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Carbon storage estimation of Moso bamboo (*Phyllostachys pubescens*) forest stands in Fujian, China

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Abstract: Moso bamboo (*Phyllostachys pubescens*) forest is one of the important terrestrial forest ecosystems with a high potential for carbon fixation. However, the estimation of carbon storage in Moso bamboo stands has shown great variation in methods and results. A detailed field survey of 27 plots (10 m × 10 m) was conducted to investigate carbon storage of pure Moso bamboo stands in Jian-ou city, a typical bamboo site in Fujian province of China. Bamboo biomass was estimated using an allometric equation based on diameter at breast height (DBH) and age, which was validated with measured data *in situ*. Aboveground litter and soil (0 - 60 cm) samples were collected and measured on the basis of area. Results showed the biomass carbon of Moso bamboo was approximately 14.0 kg culm^{-1} of which the bamboo culm accounted for 60 %. Total biomass carbon storage was calculated as 54.6 Mg ha^{-1} on average in the study site. Soil carbon storage was approximately 90.6 Mg ha^{-1} within the soil layer from 0 to 60 cm. The carbon storage of Moso bamboo stands in Jian-ou was estimated to be 145.3 Mg ha^{-1} in total. According to the age distribution of stands, the annually yielded carbon removed by harvest was estimated to be 3.97 Mg ha^{-1} yr^{-1} accounting for 7.3 % of the total bamboo biomass carbon. Based on the bamboo area, the total carbon storage in bamboo stands in Jian-ou city was estimated to be 12.49 Tg C and extrapolated to China 842 Tg C. Carbon storage in Moso bamboo stands was not high compared to other forests, but the high yielded carbon removed by harvest annually implies a great growth rate and relatively high potential for carbon fixation. The contribution of Moso bamboo stands to carbon stabilization merits further study and should be recognized.

Resumen: El bosque de bambú moso (*Phyllostachy spubescens*) es uno de los ecosistemas forestales terrestres importantes porsu potencial alto de fijación de carbono. Sin embargo, la estimación de los almacenes de carbono en los bosques de bambú moso ha mostrado una gran variación en los métodos y resultados. Se realizó un estudio de campo detallado en 27 parcelas (10 m × 10 m) para investigar el almacén de carbono en rodales puros de bambú moso en la ciudad de Jian-ou, un sitio de bambú típico en la provincia de Fujian de China. La biomasa del bambú fue estimada utilizando una ecuación alométrica basada en el diámetro a la altura del pecho (DAP) y la edad, la cual fue validada con datos medidos *in situ*. Se obtuvieron muestras de hojarasca y de suelo (0 - 60 cm) y éstas fueron medidas sobre una base de área. Los resultados mostraron que el carbono de la biomasa de bambú moso fue aproximadamente 14.0 kg culmo^{-1}, de los cuales el culmo del bambú representaba 60 %. Se calculó que en promedio el almacén total de carbono de biomasa es de 54.6 Mg ha^{-1} en el sitio de estudio. El almacén de carbono en el suelo fue de aproximadamente 90.6 Mg ha^{-1} en la capa de suelo de 0 a 60 cm. Se estimó que el almacén total de carbono en los rodales de bambú moso en Jian-oues de 145.3 Mg ha^{-1}. De acuerdo con la distribución por edades de los rodales, se estimó que el carbono producido anualmente y removido a través de la cosecha es de 3.97 Mg ha^{-1} año^{-1}, cifra equivalente a 7.3 % del carbono total de la biomasa de bambú. Con base en el área de bambú, se

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estimó que el almacéntotal de carbono en rodales de bambú en la ciudad Jian-oues de 12.49 Tg C, y extrapolando a toda China, el almacén total de C es de 842 Tg. El almacén de carbono en los rodales de bambú moso no es alto en comparación con otros bosques, pero lagran cantidad de carbono producido y removido anualmente a través de la cosecha implica que existe una tasa de crecimiento alta y un potencial relativamente bueno de fijación de carbono. La contribución de los rodales de bambúmoso a la estabilización de carbono debe ser reconocida y amerita más estudio.

