Comparisons of carbon storages in *Cunninghamia lanceolata* and *Michelia macclurei* plantations during a 22-year period in southern China

NIU Dong¹, WANG Silong², OUYANG Zhiyun^{1,*}

1. State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China. E-mail: niudong@cashq.ac.cn

2. Huitong Experimental Station of Forest Ecology, Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang 110016, China

Received 23 May 2008; revised 30 June 2008; accepted 07 August 2008

Abstract

Tree species composition was important for carbon storage within the same climate range. To quantify the dynamics of ecosystem carbon allocation as affected by different tree species, we measured the above- and below-ground biomass accumulation in 22 years, as well as the tissue carbon concentrations of trees in *Cunninghamia lanceolata* plantation and *Michelia macclurei* plantation. Results indicated that *M. macclurei* plantation significantly stored more carbon (174.8 tons/hm²) than *C. lanceolata* plantation (154.3 tons/hm²). Most of the carbon was found in the soil pool (57.1% in *M. macclurei* plantation, 55.2% in *C. lanceolata* plantation). Tree and soil component of *M. macclurei* plantation possessed significantly higher carbon storage than that of *C. lanceolata* plantation ($p < 0.05$). No significant difference was found in the carbon storage of understory and forest floor. These results suggest that the broadleaved species (*M. macclurei*) possesses greater carbon sequestration potential than the coniferous species (*C. lanceolata*) in southern China.

Key words: *Cunninghamia lanceolata* plantation; *Michelia macclurei* plantation; carbon storage; carbon allocation patterns

DOI: 10.1016/S1001-0742(08)62344-X

Introduction

Forest ecosystems are a major sink of terrestrial carbon, which is dependent on environmental, biogeochemical, and land-management factors. Land use change can have a remarkable effect on ecosystem carbon contents. Such changes are important from the viewpoint of soil fertility and long-term sustainability, and their influence on atmospheric CO₂ and global warming (Bouwman, 1990). Reforestation can capture significant amounts of atmospheric carbon, and it is expected to contribute to soil quality and conservation (Schroeder, 1992). However, the effects of tree species composition, developmental stage, soil type, and management practices on forest ecosystem carbon storage should not be neglected (Cannell, 1982; Harmon *et al.*, 1990; Dewar and Cannell, 1992; Grigal and Ohmann, 1992; Yang *et al.*, 2005). To understand the effects of tree species composition on forest carbon storage, it is necessary to examine carbon pools and their allocation patterns in different ecosystems to determine the most appropriate reforestation species.

Cunninghamia lanceolata, an important coniferous timber species, has been widely planted for more than 1000 years in southern China due to its fast growth and good timber quality (Wu, 1984). Planting area has covered 12 million hm², accounting for about 24% of all forested area

in China, and the successive cropping system has been widely used (Chen and Wang, 2004). In recent decades, however, this practice has led to remarkably decline in soil fertility and timber productivity because of nutrient depletion and deterioration of physical, chemical and biochemical properties (Feng *et al.*, 1988; Chen *et al.*, 1990) which resulted from successive cropping, whole-tree harvest and site preparation. Fortunately, some scientists have found that planting broadleaved tree could improve the quality of forest land (Feng *et al.*, 1988; Chen *et al.*, 1990). In contrast, few studies examine the change of carbon storage due to broadleaved species and coniferous species in southern China.

The main objective of this study is to quantify the dynamics of ecosystem carbon allocation as affected by tree species. For this, we assessed the overall impact of two typical forest types (i.e., plantations of *C. lanceolata* and *Michelia macclurei*) on ecosystem carbon allocation patterns, by means of quantifying above- and below-ground carbon pools. This study also provided a management baseline for enhancing the carbon sequestration potential of forest ecosystems.

1 Materials and methods

1.1 Study area

This study was conducted at Huitong Experimental

* Corresponding author. E-mail: zouyang@rcees.ac.cn

Station of Forest Ecology, Chinese Academy of Sciences (latitude 26°40'–27°09'N and longitude 109°26'–110°08'E), Hunan Province, China. This experimental station lies at the transition zone from the Yunnan-Guizhou plateau to the low mountains and hills on the southern side of Yangtze River at an altitude of 300–1100 m above mean sea level. The climate of this region is humid mid-subtropical monsoon with mean annual temperature of 15.8°C with a mean minimum of 1.9°C in January and a mean maximum of 29°C in July. Therefore, four seasons are divided as follows, spring (March–May), summer (June–August), autumn (September–November) and winter (December–February). The mean annual precipitation was 1200 mm of which about 67% occurred between 34% and 93% during 1998–2004 (Wang *et al.*, 2008).

