Comparative Study of Carbon Storage in Different Forest Stands in Subtropical China

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Abstract Selection and development of tree species with high fixing CO_2 capacity is an increasing problem worldwide. A comparative study on carbon fixation ability of three forest stands was conducted at Linlong Mountain, Li'nan County, Zhejiang Province, China. The results showed that total carbon storage in the ecosystems of Moso bamboo, Chinese fir, and Masson pine stands were 104.83, 95.66, and 96.49 tC/ha, respectively. The spatial distribution of carbon storage in the three ecosystems decreased in the order: soil > tree story > the vegetation under the forests. Carbon storage in the soils under Moso bamboo, Chinese fir, and Masson pine stands accounted for 65.3, 61.4, and 55.6% of the total CSs, respectively. The Moso bamboo forest ecosystem fixed 1.69 and 1.63 times as much C (9.64 tC/ha/year) as the Chinese fir and Masson pine forest ecosystems, respectively.

Keywords Moso Bamboo (*Phyllostachy pubescens*) Stand · Carbon Sink · Carbon Storage · Carbon Fixation Abilities · Subtropical China

Introduction

Forests cover nearly one-third of the Earth's land area, containing up to 80% of the total above-ground terrestrial carbon and 40% of below-ground carbon, thus having a critical role in global carbon cycle (Dixon et al., 1994). Forests store 86% and 73% of the carbon pool of vegetation and soils, respectively (Brown et al., 1993), thus they play a very important impact on the global C balance. For forest ecosystems, the carbon storage and the cycling of carbon are common indicators to assess the CO_2 -fixation capacity.

The selection of tree species is an important management decision-making for increasing carbon sink in the forest ecosystem (Vesterdal & Feifeld, 2010; Vallet et al. 2009; Schulp et al., 2008; Niu et al., 2009; Zheng et al., 2008). Because of the different species selection, the carbon storage and its allocation pattern of forest carbon storage vary significantly. Zheng et al. (2008) studied the variation of carbon storage by different reforestation types in the hilly red soil region of southern China

and reported that natural secondary forest (*Pinus Massoniana* and *Cyclobalanopsis glauca*) stored significantly more carbon (141.99 tha^{-1}) than slash pine (*Pinus elliottii*) (104.07 t/ha), Chinese fir (*Cunninghamia lanceolata*) (102.95 t/ha), and tea-oil camellia (*Camellia oleifera*) (113.09 t/ha).The results of the study by Niu et al. (2009) showed that *Michelia .macclurei* plantation significantly stored more carbon (174.8 t/ha) than *Cunninghamia lanceolata* plantation (154.3 t/ha) in southern China.

In southern China, Moso bamboo (*Phyllostachy pubescens*), Chinese fir (*Cunninghamia lanceilata*) and Masson pine (*Pinusmassoniana Lamb.*) are the most important forest resources.

Bamboo is the fastest growing, highest yielding renewable natural resources (Lessard & Chouinard 1980). Bamboo includes about 1200 species belonging to over 70 genera whose area is about 22.0×10^6 ha, accounting for about 1.0% of the total forest areas in the world (Guo et al., 2005). Although the total forested areas in many countries have decreased drastically, the area of bamboo forests has progressively increased at a rate of 3% annually.

China is the center of the origin and distribution of bamboo in the world. The existing area of bamboo forests is 7.2×10^6 ha, in which Moso bamboo stands account for over two-thirds of all bamboo forest area. Chinese fir and Masson pine are widely planted in south China. The planting area of Chinese fir was over 12×10^6 ha, accounting for about 6.5% of all plantation forests in the world (FAO, 2006). The planting area of Masson pine occupies the first place in the coniferous forest in China and its stand volume accounts for 50% of total forest one in south China. Therefore, these three forests should play a significant role in C sequestration in south China.

Moso bamboo stands have huge biomass and carbon storage and its ecological function plays an important role in global carbon sink (Du et al., 2010). Since the early 21th century, Moso bamboo has been considered a tree species with higher fixation carbon capacity relative to Chinese fir, Masson pine, and other tree species (Zhou & Jiang, 2004; Zhou et al., 2009; Guo et al., 2005; Xiao et al., 2007; Yuan et al., 2004). However, these results were obtained by comparing the annual fixation carbon amounts of the tree species with different tree ages studied in the different regions, are therefore difficult to compare. The objectives of this experiment were to (1) determine carbon storage and its spatial distribution in the ecosystems of the three forest stands with the same tree ages in the same region and (2) compare carbon fixation abilities in the ecosystem of the three forest stands.