Resumo: A floresta de bambu"Moso" (*Phyllostachys pubescens*) é um dos importantes ecossistemas florestais terrestres com alto potencial de fixação de carbono. No entanto, a estimação do estoque de carbono em povoamentos de bambu "Moso" mostrou grande variação nos métodos e nos resultados. Para investigar o armazenamento de carbono empovoamentos puros de bambu "Moso" puro, realizou-se uma pesquisa de campodetalhadaem 27 parcelas (10 m × 10 m) na cidade de Jian-ê, um sítio de bambu típico na província de Fujian, China. A biomassa de bambu foi estimada utilizando uma equação alométrica com base no diâmetro à altura do peito (DAP) e a idade e que foi validada com dados medidos *in situ*. As amostras da folhada aérea e do solo (0 - 60 cm) foram coletadas e medidasna base da área. Os resultados mostraram que o carbono da biomassa de bambu "Moso" foi de aproximadamente 14,0 kg. colmo^{-1} tendo o colmo de bambu representado 60 %. O armazenamento total médio de carbono na biomassa foi calculada como atingindo 54,6 Mg.ha^{-1} na área de estudo. O armazenamento de carbono na camada de solo de 0 a 60 cmfoi aproximadamente de 90,6 Mg.ha^{-1}. O armazenamento total de carbono nas parcelas de bambu "Moso" em Jian-ou foi estimado em 145,3 Mg ha^{-1}. De acordo com a distribuição etária das parcelas, a remoção anual de carbono removido através da abate foi estimado em 3,97 Mg. ha. ano^{-1}, representando 7,3 % do carbono total de na biomassa de bambu. Com base na área de bambu, o armazenamento de carbono total nas parcelas de bambuna cidade de Jian-ê foi estimado em 12,49 Tg C,ou extrapolando para o conjunto da China,num valor de armazenamento de 842 Tg C. O armazenamento de carbono em povoamentos de bambu"Moso" não era elevado em comparação com outras florestas, mas o elevadorendimento em carbono removidoanualmente por colheita implica uma taxa de crescimento relativamente grande e elevado potencial de fixação de carbono. A contribuição das parcelas de bambu "Moso"para a establização de carbono merece estudo futuro e deve ser reconhecida.

Key words: Bamboo biomass, carbon storage, culm density, moso bamboo; soil carbon.

Introduction

With the rising attention given to global warming, many countermeasures have been proposed to mitigate the trend of increased carbon dioxide concentration in the atmosphere (IPCC 2006). Forests play a major role in global terrestrial carbon cycling and storage: 893 Pg C or 45.7 % of the terrestrial carbon storage (Yoda 1993). However, deforestation is an important source of carbon dioxide emissions and second only to fossil fuel combustion. The net emission of carbon dioxide due to deforestation from 1860 to 1980 has been estimated to be as high as 135 - 220 Pg C (Houghton *et al*. 1983). Therefore, afforestation with plantations of fast - growing species is one of the candidate countermeasures to mitigate global warming. Bamboo is one candidate species with a high potential for carbon sequestration and fixation (Chen *et al*. 2009; Nath & Das 2012; Nath *et al*. 2009; Yen *et al*. 2010).

Bamboo is the vernacular or common term for members of a particular taxonomic group of large woody grasses (subfamily *Bambusoideae*, family *Andropogoneae*/*Poaceae*). Bamboos encompass 1250 species within 75 genera, most of which are relatively fast-growing, attaining stand maturity within 5 years, but flowering infrequently (Dransfield 1992; Tewari 1992). Asia possesses about 1000 species, covering an area of over 180,000 km^2. Most of this comprises natural stands of native species rather than plantations or introductions. China has about 300 species in 44 genera, occupying 33,000 km^2 or 3 % of the country's total forest area (Qiu *et al.* 1992). Moso bamboo (*Phyllostachys pubescens*) occurs extensively (20,000 km^2 or 70 % of the total area covered by bamboo) in China (SFAPRC 2005). This species is large and harvested for both culms and edible shoots throughout South-East Asia. Moreover, in the past three decades, the area of bamboo stands in China has increased by 51.04 %, from 3.2 Mha in the late 1970s to almost 5.0 Mha early this century due to afforestation on wastelands (Chen *et al.* 2009). Therefore, the significance of Moso bamboo in carbon sequestration is likely to increase in the future.