The native vegetation being evergreen broadleaved forest typical of the subtropics, with the major species component of *Castanopsis* spp. and *Lithocarpus* spp., has almost been extirpated by human activities, and *C. lanceolata* has become the major forest community. After clear-cutting of native broadleaved forest at an altitude of 480–560 m above mean sea level in autumn of 1982 and slash burning in winter, a pure *C. lanceolata* stand and a evergreen broadleaved stand of *M. macclurei* in total 10 hm² were established in early spring of 1983. Planting density was 950 trees/100 hm² in the both stands. Tree density was 940 stems/100 hm² *C. lanceolata* in pure stand, and 975 stems/100 hm² *M. macclurei* in evergreen broadleaved stand at the investigation. Three replicate plots were selected in each of the stands giving three permanent plots of 20 m × 20 m in size. Chen *et al.* (2000) documented that the background value, including soil profile characteristics, textures and mineral composition, were almost identical in different plots. All the plots were situated in area of similar soil moisture class, topography, aspect, slope position. The common management practices used in the early stage was: weeding and chemical fertilizer in surface soil around 1 m² area of tree trunk.

According to US taxonomy, the soil is Oxisol developed from slate and shale. The soils in both stands have developed from the same parent material. Forest soil is 50–70 cm deep and reddish in colour. Prior to the experiment, soils were sampled at random locations in each permanent plot and analyzed in February 1983. The soil texture is medium-clayey loam (sand 32%, silt 22%, clay 46%) and soil pH ranges from 4.8 to 5.0 (Chen *et al.*, 2000). Soil total N and total P were 2.4 and 0.66 g/kg, respectively.

Soils in each plot were sampled by depth (five replicate cores per plot along a diagonal transect) in March 2005. Soil pH was determined in a 1:2.5 soil-water slurry using a combined glass electrode. Soil organic carbon was also established by the oil-bath K₂Cr₂O₇ titration method. Total nitrogen was determined by the semi-micro Kjeldahl method. Available nitrogen was ascertained by a microdiffusion technique after alkaline hydrolysis. Available phosphorus was extracted with a 0.5 mol/L NaHCO₃ solution (pH 8.5). Phosphate-P in solution was analyzed colorimetrically by the formation of a blue phosphomolybdate complex following a reduction with

ascorbic acid. Available potassium was evaluated using the CH₃COONH₄ extraction method (Lao, 1988) (Table 1).

Table 1 Soil and vegetation properties

Parameter	<i>Cunninghamia lanceolata</i> plantation	<i>Michelia macclurei</i> plantation
Soil property		
Bulk density (g/cm ³)	1.06 (0.03) b	0.94 (0.02) a
pH	3.99 (0.11) a	4.30 (0.11) a
Soil organic carbon (g/kg)	20.31 (1.19) b	23.81 (1.46) a
Total nitrogen (g/kg)	1.78 (0.10) b	2.08 (0.10) a
Total phosphorus (g/kg)	0.14 (0.01) b	0.18 (0.01) a
Total potassium (g/kg)	12.85 (1.46) a	14.80 (0.84) a
Vegetation property		
Average tree density (per hm ²)	940	975
Average DBH (cm)	16.0	22.7
Average tree height (m)	17.9	26.2

* The samples were collected in 0–10 cm depth in March 2005 and determined in December 2005.

DBH: diameter at breast height diameter. Standard deviations are provided within parentheses. Values in the same row followed by the same letter are not significantly different at $p < 0.05$ level.

1.2 Biomass estimation

In March 2005, three 20 m × 20 m plots were re-established at each forest site. The diameter at breast height (DBH) and the height of all living trees were measured. A total of eight standard trees belonging to two dominant species (i.e., four individuals of each of the species *C. lanceolata* and *M. macclurei*) were harvested for above- and below-ground measurements of biomass and tissue carbon concentrations.

Aboveground biomass was separated into different tissue types (e.g., stem wood, stem bark, branch, and foliage). The 4–6 representative branches were sampled from each tree at regular intervals over the entire length of the crown. Foliage was collected from each of the sampled branches. The trunk was sectioned into meter-long pieces using a chainsaw. Bark was then collected immediately. For each tree, root samples were obtained in soil blocks by excavation with the assumption that the foreign fine roots collected within the block would be balanced with the intrinsic fine roots left in the soil. All samples were weighed in the field, placed into plastic bags, and kept refrigerated and transported to the lab.

Understory biomass was also determined using destructive sampling techniques (i.e., total harvesting, including roots), within five randomly selected 2 m × 2 m subplots within each 20 m × 20 m plot.

