry Land Farming on Loess Plateau, Yangling 712100, China
**Suqian College, Jiangsu 233800, China
Corresponding Author: Wanzhong Wang

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ABSTRACT

Soil organic carbon distribution and its storage were estimated in two classical small watersheds that based on 163 samples under different land uses and landscape positions. Land use conversion may alter land cover, which results in carbon stock changes in biomass as well as in the soil. After the project of Grain for Green, initiated in Loess Plateau, most area has been conducted vegetation restoration same as the comprehensive managed watershed (Shanghuang), with spread vegetation-covered region and lower slope farmland. However, it is not clear that how effective the newly initiated project will be. In this study, we found an original watershed (Sidigou) as the reference, which has not done any ecological restoration projects, and kept primitive cultivated management. The results show that soil organic carbon (SOC) in comprehensive managed watershed (Shanghuang) was higher than the untreated watershed (Sidigou). As the soil depth increases, the SOC content gradually decreases. Soil organic carbon concentration and distribution were significantly influenced by land uses and landscape positions. The SOC of the shrub land and natural grassland were significantly higher than for the other land uses. The SOC of the valley was greater than that for the top of mound crests and mound slope. The total SOC storage of untreated watershed and comprehensively managed watershed were 20099.42 t and 46527.12 t, respectively. The area proportion of land uses is the important reason for income gap of the two study areas. Land use conversion from farmland to shrub land and or artificial grassland was better for loess hilly area. It was found that the projects to restore vegetation, such as Grain for Green would be beneficial for the ecological restoration of Loess Plateau in China.

INTRODUCTION

With the key indicator of soil quality assessment, soil organic carbon (SOC) is a crucial component. As a common global issue, soil carbon sequestration is a natural, cost-effective, and environmental strategy to achieve food security by improving soil quality (Lal 2004). Soil organic carbon pool is a significant part of the global carbon stock; it has been estimated at approximately 3.3 times the size of the atmospheric pool and 4.5 times the size of the biotic pool (Lal 2004, Janzen 2004). At the small watershed scale, a classical erosion landscape has formed that includes hilly-gully loess regions. The spatial heterogeneity of soil organic carbon is influenced by the combined factors of climate condition, soil quality, vegetation distribution, land use and so on. Landscape positions and land uses are the most important factors among them (Batjes 2004, Ritchie et al. 2007, Fu et al. 1999, Guo et al. 2003). The vegetation coverage, land uses and ecological process are mainly controlled by landscape positions due to alteration of soil nutrients and soil moisture. Soil erosion and surface runoff affect biogeochemical cycle (Fu et al. 1994). The changes of land uses can cause a change in land coverage as well as associated in carbon stocks (Bolin & Sukumar 2000). Long-term and poor land use management strategies are the major reasons for the losses. They affect vegetation distribution and cause soil erosion acceleration and ecological environment deterioration such as deforestation, overgrazing and over-reclamation (Fu et al. 2009, Zheng 2006). During the past two centuries, land use practices modify decomposition dynamics by changing soil aeration, water dynamics and aggregation, as well as the biochemistry and quantity of crop residues.

The ecosystems have been impacted by various forms of human activities. During the last century, backward agricultural management, fragmentation of ecological environments and serious soil erosion have been accelerated due to increasing population pressure. On the Loss Plateau, in order to withstand further deterioration of the natural ecosystem, the Chinese government has launched a serious nation-wide conservation project that focus on the vegetation rehabilitation and land recovery (An et al. 2010). One of the most urgent task to achieve sustainable ecological restoration for the Loess Plateau was Grain for Green project. It was initiated for soil erosion control and land quality improvement using widespread return of sloping cropland to other uses in the loess hilly area. It was also suggested to convert all croplands with slopes of greater than 15° to green land. After project was implemented, the area of Loess Plateau has been conducted vegetation restoration same as the comprehensive managed watershed (Shanghuang). Many studies have been conducted to assess the effects of land uses conversion on soil carbon stocks (Degryze et al. 2004, Groenendijk et al. 2002, Murty et al. 2002, Paul et al. 2002, Scott et al. 2002). After the management practices of the Grain to Green project were executed, the SOC content increased by 9.29% after 7 years, and it is expected to increase to 18.48% after 20 years later (Fang et al. 2006). In order to judge and measure the effect of land uses conversion on ecological restoration, many studies focus on the method of temporal. Its result is carried out by comparing the historical data with the current one. The soil organic carbon in the Loess Plateau is decreasing each year, and the content is lower than the average level (Yu et al. 2007).