Up to now, many studies have been conducted to estimate carbon storage and fixation in Moso bamboo stands (Chen *et al.* 2009; Wang *et al.* 2008; Wang *et al.* 2011; Yen & Lee 2011; Zhou & Jiang 2004), however, a great variation is observed in the data available. As summarized by Chen *et al.* (2009), the biomass of Moso bamboo stands ranges from 23.7 to 572.29 Mg ha^{-1} and that of culms from 16.24 to 163.41 kg $culm^{-1}$. We believed that most of the variation in the data available is attributable to inconsistencies in calculation or citation. For example, Scurlock *et al.* (1999) pointed out that the high productivity of bamboos may have been exaggerated. Moreover, carbon storage of Moso bamboo has not been adequately assessed at the regional level and would be useful for policy decision makers and for bridging the gap in carbon accounting in the forest sector. Therefore, a precise estimation of carbon storage in Moso bamboo stands is needed to evaluate its potential in carbon stabilization. The objective of this study was to investigate carbon storage and allocation in Moso bamboo stands of a typical site in China and to gain a better understanding of the role of Moso bamboo in carbon sequestration.

Materials and methods

Study site description

The study was conducted in Jian-ou city, north part of Fujian province of China (26º38' - 27º20' N, 117º58' - 118º57' E). It belongs to a subtropical monsoon climate zone with a mean annual temperature of 19.3 ºC and mean annual rainfall ranging from 1600 to 1800 mm. Hilly landform dominates this region, which is near Wuyi Mountain, the likely center of origin of Moso bamboo in China (Fu 2000). The soil of this site is red soil which is classified as Ferralsols (WRB 2006). As one of the "bamboo hometowns" in China, Jian-ou has the largest areas (8.6×10^4 ha) of Moso bamboo (*Phyllostachys pubescens*), which is distributed in all towns of this city. According to the local forestry bureau (SFAPRC 2005), Jian-ou has 2.8×10^8 trees in bamboo stands. Bamboo plays an important role in the local socio-economy. In 2010, the economic income from the bamboo industry reached ¥5.3 billion that accounted for 50 % of GDP of Jian-ou city.

Survey and sampling method

The bamboo survey was conducted in September of 2011 in three typical towns: Fangdang, Ouning and Xiaoqiao, where Moso bamboo covers an area of 8705 ha, 4442 ha and 8537 ha, respectively. In each town, three pure Moso bamboo sites with an area lager than 10 ha were selected. Three 10 m × 10 m bamboo plots were chosen at random locations in each site, for a total of 27 plots selected in this survey. We recorded the age and diameter at breast-height (DBH) of each bamboo culm in each plot *in situ*. The bamboo age was identified as described by Fu (2000). According to the bamboo age classification, 3 representative bamboo plants in every age class were excavated, including all aboveground and belowground parts. Each plant was divided into foliage, culm, root and rhizome. Each section was weighed *in situ* and sampled for laboratory analyses. Before the belowground sampling, we calculated the excavating area for each bamboo plant because bamboo rhizome grows in different directions. According to the number of bamboo plants (n) in each plot, we estimated the excavating area of each bamboo to be 100 m^2. Therefore, we dug the bamboo rhizome in this area around each selected plant. Because bamboo is a shallow-rooted plant with its roots generally concentrated in the upper 40 cm of soil (Chen *et al.* 2009), and to compare our data with other bamboo studies, we collected soil samples downward to 60 cm. Soil samples were divided into 4 layers: 0 - 10 cm, 10 - 20 cm, 20 - 40 cm and 40 - 60 cm, respectively. Soil bulk density was measured using the core ring method in each layer. Litter above the ground was also collected in three 1 m × 1 m subplots per plot.

Sample analysis

Organic carbon in bamboo and litter was determined by Elemental Analyzer (Vario-MAX, Germany). Soil organic matter was measured using K_2CrO_4 oxidation method. Soil bulk density was calculated on the basis of mass weight. Dry biomass was obtained after the deduction of water content.

