COMPARISON OF SOIL ACTIVE ORGANIC CARBON FRACTIONS IN DIFFERENT VEGETATION ZONES IN PURPLE-SOIL OF HILL SLOPE

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Abstract

To explore the effect of vegetation restoration on soil carbon cycle and fractions of soil organic carbon pool on purple-soil hill slope in Hengyang City of Hunan Province, China was selected. The soil samples of 0 - 10 and 10 - 20 cm soil layers under three types of vegetation, i.e., grassland zone (GZ), grassland-forest zone (GFZ) and forest zone (FZ). The dynamics of soil active organic carbon (SAOC) fractions to provide theory basis for the influence of soil carbon cycle and different vegetation zones on the fractions of organic carbon pool and its stability. Results show: Microbial biomass carbon and easily oxidizable organic carbon exhibited a decreasing pattern: FZ, GZ, GFZ ($p < 0.05$); Dissolved organic carbon exhibited a decreasing pattern: FZ, GFZ, GZ ($p < 0.05$); Light fraction organic carbon was the highest in FZ ($p < 0.05$), and the second in GZ and GFZ; The availability of active organic carbon in 0 - 10 cm soil layer was higher than that of 10 - 20 cm soil layer ($p < 0.05$); In comparison with GFZ, the herb in GZ could increase the contents of active organic carbon.

Introduction

Soil active organic carbon (SAOC), the active part of soil organic carbon (SOC), is considered as the organic carbon of high availability which is easy to be decomposed and mineralized by microorganism and directly supply nutrients to plants (Vieira *et al.* 2007). Some workers believe that the content of SOC is the result of the balance between the accumulation of organic carbon and its mineralization decomposition. Thus it cannot appropriately reflect the change in soil quality (Dodla *et al.* 2012). Although SAOC accounts for only a small part of the total SOC, it plays an important role in maintaining land productivity and reflecting the soil carbon storage variation, and is more sensitive to the micro-environment change of various vegetation than SOC. SAOC directly takes part in the process of soil biochemical conversion, and also acts as the energy for soil microbial activities and the driving force of soil nutrients (Wander *et al.* 1994). It reflects better availability of SOC and the soil quality (Boone *et al.* 1998, Wang *et al.* 2005). So, the investigation of SAOC is an important element for the research of dynamics and regulation mechanism of vegetation-soil carbon pool.

Purple-soil hilly slope land, covering an area of 1.625×10^5 hm^2, is one of the poorest areas in ecological environment in Hengyang city of Hunan Province, and also a typical area frequently hit by ecological disasters. The purple soil, with a short period of development, is extremely vulnerable to water erosion and infertile. Together with its strong heat absorptivity for its dark color, intensive evaporation for the heat on ground in summer, regional unbalanced allocation of water and heat resources and irrational development, the region has been faced with problems like sparse vegetation, severe water and soil erosion and seasonal draughts for a long time. The deteriorated ecological environment has seriously curbed the local rural economic development.

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At present, the studies of SAOC mostly focused on land use type (Fontaine *et al*. 2007, Paul *et al*. 2001), fertilization (Zhang *et al*.2007, Zhang *et al*. 2013), and the effect of specific region on SAOC (Whitbread *et al*. 1998, Bauhus *et al*. 1998). There are a few studies on the effect of different vegetation zones on the distribution of SAOC fractions. This study selected three vegetation types on the purple-soil hilly slope land in Hengyang city to investigate SAOC and its fractions. The results will be helpful to further understanding the effect of different vegetation zones on SOC accumulation, leaching and loss. Also, a basis is provided for the studies on SAOC, soil carbon cycle and the effect of vegetation restoration on the organic carbon pool's fractions and stability in purple-soil hilly slope land in Hengyang city.

Materials and Methods

The purple-soil hilly slope land is located in the south central Hunan, which is located in the middle reaches of Xiangjiang (geographical coordinate: $110^0 32'16''$ - $113^0 16'32''$ E, $26^0 07'05''$ - $27^0 28'24''$ N). Hengyang have the hillock as the main geomorphological type which is distributed in the middle of 60 - 200 m above sea level. This region has a subtropical monsoon humid climate, with an annual average temperature of 18°C, extreme maximum temperature of 40.5°C, extreme minimum temperature of –7.9°C, average annual rainfall of 1325 mm and annual average evaporation of 1426.5 mm. The average relative humidity is 80%, and the annual frost free period is 286 days (Yang *et al*. 2013).