Materials and Methods

Climate and Soil of Districts Studied

Experimental area was located at Linlong Mountain, Lin'an County (119°42E and 30°14′), Zhejiang Province, China. The site has a central-subtropical climate with an average annual temperature of 15.9°C, an average annual rainfall of 1424 mm, and an average annual number of sunshine hours and days free of frost of 1774 h and 236 d, respectively. The soil under the three forest stands was a red soil derived from

tuff and classified as Ferrisols in the U.S taxonomic classification system. The selected soil chemical properties of the soils (0–20 cm) under the three kinds of forest vegetations are given in Table 1.

Selected Growth Situation of Three Forest Stands

The three forest stands studied were artificial Moso bamboo, Chinese fir and Masson pine which were originally planted by farmers: Masson pine stand: 14-year-old stand with 70% of crown density and tree density and about 2100 plant/ha of tree density; Chinese fir stand: 14-year-old stand with 95% of crown density and 3100 plant/ha of tree density; Moso bamboo stand: 14 years of cultivation history, and 3500 plants/ha of plant density.

Plant and Soil Sampling

Five standard sampling plots (20×20 m^2) were established in each forest stand in December 2009, and the height and breast height diameter of every tree were measured in the sampling plots. The two standard trees were cut down from every standard sampling plot and the biomass of each organ of aerial part was determined. The biomass of each organ of the aerial part for Chinese fir and Masson pine stands was calculated using the relative growth equations as modified by Zhang et al. (2005).

Breast height diameter of each plant in the sampling plots was determined, and mean breast height diameter of bamboo plants with different ages were calculated from above the results. Three normal growth bamboo plants of different ages in each sampling plot were selected and divided into leaves, branches, culms, root, bamboo stumps, and bamboo rhizomes. Fresh weights in various organs of bamboo plants were determined and 500–1000 g of fresh samples was taken from every organs. Five subplots with 2×2 m^2 were selected from every sample plot. All of the shrubs, weeds, and litter were also collected and weighed. Samples (100 g) 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 determined and ground to pass through a 30 mesh screen.

Soil samples (2.0 kg) for determining organic C and volume weight were taken at 0 to 15, 15 to 30, 30 to 45, and 45 to 60 cm depth in December, 2009, respectively. Five sample points per plot were randomly taken and mixed together. Soil samples were air-dried and ground to pass through a 0.5 mm screen prior to analysis.

Table 1 Selected Chemical Properties of the Soils (0–20 cm) under Three Forest Stands

Forest kinds	OM (g/kg)	Soil pH	Total N (g/kg)	Hydrolyzed N (mg/kg)	Avail. P (mg/kg)	Avail. K (mg/kg)
Masson Pine stand	12.67	4.67	0.75	94.6	9.3	94
Chinese Fir stand	13.98	4.98	0.75	109.1	13.2	85
Moso bamboo stand	13..59	5.02	1.01	107.0	16.9	115

Plant and Soil Analysis

Total N of soil was measured using the semi-micro-Kjeldahl method. Available N, P, and K were determined by the diffusion absorption method, Bray-1 method, and the NH_4OAc extract-flame photometric method (SSSC, 2000), respectively. Soil pH was determined by electrode method at a 1:5 soil to water ratio. Organic C of plants and soils were determined by the $K_2Cr_2O_7+H_2SO_4$ digestion method (SSSC, 2000). Volume weights of the soil were determined by the volume weight ring method (SSSC, 2000).

Calculation of Carbon Storage

Carbon storage (CS) in different organs of different stands (t/ha) = carbon density (t/t)× biomass (t/ha).

CS in 15 cm soil depths (t/ha) = organic C content (kg/t)×soil volume weight (t/m^3)× 0.15 m×10000 (m^2)/1000

Results and Discussion

Carbon Densities in Different Organs of Three Forest Stands

Average carbon densities (CD) in the different organs of 3 forest stands decreased in the order: Moso bamboo stand (0.504 g/g) > Chinese fir stand (0.478 g/g) > Masson pine stand (0.464 g/g) . CD in different organs of 3 forest stands ranged from 0.418 g/g to 0.542 g/g. CD in different organs of Moso bamboo stand decreased in the order: culms > roots > branches ≈ bamboo stumps > leaves ≈ bamboo rhizomes. CD in different organs of Chinese fir stand decreased in order: barks > leaves > roots ≈ trunks ≈ cone > branches. CD in different organs of Masson pine stand decreased in the order : roots > branches ≈ barks ≈ leaves ≈ trunks (Table 2).These observations were similar to those of earlier findings of Moso bamboo stands (Zhou & Jiang, 2004; Liu et al., 2010), Chinese fir stands (Xiao et al., 2007; Fang et al., 2002), and Moso bamboo stands (Fang et al., 2003). It is known that average CD in the different organs of 3 forest stands increased with increasing forest stand ages (Tian et al., 2004) or class ages

