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Distribution of microbial biomass and activity within soil aggregates as affected by tea plantation age

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ABSTRACT

Variations in microbial biomass and activity within aggregate fractions can provide valuable information regarding mechanisms for enhancing carbon (C) sequestration and nutrient status in agricultural soils. The effects of different chronosequence phases on these variations in tea (*Camellia sinensis* L.) plantations have not yet been well documented. In this study, we assessed the relationship between tea plantation age and microbial biomass and activity at the aggregate scale. Microbial biomass C and respiration rate were determined in different size fractions from soil depths of 0–20 and 20–40 cm under four tea plantations of varying ages (16, 23, 31, and 53 years) in the hilly region of Western Sichuan, China. Aggregates were separated by an improved dry-sieving procedure into four fractions: >2 mm (large macro-aggregates), 2–1 mm (medium macro-aggregates), 1–0.25 mm (small macro-aggregates), and <0.25 mm (micro-aggregates). All the tea plantations we observed were dominated by large macro-aggregates with values of 41.25%–61.12% at both soil depths. Their proportion and mean weight diameter (MWD) were higher in 23-year tea plantation than those in other plantations, indicating that the soil structure in the 23-year tea plantation was more stable than the others. Notably, we found that aggregate stability is closely correlated with microbial biomass and their relationship is dependent on aggregate size. Aggregates with different particle sizes exhibited different levels of microbial biomass C and respiration rate regardless of tea plantation age. The soil properties we examined were at their highest levels in large macro-aggregates, implying that microorganisms associated with these fractions are more biologically active there than elsewhere in the present ecosystem. Decreases in soil microbial biomass and activity after 23 years of tea planting occurred mainly due to reduction in large macro-aggregates in the whole soil over time. To this effect, it is crucial to establish appropriate management protocol tailored to the prevention of soil structure degradation after 23 years of tea planting in such plantations.

1. Introduction

Microbial biomass is crucial for regulating energy flow and nutrient cycling, despite comprising an almost negligible proportion (1%–3%) of the total soil organic matter (SOM) (Jiang et al., 2013a). It is thus crucial to the long-term sustainability and nutrient management of the agricultural ecosystem (Galvez et al., 2012). Fluxes of nutrients through microorganisms take place one order of magnitude (or more) faster than through SOM (Jiang et al., 2013a), so accurate quantification of microbial activity is necessary to better understand the processing and stabilization of SOM (Bach and Hofmockel, 2014). The environment in which soil microorganisms live is controlled by soil aggregates that vary considerably in size and shape, and have a complex spatial arrangement and grouping (Lavelle et al., 2006). The distribution of soil aggregates forms a complicated and discrete pattern of pore spaces of varying sizes and shapes filled with air or water (Young and Ritz, 2000; Jiang et al., 2011a). Aggregates are indeed an ecological niche characterized by unique physical and chemical properties which lead to the heterogeneous distribution of microbial biomass and activity associated with different size fractions (Young et al., 2008; Zhang et al., 2015).

The primary influence of management practices regarding soil microbial biomass and activity is the disturbance to soil aggregates. The intra-aggregate microorganisms are most sensitive to disturbance, so any analysis of individual fractions generally returns more useful data than analysis of the whole soil (Six et al., 2004; Udawatta et al., 2008; Jiang et al., 2011b). However, impacts of agroecosystem disturbance on the distribution pattern of microorganisms associated with aggregate fractions are not commonly reported. Furthermore, the results vary greatly due to differences in pore size and organic matter among aggregate fractions (Six et al., 2004; Alvear et al., 2005; Jiang et al., 2011a). The microbial biomass and activity can be higher in micro-aggregates (<0.25 mm) (Jiang et al., 2013b; Zhang et al., 2013), but also concentrated in macro-aggregates (>0.25 mm) (Helgason et al., 2010; Li et al., 2015a; Zhang et al., 2015).

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Tea (*Camellia sinensis* L.) is an important cash crop in China. By 2013, the total area of tea plantations in China was 2.58 million ha, accounting for 52% of the world's total tea lands (International Tea Committee, 2014). As a perennial evergreen woody crop, tea plantations gradually form an unusual regional ecosystem because of the plant's root absorption characteristics, root exudates, and branch and leaf litters (Li et al., 2015b). Recent studies on the annual variations of microbial biomass and activity in the soil under tea plants have yielded generally poor results. Different researchers have reported different peak levels of soil microbial biomass and activity in tea plantations of varying ages (Yu et al., 2003; Han et al., 2007). Also, these studies concentrated solely on analyzing the whole soil as opposed to aggregate fractions.

Further research is needed to determine how tea plantation age-induced changes in soil structures affect microbial biomass and activity in the agroecosystem. The primary goals of the present study were to ascertain the influences of short- and long-term tea planting to the (1) aggregate distribution and stability and (2) variations in microbial biomass carbon (MBC) and respiration rate within aggregate fractions. The results presented here could provide a valuable, soil-focused reference for the sustainable development of tea plantations in the hilly region of Western Sichuan, China.

2. Materials and methods

2.1. Field site

We conducted our experiment at the Zhongfeng long-term agricultural research site of Sichuan Agricultural University in Ya'an, Sichuan, China (Fig. 1). The station is located in a subtropical monsoon zone. The mean annual temperature and precipitation are 15.4 °C and 1500 mm, respectively, and >72% of the yearly precipitation falls from July to September. The exposed layer is mainly post-Mesozoic sedimentary rock, and the soil is classified taxonomically as Typic Haplic-Perudic Argosol (Soil Survey Staff, 2010). As the extension of a reforestation project, Sichuan tea began to be contiguously cultivated in the Upper Yangtze River Basin in the early 1950s. Thus, Sichuan tea of varying age is the dominant cultivar in the study area; tea planting in the region is no-tillage.