In the middle of September 2017, three different vegetation types, i.e., grassland zone (GZ), grassland-forest zone (GFZ) and forest zone (FZ), were selected as the study object and the sample plots with an area greater than 1 hm^2 each were set in each vegetation zone (the vegetation zones were abandoned land initially) (Table 1). In each sample plot, three 20 m × 20 m quadrats were set with an interval greater than 20 m. In each quadrat, five sample points were taken in the shape of 'S'; soil samples at the depth of 0 - 10 and 10 - 20 cm soil layers were collected with a soil drill and those in the same layer were mixed. The soil samples were sealed in plastic bags and taken back to the lab. The visible plant debris and soil animals were removed carefully. Some of the soil samples were dried and some were stored at –20°C.

Table 1. The basic condition of different vegetation types.

Vegetation types	GPS position	Slope/(°)/Aspect	Altitude/(m)	Dominant plants
Grassland zone (GZ)	$111^0 44'20''$ E, $26^0 46'35''$ N	25/SW	120	*Setaria viridis* (*SV*); *Cynodon dactylon* (*CD*)
Grassland-forest zone (GFZ)	$110^0 30'56''$ E, $27^0 15'27''$ N	30/SW	125	*SV*; *Lagerstroemia indica* (*LI*); *Abelia chinensis* (*AC*); *Serissa japonica* (*SJ*)
Forest zone (FZ)	$112^0 37'56''$ E, $26^0 55'36''$ N	25/SW	120	*Liquidamdar formosana* (*LF*); *LI*

Soil pH was determined with electrode potential method; soil bulk density (SBD) was determined with cutting ring method; total nitrogen (TN) was determined with semi-micro Kjeldahl method; total phosphorus (TP) was determined with NaOH melting/Mo-Sb colorimetry/UV spectrophotometry; total potassium (TK) was determined with NaOH melting-flame photometry; SOC was determined with potassium dichromate oxidation-heating method (Bao 2000); microbial biomass carbon (MBC) was determined through chloroform fumigation-K_2SO_4 extraction and the carbon concentration of the extraction was determined with Shimadzu

TOC-VCPH analyzer (conversion coefficient K was 0.45) (Vance *et al.* 1987); easily oxidizable organic carbon (EOC) was determined with potassium permanganate (333 mmol/l) oxidation method (Wu *et al.* 2004); light fraction organic carbon (LFOC) was first separated by following methods of Janzen *et al.* (1992) method, and weighed after dried at 60°C for 24 hrs, followed by the measurement through potassium dichromate heating method; dissolved organic carbon (DOC) was represented by the carbon content in the soil extract before fumigation.

SPSS13.0 software was used for data processing and statistical analysis. One-way ANOVA and least significant difference method (LSD) were adopted to compare the difference between different data. Pearson's correlation coefficient was used to analyze the correlation between SOC and SAOC. All data were the average value of three repeated measurements.

Results and Discussion

Table 2 shows that in the 0 - 10 and 10 - 20 cm soil layers, the SBD in FZ was significantly lower than that of GZ and GFZ ($p < 0.05$). In 0 - 10 cm soil layer, the SBD in GZ and GFZ were 1.15 and 1.22 times than that of FZ, respectively; in 10 - 20 cm soil layer, they were 1.21 and 1.22 times than that of FZ. The difference between the SBD in 0 - 10 and 10 - 20 cm soil layer of all vegetation types was not significant ($p > 0.05$). In 0 - 10 cm soil layer, the TN content in GZ and GFZ was significantly lower than that in FZ ($p < 0.05$), being 24.77 and 26.15% of the latter, respectively. In 10 - 20 cm soil layer, the TN content in the three types of vegetation exhibited a decreasing pattern: FZ, GFZ, GZ ($p < 0.05$). For all the vegetation types, the TN content in 0 - 10 cm soil layer was significantly higher than that in 10 - 20 cm soil layer ($p < 0.05$). As for 0 - 10 and 10 - 20 cm soil layers, the TP content in FZ was significantly higher than that in GZ and GFZ in the same soil layer ($p < 0.05$). In 0 - 10 cm soil layer, the TP contents in GZ and GFZ were 80.00 and 80.00% of that in FZ, respectively; they were 86.76 and 85.29% of that in FZ in 10 - 20 cm soil layer. The difference between the TP content in 0 - 10 and 10 - 20 cm soil layers in GZ, GFZ and FZ was not significant ($p > 0.05$). The TK content in different types of vegetation and different soil layers did not change significantly (change range 18.42 - 19.74 g/kg) ($p > 0.05$).

