Chin. Geogra. Sci. 2014 Vol. 24 No. 4 pp. 454–460
doi: 10.1007/ s11769-014-0699-9

Springer Science Press
www.springerlink.com/content/1002-0063

Carbon Storage Capacity of Different Plantation Types Under Sandstorm Source Control Program in Hebei Province, China

SHEN Huitao[1], ZHANG Wanjun[1], YANG Xue[2], LIU Xiuping[1], CAO Jiansheng[1], ZENG Xinhua[1], ZHAO Xin[1], CHEN Xuexun[3], ZHANG Wenxi[4]

(1. *Key Laboratory of Agricultural Water Resources*, *Hebei Key Laboratory of Agricultural Water-Saving*, *Center for Agricultural Resources Research*, *Institute of Genetics and Developmental Biology*, *Chinese Academy of Sciences*, *Shijiazhuang* 050021, *China*; 2. *Agriculture School*, *Kunming University*, *Kunming* 650214, *China*; 3. *Forestry Bureau of Aohan Banner*, *Aohan* 024300, *China*; 4. *Forestry Bureau of Hexigten Banner*, *Hexigten* 025350, *China*)

Abstract: Afforestation and reforestation are effective and ecological ways of mitigating elevated atmospheric carbon dioxide (CO_2) concentration and increasing carbon (C) storage in terrestrial ecosystems. In this study, we measured the above-ground (tree, herbaceous plants and litter) and below-ground (root and soil) C storage in an aspen plantation (*Populus davidiana*) monoculture (PD), a larch plantation (*Larix pincipis-rupprechtii*) monoculture (LP), a pine plantation (*Pinus tabulaeformis*) monoculture (PT), a larch and birch mixed plantation (*L. pincipis-rupprechtii* and *Betula platyphlla* mixed) (MLB), and an apricot plantation (*Armeniaca sibirica*) monoculture (AS) under the Desertification Combating Program in Hebei Province, the northern China. The objective was to assess the effect of afforestation species on ecosystem C pools of different plantation types. Results showed that C storage of LP stand (258.0 Mg/ha) and MLB (163.4 Mg/ha) were significantly higher than the C storage in PD (45.5 Mg/ha), PT (58.9 Mg/ha) and AS (49.4 Mg/ha), respectively. Soil C was the main carbon pool of the ecosystem C storage in the five plantation stands, ranging from 31.4 Mg/ha to 232.5 Mg/ha, which accounted for 69.0%–90.1% of the total ecosystem C storage. The C storage in tree layer was about 5.2%–23.2% of ecosystem C storage. The herbaceous plants and litter layers contained 1.0%–6.0% and 1.5%–3.3% of ecosystem C storage, respectively. Our results suggest that tree species should be incorporated to accurately develop regional C budget of afforestation program, and also imply that substantial differences in ecosystem C stocks among plantation types can facilitate decision making on C management.
Keywords: carbon content; carbon storage; forestry program; tree species

Citation: Shen Huitao, Zhang Wanjun, Yang Xue, Liu Xiuping, Cao Jiansheng, Zeng Xinhua, Zhao Xin, Chen Xuexun, Zhang Wenxi, 2014. Carbon storage capacity of different plantation types under Sandstorm Source Control program in Hebei Province, China. *Chinese Geographical Science*, 24(4): 454–460. doi: 10.1007/s11769-014-0699-9

1 Introduction

Rapidly increasing carbon dioxide (CO_2) concentrations, primarily resulting from anthropogenic activities and land use changes, have led to growing concerns about measures for emission mitigation and carbon (C) sink enhancement (Huang *et al*., 2012; Verma *et al*., 2012; Zhou *et al*., 2013). Afforestation and reforestation have become the important methods to enhance the C sequestration capacity in the terrestrial ecosystems and mitigate the increasing atmospheric CO_2 concentration (Chen *et al*., 2009; Wang *et al*., 2012). Global afforestation and reforestation have the potential to sequester 60–90 Pg C between 1995 and 2050 (Huang *et al*., 2012).

