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Temporal Evolution of Carbon Storage in Chinese Tea Plantations from 1950 to 2010

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ABSTRACT

Tea (*Camellia sinensis*), an economically important crop grown in mountain regions, has been planted for thousands of years in South China. Tea plantations can potentially act as carbon (C) sink in local agrosystems due to their high plant biomass and provide soil conservation service. To assess the contribution of tea plantations to C sequestration, the chronosequence variations of C storage were assessed in the plants and soils (0–20 cm) of tea plantations in China from 1950 to 2010, and then the inter-annual and decadal variabilities of total C storage were estimated. Total C stocks in tea plants and soils in 2010 were 34.4 and 93.45 Tg, respectively. Carbon sequestration from 1950 to 2010 was 30.6 and 39.0 Tg in the plants and soils, respectively. The highest C sequestration happened during the 1980s and the lowest during the 1950s. The decadal average C sequestration rate ranged from 20.4 to 113.9 g m^{-2} $year^{-1}$ in the standing tea plants, and from 54.6 to 98.8 g m^{-2} $year^{-1}$ in soils during the period of 1950 to 2010. The average ratio of C storage in soils to that in plants was 3.00 ± 0.35 before 1970 and 2.44 ± 0.18 after 1970. The results suggested that tea plantation ecosystems made an important contribution to the C sinks in Chinese tea-producing regions.

Key Words: *Camellia sinensis*, carbon sequestration, carbon stock, economic crop, plantation age, plant biomass

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INTRODUCTION

Tea (*Camellia sinensis*), an evergreen shrub, is widely planted in tropical and subtropical regions in mountainous areas as an economically important crop. Its buds are harvested to produce green tea and black tea, which are popular healthy beverages consumed worldwide. Tea plantations cover approximately 3 × 10^6 ha of the world's arable land, and this area is now rapidly expanding. As perennial agroecosystems, tea plantations have high vegetation coverage (80%–90%) and are subjected to fewer management practices than other croplands. The harvested carbon (C) output is small because the economic coefficient is only 0.2 (Tanton, 1979; Yao and Ge, 1986; De Costa *et al.*, 2007). Most of the pruned plant materials are returned to the field floor. This practice also minimizes the C output from the ecosystem. Therefore, apart from their economic profitability, tea plantations represent a stable agroecosystem and provide a sustained C sequestration in these producing regions (Xue *et al.*, 2013).

It has been reported that soil C content in various areas increases with increasing tea plantation age (Yu *et al.*, 2003; Xue *et al.*, 2007a; Kamau *et al.*, 2008; Gao and Xia, 2009). With a similar land-use history, soil C content in mature tea plantations is not only higher than that of other croplands, but also exceeds that in other plantations such as bamboo. Given suitable management regimes, soil C content in tea plantations older than 50 years even approaches that of native forests (Zhang *et al.*, 2004; Li *et al.*, 2007). However, most studies have paid more attention to the economic properties of tea plants than to their ecological function. Reports of C storage in tea plantations have only been published within the past several years (Kamau *et al.*, 2008; Li *et al.*, 2011; Xiao *et al.*, 2012; Zhang *et al.*, 2013). Zhang *et al.* (2013) quantified the biomass C of tea plants in China using growth models and suggested that the value was as high as 30.6 Mg ha^{-1} in 25-year-old plantations. In western Kenya, the total C

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stocks in 14–76-year-old tea plantations ranged from 44 to 72 Mg ha^{-1} (Kamau *et al.*, 2008). After extensive field investigations in China, Li *et al.* (2011) found a higher average C stocks in the plants and soils of tea plantations than forests, grasslands or timber plantations. The above results provide strong evidence for large C stocks in tea plantations. Although C sequestration could contribute substantially to the functioning of C sinks in tea-producing regions, few studies assessing C sequestration in tea plantations have been conducted.

