

Stock characteristics of soil organic carbon pools under three subtropical forests in South China

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Abstract. Vegetation biomass and soil organic carbon (SOC) pools for the three representative forest types, i.e. conifer forest (CF), mixed conifer and broad-leaf forest (CBF), evergreen broad-leaf forest (EBF) in South China were investigated. We found that SOC stock of the three chief forest ranged from 55.54 to 151.16 MgC·ha⁻¹, and it increased with increasing vegetation biomass under the same type forest within 100cm depth. The organic carbon contents at an equivalent level of forest maturity tended to be in the following decreasing order: EBF > CBF > CF, various active organic carbon (AOC) fractions in the 0-20cm topsoil layer tended to be in the following decreasing order: light fraction carbon (LFC) $\approx$ particulate organic carbon (POC) > easily oxidisable carbon (EOC) > microbial biomass carbon (MBC) > water-soluble carbon (WSC). At an equivalent level of forest maturity, there was a trend that each of these five AOC fractions increased from CF to CBF to the EBF.

1. Introduction

It is generally believed that estimates of quantity and distribution of forest soil carbon pool are essential to better understand the role of the forest ecosystem in global carbon cycling [3]. A major proportion of atmospheric CO₂-C sequestered by forest vegetation eventually enters into soils and is stored as soil organic carbon (SOC), and a research reveals that site forest vegetation biomass alone provides no indication of carbon-sequestering capacity of a given forest ecosystem because about two-thirds atmospheric CO₂-C sequestered by forest vegetation is stored as SOC within the top 100cm of the soil layer [9]. However, less studies emphasis on active organic carbon (AOC) fraction in the surface layer, which has an important role to play in regulating global carbon balance, especially in tropical and subtropical forest ecosystem [16], therefore, gaining content characteristics of AOC fraction in the surface layer under site forest vegetation would be helpful to define the role of SOC in regulating atmospheric CO₂ concentrations. Differing degrees of intervention on forest ecosystems adds uncertainty to estimate the forest soil carbon pool [19]. Taking vegetation carbon stock (tree, undergrowth vegetation, coarse woody debris and litter) into account, the objective of our study was to stress on characterizing the SOC stock within 100cm and its AOC content within 20cm under three representative secondary subtropical forest types in South China.



2. Materials and methods

2.1. Site descriptions

The study site is located in Guangzhou of Guangdong Province ($112^{\circ}57' \sim 114^{\circ}3'E$, $22^{\circ}26' \sim 23^{\circ}56'N$), southern China, where the regional climate is subtropical monsoon climate. The original forests vanished and currently there are three dominant types of secondary forests in the area: conifer forest (CF), mainly *Pinus massoniana*, evergreen broad-leaf forest (EBF), mainly *Engelhardtia roxburghiana*, *Schima superba* and *Castanopsis chinensis*, and mixed conifer and broad-leaf forest (CBF). Red soil is approximately 100 cm thick in the study site, which was formed from arenaceous shale. According to Soil Taxonomy of China, soil at the site is classified as a fine loamy, hyperthermic, acidic and Udic Cambisol.

2.2. Experimental design, sampling and measurements

Nine plots were selected in this study. They represented young forest stands (plot 1, 4, 7) with less than 10 years old, middle forest stands (plot 2, 5, 8) with 40-50 years old and mature forest stands (plot 3, 6, 9) with more than 80 years old for each of the three forest types. Each plot was $50 \times 50 \text{ m}^2$. Within each plot, six sampling locations were established along the “S-shaped” pattern with each sampling location was 10m apart. Soil samples were collected at each sampling location from the following four soil layers: 0-20, 20-40, 40-60 and 60-100 cm. Soil samples were sealed in plastic bags and transported to the laboratory for determining bulk density and carbon contents. Soil samples were air dried and sieved to 2mm, in order to remove litter, large pieces of roots and stones ($>2 \text{ mm}$).