Computation and statistics

Carbon storage in Moso bamboo biomass was calculated by summing up carbon in various bamboo sections. We adopted the empirical equation to estimate bamboo biomass of each plot as follows (Zhou & Jiang 2004):

$$M = 747.787D^{2.771} [0.148A/(0.028 + A)]^{5.555} + 3.772 \qquad (1)$$

Where, M is biomass of single bamboo plant in kg; D is DBH of the bamboo culm in cm; and A is a value related to bamboo age, which is dimensionless. In China, a new Moso bamboo culm grows usually every 2-years. Thus, A = 1 corresponds to 1-2 years of bamboo age, and A = 2, 3 and 4 correspond to 3 - 4, 5 - 6 and 7 - 8 year-old culms, respectively (Fu 2000). The equation parameters were tested and validated using the measured data *in situ*; however, there was no significant difference between the predicted and the observed parameters, suggesting the equation obtained by Zhou & Jiang (2004) was suitable for this study. On the basis of each bamboo biomass, the total biomass carbon storage in each plot was calculated in Mg C ha^{-1}.

Soil organic carbon storage was estimated based on the area of bamboo stands and SOC storage per hectare (Chen *et al*. 2009):

$$SOC = 0.58 \cdot \sum SD_i SOM_i D_i \times 10^2 \qquad (2)$$

where, 0.58 is the coefficient to transform soil organic matter into *SOC*; SD_i represents soil bulk density of each layer; SOM_i is the content of soil organic matter in the layer and D_i is the thickness of layer depth, i.e. 10 cm, 10 cm, 20 cm and 20 cm respectively. Carbon storage in bamboo stands was calculated by adding biomass carbon, soil carbon and litter carbon.

Differences of Moso bamboo culm density, biomass and litter carbon among towns were tested by a simple one-way ANOVA using SPSS software. The tests of soil bulk density, soil organic matter content and soil carbon storage among sites and soil layers were performed by a split-plot ANOVA with two factors. Multiple comparisons with Duncan's method were used to identify the differences among various treatments. Data were reported as means with standard errors. Differences were considered significant at the $P \leq 0.05$ level.

Results

Bamboo biomass and carbon storage

As shown in Fig. 1, the biomass of a single Moso bamboo ranged from 6.11 to 13.99 kg d.m. per culm in various age classes and it increased with bamboo age. During the survey *in situ*, there were no 8 year-old culms recorded, indicating that all culms older than 7 years were removed by harvest. The pattern of bamboo biomass accumulation as a function of age could be described as a mono-exponential equation: Biomass = $B_0 \times (1\text{-}e^{-0.6736(t-0.1724)})$, where B_0 is the maximum bamboo biomass (kg culm^{-1}), t is the bamboo age (year) (Fig. 1). After 4.62 years, the biomass showed no significant increase (we assumed that the increase was not significant when the biomass increase was less than 5 % of the maximum). The proportion of each bamboo section in biomass is shown in Fig. 2. The bamboo culm was the major part and accounted for about 60 % of the whole bamboo plant. According to equation 1, we calculated the bamboo biomass in each plot from the DBH and bamboo age data. As shown in Table 1, the bamboo culm density ranged from 3330 to 3800 culms ha^{-1} and the bamboo biomass ranged from 47.35 to 58.70 Mg ha^{-1}. Litter carbon in the bamboo stands ranged from 1.58 to 1.71 Mg ha^{-1}, which accounted for 3.4, 3.0 and 2.9 % of the bamboo biomass in Fangdang, Ouning and Xiaoqiao, respectively. Therefore, the total biomass carbon was estimated to be 48.98, 53.53 and 60.41 Mg ha^{-1}, respectively (Table 1).