In the late 1990s, the Chinese Government has initiated six forestry programs including the Natural Forest

Received date: 2013-10-16; accepted date: 2014-01-21
Foundation item: Under the auspices of Strategic Priority Research Program of Chinese Academy of Sciences (No. XDA05060600), Knowledge Innovation Programs of Chinese Academy of Science (No. KSCX2-EW-J-5)
Corresponding author: ZHANG Wanjun. E-mail: zhangwj@sjziam.ac.cn

Protection (NFP) program, Grain for Green (GFG) program, Beijing-Tianjin Sandstorm Source Control (BTSSC) program, Three-North Shelterbelt Forest (TSF) program in the Three-Norths and the Changjiang (Yangtze) River Basin, Wildlife Conservation and Nature Reserve Development Program (WCNR) and Industrial Timber Plantation Program (ITPP) (Liu *et al*., 2010). Afforestation and reforestation are playing a vital role in the terrestrial C sink to sequester C in biomass and soil (IPCC, 2007; Wang *et al*., 2009; Toriyama *et al*., 2011). Guo *et al*. (2008) reported that planting pine trees onto a temperate pasture sequestered a significant amount of C (net 86 Mg C/ha, averaging 5.4 Mg C/(ha·year)) from the atmosphere in Australia. Wang *et al*. (2006) found that ecosystem C stores (soil, forest floor, and biomass C) had increased by 103 Mg C/ha and 95 Mg C/ha during 33 years after afforestation with larch and Korean pine in the northeastern China. Additionally, tree species expected to differ in C sink capacity, which affected the amounts of C accumulation (Schulp *et al*., 2008). For example, Hu *et al*. (2008) indicated that poplar plantation would sequester more C than would Mongolian pine plantation in the northeastern China. The results from Pérez-Cruzado *et al*. (2012) showed that the mean rate of C sequestration (biomass and soil) in Eucalyptus plantation was higher than that of Pinus plantation in the northern Spain. Most previous studies were conducted at ecological experimental stations which may have been protected for such a long time. However, few researches have been focused on C storage in different plantation forests in the forestry programs, especially in North China.

In this study, we investigated ecosystem C storage in five typical plantation types (i.e., an aspen plantation (*Populus davidiana* Dode) monoculture, a larch plantation (*Larix pincipis-rupprechtii* Pilg.) monoculture, a pine plantation (*Pinus tabulaeformis* Carr.) monoculture, a larch and birch mixed plantation (*L. pincipis-rupprechtii* and *Betula platyphlla* Suk.mixed), and an apricot plantation (*Armeniaca sibirica* Lam.) monoculture under BTSSC program, Hebei Province of North China. The objective was to evaluate the effect of afforestation species on the capacities of C storage, and provide a baseline of management for enhancing C sequestration and valuable plantation species cultivation in North China.

2 Materials and Methods

2.1 Study area

The study area is the region of the BTSSC program in Hebei Province (39°34′53″–42°37′43″N, 113°54′21″–119°14′05″E, 120–1400 m above sea level). The climate is temperate, with an average annual temperature of 12℃. Annual precipitation ranges from 460 mm to 595 mm, 65% of which occurs between June and September (Gao *et al*., 2008). The planted species under BTSSC program in Hebei Province mainly include aspen (*P. davidiana*), larch (*L. pincipis-rupprechtii*), Chinese pine (*P. tabulaeformis*), white birch (*B. platyphlla*), Siberian Apricot (*A. sibirica*), and Mongolian oak (*Quercus mongolica* Fisch.) (Gao *et al*., 2008). In the present study, we selected five plantation types grew under the similar climate conditions and with similar stand years (years since planting), representing the main plantation types under the BTSSC program. They were an aspen plantation (PD), a larch plantation (LP), a pine plantation (PT), a larch and birch mixed plantation (MLB), and an apricot plantation (AS). Characteristics and conditions of the five sites were summarized in Table 1. From August to September 2011, three 20 m × 20 m experimental plots were established in each plantation types.