The method described by Zheng et al. (2008) has been used to estimate the forest vegetation biomass of each plot. SOC content from 0 to 100-cm was measured while the active organic carbon (AOC) was measured at the 0-20cm layer. SOC was determined by wet combustion with $\text{K}_2\text{Cr}_2\text{O}_7$ [5, 8]. Various AOC fractions were determined the follows methods: (1) water-soluble carbon (WSC) was determined at 25°C using the distilled water-extraction method [8]; (2) microbial biomass carbon (MBC) was determined by using the fumigation-extraction method [8, 15]; (3) easily oxidable carbon (EOC) was determined after oxidation of the sample with $333 \text{ mmol L}^{-1} \text{ KMnO}_4$ at 25°C [18]; (4) light fraction carbon (LFC) was determined by using the method showed by Shi et al. (2007); and (5) particulate organic carbon (POC) was determined by using the method described by Cambadella and Elliott (1992).

2.3. Statistical analysis

Average density of soil organic carbon (SOCD) of the top 100cm soil profile was estimated by using the following formula:

$$\text{SOCD} = \sum_{i=1}^n T_i \times \theta_i \times C_i \times (1 - \delta_i) / 100 \quad (1)$$

Where n denotes the number of soil layers involved, $\delta_i\%$ is the gravel content ($>2\text{mm}$) in Soil layer i ; θ_i signifies the soil bulk density in Soil layer i ($\text{g}\cdot\text{cm}^{-3}$); C_i represents the organic carbon content in Soil layer i ($\text{g}\cdot\text{kg}^{-1}$); and T_i stands for the thickness of Soil layer i (cm).

All data statistical analysis were performed with the SPSS16.0 software package. Significant difference of a soil organic carbon parameter among the nine plots were tested using a Duncan's multiple range test method; Pearson linear correlations has been used to assess the relationships between various AOC fractions and SOC in the soil surface layer(0-20cm).

3. Results

3.1. Vegetation biomass and carbon stock in the nine investigated plots

The living tree biomass dominated the above-ground plant biomass for all the nine investigated plots (Table 1). Results show that living tree biomass, litter biomass and coarse woody debris (CWD) increased with increasing forest maturity. At an equivalent forest age stage, tree biomass tended to be higher in EBF plot than in CF plot or in CBF plot. Litter biomass in CF and CBF were higher than EBF did at an equivalent level of forest age stage while the coarse woody debris biomass tended to be in the following decreasing order at an equivalent level of forest age stage: EBF >CBF >CF. Undergrowth vegetation biomass tended to be lower in CF than in CBF or in EBF. For all the three forest types, undergrowth vegetation biomass was in the following decreasing order: middle-age stands >mature-age stands >young-age stands.

Vegetation carbon stock ranged from 25.39 Mg·ha⁻¹ to 194.74 Mg·ha⁻¹ in the nine investigated plots, and EBF tended to be higher than the other two forest type when they at equivalent forest age stage, which was consistent with the allocation of their total vegetation biomass.

Table 1. Vegetation biomass and carbon density of the three investigated forest types.

Forest type		Biomass (Mg·ha ⁻¹)				Carbon density	
		Tree	UV ^a	CWD ^b	Litter	(MgC·ha ⁻¹)	
CF	Plot 1	36.87	8.93	0.25	6.25	52.30	25.39
	Plot 2	95.38	13.21	0.36	8.58	117.53	57.68
	Plot 3	190.62	11.65	1.07	11.79	215.13	106.39
	Plot 4	43.59	12.47	2.41	5.87	64.34	31.25
CBF	Plot 5	97.85	16.65	6.48	7.46	128.44	63.01
	Plot 6	179.46	15.13	10.55	10.54	215.68	106.56
	Plot 7	45.74	12.06	3.84	4.74	66.38	32.35
EBF	Plot 8	160.35	15.24	11.03	7.03	193.65	95.71
	Plot 9	350.23	14.39	17.55	9.72	391.89	194.74

^a Undergrowth vegetation.

^b Coarse woody debris.