The objectives of this paper were the following: (1) to judge and measure the effect of Grain for Green project implemented on Loess Plateau, (2) to examine the differences in soil organic carbon content between a comprehensive management watershed (the Shanghuang research site) and an untreated watershed (Sidigou), (3) to analyse the influence of soil organic carbon in relation to different land uses and landscape position.

MATERIALS AND METHODS

Outline of the study area: The study areas are the Shanghuang and Sidigou watershed. Under 30 years comprehensive management in Shanghuang watershed (106°262’ -106°302’ E and 35°592’-36°022’ N), and untreated watershed (Sidigou) (106°242’-106°262’ E and 35°572’-36°592’ N; Fig. 1) are situated in the hilly-gully region of the Loess Plateau. They have a semi-arid climate. The average annual temperature is 6.9°C and the average annual rainfall is 419 mm (1982-2002). The rainy season starts in July and continues until October. The average rainfall in August accounts for 24% of the total annual precipitation. The dominant soil in the study area is classified as a loessal soil Cambisol by Chinese soil taxonomy (Chinese Soil Taxonomy Research Group 2001).

The land use type in Shanghuang was dominated by farmland and natural grassland and composed of seven types: (I) shrub land (*Caragana korshinskii,* hickory and Ansu apricot), (II) manmade grassland (*Medicago sativa L.*), (III) natural grassland (*Artemisia gmelinii*, *Stipa bungeana*, *Artemisia scoparia*, *Artemisaia stelleriana, Stipa grandis, Thyme* and *Potentilla chinensis*), (IV) orchard (Apricot, Early crisp pear and Apple), (V) farmland (Corn and Wheat), (VI) abandoned land, (VII) terraced land.

Sample collection and methods: One hundred sixty three samples were collected in the study areas in July 2010 and 2011 according to the different land uses (Table 1) and landscape positions (Table 2). According to the difference of two study areas, distribution and area proportion of land uses and landscape position to confirm the sample numbers, a non-equidistant irregular grid method was used in which samples were collected from 6-7 replicated points using a 20×5 cm soil auger. The 60 cm soil depth was divided into 3 layers: 0-10 cm, 10-30 cm and 30-60 cm. The fresh soil (1.5-2.0 kg) was put into plastic bags and air dried for analysis. The soil samples were subjected to 5 replicates to assay the soil bulk density, which was collected in each layer using a 100 cm^3 cylinder. A portable global positioning system (GPS) was used to record the sampling site coordinates and basic information, including land use, vegetation types and dominant species. Afterward, all of the samples were air-dried and polished to pass through a 0.25mm sieve. The SOC was measured by the potassium dichromate volumetric method (Nelson & Sommers 1975). The core ring method was used to measure the soil bulk density.

Statistics: The geostatistics software GS+ (Geostatistics for the Environmental Sciences) was used to determine the related parameter of semi-variogram (nugget, sill and range)

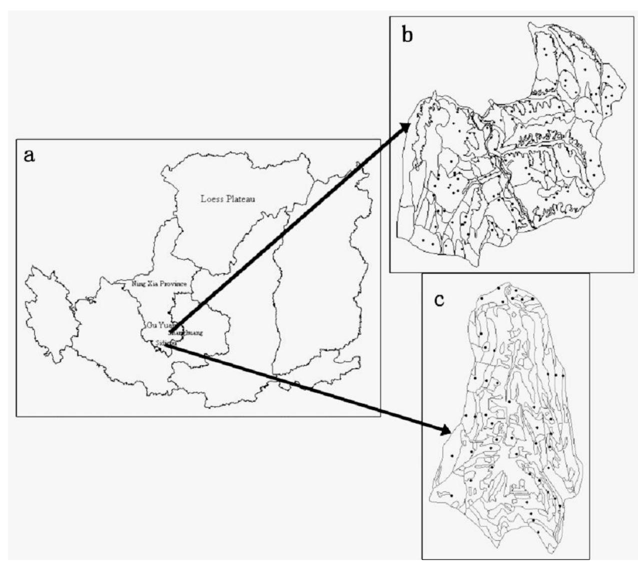

Fig. 1: Location of the Ningxia Province in the Loess Plateau, China, and the untreated small watershed (Sidigou) and the comprehensive watershed (Shanghuang) in Ningxia Province.