Forest floor components (i.e., dead plant material on the forest floor) were also sampled within five 1 m × 1 m subplots randomly chosen in each 20 m × 20 m plot. A total of fifteen 1 m × 1 m subplots were sampled in each forest type. All plant materials collected within these 1 m × 1 m subplots were sorted into three components: coarse wood with a diameter greater than 2 cm and height at least 40 cm, litter (leaves and twigs), and the fragmentation layer. Forest floor components were bagged separately and transported to the lab.

1.3 Soil carbon pool

Volumetric samples of mineral soil were collected at different depth for determining carbon concentrations, as well as bulk density. On each plot of two forests from five systematically located points, three samples were taken from the following depth ranges: 0–10, 10–20, 20–40, 40–60, 60–80, and 80–100 cm, and pooled by sampling point and layer.

1.4 Sample treatment and chemical analyses

Sealed tree tissue samples, as well as samples collected from the forest floor and understory were weighed in the field and recorded as wet-weight. They were then oven-dried at 70°C and reweighed to calculate tissue-specific wet-to-dry mass conversion factors.

All plant material samples were ground by means of a mortar and pestle with liquid nitrogen, and the oil-bath $K_2Cr_2O_7$ titration method was used to determine organic carbon (Dong, 1997). Soil samples were air dried and sieved with a 2-mm mesh to remove any vegetation or gravel. Soils were also analyzed for soil organic carbon by the oil-bath $K_2Cr_2O_7$ titration method (Liu, 1996).

1.5 Statistical analyses

One-way variance analyses were used to test the significant differences in the various soil chemical properties, carbon concentrations, biomasses, and carbon pools among these treatments. Total forest carbon storage was also compared, including the cumulative carbon storage of trees, understory, forest floor, and soil. When a treatment difference was detected, the Tukey's multiple range test was used to examine the differences of treatment means at the significance level of $p < 0.05$. All these statistical analyses were conducted using the SPSS version 11.0.

2 Results

2.1 Tree carbon storage

Stem wood constituted approximately 60% of the entire tree mass (Table 2). Although the carbon concentration of all the plant tissues was approximately 45%, significant differences were observed among specific tissues of the

two species (Table 2). And the tissue carbon concentration of *C. lanceolata* is significant lower than that of *M. macclurei*.

The largest tree carbon storage was located in the *M. macclurei* plantation (72.4 tons/hm²) and was significantly different from that of *C. lanceolata* plantation (66.9 tons/hm²) (Table 2). The carbon storage ranking for above- and below-ground was identical to the total tree carbon storage, except for stem wood (Table 2).

2.2 Carbon storage of understory and forest floor

Significant difference in the understory biomass was found among the two forest types (Table 2). However, no significant differences were observed among the means of the understory carbon storage (Table 2).

A significant difference was also found among the means of the forest floor components collected in the two forest types (Table 2). Biomass of the forest floor in the *C. lanceolata* plantation was significantly lower than those in the *M. macclurei* plantation, but no significant difference was observed for the carbon storage of forest floor between *M. macclurei* plantation and *C. lanceolata* plantation.

2.3 Soil carbon storage

The combined bulk density and carbon concentration of various soil samples across the forest types provide a general picture of carbon storage at different depths. Significant differences were found when comparing the average surface soil (0–10 cm) bulk densities and organic carbon concentrations of the two forest types (Fig. 1). Similar differences were also found in other layers, including 10–20, 20–40, 40–60, 60–80, and 80–100 cm layers.

Adjusted by soil bulk density and organic carbon concentration, the soil organic carbon storage in the 0–100 cm range for the two forest types were also significantly different, with the highest value (99.80 tons/hm²) in the *M. macclurei* plantation and the lowest value (85.27 tons/hm²) in the *C. lanceolata* plantation (Fig. 2).

2.4 Ecosystem carbon storage and their allocation patterns

Figure 3 summarizes the results obtained for ecosystem carbon storage in the two forest types. Forest carbon

Table 2 Biomass, tissue carbon concentration and carbon storage for plant in two forest types