Table 2 Carbon Density (CD) in Different Organs of the Three Forest Stands

Moso Bamboo stand	CD (g/g)	Chinese fir stand	CD (g/g)	Masson pine stand	CD (g/g)
Leaf	0.480±0.050	Leaf	0.481±0.053	Leaf	0.444±0.050
Branch	0.497±0.020	Branch	0.459±0.022	Branch	0.476±0.025
Culms	0.542±0.022	Trunk	0.473±0.020	Trunk	0.418±0.021
Root	0.532±0.016	Root	0.474±0.023	Root	0.507±0.026
Bamboo stump	0.494±0.051	Bark	0.510±0.054	Bark	0.472±0.024
Bamboo rhizome	0.477±0.023	Cone	0.471±0.025		
Mean	0.504		0.478		0.464

Table 3 Carbon Storage (CS) in Vegetation Storey of the Three Forest Stands

Bamboo stand			Chinese fir stand			Masson pine stand		
Organ	Biomass (t/ha)	CS (t/ha)	Organ	Biomass (t/ha)	CS (t/ha)	Organ	Biomass (t/ha)	CS (t/ha)
Leaf	3.19±0.348	1.53±0.13	Leaf	9.03±0.33	4.43±0.23	Leaf	5.52±0.26	2.45±0.23
Branch	4.06±0.42	2.01±0.17	Branch*	8.86±0.32	4.06±0.35	Branch*	12.69±1.22	6.00±028
Culm	30.63±3.27	16.60±1.35	Trunk	36.90±2.31	17.45±1.33	Trunk	45.52±3.21	19.02±1.63
BT#	3.53±0.28	1.88±0.15	Root	12.03±0.76	5.70±0.23	Root	9.62±0.73	4.81±0.18
BR#	7.88±0.72	3.89±0.34	Bark	6.76±0.43	3.45±0.31	Bark	10.21±0.63	4.81±0.19
Root	11.67±1.04	5.67±0.52						
Total	60.96	31.58	Total	73.58	35.09	Total	83.56	37.09

#BT bamboo stump; BR Bamboo rhizome

*Biomass of branch includes biomass of the cone

(Liu et al., 2010). Average CD in 20, 14, 11 and 10 year-old CF stands in Huitong county, Hunan province were 0.541, 0.480, 0.4799, and 0.4756 gC/g, respectively (Tian et al., 2004). CD in Moso bamboo stands with class ages of IV (>7- year-old plants), III (5 and 6-year-old plants), II(3 and 4-year-old plants),I (1and 2-year-old plants) were 0.523, 0.488, 0.514, and 0.508 gC/g, respectively (Liu et al., 2010). The reason for this was related to the ageing of the branches and leaves.

Carbon Storage and its Spatial Distribution in Vegetation

Biomass and carbon storage (CS) in the vegetation of the three forest stands decreased in order: Masson pine stand > Chinese fir stand > Moso bamboo stand. Biomass in the vegetation of Masson pine and Chinese fir stands were 37.1% and 20.7% greater than Moso bamboo stand, respectively, but CS in the first two stands were only 17.5% and 11.1% greater than Moso bamboo stand, respectively (Table 3). This could be explained by the facts that the thinning of the Moso bamboo stands was carried out once every 2 years.

Differences in spatial distribution of CS in vegetation floors among various forest stands were found. CSs in the culms or trunks were the main body of those in vegetation floors. CSs in the culms or trunk of Moso bamboo, and of Chinese fir, and Masson pine stands accounted for 52.57, 49.73, and 51.27% of total CS in the vegetation, respectively. CSs in the underground part of Moso bamboo stand occupied 36.21% of total CS in the vegetation, whereas CSs in roots of Chinese fir and Masson pine stands only occupied 12.95–16.25% of total CS in the vegetation. (Table 4).

Carbon Storage and its Spatial Distribution in the Ecosystems

There were no significant differences in total CSs in the ecosystems of different forest types. Total CSs in the ecosystems of Moso bamboo, Chinese fir and Masson pine stands were 104.83, 95.66, and 96.49 tC/ha, respectively (Table 5).