Table 1 Characteristics and geomorphology of five plantation types

Forest type	Altitude (m)	Age (year)	Density (trees/ha)	Mean DBH or BD (cm)	Mean tree height (m)	Latitude and longitude
PD	598	9	766 (298)	10.60 (3.34)^{DBH}	11.47 (4.50)	41°09′43″N, 116°45′24″E
LP	1014	8	2525 (139)	6.24 (1.14)^{DBH}	4.39 (0.62)	41°50′47″N, 117°45′36″E
PT	930	7	2283 (825)	3.03 (0.75)^{DBH}	2.77 (0.38)	41°08′06″N, 116°30′17″E
MLB	1228	10	3566 (300)	5.71 (1.25)^{DBH}	5.10 (0.79)	42°12′44″N, 117°30′24″E
AS	625	8	1416 (431)	4.66 (1.71)^{BD}	1.97 (0.37)	41°10′14″N, 116°44′53″E

Notes: PD, LP, PT, MLB and AS represent aspen, larch, pine, mixed larch-birch, and apricot stands, respectively. DBH is diameter at breast height of 1.3 m high for PD, LP, PT, and MLB stands, respectively. BD is basal diameter of 0.1 m high. The numbers in parentheses are standard deviations (n = 3)

2.2 Methods

2.2.1 Overstory and understory biomass

In each plot, basal diameter (BD) of 0.1 m high for apricot plantation and diameter at breast height (DBH) of 1.3 m high (centimeters) for the other plantation types were measured for all trees. Three dominant, three intermediate and three suppressed trees of each species were destructively sampled in the present study. After a tree was felled, total height with a steel tape was measured. Bole was then cut into sections in 1-m each, and each section was separated into different partitions: stem, branch, and foliage. The fresh mass of each partition was determined approaching 1 g with an electronic balance. For each partition, approximately 500–1000 g of fresh mass were randomly sampled and placed in a labeled bag for moisture content determination (Wang, 2006). All components were dried at 65℃ to constant weight. Allometric equation between biomass and independent variables (DBH) in partition (stem, branch, and foliage) were developed by using simple linear regression. The form of allometric equation was as the follow:

$$\log_{10}B = a + b(\log_{10}DBH) \quad (1)$$

where B is partition biomass, a and b are the constant (Wang *et al.*, 2009). Then this equation was used to calculate the biomass of each tree aboveground.

Roots were also excavated from stumps of the harvested trees at 100 cm depth in these plots, and then fresh mass of roots were collected from the harvested tree, washed and dried at 65℃ until a constant weight (Wang *et al.*, 2009). In each plot, grasses and litter were sampled from five squares of 1 m × 1 m located randomly, and then dried at 65℃ to constant weight for biomass determination.

2.2.2 Soil sampling

In each plot, three soil pits were dug randomly at 100 cm depth. At these pits, three 100 cm^3 soil columns were taken to determine soil bulk density from the following depth ranges: 0–20 cm, 20–40 cm, 40–60 cm and 60–100 cm. Meanwhile, a soil subsample of approximately 500 g was collected at the same horizon and then air-dried for soil organic C determination (Han *et al.*, 2010).

2.2.3 Laboratory analysis

Samples of plant material (stems, foliage, branches, roots, litters and material of grasses) were oven-dried and ground into 500 μm, and soil samples were ground to 250 μm before chemical analysis. Carbon contents of plant and soil samples were measured with the method of potassium dichromate oxidation (external heat applied) (Han *et al.*, 2010). Carbon density of plant was determined with multiplying the dry mass followed by the corresponding C content (Zhang and Wang, 2010). The soil C density was calculated from the bulk density, soil depth and corresponding C content (Toriyama *et al.*, 2011).

2.2.4 Data analysis

Variation of aboveground biomass, litter and roots of plantations, grasses and soils was analyzed by using one-way analysis of variance. When the difference was significant, multiple comparisons were made with the Tukey′s test. Significance levels were set at $p < 0.05$ in all statistical analyses. Data analyses were performed by using SPSS version 15.0 for Windows (SPSS Inc., Chicago, IL, USA).

3 Results

3.1 Carbon content

There was no significant difference in C content for branches and roots among the five tree species (Table 2). However, the C contents in stem and foliage in PT were significantly higher than those in the other four species ($p < 0.05$). The mean C content of PT was significantly higher than that of AS ($p < 0.05$).

