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Spatial variation of organic carbon density in topsoils of a typical subtropical forest, southeastern China

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ABSTRACT

Spatial variation of regional soil organic carbon (SOC) stocks and the effects of environmental factors on SOC in forest soils play an essential part in modeling the global carbon cycle and climatic change. In this study, we analyzed topsoil samples (0–30 cm) from 838 plots in a typical subtropical forest of Zhejiang Province, southeastern China, using Moran's I, geostatistics and geographical information system (GIS) techniques. The results showed that the mean SOC density in the topsoils was 71.15 Mg ha^{-1} and the total storage in topsoils of Zhejiang Province was 0.47 Pg (Pg = 10^{15} g). The spatial distribution of SOC density based on kriging interpolation and local Moran's I hotspot analysis showed a decreasing trend from the southwest to northeast area, roughly in line with Zhejiang Province's topographic feature, as well as differences in land use, economic and social development. The results herein revealed that both dominant tree species and altitude ($P < 0.01$) have markedly affected SOC balance and accumulation in a typical subtropical forest of Zhejiang Province. Therefore, management of SOC should focus on the selection of dominant tree species (broad-leaved species), management of forest stand-age structures and implementation of sustainable practices so that the potential for carbon sequestration in forest soils can be maximized in the future.

1. Introduction

The global climate change has become a current hotspot research topic (Shang et al., 2011; Mathieu et al., 2015; Tashi et al., 2016; Fang et al., 2017). There is an ongoing increase of CO_2 concentration in the atmosphere during recent decades (Yu et al., 2014; O'Rourke et al., 2015), mainly attributed to rapid population growth, biomass burning, land-use change, forest deforestation, and environmental pollution (Batjes, 1996). Carbon sequestration in forest soils has been identified as a potential approach for mitigating the increase of atmospheric CO_2 concentration (Smith et al., 2007; O'Rourke et al., 2015; Conforti et al., 2017), as well as for improving productivity, ecosystem functioning, and sustainability of the Earth System (Liao et al., 2009).

Soil organic carbon (SOC) is the largest carbon pool in the terrestrial ecosystem that can act as an important sink or source of atmospheric CO_2, and plays an important role in global carbon dynamics (Martin et al., 2011; Wang et al., 2013). The world's soils hold as much as 1502 Pg of organic carbon to a depth of 100 cm in the terrestrial ecosystem (Stockmann et al., 2013), which is almost three times the amount stored in terrestrial forest vegetation, and twice the amount of carbon in the atmosphere (O'Rourke et al., 2015). Because of the large amount of carbon stored in soils, even minor changes in SOC could significantly increase the atmospheric CO_2 concentration, which further exacerbates the greenhouse effect and global climate change (Liu et al., 2011). For this reason, an accurate estimate of SOC stocks requires an assessment of the role of soils in the global carbon cycle (Parisa et al., 2012). Therefore, much effort has focused on estimates of SOC densities and stocks in ecosystems at national or regional scales. For example, the

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carbon stored in soils at the national scale has been estimated in Japan (Morisada et al., 2004), Belgium (Meersmans et al., 2011), France (Arrouys and Balesdent, 2002; Martin et al., 2011), Australia (Viscarra-Rossel et al., 2014), Spain (Martín et al., 2016), and China (Wang et al., 2000; Wu et al., 2003; Yang et al., 2007). At the regional scale in China, the Taihu Lake region (Pan et al., 2008), the Loess Plateau region (Han et al., 2010; Liu et al., 2011), and the Upper Yangtze River Basin (Wang et al., 2013) were also studied. However, due to a lack of complete inventory and the inherent spatial variation of SOC, the problem of uncertainty linked to the estimate of SOC stocks and its spatial patterns still remains unsolved (Liao et al., 2009). Meanwhile, environmental factors, such as climatic variables, parent material, topography, forest type and landscape position (Don et al., 2011; Conforti et al., 2016; Bojko and Kabala, 2017; Fissore et al., 2017) also significantly contributed to the variation of SOC density and stocks.

Yu et al. (2014) reported that the subtropical forest ecosystems played a significantly important role in global climate change and CO_2 sequestration, and soil carbon comprises approx. Two-thirds of the total forest ecosystems C stocks, especially in the surface soils (0–30 cm). Therefore, these findings indicated that the role of subtropical forest soils in the global carbon cycle and dynamics should not be ignores. However, previous research mostly focused on spatial patterns of forest biomass and forest litter carbon stocks (Zhang et al., 2007; Ren et al., 2011; Fu et al., 2014, 2015), little information is available on the spatial variation of topsoil SOC stock in the typical subtropical forest region, southeastern China. In addition, it has been reported that the SOC in the topsoil is noticeably responsive to global climate change and human disturbances (e.g., land use change) (Liao et al., 2009; Don et al., 2011; Grüneberg et al., 2014; Li et al., 2017), and the variation of topsoil carbon stock approx. Accounts for 80%–90% of the stock variations (Arrouys and Balesdent, 2002). IPCC (1997) guidelines introduced SOC accounting to a depth of at 0–30 cm, because this is the labile part of carbon pool that actively responds to global climate change and/or management effects and other human disturbances. Meanwhile, estimates for the SOC pool in the top 30 cm have been widely reported (Martin et al., 2011; Grüneberg et al., 2014; Lugato et al., 2014; Martín et al., 2016). Therefore, to provide comparable results, the forest topsoil samples at a depth of 0–30 cm were chosen in this study for analyses of the spatial variation. Such information is now important as it could be used to accurately estimate the SOC storage in subtropical forest regions and support further carbon sequestration research in the future.