Table 4 Spatial Distribution of Carbon Storage in Different Organs of the Three Forest Stands

Moso bamboo stand		Chinese fir stand		Masson pine stand	
Organ	%	Organ	%	Organ	%
Leaf	4.85	Leaf	12.62	Leaf	6.60
Branch	6.37	Branch	11.57	Branch	16.17
Culm	52.57	Trunk	49.73	Trunk	51.27
Bamboo stump	5.95	Root	16.25	Root	12.98
Bamboo rhizome	12.31	Bark	9.83	Bark	12.98
Root	17.95	–	–	–	–
Total	100.0		100.0		100.0

Table 5 Carbon Storage (CS) and Spatial Distribution in the Ecosystems of the Three Forest Stands

Component	Moso bamboo stand		Chinese fir stand		Masson pine stand	
	Biomass (t/ha)	CS (t/ha)	Biomass(t/ha)	CS (t/ha)	Biomass (t/ha)	CS (t/ha)
Tree storey	60.96 (86.37)*	31.58 (30.12)	73.58 (95.27)	35.09 (36.68)	104.45 (90.24)	37.09 (38.39)
Shrub-storey	6.50 (9.21)	3.31 (3.15)	0.58 (0.75)	0.23 (0.24)	–	–
Herb-storey	1.21 (1.71)	0.53 (0.50)	1.32 (1.71)	0.85 (0.88)	–	–
Forest floor	1.88 (2.66)	0.71 (0.68)	1.75 (2.27)	0.77 (0.80)	11.3 (9.76)	5.76 (5.97)
Subtotal	70.58 (100.0)	36.13 (34.46)	77.23 (100.0)	36.94 (38.62)	115.75	42.85 (44.41)
0~15 cm soil depth	–	31.54	–	23.36	–	21.60
15~30 cm soil depth	–	20.29	–	15.02	–	14.65
30~45 cm soil depth	–	9.22	–	10.52	–	9.23
45~60 cm soil depth	–	7.65	–	9.82	–	8.16
Subtotal	–	68.70 (65.54)	–	58.72 (61.38)	–	53.64 (55.59)
Total	–	104.83NS** (100.0)	–	95.66NS (100.0)	–	96.49NS (100.0)

*Figures in parenthesis are percentages of each biomass or carbon storage accounting for total biomass or carbon storage

**NS, non-significant.at $p > 0.05$

Total CS in the ecosystems of Moso bamboo stand obtained from this study was very close to those reported (105.07–106.36 tC/ha) in Northern Zhejiang (Zhou & Jiang, 2004) and Southern Sichuan (Liu et al., 2010), but was much lower (139.59 tC/ha) than that in Western Hunan (Xiao et al., 2007). The reasons for this might be contributed to the differences of climate and soils.

Spatial distribution of CS in the ecosystems of different forest stands decreased in the order: soil > tree story > the vegetation under the forests. Soil was the main carbon pool for the three forest types. CSs in the soils under Moso bamboo, Chinese fir, and Masson pine stands accounted for 65.34%, 61.38%, and 55.59% of total CS, respectively (Table 5).

CSs in the soils under different forest stands decreased in the order: Moso bamboo stand > Chinese fir stand > Masson pin stand, which was due to different rates of organic manure applied in the management. CSs in the soil storey of the three forest stands decreased with soil depth, but it was mainly distributed in 0–15 cm of surface soil, CSs in the 0–15 cm of soil depth under Moso bamboo, Chinese fir, and Masson pine stands accounting for 45.9%, 39.8%, and 37.7% of CS in 0–60 cm of soil depth, respectively (Table 5).

Carbon Fixation of Forest Stands

The annual carbon fixation amounts in the vegetations of Moso bamboo, Chinese fir, and Masson pine stands were 6.34, 3.13, and 3.69 tC/ha/year, respectively. Annual carbon fixation amounts in the vegetation of bamboo stand were 102.6 and 71.8% greater than Chinese fir and Masson pine stands, respectively. Annual carbon fixation amount in the soil floor of Moso bamboo stand were 27.9 and 48.6% greater than Chinese fir and Masson pine stands, respectively (Table 6).