3.2. Soil organic carbon stock in the nine investigated plots

For CF (Table 2), there was no statistical difference in SOC contents among the three plots (Plots 1-3) representing the different stage of forest maturity for all the four soil layers. For the CBF, except for the surface soil layer (0-20cm) where SOC contents in Plot 6 was significantly higher than those in Plots 4-5, all the soil layers showed no statistical difference in SOC contents among the three plots (Plots 4-6) representing the different stage of forest maturity. For EBF, except for the bottom soil layer (60-100cm) where no statistically significant difference in SOC contents existed among the three plots (Plots 7-9) representing the different stage of forest maturity, all the soil layers showed certain statistical difference in SOC contents among these three plots; there is a trend that the SOC contents increased with increasing forest maturity.

Table 2. Comparison of SOC contents and SOC density among the nine investigated plots.

Forest type		SOC contents (g·kg ⁻¹)				SOC density (MgC·ha ⁻¹)
		0~20cm	20~40cm	40~60cm	60~100cm	
CF	Plot 1	12.59±2.85a	4.47±0.79a	2.11±0.34a	1.75±0.24a	55.54±4.81a
	Plot 2	13.57±2.06a	4.26±0.96a	2.14±0.28a	1.96±0.31a	58.53±7.46a
	Plot 3	14.79±3.57a	5.63±1.27a	2.70±0.41a	2.05±0.17a	66.69±6.39a
	Plot 4	12.83±1.78a	5.27±1.35a	2.31±0.25a	1.99±0.26a	59.76±8.55a
CBF	Plot 5	15.09±3.32a	6.44±1.49a	2.98±0.50a	2.01±0.32a	69.90±10.34a
	Plot 6	20.85±4.54b	8.52±2.29a	3.17±0.62a	2.05±0.43a	89.77±9.51b

	Plot 7	19.28±5.25b	8.13±1.61a	3.09±0.47a	2.08±0.33a	84.91±7.87b
EBF	Plot 8	25.19±5.43bc	12.51±2.29b	5.98±0.69a	3.46±0.56a	123.97±20.42c
	Plot 9	31.06±4.58c	14.37±2.74b	9.03±1.15b	4.12±0.68a	151.16±34.95c

Values within a column followed with different letters are significantly different at $P < 0.05$.

When the nine plots are considered together, there is no significant difference in SOC among each of the nine plots for the bottom soil layer (60-100cm). Except for Plot 9, no significant difference in SOC existed among each of the nine plots for the soil layer 40-60cm. Further upward to the soil layer 20-40cm, SOC contents was significantly higher in Plots 8-9 than in any other plots. SOC contents was significantly higher in Plots 8-9 than in Plots 6-7 which, in turn, had significantly higher SOC than the other five plots did; there is no significant difference in SOC among Plots 1-5.

3.3. Various active organic carbon fractions in the nine investigated plots

For CF (Table 3), there was no statistically significant difference in each of the five AOC fractions among the three different plots (Plots 1-3) representing different forest development stages. For CBF, there was no statistically significant difference in each of the five AOC fractions between Plot 4 and Plot 5 except for EOC which was significantly higher in Plot 5 than in Plot 4. Each of the five AOC fractions was significantly higher in Plot 6 than in either Plot 4 or Plot 5 except for EOC which showed no significant difference between Plot 5 and Plot 6. For EBF, mixed situations were observed: there was no significant difference in LFC among the three plots; WSC, EOC and POC were significantly lower in Plot 7 than in Plots 8 and Plot 9 but no significant difference in WSC, EOC and POC existed between Plot 8 and Plot 9; MBC was significantly higher in Plot 9 than in Plots 7 and Plot 8 but no significant difference in MBC existed between Plot 7 and Plot 8.

Table 3. Contents ($\text{g} \cdot \text{kg}^{-1}$) of various AOC fractions in 0-20cm soil layer of three forest types.

