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Quantifying carbon storage for tea plantations in China

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ABSTRACT

Quantifying carbon (C) storage is an essential task when assessing the particular C budget of a specific ecosystem. Tea is an important cash crop, and tea plantations commandeer large amounts of arable land throughout the world. In China, 1.3 million hectares dedicated to tea plantation cultivation have been established throughout the last five decades, resulting in a current total of 1.6 million hectares countrywide. For this study, C density and C pools related to biomass as well as the soil and the litter layer were estimated based upon 563 biomass and 255 soil samples procured from both field survey data and data obtained from literature. Subsequent estimations reveal that the total amount of C stored within biomass, the litter layer, and the soil of tea plantations in China is 83.3 Tg C (1 Tg = 10^{12} g C), 8.0 Tg C and 225.0 Tg C, respectively, and the average C density of biomass, the litter layer, and the soil is 50.90 Mg, 4.91 Mg, and 137.5 Mg C ha^{-1}, respectively. Despite varying climatic conditions and tea plant types specific to the three separate zones, no significant differences were found in biomass C densities. This suggests that the similar managerial (e.g., pruning) practices applied in their maintenance may in fact be the primary factor that shapes tea plantation C storage. Although tea plantations store less C than do resident mature forests, the considerable C storage of tea plantations makes them a factor of critical importance in regional C accounting that cannot be ignored in future research and policymaking initiatives.

1. Introduction

Atmospheric greenhouse gases released through agricultural processes (e.g., tillage, harvesting, and rotation) are generally accepted to be one of the primary contributors to global warming (Pfaff et al., 2000). An important anthropogenic driver of greenhouse gas emissions takes place during agricultural activity with regards to managerial practices that influence and modify regional carbon (C) storage (West and Marland, 2002). Designed with the intention to meet societal needs, crop plantations are intensively managed agricultural ecosystems that can only be sustained by means of pruning, tillage, harvesting, and the application of fertilizers. It is important to note that this specialized ecosystem may generate new traits in relation to C storage and, hence, alter regional C balances as a result of its rapid expansion throughout the world (FAO, 2007). In spite of this fact little interest has been sparked among carbon balance researchers with respect to crop plantation C storage while forest systems (Houghton, 2005; Chapin et al., 2009) and timber plantations (Jandl et al., 2007) have been extensively studied due to the belief that they hold considerable influence over the global C cycle. At present only a finite number of studies specifically related to the effect of crop plantations (such as coffee, cocoa, and rubber) on C fixation in tropical regions have been carried out (Suárez Pascua, 2002; Steffan-Dewenter et al., 2007; Li et al., 2008). Although a growing awareness is emerging for the need of such information to support the sustainable management of crop plantations, conditions of C storage and dynamics within these perennial ecosystems remain poorly understood.

Tea (*Camellia sinensis* L.) is an intensively managed perennial evergreen broad-leaved cash crop. It is one of three common beverages (coffee, tea, and cocoa) consumed worldwide. As a result, tea plantation area covers approximately three million hectares of the world's arable land (FAO, 2007). Most of these plantations have expropriated large areas originally occupied by forests, and they are continuing to expand. Unlike the intensively studied C storage dynamics of forest systems, data on tea plantation C storage

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is scarce (Kamau et al., 2008). Published literature related specifically to research on tea plantation C storage is limited solely to soil organic matter (SOM), most of which is only concerned with increasing production or improving tea quality (Dang, 2005; Han et al., 2007; Zhang et al., 2007). Other studies have been carried out on soil erosion (Othieno, 1975; Hartemink, 2006), and a few studies exist in connection to the C storage of tea plants (Kamau et al., 2008). Although tea production today is the principal function for the establishment of tea plantations, its relative long rotational life cycle from 40 years to 90 years (Yang, 2005; Han et al., 2007) may represent a potential to sequester and store large amounts of C.

Total tea plantation area in China (1.64 million ha) covers approximately 50% of all cultivated tea plantation area worldwide and has expanded 900% in the last six decades (NBS, 2008). In China, tea plantations cover vast areas from lat 18° to 37°N and from long 95° to 122°E. They have been established within varied climatic zones and are managed by way of diverse approaches and styles. The objectives of this study were: (a) to quantify C storage in biomass, the litter layer, and the soil of tea plantations; (b) to determine the spatiotemporal dynamics of tea plantation C storage in China; and (c) to determine tea plantation's contribution to regional C storage.

2. Materials and methods

2.1. Study area

The tea plantations investigated for this study were divided into three cultivation zones according to tea plant type, climate, and soil type (Fig. 1, based on Yang, 2005). The first cultivation zone is the western zone (the southwest zone) that primarily produces green and black tea under the stimulus of an annual mean temperature from 15 °C to 19 °C and a precipitation rate from 1000 mm to 1700 mm. The soil type is Haplic Acrisol. The primary cultivation type is small arborescence, although certain arbuscle types are also cultivated within this zone. The second cultivation zone is the southern zone that primarily produces Oolong and black tea under the stimulus of an annual mean temperature from 17 °C to 22 °C and a precipitation rate from 1500 mm to 2600 mm. The soil types are Humic Acrisol and Haplic Acrisol. Arborescence is the primary cultivation type, but small amounts of arbuscle are also produced. The third cultivation zone is the eastern zone where the majority of production is devoted to green tea with a certain amount of black tea produced under the stimulus of a mean annual temperature from 12 °C to 18 °C and an annual mean precipitation rate from 700 mm to 1700 mm. The soil types are Haplic Acrisol and Ferric Alicols. Arbuscle is the primary cultivation type while a minute proportion of the overall production is arborescence.