Although Moso bamboo stand stored a lower amount of carbon in the vegetation floor than Chinese fir and Masson pine stands (Table 5), the annual carbon fixation amount in Moso bamboo stand was greater than that in Chinese fir and Masson pine stands. The reasons for this might be: Firstly, the growth of Moso bamboo is very rapid, and the growth of increasing diameter and height is accomplished in 35–40 d. It takes 4–5 years to grow a luxuriant bamboo forest. Cannell (1996) pointed out that a fast-growing plantation would accumulate carbon more rapidly than a slow-

Table 6 Comparison of Annual Carbon Fixation Amounts of Different Stand Ecosystems (t C/ha/year)

Forest stand	Vegetation floor			Soil floor[3]	Total
	Current C[1]	Thinned C[2]	Subtotal		
Moso bamboo stand	2.58	3.76	6.34	3.30	9.64
Chinese fir stand	2.63	0.50	3.13	2.58	5.71
Masson pine stand	3.06	0.63	3.69	2.22	5.91

1) Annual fixation amount in the current vegetation floor (t C/ha/year) = CS in the vegetation floor/14

2) Annually fixation amount of the thinned trees (t/ha/year) = CS in the thinned trees in 14 year/14

3) Annual fixation amount of 0–60 cm of soil depth (t/ha/year) = (CS in 0–60 cm of soil depth in 2009—CS in 0–60 cm of soil depth in 1995)/14

growing one up to the time of harvest. Secondly, thinned biomass of Moso bamboo stand is much greater than that of Chinese fir and Masson pine stands. Selective cutting is adopted in the management of mature Moso bamboo stands. Usually, 4 or 5 year old bamboo plants are cut down in alternate years and the thinned bamboo biomass accounts for about one-third of the current total one. In contrast, the thinning of Chinese fir and Masson pine is usually conducted once 12 years after forestation. The thinned biomass of Chinese fir and Masson pine accounts for about 30–40% of the current total one. Thirdly, CSs in the soils under Moso bamboo stands are much greater than that under Chinese fir and Masson pine stands (Xiao et al., 2007; Wang et al., 2009; Zhou & Jiang, 2004), which may be due to application of high rate of organic manure and adopting winter mulching in the intensive management of Moso bamboo stands.

The annual carbon fixation amounts in the ecosystems of Moso bamboo, Chinese fir, and Masson pine stands were 9.64, 5.71, and 5.91 tC/ha/year, respectively (Table 6). The Moso bamboo forest ecosystem fixed 1.69 and 1.63 times as much C as Chinese fir and Masson pine forest ecosystems, which was supported by other results who reported that the annual carbon fixation amounts in Moso bamboo stands were 2.23 and 1.33 times greater than Chinese fir stands and Masson pine stand (Xiao et al., 2007; Wang et al., 2009; Zhou & Jiang, 2004), respectively.

The annual carbon fixation amount in the ecosystems of Moso bamboo stands did not decrease with cultivation years, whereas those in the ecosystems of near-mature Chinese fir and Masson pine stands decreased with tree age (Fang et al., 2003; Zhang et al., 2005).

Conclusions

The results of this study suggested that Moso bamboo forest ecosystem fixed 1.69 and 1.63 times as much C as Chinese fir and Masson pine forest ecosystems. It was concluded that Moso bamboo stands are a greater carbon sink relative to Chinese fir and Masson pine stands. Moreover, the thinned bamboo plants are mostly used in producing furniture, floor boards, paper, etc., in which carbon may be stored for a long period. Therefore, moderate development of Moso bamboo stands in south China may help to offset CO_2 emissions by sequestering more CO_2 from atmosphere.

Literature Cited

Brown, S., C. A. S. Hall, W. Knabe, J. Raich, M. C. Trexler & P. Woomer. 1993. Tropical forests: their past, present, and potential role in the terrestrial C budget. Water, Air and Soil Pollution. 70: 71–94.
Cannell, M. G. R. 1996. Forests as carbon sinks mitigating the greenhouse effect. Commonwealth Forestry Review 75: 92–99.

Dixon, R. K., S. Brown, R. A. Houghton, A. M. Solomon, M. C. Trexler & J. Wisniewski. 1994. Carbon pools and flux of global forest ecosystems. Science 263: 185–190.

Du, H. Q., G. M. Zhou, W. Y. Fan, H. L. Ge, X. J. Xu, Y. J. Shi & W. L. Fan. 2010. Spatial heterogeneity and carbon contribution of aboveground biomass of moso bamboo by using geostatistical theory. Plant Ecol. 207: 131–139.