Forest type		WSC	MBC	EOC	LFC	POC
CF	Plot 1	0.10±0.03a	0.30±0.05a	0.36±0.05a	2.16±0.15a	2.34±0.14a
	Plot 2	0.13±0.05a	0.37±0.03a	0.43±0.07a	2.48±0.20a	2.56±0.22a
	Plot 3	0.14±0.02a	0.46±0.09a	0.55±0.09a	2.81±0.25a	2.79±0.18a
CBF	Plot 4	0.14±0.04a	0.32±0.06a	0.71±0.11a	2.54±0.38a	2.88±0.16a
	Plot 5	0.17±0.05a	0.39±0.05a	1.24±0.10ab	2.82±0.41a	3.22±0.27a
	Plot 6	0.24±0.06b	0.59±0.11b	2.22±0.13b	4.05±0.57ab	4.20±0.41ab
EBF	Plot 7	0.21±0.04b	0.57±0.08ab	2.00±0.14b	3.81±0.49a	4.28±0.39ab
	Plot 8	0.29±0.06bc	0.81±0.17b	3.37±0.23c	5.49±0.66ab	6.04±1.04b
	Plot 9	0.39±0.08c	1.10±0.22c	4.35±0.37c	7.24±1.24b	7.50±0.95b

Values within a column followed with different letters are significantly different at $P < 0.05$.

4. Discussion

In this study, SOC density of the nine plots ranged from $55.54 \text{ MgC} \cdot \text{ha}^{-1}$ to $151.16 \text{ MgC} \cdot \text{ha}^{-1}$ within 100 cm of soil profiles. It was reported that, average SOC density of Chinese forests was $107.8 \text{ MgC} \cdot \text{ha}^{-1}$ [10], by comparison, only SOC density of plot 8 and plot 9 under EBF is higher than the results mentioned above, which indicates SOC density of subtropical forest in South China was relatively low. The reason is that in China, soil had a lower capacity for carbon sequestration under subtropical forest than that under temperate forests [20], which was consistent with the distribution pattern in the northern hemisphere [11].

It is interesting to note that the proportion of SOC stock in the total forest ecosystem carbon pool decreased with increasing maturity of forest development within a forest type (Figure. 1). At the young forest stands, the vegetation carbon stock was smaller than the SOC stock, suggesting that it is unlikely that a major proportion of SOC was contributed by the existing forest vegetation. Therefore, the SOC in these plots mainly consisted of residual soil organic carbon originated from previous forest

vegetation. The reason is that ecological components such as coarse root biomass, large amounts of CWD, and a thick forest floor layer are important contributors to long-term C storage within these ecosystems [1].