Table 2 Carbon content (g/kg) in various components of five tree species

Component	PD	LP	PT	BP	AS
Stem	$455.6±1.8^{ab}$	$445.3±18.0^{ab}$	$463.6±25.0^{b}$	$447.3±20.8^{ab}$	$363.0±86.7^{a}$
Branch	$394.5±68.6^{a}$	$441.5±16.0^{a}$	$444.7±37.5^{a}$	$440.5±6.3^{a}$	$381.5±71.4^{a}$
Foliage	$407.2±5.3^{ab}$	$400.6±16.9^{a}$	$478.3±20.8^{c}$	$442.6±9.9^{bc}$	$405.0±15.0^{a}$
Root	$436.2±1.6^{a}$	$442.2±23.1^{a}$	$453.5±44.1^{a}$	$427.8±9.7^{a}$	$442.0±14.3^{a}$
Mean	$423.4±19.3^{ab}$	$432.4±18.5^{ab}$	$460.0±28.3^{b}$	$439.5±11.7^{ab}$	$397.9±46.9^{a}$

Notes: PD, *Populus davidiana*; LP, *Larix pincipis-rupprechtii*; PT, *Pinus tabulaeformis*; BP, *Betula platyphlla*; AS, *Armeniaca sibirica*. Data are means ± standard deviations. Different letters in the same row means different levels of significance based on Tukey′s tests ($p < 0.05$)

For herbaceous layer, the C contents aboveground were higher than the belowground among the five plantation types (Table 3). There was no significant difference in C contents for the herbaceous layer or litter layer among the five plantation types (Table 3).

Soil C contents decreased with the increase of depth (Table 3). The C contents of the topsoil (0–20 cm) were 1.9–3.8 times more than those of the substrate (40–100 cm depths). In each soil layer, LP plantation had significantly higher C content than the other plantations ($p < 0.05$) (Table 3).

3.2 Carbon storage

Among the tree partitions, C storage of stem, branch, and foliage varied with plantation types ($p < 0.05$), whereas C storage of root did not differ among the five forest types (Table 4). The AS plantation had the lowest C storage (3.3 Mg/ha), on the contrary, the LP had the highest value (13.4 Mg/ha).

Herbaceous C storage in LP plantation (8.6 Mg/ha) was significantly higher than the storage in AS (0.5 Mg/ha) (Table 4). The C storage ranking of below-ground partition was the same with that of total herbaceous. There was no significant difference in the C storage of litter among the five forest types (Table 4).

The total C storage of soil in LP (232.5 Mg/ha) and MLB (146.1 Mg/ha) plantations was significantly higher than the other three plantation stands ($p < 0.05$) (Fig. 1). The C storage of soil layers decreased following the increasing depth. Additionally, 32.5%–56.9% of the total C storage in the soil occurred at a depth of 0–20 cm in the five plantation stands.

3.3 Ecosystem carbon storage and their allocation patterns

Ecosystem C storage varied in different forest types (Fig. 2). Forest C storage in LP (258.0 Mg/ha) and MLB (163.4 Mg/ha) were significantly higher than the storage in PD (45.5 Mg/ha), PT (58.9 Mg/ha) and AS (49.4 Mg/ha). Most C was stored in the soil for each plantation type

Table 3 Carbon content (g/kg) in herbaceous plants, litter, and soil layers under five plantations

Layer	Component	PD stand	LP stand	PT stand	MLB stand	AS stand
Herb	Above-ground	385.2±8.9^{a}	392.8±12.6^{a}	411.0±33.5^{a}	373.6±28.0^{a}	363.3±13.9^{a}
	Below-ground	360.2±26.1^{a}	364.2±26.8^{a}	339.4±28.6^{a}	311.2±73.3^{a}	348.9±44.8^{a}
	Mean	372.7±17.5^{a}	378.5±19.7^{a}	375.2±31.1^{a}	342.4±50.6^{a}	356.1±29.3^{a}
Litter		326.1±80.5^{a}	356.9±79.1^{a}	344.6±75.6^{a}	340.9±22.9^{a}	338.6±28.0^{a}
Soil	0–20 cm	8.9±1.2^{a}	36.5±0.1^{c}	7.3±2.7^{a}	21.5±3.2^{b}	5.2±2.2^{a}
	20–40 cm	4.6±0.5^{a}	28.0±0.9^{c}	3.9±0.4^{a}	18.0±4.9^{b}	3.2±1.2^{a}
	40–60 cm	4.5±0.8^{a}	23.5±1.7^{b}	2.4±0.2^{a}	8.4±5.6^{a}	2.6±0.8^{a}
	60–100 cm	4.4±0.3^{a}	11.2±1.3^{b}	2.3±0.3^{a}	5.7±2.5^{a}	2.4±0.8^{a}
	Mean	5.6±0.7^{a}	24.8±1.0^{c}	4.0±0.9^{a}	12.9±4.1^{b}	3.4±1.3^{a}