Global warming and climate change strongly influence the growth of tea through frost incidence and the occurrence of dry and cold weather, which can induce tea underproduction and even death. The vulnerability of tea industry to climate change has been reported in prime tea-growing areas (Wijeratne, 1996; Wijeratne *et al.*, 2007), such as China, Sri Lanka and Kenya. The area of tea plantation in China represents approximately 50% of all tea plantation areas in the world. This area has increased by 69% during the past decade to a total of 2 × 10^{6} ha, equal to 0.9% of the country's total forest area (Jiang and Cheng, 2012). In Chinese tea-producing regions, tea plantations occupy a high proportion. For example, in Zhejiang Province, the area planted with tea is equal to 3.1% of the local forest area and 15.5% of the shrubland area. The C storage in tea plantations should be an important component of C pools in the tea-producing regions. Carbon stock fluctuations, induced by land-use change or climate change in tea plantations since 1950, could have an important influence on the C balance in the tea-producing regions. In view of previous studies on C stocks in tea plantations, this study aimed to quantify the temporal evolution of C pools in the plants and soils of tea plantations from 1950 to 2010 in China, and to determine C sequestration in tea plantations during the same period.

MATERIALS AND METHODS

Study area

Tea plantations are widely distributed in 18 provinces of China at altitudes from 50 to 2 600 m, ranging from 18° to 37° N and from 95° to 122° E. The tea-producing areas in China are divided into 4 regions as follows (Yang, 2005; Li *et al.*, 2011): 1) the southwestern region, which experiences a subtropical monsoon climate with an average temperature of 15.5 °C and a precipitation of 1 000–1 200 mm and produces arboreal and shrub tea plants; 2) the southern region with an air temperature of 19–22 °C, an average precipitation of 1 600 mm, and mainly arboreal tea plants with large leaves; 3) the south of Yangtze River region, which experiences an air temperature of 15–18 °C and a precipitation of 1 500 mm, and produces tea plants with medium-sized and small leaves; and 4) the north of Yangtze River region, with an air temperature of 15–16 °C, an average precipitation of 850 mm, and tea plants with medium-sized and small leaves. Tea plants are commonly pruned to 80 cm in height and 100–120 cm in crown diameter, and similar planting models and management practices are used in different tea-producing regions (Yang, 2005; Kibblewhite *et al.*, 2014). The soils that tea trees grown on are Orthic Acrisol, charictarized by a low pH and high contents of Fe/Al ions.

Data sources

The data used in the C stock analyses or for the model assessments were obtained from former study. Data regarding the total area, yield area, and tea yield of Chinese tea plantations for 1950–2010 (Fig. 1) were obtained from the national inventory (Jiang and Sha, 2008; Jiang, 2009; Jiang and Cheng, 2012) and used to estimate the total C stock of tea plantations.

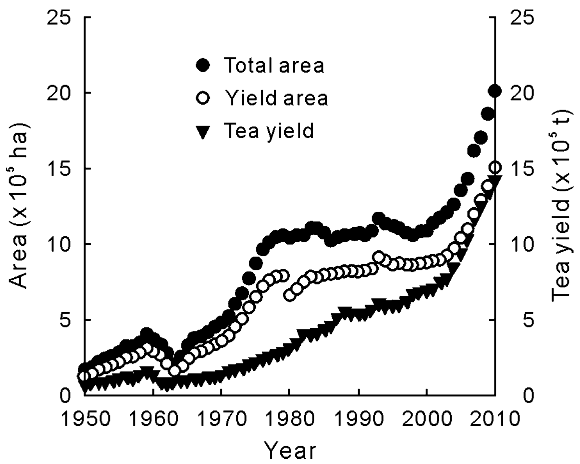

Fig. 1 Total area, yield area and tea yield of Chinese tea plantations from 1950 to 2010 (Jiang and Sha, 2008; Jiang, 2009; Jiang and Cheng, 2012).

Chronosequence variation of plant C stock in tea plantations

From 1950 to 2010, 3 types of planting models were used for tea plantations in China: 1) clump planting models with an average of 1 200 individual plants per 667 m^{2} before 1955; 2) single-row planting models with 3 000 individual plants per 667 m^{2} from 1955 to 1980 (almost all tea plantations established before 1950 were gradually replaced by single-row planting prior to 1966 according to the national statistics for the annual tea