Table 1: Land uses area, sample size and proportion for different land uses in two classical watersheds.

Land uses	The comprehensive managed watershed Shanghuang				The untreated watershed Sidigou			
	Area (hm^2)	Area proportion (%)	Sample size	Sample proportion (%)	Area (hm^2)	Area proportion (%)	Sample size	Sample proportion (%)
Shrub land	3489369.30	48.79	30	20.84	295856.73	5.83	6	12.24
Natural grassland	1772888.39	21.64	8	5.56	936337.73	18.46	8	16.33
Artificial grassland	145410.70	1.78	12	8.33	1012889.07	19.96	5	10.20
Abandoned land	409727.09	5	38	26.39	3879.93	0.08	13	26.53
Orchard	461402.60	5.63	7	4.86	143289.69	2.82	7	14.29
Farmlands	1289130.5	15.74	12	8.33	2681112.62	52.85	10	20.41
Terrace land	85157.13	1.01	7	4.86				

Table 2: Sample size and proportion for landscape positions in two classical watersheds.

Slope position	The comprehensive managed watershed Shanghuang		The untreated watershed Sidigou	
	Sample size	Sample proportion (%)	Sample size	Sample proportion (%)
Top of mound crests	23	20.17	14	28.57
Mound slope	64	56.14	16	32.65
valley	27	23.68	19	38.78

Table 3: Descriptive statistical analysis of soil organic carbon (SOC), soil bulk density (BD) and soil organic carbon density (SOCD).

		SOC(g/kg)			BD(g/cm^3)			SOCD(kg/m^2)		
Soil layer(cm)		0-10	10-30	30-60	0-10	10-30	30-60	0-10	10-30	30-60
Shanghuang	Mean	9.98	7.31	4.51	1.15	1.2	1.22	1.13	1.73	1.64
	S.D.	5.29	3.54	2.11	0.1	0.11	0.1	0.60	0.82	0.76
	Min	1.28	1.11	0.98	0.89	1.01	1.05	0.16	0.27	0.32
	Max	24.55	20.02	10.66	1.48	1.47	1.54	2.70	4.09	3.62
	C.V.	53.06	48.40	46.67	8.73	9.48	8.19	53.13	47.66	46.61
	Skewness	0.865	0.721	0.683	0.336	0.333	0.907	0.958	0.815	0.721
	Kurtosis	0.146	0.601	-0.116	0.308	-0.745	0.812	0.213	0.552	-0.156
Sidigou	Mean	8.04	5.98	4.73	1.18	1.23	1.24	0.94	1.46	1.74
	S.D.	3.54	2.22	1.93	0.06	0.73	0.82	0.39	0.52	0.68
	Min	2.46	2.28	1.29	1.03	1.08	1.07	0.29	0.55	3.48
	Max	22.54	12.32	9.8	1.31	1.43	1.43	2.5	3	3.48
	C.V.	44	37.15	40.94	5.16	5.91	6.66	41.45	35.57	39.24
	Skewness	1.619	0.625	0.702	-0.334	0.362	0.330	1.263	0.642	0.620
	Kurtosis	5.668	0.422	0.200	-0.110	0.363	-0.093	4.432	0.666	0.071

which indicated the spatial variation of regionalized variables in definite scale. Followed the distribution map of sampling sites that was generated by ArcGIS9.3 which divide the soil profile data to the different slope positions and land-using types.

Descriptive statistical analysis was carried out with SPSS16.0. One-way analysis of variance (ANOVA) followed by the Duncan test (the level for significant differences ($p<0.05$) was used to compare soil organic carbon content (SOC), soil bulk density (BD) and soil organic carbon density (SOCD) for different land-using types, slope position and soil layer in the two study areas. All statistical analyses were performed with SPSS16.0 and SAS Enterprise Guide, Version 4.1 (SAS Institute 2006).