	Biomass (tons/hm ²)		Tissue carbon concentration (%)		Carbon storage (tons/hm ²)	
	<i>Cunninghamia lanceolata</i> plantation	<i>Michelia macclurei</i> plantation	<i>Cunninghamia lanceolata</i> plantation	<i>Michelia macclurei</i> plantation	<i>Cunninghamia lanceolata</i> plantation	<i>Michelia macclurei</i> plantation
Tree						
Stem wood	89.9 (4.6) a	101.5 (9.6) a	48.1 (0.78) a	46.0 (0.45) b	43.2 (2.33) a	46.7 (5.40) a
Stem bark	9.5 (0.9) b	16.4 (0.8) a	43.8 (0.51) a	38.2 (0.7) b	4.2 (0.38) b	6.3 (0.39) a
Branch	12.5 (1.1) a	9.7 (1.0) b	44.2 (0.84) a	39.4 (0.37) b	5.5 (0.41) a	3.8 (0.51) a
Foliage	12.3 (1.1) a	12.0 (2.0) a	46.5 (0.84) a	43.7 (0.39) b	5.7 (0.47) a	5.2 (0.97) a
Root	18.5 (1.4) b	25.1 (1.9) a	45.2 (0.68) a	41.4 (0.4) b	8.3 (0.51) b	10.4 (0.88) a
Subtotal	142.7 (5.3) b	164.7 (8.7) a	—	—	66.9 (2.48) b	72.4 (5.00) a
Understory	3.2 (0.3) b	4.0 (0.4) a	38.7 (0.62) a	37.3 (0.36) b	1.2 (0.14) a	1.5 (0.14) a
Forest floor	1.9 (0.2) b	2.7 (0.3) a	45.8 (0.53) a	39.4 (0.41) b	0.9 (0.08) a	1.1 (0.10) a
Total	147.8 (5.1) b	171.5 (8.8) a	—	—	69.1 (2.44) b	75.0 (5.08) a

Values in the same row followed by the same letter are not significantly different at $p < 0.05$ level.

Fig. 1 General pattern of bulk density and organic carbon concentration as affected by depth. CL: *Cunninghamia lanceolata*; MM: *Michelia macclurei*. The coarse lines and the thin lines denote bulk density and organic carbon concentration, respectively.

storage in *M. macclurei* plantation was 174.8 tons/hm², which was significantly greater than the storage in *C. lanceolata* plantation measured at 154.3 tons/hm². The majority of the carbon was located in the soil pool (*M. macclurei* plantation: 57.1%; *C. lanceolata* plantation: 55.2%) in the *C. lanceolata* and *M. macclurei* plantations. The forest floor and understory contained 1.23%–1.49% of ecosystem carbon pools, respectively, which is less than the other components (Fig. 3).

Fig. 2 Soil carbon storage values in the soil (0–100 cm) in each forest type. CL: *Cunninghamia lanceolata*; MM: *Michelia macclurei*. Values followed by the same letter are not significantly different (0–100 cm soil carbon storage) at $p < 0.05$ level.

Fig. 3 Carbon storage in plant and soil of each forest type. CL: *Cunninghamia lanceolata*; MM: *Michelia macclurei*. Vertical lines denote standard deviations. Values followed by the same letter are not significantly different (forest carbon storage) at $p < 0.05$ level.

Michelia macclurei plantation possessed the highest biomass in the components (i.e., trees, understory, and forest floor) and the highest carbon storage in trees and upper 100 cm of soil (Table 2 and Fig. 2).

3 Discussion

In this study, forest carbon storage includes the carbon stored in the trees, understory, forest floor, and top soils (i.e., between 0 and 100 cm). Because of the different species selection, the carbon storage and its allocation pattern of forest carbon storage varied significantly.

Compared with *C. lanceolata* plantation, the tree carbon storage in *M. macclurei* plantation was significantly higher (Table 2). The difference is believed to result from species selection during reforestation. *M. macclurei* is a broadleaved species and the carbon dioxide fixing capacity of a deciduous forest is generally higher than that of a coniferous forest (Zhou *et al.*, 2000).

There exists no significant difference for the carbon storage of understory between the *M. macclurei* and *C. lanceolata* plantations. However, the biomass of understory and forest floor in *M. macclurei* plantation is significant high than that in *C. lanceolata* plantation.

Soil was the main carbon pool for the two forest types. The difference in soil carbon storage in the different forest ecosystems are believed to result from the root biomass and litter production. Root biomass and litter production constitute important factors affecting the soil organic carbon. The large root biomass and litter production in *M. macclurei* plantation enhanced its soil organic carbon contents. Broadleaved tree species increase litter production and nutrient returns, and are helpful to restore soil fertility of degraded monoculture forests (Wang *et al.*, 2008). The changes in the carbon stocks of the soils in the different forest types might also reflect the differences in quantity and quality of above- and below-ground litter inputs, litter carbon decay (Mo *et al.*, 2002), and root biomass carbon. Yang *et al.* (2004c) noted that the leaf-litter of Chinese fir possesses higher lignin concentration and lignin/N ratio than that of broad leaf tree. In addition, broadleaved trees may allocate more biomass to their roots, especially the fine roots at the shallow soil horizons, which can fix a greater amount of carbon and transfer more root detritus to the top soil (Yang *et al.*, 2004a, 2004b).

