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Research article

Spatial distribution and variability of carbon storage in different sympodial bamboo species in China

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ABSTRACT

Selection of tree species is potentially an important management decision for increasing carbon storage in forest ecosystems. This study investigated and compared spatial distribution and variability of carbon storage in 8 sympodial bamboo species in China. The results of this study showed that average carbon densities (CDs) in the different organs decreased in the order: culms (0.4754 g g^{-1}) > below-ground (0.4701 g g^{-1}) > branches (0.4662 g g^{-1}) > leaves (0.4420 g g^{-1}). Spatial distribution of carbon storage (CS) on an area basis in the biomass of 8 sympodial bamboo species was in the order: culms (17.4–77.1%) > below-ground (10.6–71.7%) > branches (3.8–11.6%) > leaves (0.9–5.1%). Total CSs in the sympodial bamboo ecosystems ranged from 103.6 Mg C ha^{-1} in *Bambusa textilis* McClure stand to 194.2 Mg C ha^{-1} in *Dendrocalamus giganteus* Munro stand. Spatial distribution of CSs in 8 sympodial bamboo ecosystems decreased in the order: soil (68.0–83.5%) > vegetation (16.8–31.1%) > litter (0.3–1.7%). Total current CS and biomass carbon sequestration rate in the sympodial bamboo stands studied in China is 93.184 × 10^6 Mg C ha^{-1} and 8.573 × 10^6 Mg C yr^{-1}, respectively. The sympodial bamboos had a greater CSs and higher carbon sequestration rates relative to other bamboo species. Sympodial bamboos can play an important role in improving climate and economy in the widely cultivated areas of the world.

1. Introduction

The global dioxide (CO_2) emission rate reached 3.11 × 10^{11} Mg yr^{-1} in 2010 (DOE, 2008), and such a high rate of CO_2 emission is having a marked influence on the global climate. Forests are known to store large quantities of carbon, which have the potential to modify climate change through their influence on the global carbon cycle. Forests store 86% and 73% of the global carbon pool in vegetation and soils (Brown et al., 1993), respectively. Thus carbon sequestration by growing forests with higher carbon sequestration rates is a cost-effective option for mitigation of CO_2 emissions caused by human activities (Jiang et al., 2011; Wang et al., 2013).

China has 500 bamboo species belonging to 48 genera, compared with 1500 species and 87 genera worldwide (Chen et al., 2009). The total area of bamboo forests in China is 4.2 × 10^6 ha, representing 19.1% of world's total area (22 × 10^6 ha) and 3.3% of China's total forest area (129.2 × 10^6 ha).

Sympodial bamboo is also an important component of bamboo resources and accounts for more than 70% of the total number of bamboo species in the world, which is widely distributed in east South Asia, South Asia, Latin America, central and southern Africa and Pacific island countries (Chen et al., 2007). Carbon dioxide fixation of Sympodial bamboo helps to improve the local climate, and the bamboo products can improve the local economic. China has 16 genera and about 160 species covering more than 80 × 10^4 ha and producing 500 × 10^4 t in annual bamboo timber (Ma, 2004).

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At present, carbon storage (CS), area basis in bamboo stands accounts for more than 11% of the total carbon storage in all the forests of China. Since the early 21st century, the studies on CS in bamboo stands have focused mainly on cluster bamboo stands (Du et al., 2010; Ji et al., 2013; Liu et al., 2010; Wang et al., 2009a, 2013; Xiao et al., 2010; Yen and Lee, 2011; Zhou and Jiang, 2004; Zhou et al., 2009), but limited studies (Wang et al., 2009b) were conducted to examine CSs in sympodial bamboo stands.

The objective of this experiment were to (1) quantify CS and its spatial distribution in 8 sympodial bamboo ecosystems in China, (2) compare the variability of CS among sympodial bamboo species, and (3) estimate total CSs and biomass carbon sequestration rates of 8 sympodial bamboo species in China.

2. Materials and methods

2.1. Description of zones studied

This study examined variability of aboveground carbon storage in 8 sympodial bamboo species (Table 1): *Dendrocalamus latiflorus* Munro (DLM), *Dendrocalamus membranaceus* Munro (DMM), *Bambusa textilis* McClure (BTM), *Dendrocalamopsis oldhami* (Munro) Keng f. (DOK), *Bambusa burmanica* McClure (BBM) *Bambusa chungii* McClure (BCM), *Neosinocalamus affinis* (Rendle) Keng f. (NAK), and *Dendrocalamus giganteus* Munro (DGM). They were mainly distributed in Fujian, Zhejiang, Yunnan, Guangdong, Guangxi, Sichuan, Taiwan, Hainan, Hunan, and other provinces. Hectarage of the 8 sympodial bamboo species accounted for 80% of total area of sympodial bamboo stands examined. The sample areas in this study were all in natural areas, which minimized the effects of human activities. Distribution and growth characteristics of the 8 sympodial bamboo species studied are given in Table 1.