Tea bushes are set in rows and the compact branching is typically allowed to overlap between plants (S Photo 1 in Supplementary Materials). Tea community coverage ranges from 60% to 100% while height ranges from 60 cm to 110 cm. Harvesting is typically carried out twice per year: between March and May (spring tea) and between September and October (autumn tea). Similarly, tea bushes are pruned twice per year once during the summer and once during the winter after harvest is completed. Cuttings are left *in situ* to act as surface mulch. Rapeseed cake fertilizer or other kinds of organic manure are generally used for tea plantation fertilization as are certain chemical fertilizers such as synthetic fertilizers and urea. All plots are tilled (depth < 20 cm) annually in winter.

2.2. Data sources

Data was acquired from two sources to calculate plant and soil organic carbon (SOC) content. First, data was collected in the form of field samples taken from all three tea cultivation zones between September and December (during the late growing season) in 2007, 2008, and 2009 (see Appendix A in Supplementary Materials). A total of 563 plants and 90 soil samples were obtained from 15 sites (Fig. 1). Second, soil organic matter (SOM) and soil bulk density (BD) data were collected from literature. All literature used for this study was originally undertaken in the three tea cultivation zones under investigation. In total, 165 soil data sample points were collected from 51 sites. In addition, information concerning tea plantations (e.g., stand age, time of pruning, fertilization, and harvest) was gathered during the period when field sampling and literature data collection took place whenever possible.

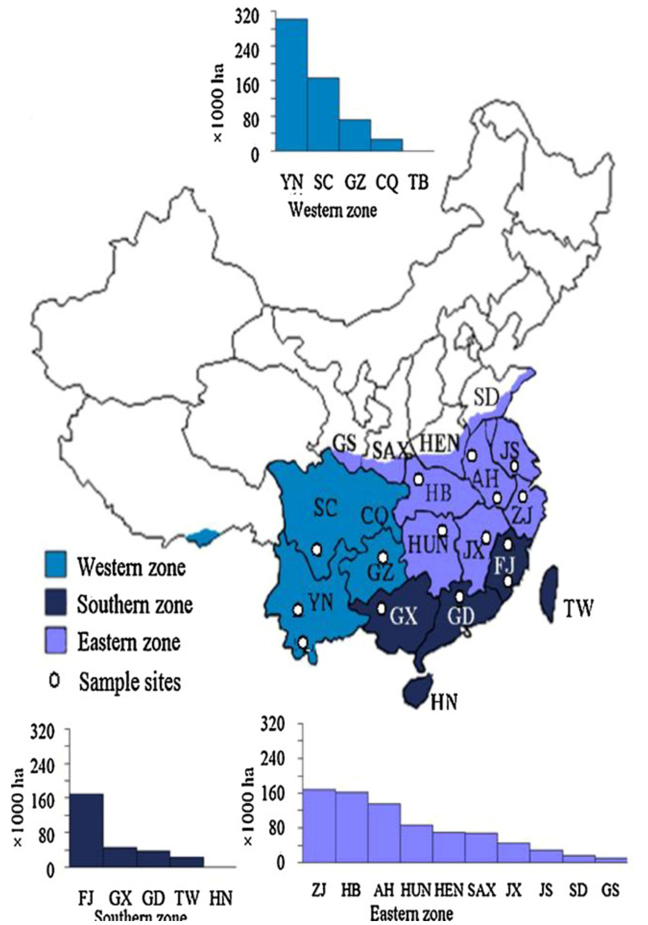

Fig. 1. Tea producing regions of China. The western zone includes Yunnan (YN), Sichuan (SC), Guizhou (GZ), Chongqing (CQ), and Tibet (TB). The southern zone includes Fujian (FJ), Guangxi (GX), Guangdong (GD), Taiwan (TW), and Hainan (HN). The eastern zone includes Zhejiang (ZJ), Hubei (HB), Anhui (AH), Hunan (HuN), Shaanxi (SAX), Jiangxi (JX), Henan (HeN), Jiangsu (JS), Shandong (SD), and Gansu (GS). Column size represents the size in area of each province (2007). Data from Taiwan Province (2005) was used for this study since no available data was found for 2007. White dots represent sampling sites.

2.2.1. Plant C and litterfall C: field samples

Depending upon the area and cultivation type in which the tea plantation was located, four sample sites were selected in the western zone, four in the southern zone, and seven in the eastern zone. At each site three sample plots were selected and a further three to five subplots were chosen at random. Two to four tea bushes in each subplot were then selected at random.

The tea bush sample plants were pruned twice per year and cuttings were subsequently collected from each. The base of the stem was cut after the second pruning took place. All roots were excavated to approximately a 1 m depth based upon plant spacing.