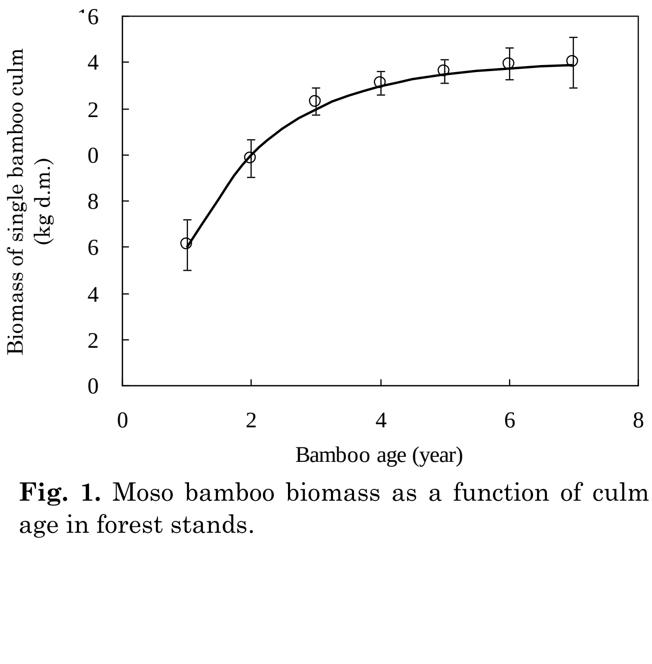

Fig. 1. Moso bamboo biomass as a function of culm age in forest stands.

Table 1. Bamboo and litter biomass in three sites of Jian-ou city in China (mean ± SE).

Sampling site	Bamboo density (culm ha^{-1})	Bamboo biomass (Mg C ha^{-1})	Litter biomass (Mg C ha^{-1})	Total biomass Carbon (Mg C ha^{-1})
Fangdang	3430 ± 124^{a}	47.35 ± 2.65^{a}	1.63 ± 0.45^{a}	48.98 ± 3.01^{a}
Ouning	3800 ± 135^{a}	51.95 ± 1.96^{ab}	1.58 ± 0.54^{a}	53.53 ± 2.43^{ab}
Xiaoqiao	3330 ± 201^{a}	58.70 ± 4.12^{b}	1.71 ± 0.61^{a}	60.41 ± 4.34^{b}

Different superscript letters in a column indicate significant differences at 5 % level.

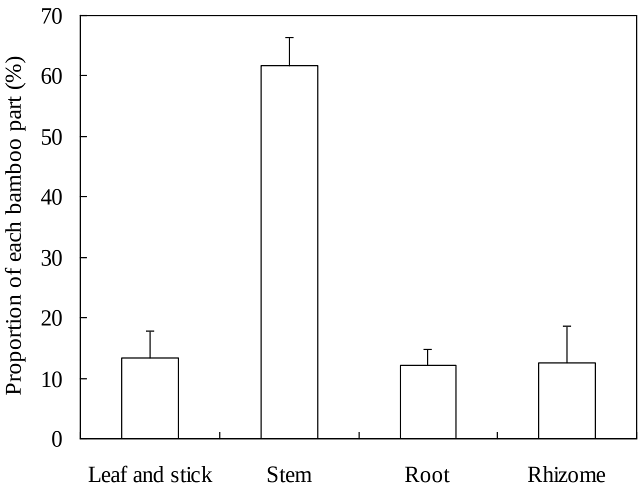

Fig. 2. Proportion of each bamboo section in the total culm biomass.

Soil carbon storage in bamboo stands

As shown in Table 2, soil bulk density increased with increasing soil depth. However, different sites showed a great variation in bulk density. The smallest value was 0.743 g cm^{-3} while the largest was 1.113 g cm^{-3} in the layer of 0 - 10 cm. Soil organic matter (SOM) content in this layer was highest in Fangdang town (56.01 g kg^{-1}), and lowest in Xiaoqiao town (28.91 g kg^{-1}). At all sites, SOM decreased with soil depth. Soil carbon storage in Moso bamboo stands, as calculated using equation 2 is shown in Table 3. Carbon storage distribution in layers showed no consistent trend, it was relatively high in the 20 - 40 cm layer. Summed C storage in all layers (0 - 60 cm), that is, the total soil C storage in Moso bamboo stands was 96.45, 96.73 and 79.14 Mg ha^{-1} for the towns of Fangdang, Ouning and Xiaoqiao. Adding the estimates of carbon storages in biomass and soil, the total carbon storage in Moso bamboo stands was estimated to be 146.4, 149.9 and 139.6 Mg ha^{-1} in the three towns.