Table 2 Soil basic physio-chemical properties under different vegetation types.

Vegetation types	Soil layer/ (cm)	Soil bulk density/ (g/cm^3)	Total nitrogen /(g/kg)	Total phosphorus/ (g/kg)	Total kalium/ (g/kg)	Soil pH
Grassland zone (GZ)	0 - 10	1.09 Aa	0.54 Aa	0.60 Aa	18.42 Aa	8.84 Aa
	10 - 20	1.21 Aa	0.39 Ab	0.59 Aa	18.86 Aa	8.90 Aa
Grassland-forest zone (GFZ)	0 - 10	1.16 Aa	0.57 Aa	0.60 Aa	19.26 Aa	8.94 Aa
	10 - 20	1.22 Aa	0.45 Bb	0.58 Aa	19.65 Aa	8.95 Aa
Forest zone (FZ)	0 - 10	0.95 Ba	2.18 Ba	0.75 Ba	19.74 Aa	8.44 Ba
	10 - 20	1.00 Ba	1.24 Cb	0.68 Ba	19.70 Aa	8.63 Ba

Different capital letters meant significant difference for the same soil layer and different vegetation types, and different small letters meant significant difference for the same vegetation types and different soil layers at 0.05 level. The same in below table.

The soil in different vegetation was all weak alkaline but the soil pH in FZ was significantly lower than that in GZ and GFZ ($p < 0.05$). The soil pH in GZ and GFZ was 1.05 and 1.06 times than that of FZ of 0 - 10 cm soil layer and was 1.03 and 1.04 times that of FZ in 10 - 20 cm soil layer,

respectively. The difference in the pH value of 0 - 10 and 10 - 20 cm soil layers was not significant for all vegetation types (p > 0.05).

Table 3 shows that the SOC content in different types of vegetation exhibited a decreasing pattern: FZ, GZ, GFZ (p < 0.05). In 0 - 10 cm soil layer, the contents of SOC in GZ and GFZ were just 69.25 and 30.90% of that in FZ; they were 79.65 and 51.36% than that of 10 - 20 cm soil layer. In GFZ, the difference of SOC content in 0 - 10 and 10 - 20 cm soil layers was not significant (p > 0.05). In GZ and FZ, the content of SOC of 0 - 10 cm soil layer was significantly higher than that in 10 - 20 cm soil layer (p < 0.05); the content of SOC in 0 - 10 cm soil layer was 1.47 and 1.69 times that of 10 - 20 cm soil layer.

Table 3. SOC content under different ecosystem (g/kg).

Soil layer/ (cm)	Vegetation types		
	Grassland zone (GZ)	Grassland-forest zone (GFZ)	Forest zone (FZ)
0 - 10	14.12 Aa	6.30 Ba	20.39 Ca
10 - 20	9.63 Ab	6.21 Ba	12.09 Cb

As shown in Table 4, the MBC content in 0 - 10 and 10 - 20 cm soil layers in various vegetation exhibited a decreasing pattern: FZ, GFZ, GZ (p < 0.05). As for 0 - 10 cm soil layer, the MBC contents in GZ and GFZ were 69.49 and 76.31% of that in FZ; as for 10 - 20 cm soil layer, they were 73.93 and 81.07% of that in FZ, respectively. The difference in MBC content in 0 - 10 and 10 - 20 cm soil layers was significant for all vegetation types (p < 0.05). The MBC content in 0 - 10 cm soil layer in GZ, GFZ and FZ was 1.95, 1.95 and 2.08 times that of 10 - 20 cm soil layer.