Notes: PD, LP, PT, MLB and AS represent aspen, larch, pine, mixed larch-birch, and apricot stands, respectively. Data are means±standard deviations. Different letters in the same row means different levels of significance based on Tukey′s tests ($p < 0.05$)

Table 4 Carbon storage (Mg/ha) in various components of five plantation types

Layer	Component	PD	LP	PT	MLB	AS
Tree	Stem	5.9±4.5^{ab}	7.9±0.5^{b}	1.8±0.9^{ab}	3.9±0.2^{ab}	1.0±0.5^{a}
	Branch	1.6±0.9^{ab}	2.2±0.3^{b}	2.6±0.5^{b}	4.9±0.2^{c}	0.3±0.1^{a}
	Foliage	1.1±0.9^{ab}	0.5±0.1^{a}	2.0±0.5^{b}	1.3±0.1^{ab}	0.3±0.1^{a}
	Root	1.9±1.6^{a}	2.7±0.3^{a}	1.0±0.3^{a}	3.0±0.1^{a}	1.6±0.8^{a}
	Subtotal	10.5±5.9^{ab}	13.4±1.2^{b}	8.2±1.7^{ab}	13.1±0.4^{b}	3.3±1.4^{a}
Herb	Aboveground	0.4±0.3^{a}	0.8±0.3^{a}	0.4±0.1^{a}	0.4±0.4^{a}	0.1±0.1^{a}
	Belowground	1.7±1.1^{ab}	7.8±4.9^{b}	3.2±1.0^{ab}	1.9±1.5^{ab}	0.4±0.4^{a}
	Subtotal	2.2±1.4^{ab}	8.6±5.0^{b}	3.6±1.0^{ab}	2.3±1.1^{ab}	0.5±0.4^{a}
Litter		1.0±0.7^{a}	3.5±2.0^{a}	1.9±0.3^{a}	3.3±1.7^{a}	1.2±0.5^{a}

Notes: PD, LP, PT, MLB and AS represent aspen, larch, pine, mixed larch-birch, and apricot stands, respectively. Subtotal is the sum of all components for each layer. Data are means±standard deviations. Different letters in the same row means different levels of significance based on Tukey′s tests ($p < 0.05$)

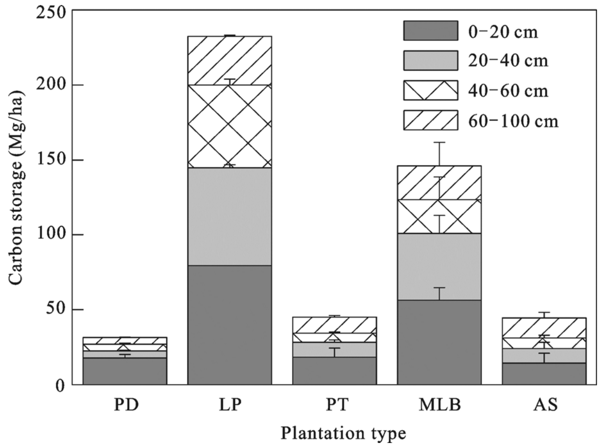

Fig. 1 Carbon storage in soil (0–100 cm) of each forest type. PD, LP, PT, MLB and AS represent aspen, larch, pine, mixed larch-birch, and apricot stands, respectively. The error bars represent standard deviations. Values followed by the same letter are not significantly different (0–100 cm soil carbon storage) at $p < 0.05$ level