RESULTS

Statistical description of the SOC: The descriptive statistical results of the SOC content, soil density and SOC density in the two study areas are given in Table 3. The SOC content and density of the two study areas varied significantly. The means of the SOC content and bulk density in the soil layers were maintained at 4.51-9.98 and 1.13-1.73

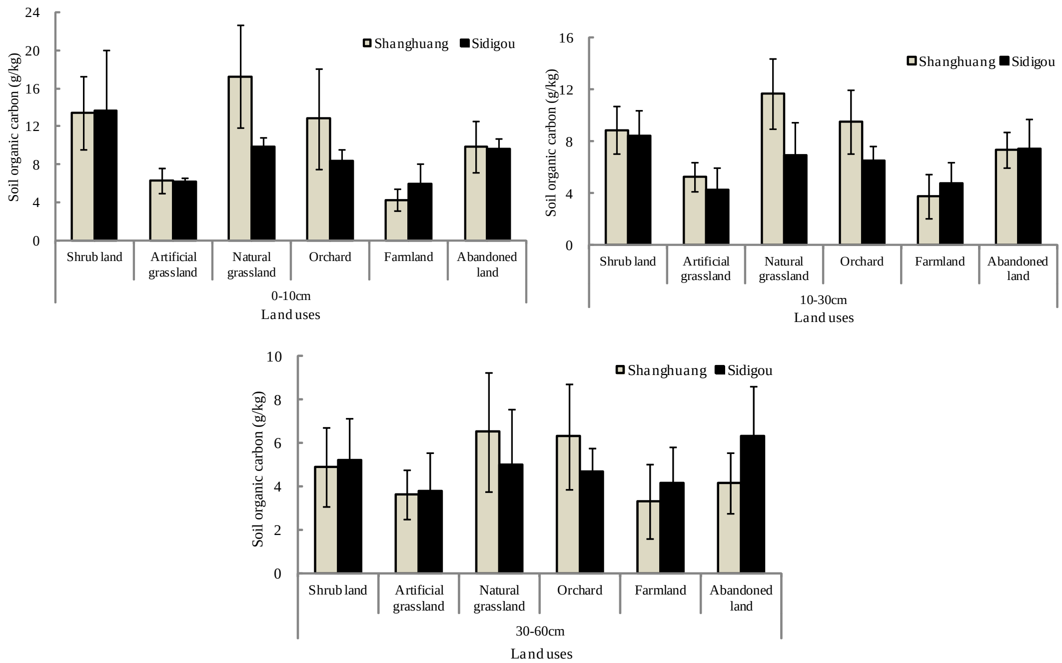

Fig. 2: Soil organic carbons under different land use of each soil layer in the comprehensive management watershed (Shanghuang) and the untreated small watershed (Sidigou).

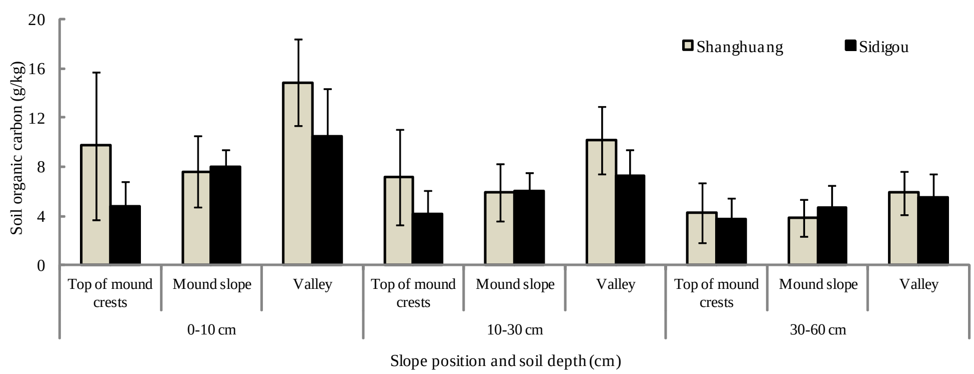

Fig. 3: Soil organic carbon in the different slope positions of the soil layers in the comprehensive management watershed (Shanghuang) and the untreated small watershed (Sidigou).

g/kg in Shanghuang watershed. It ranged between 4.72-8.04 and 0.94-1.74 g/kg, respectively in Sidigou watershed. The coefficient of variation (CV) displays the degree of dispersion of random variables and, thus, the extent of spatial variability. A CV of ≤10% indicates low variability; 10%≤ CV≤100% indicates moderate variability; and CV≥100% indicates high variability. The CV values of the soil bulk density in the two study areas ranged from 5.16 to 9.48 %, which are lower than 10 %. It indicate that BD has a low variability and clearly varied less throughout the study areas. The CV values of the SOC content and SOCD were moderate with a heterogeneous spatial distribution.