Fang, X., D. L. Tian & W. H. Xiang. 2002. Density, storage, and distribution of carbon in Chinese fir plantation at fast growing stage. Scientia Slilvae Sinica (In Chinese) 38(3): 14–18.

Fang, D. L. Tian & C. H. Xu. 2003. Productivity and carbon dynamics of Masson pine plantation. Journal of Central South forestry University (In Chinese). 23(2): 11–15.

FAO, 2006. Global forest resource assessment 2005. Food and Agricultural Organization of the United Nations, Rome.

Guo, Q. Y., G. Y. Yang, T. Z. Du & J. M. Shi. 2005. Carbon Character of Chinese Bamboo Forest. Word Bamoo and Rattan (In Chinese) 3(3): 25–28.

Lessard, G. & A. Chouinard. 1980. Bamboo research in Asia. In: Proceedings of a workshop held in Singapore, IDRC, Ottawa, Canada.

Liu, Y. F., C. D. Huang & Q. B. Chen. 2010. Carbon sorage and allocation of *Phyllostachys pubescens* ecosystem in Scenic Spot within the southern Sichuan Bamboo sea. Journal of Sichuan Agricultural University (In Chinese) 28(2): 136–140.

Niu, D., S. L. Wang & O. Y. Zhiyun. 2009. Comparisons of carbon storages in *Cunninghamia lanceolata* and *Michelia macclurei* plantations during a 22-year period in southern China. Journal of Environmental Sciences 21: 801–805.

Schulp, C. J. E., G. J. Nabulars, P. H. Verburg & R. W. De Waal. 2008. Effect of tree species on carbon stocks in forest floor and mineral soil and implications for soil carbon inventories. Forest Ecology and Management 256(3): 482–490.

Soil Science Society of China (SSSC). 2000. Analytical method of soils and agricultural chemistry. China Agricultural Science and Technology Press (in Chinese), Beijing.

Tian, D. L., X. Fang & W. H. Xiang. 2004. Carbon density of the Chinese fir plantation ecosystem at Huitong, Hunan Province. Acta Ecologica Sinica (In Chinese) 24(11): 2382–2386.

Vallet, P., C. Merdieu & I. Seynave. 2009. Species substitution for carbon storage: Sessile oak versus Corsican pine in France as a case study. Forest Ecology and Management 257: 1314–1323.

Vesterdal, L. & J. Feifeld. 2010. Land-use change and management effects on soil carbon sequestration: Forestry and agriculture. Greenhouse-gas budget of soils under changing climate and land use (BurnOut) • COST 639 • 2006–2010.

Wang, B., Y. Wang, H. Guo, G. D. Zhao & X. L. Bai. 2009. Carbon storage and spatial distribution in *Phyllostachys pubescens* forest in Dagangshan Mountain of Jiangxi Province. Journal of Beijing Forestry University (In Chinese) 31(6): 39–42.

Xiao, F. M., X. H. Fan, S. L. Wang, C. Y. Xiong, C. Zhang, S. P. Liu & J. Zhang. 2007. Carbon storage and spatial distribution in *Phyllostachy pubescens* and *Cunninghamia lanceolata* plantation ecosystem. Acta Ecologica Sinica (In Chinese) 27(7): 2794–2801.

Yuan, Z. K., D. L. Tian, C. Y. Wu, S. B. Yuan & S. C. Fu. 2004. Computing model for carbon storage in forest ecosystem and the estimation of annual storage in area of Changsha Zhuzhou and Xiangtan. Hunan Forestry Science and Technology (In Chinese). 31(4): 1–5.

Zhang, L., Y. Huang, T. X. Luo, Q. Dai & K. M. Deng. 2005. Age effect on stand biomass allocations to different components: a case study in forests of *Cunninghamia Lanceolata* and *Pinus Massoniana*. Journal of the Graduate School of the Chinese Academy of Sciences (In Chinese) 22(2): 170–178.

Zheng, H., Z. Y. Ouyang, W. H. Xu, X. K. Wang, H. Miao, X. Q. Li & Y. X. Tian. 2008. Variation of carbon storage by different reforestation types in the hilly red soil region of southern China. Forest Ecology and Management 225: 1113–1121.

Zhou, G. M. & P. K. Jiang. 2004. Density, Storage and Spatial Distribution of Carbon in *Phyllostachy pubescens*. Forestry Science (In Chinese). 40(6): 20–24.

———, P. K. Jiang & Q. F. Xu. 2009. Fixation and translation of carbon in bamboo forest ecosystem. 1–2, 176–186. Science Press (In Chinese), Beijing.