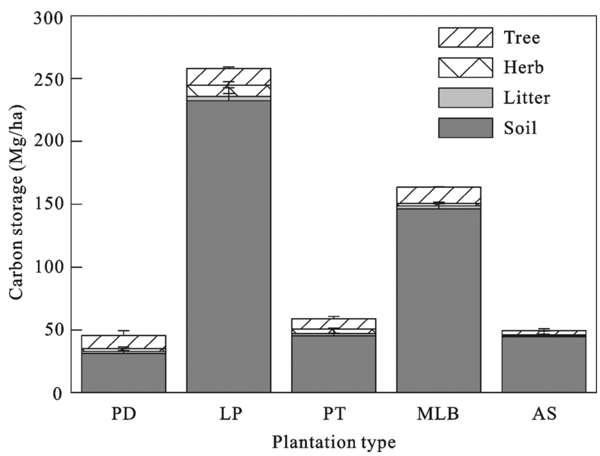

Fig. 2 Carbon storage in various components of each forest type. PD, LP, PT, MLB and AS represent aspen, larch, pine, mixed larch-birch, and apricot stands, respectively. The error bars represent standard deviations. Values followed by the same letter are not significantly different at $p < 0.05$ level

(PD: 69.0%; LP: 90.1%; PT: 76.7%; MLB: 89.4%; AS: 90.0%). The trees in the five plantation stands accounted for total ecosystem C storage of 23.2%, 5.2%, 14.0%, 8.0% and 6.6% in the PD, LP, PT, MLB and AS stands, respectively. Carbon storage of herbaceous plants ranged from 1.0% to 6.0%, and litter ranged from 1.5% to 3.3% of the total C storage (Fig. 2).

4 Discussion

4.1 Carbon content

Carbon contents vary with forest types, species compositions and site conditions in plantation ecosystems, and are positively correlated with C storage (Zhang and Wang, 2010). Mean C content of the five species varied from 397.9 g/kg to 460.0 g/kg (Table 2), and those of the herbaceous plants ranged from 342.4 g/kg to 378.5 g/kg (Table 3). These results were lower than those of previous studies (Wang *et al*., 2009; He *et al*., 2013). Carbon content in tree layer was higher than that in herbs layer, which could be attributed to more organic matter synthesized and accumulated (He *et al*., 2013).

In this study, mean C contents of litter in the five plantation types followed: coniferous types (356.9 g/kg of LP, and 344.6 g/kg of PT, respectively) > mixed coniferous and broad-leaf type (340.9 g/kg of MLB) > broad-leaf types (338.6 g/kg of AS, and 326.1 g/kg of PD, respectively). The results were lower than these three litter types of the northeastern China (462–485 g/kg) in Li and Han (2008). Wang *et al*. (2008) found that the C content of litter depended on litter type, decomposition rate, micro-environment, and litter production. In addition, Huang *et al*. (2010) revealed that litter decomposes considerably at a higher rate in broad-leaf forests than that in coniferous forests, so that C content was less in the former than that in the latter.

Mean C content of soil was significantly higher in the LP plantation than in the other four plantations ($p < 0.05$) (Table 3), and was attributed to higher litter production in LP plantation. Mo *et al*. (2002) suggested that the changes in the C stocks in the different forest types might reflect the differences in the quantity and quality of litter input, litter C decomposition and litter biomass. Moreover, C contents in soil layer decreased depending on soil depth increasing for soil C accumulation rate higher in topsoil. This result could be attributed to the decomposition of the litter and root entering the topsoil more than in deep soil layer (Wang *et al*., 2006; Shi and Cui, 2010). However, the method of potassium dichromate oxidation which is conducted in this study was suspected to underestimate the C content after compared with the methods of dry combustion and automated organic C analyzer (Schumacher, 2002; Li and Wang, 2009).

4.2 Carbon storage

Carbon storage accumulated depending on the age of plantations and species (Somogyi *et al*., 2007). The five plantation types with variable vegetation compositions in this study were growing under the same climate conditions with similar ages (7–10 years), but they had different conditions in different sites (Table 1). Carbon storage of tree layer ranged from 3.3 Mg/ha to 13.4 Mg/ha among the five plantations, and were lower than the average carbon storage of the major Chinese forest ecosystems (57.1 Mg/ha) (Zhou *et al.*, 2000). Lower C accumulation in this study might result from shorter plantation restoration time. Carbon storage level for tree in AS was significantly lower than that in the LP and MLB (p < 0.05), and the difference might result from less branch and foliage contributed to the AS (Table 4). Interference by human management artificially made carbon storage of herbaceous plants in AS the lowest among the five plantations. With respect to the litter layer, the higher C storage of LP, PT and MLB plantations might be resulted from the contribution of undecomposed needle foliage in low decomposing rate.