Distribution of SOC under different land uses and slope positions: The natural grassland, shrub land, orchard and abandoned land had significantly higher SOC contents than the other land uses. In the comprehensively managed watershed (Shanghuang), the SOC concentration in the surface layer (0-10 cm) and the 10-30 cm layer varied significantly. As shown in Fig. 2, natural grassland (11.83 g/kg) had the greatest value, followed by shrub land, orchard, abandoned land, artificial grassland and terrace land; it was lowest in farmland (3.79 g/kg). In untreated watershed, shrub land had the highest SOC content (9.11 g/kg), the artificial grassland had the lowest (4.73 g/kg).

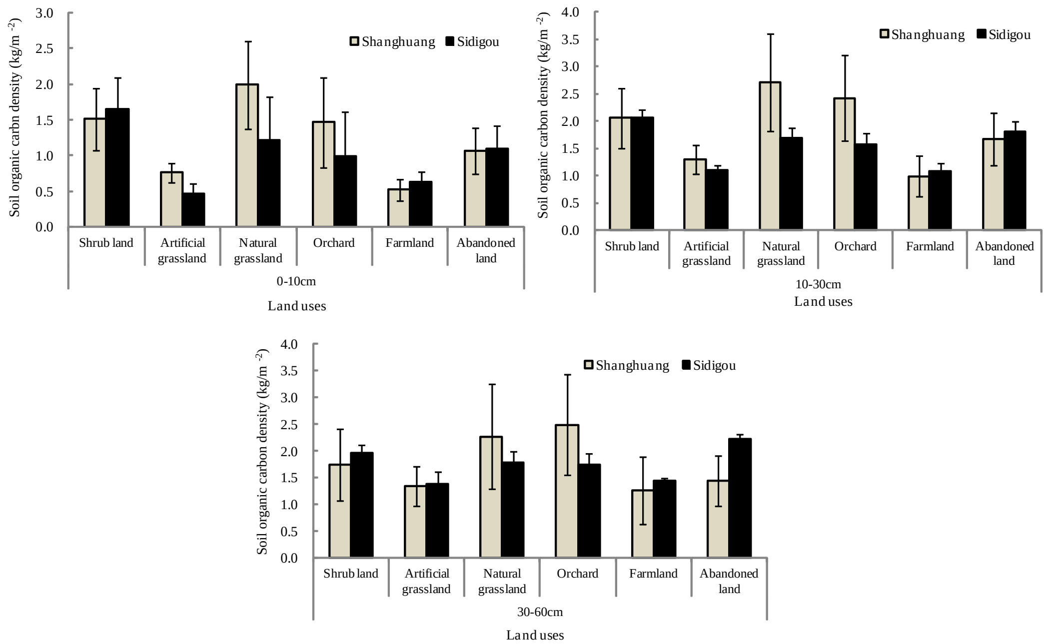

Fig. 4: Soil organic carbon density under different land uses in the comprehensive management watershed (Shanghuang) and the untreated small watershed (Sidigou).

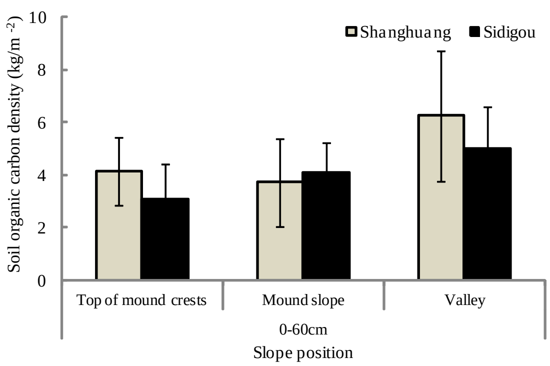

Fig. 5: Soil organic carbon density under different landscape positions of the 0-60cm soil layer in comprehensive management watershed (Shanghuang) and untreated small watershed (Sidigou).