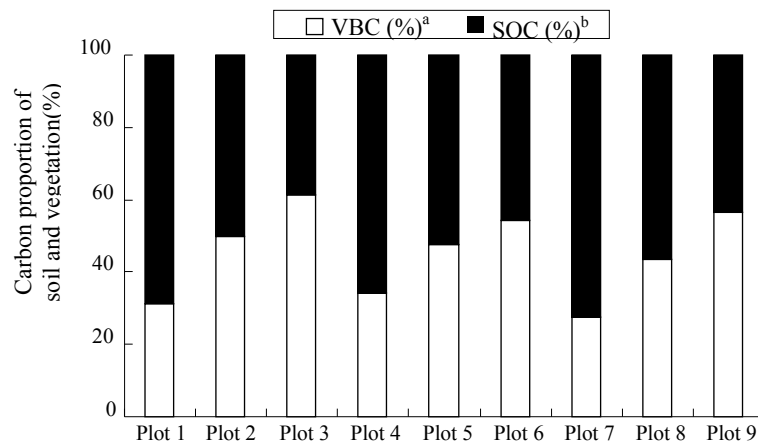
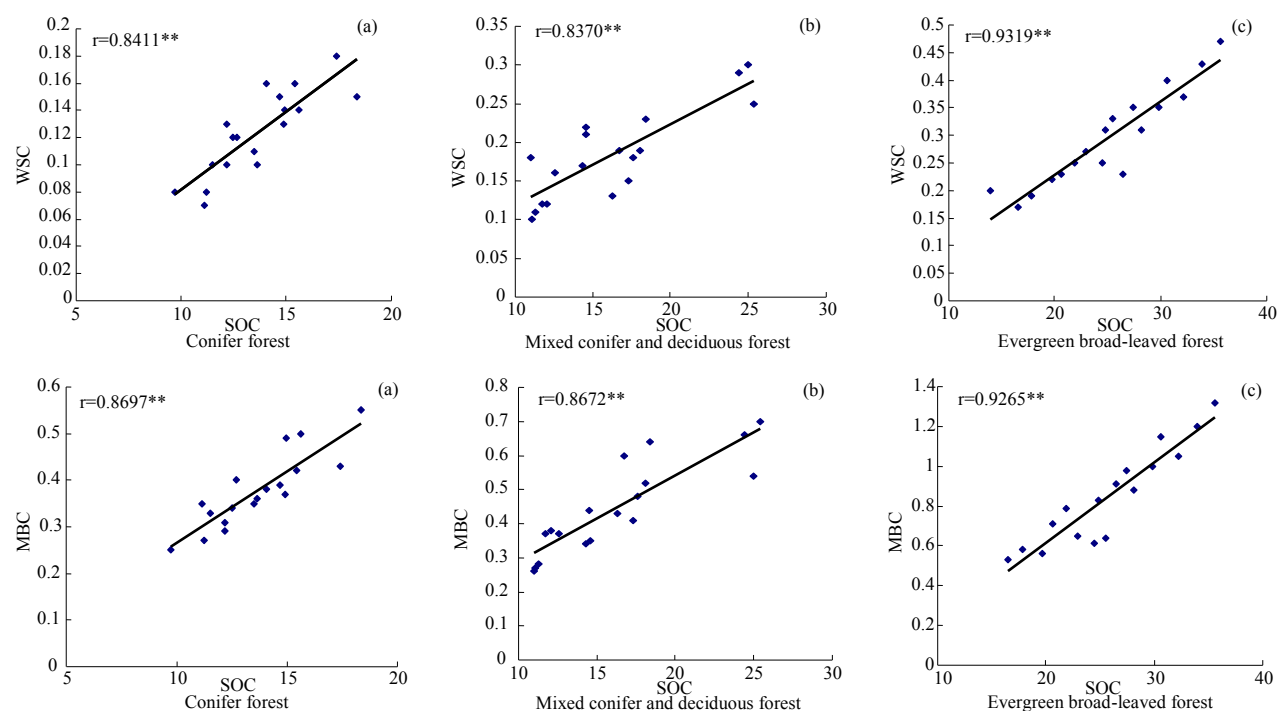


Figure 1. Proportion of soil carbon pool and vegetation carbon pool in the total forest ecosystem carbon pool .

^a Vegetation biomass carbon.

^b Soil organic carbon.