The difference in the DOC content in different types of vegetation was significant (p < 0.05). In 0 - 10 cm soil layer, the content of DOC in FZ was 2.45 and 1.27 times that of GZ and GFZ, respectively; in 10 - 20 cm soil layer, it was 4.06 and 1.51 times than that of GZ and GFZ. The content of DOC in 0 - 10 cm soil layer was significantly higher than that in 10 - 20 cm soil layer in various vegetation (p < 0.05). The content of DOC in 10 - 20 cm soil layer in GZ, GFZ and FZ was 127.40, 67.42 and 37.01% lower than that in 0 - 10 cm soil layer.

The content of LFOC in 0 - 10 and 10 - 20 cm soil layers in FZ was significantly higher than those in the same soil layer in GZ and GFZ (p < 0.05). In 0 - 10 cm soil layer, the contents of LFOC in GZ and GFZ were 57.92 and 56.88% of that in FZ, respectively; in 10 - 20 cm soil layer, they were 56.38 and 56.17% of that in FZ. As for GZ and FZ, the difference of LFOC content in 0 - 10 and 10 - 20 cm soil layers were significant (p < 0.05), the content of LFOC in 0 - 10 cm soil layer was 1.05 and 1.02 times than that of 10 - 20 cm soil layer, respectively. However, the difference between the LFOC content in 0 - 10 and 10 - 20 cm soil layers was not significant for GFZ (p > 0.05).

The content of EOC in 0 - 10 and 10 - 20 cm soil layers in different vegetation exhibited a decreasing pattern: FZ, GZ, GFZ (p < 0.05). The content of EOC in 0 - 10 cm soil layer in GZ and GFZ was 39.50 and 25.57% of that in FZ; the proportion was 67.88 and 45.26% for 10 - 20 cm soil layer. In FZ, the content of EOC in 0 - 10 cm soil layer was 1.76 times that of 10 - 20 cm soil layer, indicating a significant difference (p < 0.05). As for GZ and GFZ, the difference between 0 - 10 and 10 - 20 cm soil layer was not significant (p > 0.05).

The correlation coefficient (r) between MBC and SOC was 0.642[**]; the correlation coefficient (r) between DOC and LFOC was 0.720[**]; the correlation coefficients (r) between LFOC and SOC and between LFOC and MBC were 0.767[**] and 0.918[**], respectively; the correlation coefficients

(r) of EOC with respect to SOC, MBC and LFOC were 0.900^{**}, 0.658^{**} and 0.688^{**}, respectively; the correlation coefficients (r) of DOC with respect to SOC, MBC and EOC were 0.516^{*}, 0.522^{*} and 0.523^{*}, respectively (note: $^{*}p < 0.05$, $^{**}p < 0.01$). Thus, the contents of SAOC fractions were determined by the content of SOC to a large extent (Six *et al*. 2002).

Table 4 The properties of SAOC composition under different vegetation types.

SAOC	Soil layer/ (cm)	Vegetation types		
		Grassland zone (GZ)	Grassland-forest zone (GFZ)	Forest zone (FZ)
MBC/(mg/kg)	0 - 10	257.43 Ca	282.67 Ba	370.43 Aa
	10 - 20	131.87 Cb	144.61 Bb	178.38 Ab
DOC/(mg/kg)	0 - 10	72.45 Ca	139.90 Ba	177.39 Aa
	10 - 20	31.86 Bb	83.56 ABb	129.47 Ab
LFOC/(g/kg)	0 - 10	2.78 Ba	2.73 Ba	4.80 Aa
	10 - 20	2.65 Bb	2.64 Ba	2.70 Ab
EOC/(g/kg)	0 - 10	1. 90 Ba	1.23 Ca	4.81 Aa
	10 - 20	1. 86 Ba	1.24 Ca	2.74 Ab