Tea is planted at the site in 150 ± 15 cm broad rows and 35 ± 15 cm narrow rows, where the distance between any two plants is 16 ± 4 cm. Swine manure (15,000 kg ha^{-1}) and compound fertilizer (750 kg ha^{-1}, N:P_2O_5:K_2O = 20:8:8) are spread in mid-October yearly as the base fertilizer along the vertical edges beneath the tree canopy. The top dressing of tea plants is applied three times every year. Each mid-February, 1500 kg ha^{-1} of compound fertilizer and 600 kg ha^{-1} of urea are added to the soil. In late May and July, compound fertilizer (750 kg ha^{-1}) and urea (300 kg ha^{-1}) are applied again. The position of the top dressing is identical to that of the basal dressing (Li et al., 2015b). Yellow papers are now applied instead of chemical pesticides to control pests, and herbicides are not utilized during the planting process.

2.2. Soil sampling

The space-for-time substitution method, known as a useful approach to studying variations over time (Sparling et al., 2003), is often used to monitor soil changes in similar soils under similar climatic conditions along the tea plantation chronosequence. The establishment of tea plantations at varying time points creates an ideal opportunity for better understanding the tea planting process, as soil conditions prior to planting are significantly dependent on geomorphologic processes.

The experimental design was described in detail by Wang et al. (2016). Briefly, we selected four tea plantations of varying ages (16, 23, 31, and 53 years) located in similar geomorphologic units and

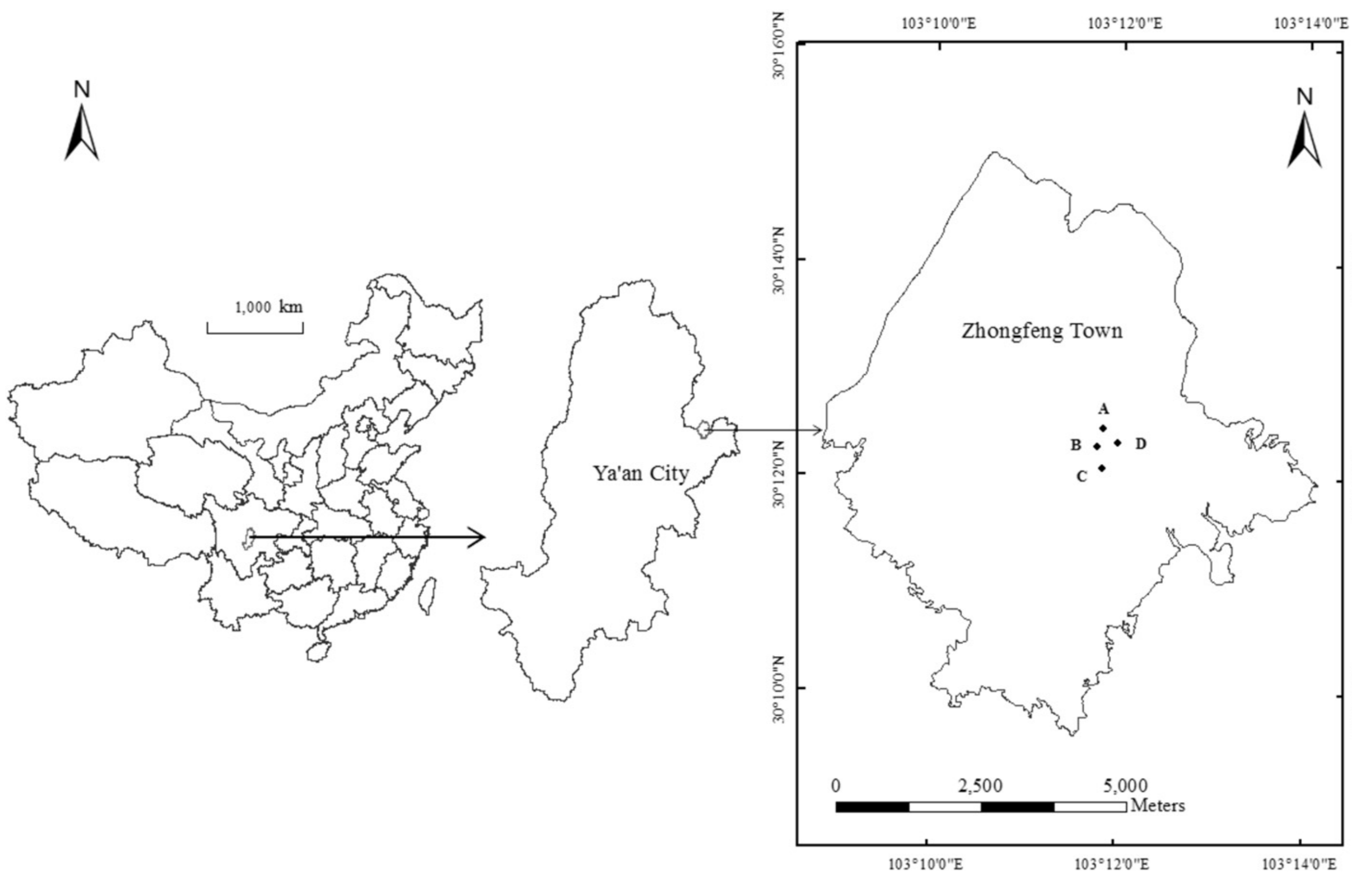

Fig. 1. Location of the study site. (A) 16-year tea plantation; (B) 23-year tea plantation; (C) 31-year tea plantation; (D) 53-year tea plantation.