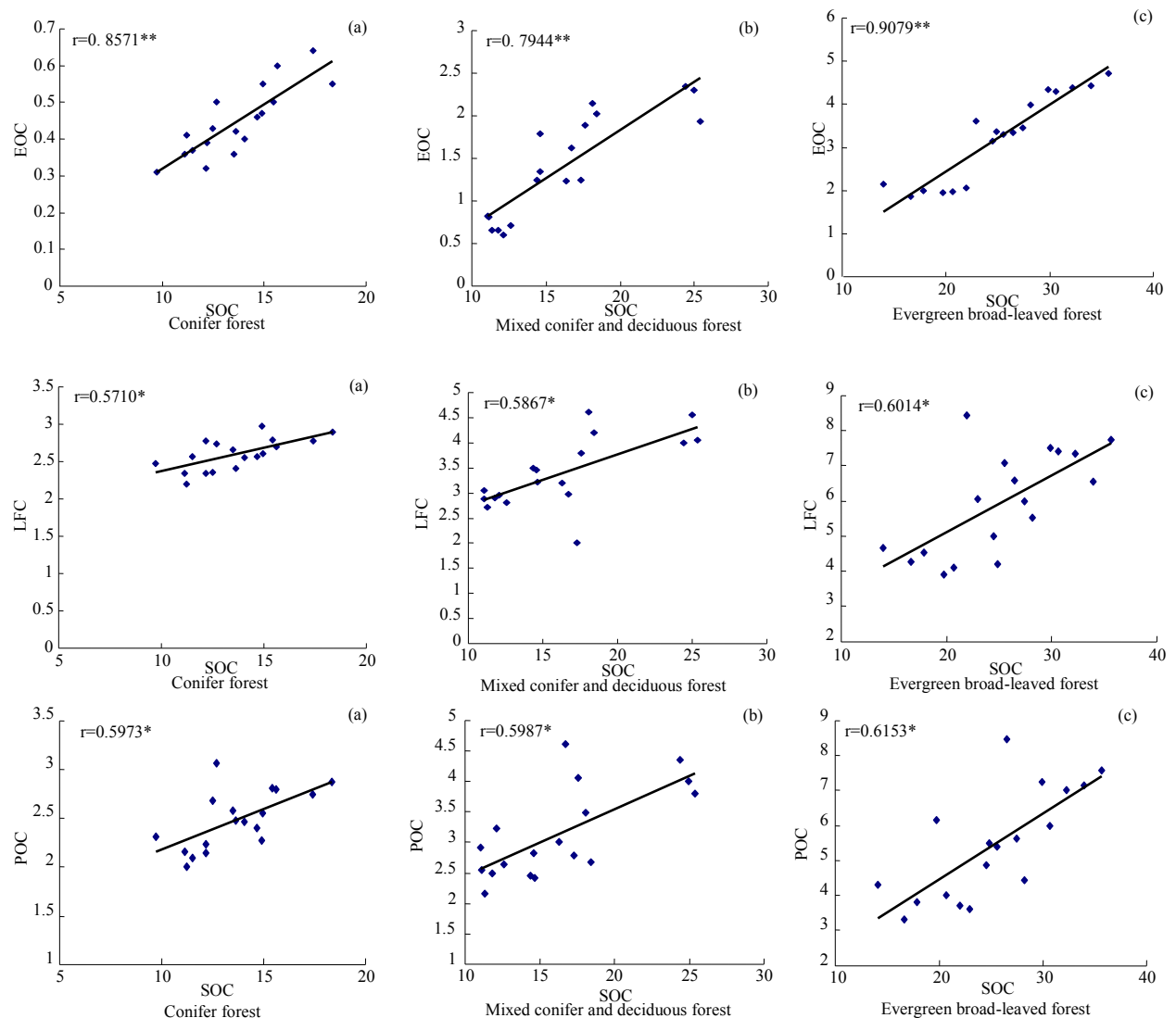


Figure 2. Relationship between AOC fractions and SOC in the topsoil layer (0-20cm).

Forest net primary productivity (NPP) can affect the contents of various AOC fractions by regulating SOC allocation so the correlations between AOCs and SOC can mirror forest NPP to certain degree [4]. In this study, correlations between WSC and SOC, EOC and SOC, MBC and SOC were at significant level ($p < 0.01$) (Figure 2), and the correlation coefficient followed the order: EBF > CF > CBF while correlations between LFC and SOC, POC and SOC, were at significant level ($p < 0.05$), and the correlation coefficient followed the order EBF > CBF > CF.

The correlation coefficients of LFC vs SOC and POC vs SOC were lower than those of WSC vs SOC, EOC vs SOC and MBC vs SOC. In the field, LFC and POC were found to be frequently associated with gravels in the soils. This observation suggests that in addition to microbial activities, soil physical properties might also affect the contents of LFC and POC [12]. Ingo and Ingrid (2006) suggested that the long-term stabilization of soil organic matter (SOM) was mainly controlled by various protection mechanisms provided by soil matrix and soil minerals rather than by the chemical structure of SOM itself.

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