The SOC content in the three types of vegetation exhibited a decreasing pattern: FZ, GZ, GFZ ($p < 0.05$). This is basically similar with the results of Chaai *et al*. (2003). In FZ, due to good physical and chemical properties of the soil (Table 2) and a large amount of litter and root exudates, the content SOC is high; the content of SOC in GZ is higher than that in GFZ and the reason may be (i) the higher herbaceous plant cover in GZ, relatively stable ecological environment and microorganisms and higher assimilation input; (ii) as the ecological transition zone, GFZ has relatively high leaching and leaching loss and relatively high stress on microorganisms. Due to the joint effects of these two factors, the organic carbon in GZ is high than that in GFZ, but the specific reasons yet to be further explored; the rank of MBC in the three types of vegetation is similar with that of SOC. This indicates on one hand that MBC has a close relationship with SOC and on the other hand that a large amount of litter concentrates in 0 - 10 cm soil layer in FZ, so the water and ventilation condition is good, which is conducive to the growth and reproduction of microorganisms. Therefore, the MBC in FZ is the highest. Due to the higher herbaceous coverage and fine roots in GZ, the MBC in GZ is higher than that in MBC. Zou *et al.* (2005) reported that the higher vegetation cover in grassland slope and a larger amount of fine roots in the soil surface and suitable soil temperature and humidity were conducive to the accumulation of MBC; the leaching and leaching loss of soil erosion in the soil surface are the determinants of the difference in the content of EOC. Soil erosion intensity has an importance impact on the content of EOC (Degryze *et al*. 2004). The dense forest and canopy and deep litter layers in FZ have a good dissipation effect on rainfall and a blocking effect on runoff, so that the soil erosion in FZ is extremely low. Compared with GFZ, GZ has higher vegetation coverage and lower soil erosion; DOC is mainly composed of Humic acid, organic acids and carbohydrates with smaller molecules and 35 - 47% of it exists in Humic acid (Carten 2002). From FZ to GZ, the litter and humus in soil organic matter decreases in turn, leading to a significant decrease in the content of DOC; LFOC is an organic matter between plant debris and humic organic matter and is composed of debris and root system of plants, which is mainly affected by plant root distribution,

root exudates and microorganisms (Wang *et al*. 2005). In FZ, the good hydrothemal condition and rich types of organisms have an obvious effect on the decomposition of litter, so the LFOC in FZ is significantly higher than that in GZ and GFZ.

In 0 - 10 cm soil layer, the MBC content in FZ is the highest, followed by GZ and that in GFZ is the lowest. The MBC content in 0 - 10 cm soil layer of the three vegetation zones has a great difference (113.00 mg/kg), but the difference in 10 - 20 cm soil layer is small (just 46.51 mg/kg) (Table 4). The microbial activities are frequent in 0 - 10 cm soil layer and the organic matter is easy to be decomposed, so the content of SAOC increases; the biologic effects in 10 - 20 cm soil layer is small, so the SAOC content is low (Shan *et al*. 2011). DOC is mainly sourced from the recent plant litter and humus in soil organic matter, including a series of organic matter from simple organic acid to complex macromolecular substances, such as humic acid and fulvic acid. That is why the content of DOC in 0 - 10 cm soil layer is higher than that in 10 - 20 cm soil layer. This is consistent with the result of Takata *et al*. (2008), i.e., DOC decreased with the increase in the depth of soil profile. Janzen *et al*. (1992) showed that the content of LFOC in 0 - 7.5 cm soil layer was 2 - 24 g/kg, which is basically consistent with the result of present study (2.64 - 4.70 g/kg in 0 - 10 cm soil layer) (Table 4). In different vegetation zones, the content of LFOC in 0 - 10 cm soil layer changes significantly (2.07 g/kg) while that in 10 - 20 cm soil layer changes very little (0.06 g/kg) (Table 4). The difference of EOC content in 0 - 10 and 10 - 20 cm soil layers in FZ is the highest (2.07 g/kg), followed by that in GZ (0.04 g/kg), and that in GFZ is the lowest (0.01 g/kg) (Table 4), which is basically consistent with the result of Harris (2003). Chiorse *et al*. (1988) argued that at a certain soil depth, the microbial activities are limited by SAOC and the content of SAOC decreases from the upper to the lower soil layer. The deeper the soil layer, the lower the SOC availability will be.

Acknowledgments

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