In the two study areas, the SOC content of the valley was significantly greater than the other slope positions. The SOC concentration in the different slope positions ranged between 6.50 and 10.32 g/kg and 4.43 and 7.78 g/kg with different distribution characteristics (Fig. 3). In the Shanghuang area in particular, the SOC content varied significantly in the following order: valley (10.32 g/kg) > mound slope (6.97g/kg) > top of mound crest (6.50 g/kg). However, the SOC content of the mound slope (6.24 g/kg) was considerably higher than the mound slope (4.43 g/kg) in the Sidigou area.

This variation was displayed most strongly in the surface layer. As the soil layer decreased, the variation became more general and less obvious. The SOC content clearly decreased with soil depth. Moreover, the SOC content of shrub land, natural grassland, orchard and abandoned land increased significantly with decreasing soil depth.

Soil organic carbon density and soil organic storage: The comparison of soil organic carbon density in the different land uses between Shanghuang and Sidigou are shown in Fig. 4. The SOC density in the different land uses varied significantly, particularly in natural grassland and orchard, which displayed distinct differences. Comparatively speaking, the differences in Sidigou were not obvious.

The comparison of the soil organic carbon density in the different slope positions between the Shanghuang and Sidigou areas is shown in Fig. 5. The SOC density in the different slope positions is displayed differently. The SOC density of the top of mound crests and valley in Shanghuang was higher than at Sidigou. On the top of mound crests, the SOC density in the two study areas maintained nearly at the same value.

The SOC storage for the different land uses was calculated (Table 4), and the total SOC storage in the two study areas was 46527.12 t and 20099.42 t. The SOC storage in shrub land and natural grassland occupied a large portion, at 47.4% and 31.32%, respectively, in the Shanghuang area. In

Table 4: Soil organic carbon density (SOCD) and storage (TSOC) in two classical watersheds.

Land uses	The comprehensive managed watershed, Shanghuang					The untreated watershed, Sidigou				
	SOCD (kg/m^2)	Area (m^2)	Percent Area (%)	TSOC (t)	Percent TSOC (%)	SOCD (kg/m^2)	Area (m^2)	Percent Area (%)	TSOC (t)	Percent TSOC (%)
Shrub land	6.32±0.14	3489369.30	48.79	22052.81	47.40	6.74±0.10	295856.73	5.83	1994.07	9.92
Natural grassland	8.22±0.18	1772888.39	21.64	14573.14	31.32	5.28±0.04	936337.73	18.46	4943.86	24.6
Artificial grassland	3.75±0.06	145410.70	1.78	545.29	1.17	3.51±0.06	1012889.07	19.96	355.24	17.69
Abandoned land	4.81±0.09	409727.09	5	1970.79	4.24	5.53±0.07	3879.93	0.08	21.46	0.11
Orchard	7.14±0.09	461402.60	5.63	3294.41	7.08	4.77±0.05	143289.69	2.82	683.49	3.4
Farmlands	2.87±0.11	1289130.5	15.74	3699.80	7.95	3.32±0.07	2681112.62	52.85	8901.29	44.29
Terrace land	4.59±0.11	85157.13	1.01	390.87	0.84					
Total	37.7	7653085.71	100	46527.12	100	29.15	5073365.77	100	20099.42	100

Sidigou, the SOC storage of farmland and natural grassland accounted for 44.29% and 24.6%, respectively.

DISCUSSION

Effects of land uses on the SOC content: It is generally assumed that much of the CO_2 released into the atmosphere results from soil degradation in tropical and subtropical land, particularly from deforestation and the conversion of forest into cropland and cultivated pastures (Abril et al. 2005). Furthermore, soil can lose its organic carbon to atmosphere because of increasing decomposition and erosion when vegetation is destroyed by converting perennial vegetation into cultivated land, which then leads to increased atmospheric CO_2 (Houghton 1991). The related studies generally consider that the SOC content in farmland is lower than that in grassland and forest. A new equilibrium was reached between residue inputs and decomposition after vegetation restoration (Aweto 1981). The SOC content decreases when grassland and forest are converted into agricultural land, while reclaiming unimproved land to grassland can increase the solid stock of SOC content (Groenendijk et al. 2002).