Acknowledgments

This work was supported by the Knowledge Innovation Program of the Chinese Academy of Sciences (No. KZCX2-YW-405) and the Innovation Group Project of National Natural Science Foundation of China (No. 40621061).

References

- Bouwman A F, 1990. Exchange of greenhouse gases between terrestrial systems and the atmosphere. In: Soils and the Greenhouse Effect (Bouwman A F, ed.). Chichester: Wiley.

- Cannell M G R, 1982. World Forest Biomass and Primary Production Data. London: Academic Press.
- Chen C Y, Liao L P, Wang S L, 2000. Ecology of Chinese Fir Plantation Forest. Beijing: Science Press. 1–39, 84–96.
- Chen C Y, Wang S L, 2004. Ecology of Mixed Plantation Forest. Beijing: Science Press. 3.
- Chen C Y, Zhang J W, Zhou C L, Zheng H Y, 1990. Researches on improving the quality of forest land and the productivity of artificial *Cunninghamia lanceolata* stands. *Journal of Applied Ecology*, 1(2): 97–106.
- Dewar R C, Cannell M G R, 1992. Carbon sequestration in the trees, products and soils of forest plantations: an analysis using UK examples. *Tree Physiology*, 11: 49–71.
- Dong M, 1997. Survey, Observation and Analysis of Terrestrial Biocommunities. Beijing: Standards Press of China.
- Feng Z W, Chen C Y, Zhang J W, 1988. A coniferous broad-leaved mixed forest with higher productivity and ecological harmony in subtropics – study on mixed forest of *Cunninghamia lanceolata* and *Michelia macclurei*. *Acta Phytoecologica et Geobotanica Sinica*, 12(3): 165–180.
- Grigal D F, Ohmann L F, 1992. Carbon storage in upland forests of the Lake States. *Soil Science Society of America Journal*, 56: 935–943.
- Harmon M E, Ferrell W K, Franklin J F, 1990. Effects on carbon storage of conversion of old-growth forests to young forests. *Science*, 247: 699–702.
- Lao J C, 1988. Handbook for Soil and Agro-chemical Analysis. Beijing: Chinese Agricultural Press.
- Liu G S, 1996. Soil Physical and Chemical Analysis and Description of Soil Profiles. Beijing: Standards Press of China.
- Mo J M, Sandra B, Peng S L, Kong G H, Zhang D Q, Zhang Y C, 2002. Role of understory plants on nutrient cycling of a restoring degraded pine forests in a MAB reserve of subtropical China. *Acta Ecologica Sinica*, 22(9): 1407–1413.
- Schroeder P, 1992. Carbon storage potential of short rotation tropical tree plantations. *Forest Ecology and Management*, 50: 31–41.
- Wang Q K, Wang S L, Huang Y, 2008. Comparisons of litterfall, litter decomposition and nutrient return in a monoculture *Cunninghamia lanceolata* and a mixed stand in southern China. *Forest Ecology and Management*, 255: 1210–1218.
- Wu Z L, 1984. Chinese-fir. Beijing: Forestry of China Publications.
- Yang Y S, Chen G S, Guo J F, Lin P, 2004a. Decomposition dynamic of fine roots in a mixed forest of *Cunninghamia lanceolata* and *Tsoongiodendron odoratum* in mid-subtropics. *Annals of Forest Science*, 61: 65–72.
- Yang Y S, Chen G S, Lin P, Xie J S, Guo J F, 2004b. Fine root distribution, seasonal pattern and production in four plantations compared with a natural forest in subtropical China. *Annals of Forest Science*, 61: 617–627.
- Yang Y S, Guo J F, Chen G S, Lin R Y, Cai L P, Lin P, 2004c. Litterfall, nutrient return, and leaf-litter decomposition in four plantations compared with a natural forest in subtropical China. *Annals of Forest Science*, 61: 465–476.
- Yang Y S, Guo J F, Chen G S, Xie J S, Zhen L, Zhao J, 2005. Carbon and nitrogen pools in Chinese fir and evergreen broadleaved forests and changes associated with felling and burning in mid-subtropical China. *Forest Ecology and Management*, 216(1-3): 216–226.
- Zhou Y R, Yu Z L, Zhao S D, 2000. Carbon storage and budget of major Chinese forest types. *Acta Phytoecologica Sinica*, 24(5): 518–522.