2.2. Plant and soil sampling

Characteristics of the sampling sites are showed in Table 2. Four representative sampling plots (20 m × 20 m) with different habitat conditions (plain, mountainous region, along river) were established for each bamboo species in February, 2013, and average height and diameter of every plant in the sampling plots was measured. Four plants with differing ages were harvested from each sampling plot, and the contribution of each organ of the above- and below-ground biomass was determined. Each group of four plants was divided into leaves, branches, culms, roots, stumps, and rhizomes. The samples of branches and culms consisted of upper, middle, and lower leaves. Fresh weights were recorded and 500–1000 g of fresh samples was taken for each organ per plant. Five subplots (2 m × 2 m) were established on the four corners and center of every sampling plot, and associated litter was collected and weighed.

About 100 g of plant or litter samples were washed for 1 min in deionized water, dried at 105 °C for 20 min and then at 70 °C for 48 h in a forced-air oven. Dry weights of every sample were measured and then ground to pass through a 30-mesh screen for chemical analysis. Composite soil samples (2.0 kg) for determining organic C, bulk density, and other soil variables were taken at 0 to 10, 10 to 30, and 30–60 cm depth in February, 2013 from seven randomly-selected sample points per plot. Soils were air-dried and ground to pass through a 0.5 mm screen prior to analysis. The basic physical and chemical properties of the soils collected from the 32 plots representing the 8 sympodial bamboo species are given in Table 3.

2.3. Plant and soil analysis

Soil pH was determined by the electrode method at a 1:5 soil to water ratio. Available N, P, and K were determined by the diffusion absorption method, Bray-1 method, and the NH_4OAc extract-flame photometric method, respectively. Bulk densities of the soil were determined by the bulk density ring method. Organic C in soil samples was determined by the $K_2Cr_2O_7 + H_2SO_4$ digestion method. Organic C in plant samples was determined by elemental analyzer. All the above-mentioned methods are presented in a Soil Science Society China monograph (2000).

2.4. Calculation of carbon storage

Total biomass in above-ground organs (Mg ha^{-1}) = single plant weight (kg $plant^{-1}$) × standing density (plant ha^{-1})/1000.

Total biomass in below-ground organs (Mg ha^{-1}) = biomass in above-ground organs in this study (Mg ha^{-1}) × the ratios of below-ground biomass/above-ground biomass from the other researchers (Chen et al., 2002; Qiou et al., 2004; Yang et al., 2008; An et al., 2009; Zhang et al., 2009).

Carbon storage (CS) in different organs (Mg ha^{-1}) = carbon density (Mg Mg^{-1}) × biomass in different organs of different sympodial bamboo species (Mg ha^{-1}).

2.5. Statistical analyses

One-way analysis of variance (ANOVA) and the least significant difference (LSD) test were used to determine the significant differences among different tissues and species.

3. Results

3.1. Carbon densities (CDs) in the different plant organs

Average carbon densities in different organs of 8 sympodial bamboo species are shown in Fig. 1. Average CDs in the different

Table 1
Distribution and growth characteristics of 8 sympodial bamboo species studied in China.

Bamboo species[a]	Area (× 10^4 ha)	Distribution (province)	Height (m)	DBH[b] (cm)
DLM	10.9	Fujian, Yunnan, Guizhou, Guangdong, Taiwan	20–25	15–30
DMM	7.0	Yunnan, Sichuan, Fujian	8–15	7–10
BTM	6.6	Guangdong, Guangxi, Fujian, Yunnan.	8–10	3–5
DOK	1.5	Zhejiang, Fujian, Taiwan, Guangdong, Guangxi, Hainan	6–12	3–9
BBM	1.0	Yunnan, Fujian, Taiwan.	20–25	15–30
BCM	8.0	Guangdong, Guangxi, Hainan, Fujian, South Huna.	5–18	3–7
NAK	21.0	Yunnan, Sichuan.	5–10	3–6
DGM	8.0	Yunnan.	20–30	20–30

[a] DLM = *Dendrocalamus latiflorus* Munro, DMM = *Dendrocalamus membranaceus* Munro, BTM = *Bambusa textilis* McClure, DOK = *Dendrocalamopsis oldhami* (Munro) Keng f., BBM = *B. burmanica* McClure, BCM = *B. chungii* McClure, NAK = *Neosinocalamus affinis* (Rendle) Keng f., DGM = *Dendrocalamus giganteus* Munro The same is below.
[b] DBH = Diameter at breast height.