Land uses and slope positions have a great influence on soil organic carbon and its spatial variability. Land uses may affect the SOC concentration distribution in the soil profile. In our study, the SOC in the surface soil was obviously higher than that in deep soil for natural grassland and shrub land. However, a small difference in SOC concentration was found between the surface and the deep soil in farmland and artificial grassland, a moderate difference in abandoned land and orchard. This was because of the residue input in the surface soil (Li et al. 1992, Wu et al. 2004, Liu et al. 2005). More specially, the 0-60cm layer has high surface litter decomposition conversion and vegetation root distribution (especially rootlets) (An et al. 2007, Zhao et al. 2002, Yang et al. 2004). Due to the characteristics of flat land, human interference via manure input as fertilizer and lower soil erosion, terrace land, orchard and abandoned land have more chance to accumulate SOC content. Farmers leave the bare fallow after harvest, and deep ploughing annually leads to soil chessom and SOC content decomposing easily. Consequently, the lowest SOC content was observed in farmland. More specifically, due to severe natural grassland degradation and excessive grazing at Sidigou, the SOC content at Shanghuang was greater, and the differences between the two study areas are significant. In orchards, the fruits trees in the Shanghuang area were in the mature period, having been planted almost 5 to 15 years old, while those in Sidigou were only approximately 4 to 5 years old. Therefore, after effective accumulation under less human interference, the SOC content of the two study areas also exhibited obvious differences.

Effects of slope position on the SOC content: The SOC content in the slope positions showed that valley in two study areas was the best position. The SOC content in the Loess Plateau is closely related to two aspects. On the one hand, there is the soil development in different topographical conditions and sediment redistribution, which result in soil and water erosion (Mao et al. 2007). On the other hand, surface runoff and soil erosion caused by slope positions are the main reasons for the differences in soil constitution (Zhang 2006, Yang 2004). Compared with the Sidigou area, the vegetation at the slope top of Shanghuang is more intensive, and thus, it could control soil and water erosion effectively and reduce the carbon output quantity of erosion sediment. However, the slope tops are the major areas of soil and water erosion. Additionally, the lack of vegetational diversity and the sparse distribution hinder SOC accumulation. Along with the impact of soil and water erosion, granular soil with high SOC content could flow away as sediment into low-lying places such as valleys. Therefore, the SOC content of valleys is greater than the other slope positions. As Detwiler & Hall (1998) showed, SOC will normally decrease after forest implantation. After a tropical forest was cultivated into farmland, the SOC content deceased by 40% compared with 20% after being turned to grassland. Motavalli et al. (2000) also showed that after tropical secondary forest was cultivated to farmland, the SOC content decreased 44%. Most studies show that afforestation has a positive effect on SOC content and density and that converting agriculture land into other land uses (except for artificial grassland) contributes to the accumulation of SOC. The conversion of agricultural land into shrub land or abandoned land should be supported because such vegetation can control soil and water erosion and spontaneous soil recovery. Furthermore, if natural grassland should be protected effectively by limiting or forbidding grazing, the SOC content of natural grassland as well as shrub land should increase. Although artificial grassland has no significant function on SOC density and cutting could impact SOC accumulation, it is a good approach to control water and soil erosion. Due to the characteristics of low demand, feedstuff supplying has relative economic benefits.

CONCLUSION

The SOC content was extremely higher in comprehensive management watershed (Shanghuang area). Land uses and slope positions have a significant effect. The SOC content under natural grassland and shrub land was significantly higher than the other land uses. Farmland and artificial grassland had the lowest SOC content of all the land uses. In the three soil layers of different land uses, the SOC content and soil bulk density decreased with soil depth. The SOC stock in the Sidigou area was 20099.42 t, with an SOC content of 4.86 g/kg (0-60cm). The SOC stock was 46527.12t, with an SOC content of 5.39 g/kg (0-60cm) in the comprehensive management area. Consequently, the Grain to Green project has been carried out in comprehensive management area which alters the slope degree and vegetational coverage that benefits SOC accumulation and the SOC stock has potential of increasing. Compared with untreated small watershed, the comprehensive management area with natural grassland and shrub land might be the optimal choices for SOC accumulation as well as soil and water erosion control. Grain for Green project, currently implemented in the comprehensive managed watershed, will contribute to the soil organic carbon sequestration while improving the regional environment.

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