Discussion

As reviewed by Chen *et al*. (2009), the biomass of Moso bamboo showed a great variation from 16.24 to 163.41 kg d. m. $culm^{-1}$. However, our results showed that the single mature Moso bamboo had an approximate biomass of only 14.0 kg d. m. $culm^{-1}$. At the same city, Zheng *et al.* (1997) estimated a culm biomass of 149.6 kg d. m $culm^{-1}$, which is 10 times higher than our estimate. Our results of bamboo density ranged from 3330 to 3800 culm ha^{-1}, which falls within the range recorded by Chen *et al*. (2009): 1350 - 4545 culm ha^{-1}. Comparatively, the bamboo density in our investigation was high, likely because farmers applied bamboo managements and removed all mature bamboo culms prior to this study. In this investigation, no 8-year-old bamboos were observed, which agrees with this interpretation. In natural bamboo stands, mature bamboo culms are usually those older than 10 years (Fu 2000). The proportion of carbon storages in different Moso bamboo sections varies among studies. However, this and previous studies consistently found that bamboo culm (stem) accounted for most of the carbon storages in biomass.

The biomass of Moso bamboo ranged from 23.7 to 572.3 Mg d.m. ha^{-1}, which falls within the range reported by Chen *et al*. (2009): 11.8 - 286.2 Mg ha^{-1}. However, we believe that some reports may have overestimated the Moso bamboo biomass because the single bamboo biomass reported in the same site (149.6 kg d.m.) was 10 times higher than our estimate (14.3 kg d.m.). Recent studies provide different estimates of Moso bamboo biomass: 30 Mg ha^{-1} (Zhou & Jiang 2004), 40.6 Mg ha^{-1} (Yen & Lee 2011), 55.9 Mg ha^{-1} (Qi *et al*. 2009), and 65.9 Mg ha^{-1} (Xaio *et al*. 2005). Similarly, bamboo C pool in the above ground biomass ranged from 21.69 Mg ha^{-1} to 76.55 Mg ha^{-1} in northeast India (Nath & Das 2012).

Table 2. Soil bulk density and soil organic matter content in Moso bamboo stands in Jian-ou city of China (mean ± SE).

	Soil layer (cm)	Site: Fangdang	Ouning	Xiaoqiao
Bulk density (g•cm^{-3})	0 - 10	0.743 ± 0.031^{a}	1.113 ± 0.138^{b}	1.091 ± 0.115^{b}
	10 - 20	0.813 ± 0.043^{a}	1.155 ± 0.195^{b}	1.072 ± 0.068^{b}
	20 - 40	0.972 ± 0.043^{a}	1.156 ± 0.164^{b}	1.030 ± 0.061^{a}
	40 - 60	1.031 ± 0.021^{a}	1.211 ± 0.111^{b}	1.187 ± 0.082^{b}
Soil organic matter (g•kg^{-1})	0 - 10	56.01 ± 6.87^{c}	35.96 ± 6.47^{b}	28.91 ± 2.88^{a}
	10 - 20	40.52 ± 4.05^{b}	28.68 ± 12.80^{ab}	22.64 ± 2.33^{a}
	20 - 40	29.11 ± 1.88^{a}	21.92 ± 10.59^{a}	20.90 ± 0.89^{a}
	40 - 60	17.02 ± 1.78^{a}	19.61 ± 8.89^{a}	15.78 ± 1.99^{a}
Soil layer (cm)	0 - 10	10 - 20	20 - 40	40 - 60
Bulk density (g•cm^{-3})	0.980 ± 0.199 a	1.104 ± 0.187^{ab}	1.058 ± 0.124^{ab}	1.149 ± 0.118^{b}
Soil organic matter (g•kg^{-1})	41.41 ± 2.53 c	32.41 ± 9.77^{bc}	25.58 ± 7.71^{ab}	17.23 ± 4.99^{a}

Different superscript letters in a row indicate significant differences at 5 % level.

Table 3. Soil carbon storage in Moso bamboo stands in Jian-ou city of China (mean ± SE).