The main objectives of this study were (1) to characterize the spatial variation of SOC density in the top 30 cm, and then estimate the SOC stocks in this layer in the typical subtropical forest soils in Zhejiang Province of southeastern China; (2) to reveal the relationship between spatial pattern of topsoil SOC density and the corresponding environmental factors.

2. Materials and methods

2.1. The study area

The study area Zhejiang Province, lying between 118°01′-123°10′ E and 27°06′- 31°11′ N, is located in a typical subtropical region of southeastern China (Fig. 1). The total land area is 101,800 km^2, accounting for 1.1% of China's total land area (Tao et al., 2014). The terrain in Zhejiang Province gradually decreases from southwest to northeast, the southwest part of the Zhejiang Province is mountainous, where most mountains have altitudes higher than 1500 m, the middle part of Zhejiang Province is hilly, with many scattered large and small basins (e.g., Jin-Qu Basin), and the northeastern part is mainly alluvial plain known as Hang-Jia-Hu Plain, with the altitudes of most areas being below 10 m (Zhi et al., 2015). Zhejiang Province has a subtropical marine monsoon climate with an average annual rainfall of 1490 mm and mean annual temperature of 16.5 °C. According to the Soil Taxonomy of China, the red soils, red-yellow soils, and yellow soils accounts for > 70% of the total area of Zhejiang soils, which are classified as ferrallisols (Liu et al., 2002). The soils derived from five major types of parent material, which include recessed parent material, alluvial parent material, estuarine alluvial parent material, lake marsh parent material, and coastal sedimentary parent material (Tao et al., 2014; Zhi et al., 2015). The total area of forest is approximate 60,406 km^2 accounting for 59.34% of the total land area in Zhejiang Province (Tao et al., 2014). The main forest types include evergreen broad-leaved forest, coniferous forest, mixed coniferous broad-leaved forest, bamboo forest and others (such as economic forest) (Zhang et al., 2007; Fu et al., 2015).

2.2. Field sampling and laboratory analysis

In order to obtain accurate SOC density data, a total of 838 sampling plots were established based on a 4-km (E-W) × 6-km (S-N) grid system in the subtropical forest of Zhejiang Province. The area of each plot was approx. 800 m^2. Relevant information related to sampling plots including soil type, soil depth, forest type and age, dominant tree species, slope aspect and position, human activities (e.g., forest harvesting and fertilizer use), was also collected and recorded. The portable global positioning system (GPS) (eTrex venture, 5-m precision in the horizontal direction) was used to record the sampling plots' longitudes, latitudes and altitudes. In each plot, three duplicate quadrats with a size of 8-m × 8-m were designed randomly, and a soil profile was established down to 100 cm by: 0–10, 10–30, 30–60 and 60–100 cm (Thickness < 100 cm of soil profiles measured at actual depth), a cutting-ring method (a stainless steel cylinder of 200 cm^3 in volume, $\Phi = 7$ cm) was used in the soil cores to determine bulk density of each layer (Agricultural Chemistry Committee of China, 1983), and approx. 1 kg soil sample was collected with a 5-cm diameter hand auger from each layer, giving a total of 2799 samples.

All soil samples were air-dried at ambient temperature in the laboratory and then sieved to pass through a 2-mm nylon mesh (Lu, 1999). A portion of each soil sample was ground in an agate mortar to pass through a 0.149-mm, and sealed in a closed polyethylene bag (Zhao et al., 2015). Soil properties were measured based on the standard methods of Agricultural Chemistry Committee of China (1983). The SOC content was determined using the potassium dichromate oxidation method (Han et al., 2010).

2.3. SOC density and stocks estimation

2.3.1. Calculation of SOC density

The SOC density in the top 30 cm was calculated as follows (Zhang et al., 2008):

$$SOCD_{30cm} = \sum_{i=1}^{n} (1 - \delta_i\%) \times \theta_i \times C_i \times T_i \times 100^{-1} \tag{1}$$

where $SOCD_{30cm}$ is the soil organic carbon density at 0–30 cm depth (in $Mg\,ha^{-1}$), $\delta_i\%$, θ_i, C_i and T_i are the percentage (%) of coarse fragments (> 2 mm), bulk density (in $g\,cm^{-3}$), soil organic carbon content (in $g\,kg^{-1}$) and soil thickness (in cm) respectively. The occurrence of coarse particles in the study area was relatively low (< 10%), and thus $\delta_i\%$ was considered to be taken from historical site data for the Zhejiang Province's forestland (Soil Survey Office of Zhejiang Province, 1994). The bulk density values were measured from the study area, ranging from 0.16 to and 4.16 $g\,cm^{-3}$, with the mean of 1.28 $g\,cm^{-3}$. The value of 0.58 (the Bemmelen index) is the conversion coefficient from organic matter to organic carbon.

2.3.2. Estimates of SOC stocks

To estimate SOC stocks in the subtropical forest region, the data on both SOC density (in $Mg\,ha^{-1}$) and the area (in m^2) were required. The

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