	Soil layer (cm)	Site: Fangdang	Ouning	Xiaoqiao
C storage in layer (Mg C·hm^{-2})	0 - 10	24.18 ± 3.74^{b}	24.61 ± 1.60^{b}	18.24 ± 1.99^{a}
	10 - 20	19.16 ± 2.79^{ab}	22.05 ± 3.85^{b}	14.04 ± 1.16^{a}
	20 - 40	32.76 ± 0.89^{a}	34.83 ± 15.30^{a}	25.01 ± 2.48^{a}
	40 - 60	20.35 ± 2.07^{a}	26.05 ± 9.80^{a}	21.86 ± 4.19^{a}
Total C storage in 0 - 60 cm (Mg C·hm^{-2})	0 - 60	96.45 ± 8.18^{a}	107.54 ± 24.75^{a}	79.14 ± 6.49^{a}

Different superscript letters in a row indicate significant differences at 5 % level.

As evaluated by Keith *et al.* (2009), estimates of total biomass in subtropical forests range from 132 to 171 Mg ha^{-1}. The biomass estimates of Moso bamboo forests found in this study (137-148 Mg ha^{-1}) were relatively low. However, Moso bamboo is a fast-growing plant with a short term of harvest in 5 to 10 years. According to the age distribution in stands, Moso bamboo age class ratio was 1:1:1:1 for 1 - 2, 3 - 4, 5 - 6 and 7 - 8 years old bamboo plants. Accordingly, on the basis of the bamboo culm density and age class, the harvested bamboo culm annually was estimated as 1/8th of the total culms every year. Carbon storage in this harvested section could be calculated as: Culm density × 1/8 × 14 × 0.5 × 60 %, where 1/8 represents the harvested percentage of bamboo culm annually, 14 was the bamboo biomass, 0.5 was carbon concentration and 60 % was the proportion of bamboo culm in total bamboo biomass. Thus, we estimate the bamboo biomass harvested annually to be 3.62 Mg ha^{-1} yr^{-1}, 3.89 Mg ha^{-1} yr^{-1} and 4.40 Mg ha^{-1} yr^{-1}, respectively, in the towns of Fangdang, Ouning and Xiaoqiao. The average fixation rate was 3.97 Mg ha^{-1} yr^{-1}, which would account for 7.3 % of the total bamboo biomass in stands. Yen & Lee (2011) estimated that the annual carbon sequestration rate in Moso bamboo was 8.13 Mg ha^{-1} yr^{-1}. Similarly, the rate of above ground C sequestration was estimated to be 18.93 - 23.55 Mg ha^{-1} yr^{-1} with a mean of 21.36 Mg ha^{-1} yr^{-1} in northeast India (Nath & Das 2012). The variation in the estimated rates of carbon sequestration in bamboo stands could be due to many factors, such as location, landform, temperature, rainfall and forest management. Comparatively, the carbon fixation rate in this study was 2.52 times that of a fast-growing *Cunninghamia lanceolata* (Fang *et al.* 2002) and 3.73 times that of a Chinese fir plantation (Ruan *et al.* 1997), suggesting that Moso bamboo has a high potential for carbon fixation, as has been reported in Viet Nam (Ly *et al.* 2012), Taiwan (Yen & Lee 2011), and India (Nath & Das 2012).

Moso bamboo is one of the evergreen C_3 species that were originally predicted to respond more strongly to elevated CO_2 concentration than C_4 species because the CO_2 concentrating mechanism of C_4 plants makes them relatively insensitive to the magnitude of changes in CO_2 concentration expected to occur within this century (Bowes 1993). In addition, compared to drought-deciduous shrubs and grasses, evergreen species may have a longer window of opportunity to respond to elevated [CO_2] throughout the growing season in response to transitory increases in water availability following small precipitation events (Newingham *et al.* 2013). Yen & Lee (2011) inferred that the mechanism of photosynthesis may allow Moso bamboo to have an inherent increased capacity of carbon sequestration. Usually, the harvested bamboo is used extensively as building material, bamboo-fiber, furniture, bamboo charcoal, paper making and food (Song *et al.* 2011), suggesting that bamboo carbon falls mostly into a long term cycle. Therefore, Moso bamboo could be a candidate species to mitigate elevated CO_2 in this region along with a high potential for carbon fixation and economic benefit.

Soil organic carbon (SOC) is the most important pool of carbon on a global scale (Bernoux *et al.* 2006; Lal 2003). The estimated global SOC pool is 1550 Pg C, which is twice that of the atmosphere (770 Pg C) and 2.5 times that of the biotic pool (610 Pg C) (Batjes 1998). Accordingly, any change in the size and the turnover of SOC pools may potentially alter the atmospheric CO_2 concentration and consequently, the global climate (Lal 1997; Six *et al.* 2002). Increasing SOC is, therefore, critical to mitigate global warming. In this study, soil carbon storage in 0 - 60 cm layer of Moso bamboo stands ranged from 79.14 to 96.45 Mg ha^{-1} in Jian-ou city (Table 3) with an average of 90.65 Mg ha^{-1}, which is higher than that in paddy (69.24 Mg ha^{-1}) and upland (49.91 Mg ha^{-1}) soils in China (Xie *et al.* 2007), but smaller than the average forest storage (97.8 Mg ha^{-1}). However, phytolith carbon of bamboos has the potential to result in considerable quantities of securely bio-sequestered carbon (Parr *et al.* 2010). Moreover, litter quality controls the decomposition of labile and recalcitrant C pools (Guendehou *et al.* 2014; Mukhopadhyay *et al.* 2014), suggesting that bamboo litter should enhance soil carbon sequestration.

Based on the carbon storages in biomass and soil, the carbon storage density in Moso bamboo stands of Jian-ou city was calculated to be 145.4 Mg ha^{-1} on average. Combined with the bamboo area, the total carbon storage in Jian-ou city was estimated to be 12.49×10^9 g C (12.49 Tg C). Jian-ou is located in the central part of the bamboo growing area, Moso bamboo in this site is typical and representative of other areas in China. As reported by Ji *et al.* (2013), carbon storage in Moso bamboo showed a significant linear relationship with zonality. Moreover, the carbon storage density obtained in Jian-ou was close to the mean value of 162 sites from the main bamboo areas of China (Zhuang unpublished data). Therefore, the averaged carbon storage in Moso bamboo in Jian-ou can be used to obtain a gross estimate of total carbon storage in Moso bamboo in China. Wang *et al.* (2008) reported that the bamboo area in China was predicted to be 5.8×10^6 ha in 2013. Accordingly, we can make a preliminary gross estimation of the total carbon storage in bamboo ecosystems in China of 842 Tg C in 2013. Wang *et al.* (2008) estimated that the total carbon storage in bamboo stands in China was 947 Tg C, while Chen *et al.* (2009) predicted it at 742 Tg C. Although the extrapolation in this study is admittedly gross and preliminary, it falls within these other estimations. A precise and reliable estimation merits more field surveys, improved models and statistical tests, including uncertainty estimates, on a regional scale.

Conclusions

On the basis of the field survey of Moso bamboo stands in Jian-ou city of China, we were able to estimate carbon storage allocation. Bamboo biomass increased with bamboo age in stands and the bamboo culm accounted for most of the total biomass. Moso bamboo density ranged from 3330 to 3800 culm ha^{-1} and bamboo biomass carbon ranged from 47.35 to 58.70 Mg ha^{-1}. Litter biomass in bamboo stands accounted for around 3 % of bamboo biomass and the total biomass carbon in Moso bamboo stands was estimated to range from 48.98 to 60.41 Mg ha^{-1}. Carbon storage in soil layer of 0 - 60 cm was estimated to be 79.14 to 96.45 Mg ha^{-1}. Thus, total carbon storage in Moso bamboo stands was calculated to be 12.49 Tg C in Jian-ou city on the basis of biomass and soil carbon. Assuming Jian-ou is representative of other bamboo areas in China and provides a good average value, the estimated carbon storage in bamboo stands in China was 842 Tg C in 2013. In order to improve our understanding of the spatial distribution of carbon storage and to provide a reliable estimation, more field-based site measurements characterizing bamboo carbon storages, field surveys, improved models and statistics are needed in the future.

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