In this study, the soil C storage accounted for 69.0%–90.1% of the total ecosystem C storage in the five plantation stands. This finding was consistent with the reports in age-sequence of temperate pine plantations of the eastern Canada (23%–92%) (Peichal and Arain, 2006) and in different plantation ecosystems of northern India (58.5%–82.5%) (Devi *et al.*, 2013). In addition, soil C storage distributed in the 0–40 cm depth accounted for 54.3%–71.7% of the total C storage within the depth of 0–100 cm, which was consistent with the previous studies of Zheng *et al.* (2008) and Wang *et al.* (2009). The soil C storage at the topsoil (0–40 cm) accounted for a large proportion of the total soil C storage in these plantations, which attributed to the organic matter being returned to the topsoil through litter decomposition and turnover of the fine roots (Wang *et al.*, 2008). In addition, the total C storage within 0–100 cm depth in LP and MLB plantations were significantly higher than those in the other three plantations (p < 0.05). Litter production, root turnover, and tree species can alter soil C storage (Paul *et al.*, 2002; Jandl *et al.*, 2007; Wang *et al.*, 2009). In this study, the large root biomass, herbaceous plants and litter production in LP and MLB plantations could enhance accumulation of C storage in the soil (Table 4).

5 Conclusions

Carbon content, affected by species composition and site conditions, is one of main factors used to determine the C storage in plantations. In the present study, the herbaceous plants and litter layers in the five plantations exhibits no difference in mean C content. However, the tree layer in AS shows significantly lower mean C content than that did in PT (p < 0.05). With regard to soil, the C content is significantly higher in the LP than that found in the others (p < 0.05). Plantation types significantly affect total C storage in ecosystem although management-induced differences in C stocks are confined to differences in tree, herbaceous plants and soil layers. Soil is the greatest C pool, accounting for 69.0%–90.1% of the ecosystem C storage among the five plantation types. In addition, the upper 0–40 cm soil stores more than 50% of the total soil C storage. These C estimations provide important information for forest managers and policy makers on a regional and national scale in China. Due to lack of control site in every plantation stand, the carbon sequestration rates were not obtained from the five plantation types in the present study. Thus, further research for the effects of tree species on the future C sequestration evaluation will be required in afforestation/reforestation projects.

References

Chen X G, Zhang X Q, Zhang Y P *et al.*, 2009. Carbon sequestration potential of the stands under the Grain for Green Program in Yunnan Province, China. *Forest Ecology and Management*, 258(3): 199–206. doi: 10.1016/j.foreco.2008.07.010

Devi B, Bhardwaj D R, Panwar P *et al.*, 2013. Carbon allocation, sequestration and carbon dioxide mitigation under plantation forests of north western Himalaya, India. *Annals of Forest Research*, 56(1): 123–135.

Gao Shangyu, Zhang Chunlai, Zou Xueyong *et al.*, 2008. *Benefits of Beijing-Tianjin Sand Source Control Engineering*. Beijing: Science Press, 14. (in Chinese)

Guo L B, Cowie A L, Montagu K D *et al.*, 2008. Carbon and nitrogen stocks in a native pasture and an adjacent 16-year-old *Pinus radiate* D. Don. plantation in Australia. *Agriculture, Ecosystems and Environment*, 124(3–4): 205–218. doi: 10.1016/j.agee.2007.09.013

Han F P, Hu W, Zheng J Y *et al.*, 2010. Estimating soil organic carbon storage and distribution in a catchment of Loess Plateau, China. *Geoderma*, 154(3–4): 261–266. doi: 10.1016/ j.geoderma.2009.10. 011

He Y J, Qin L, Li Z Y *et al.*, 2013. Carbon storage capacity of monoculture and mixed-species plantations in subtropical China. *Forest Ecology and Management*, 295(5): 193–198. doi: 10.1016/ j.foreco.2013.01.020

Hu Y L, Zeng D H, Fan Z P *et al.*, 2008 Changes in ecosystem carbon stocks following grassland afforestation of semiarid sandy soil in the southeastern Keerqin Sandy Lands, China. *Journal of Arid Environments*, 72(12): 2193–2200. doi: 10.1016/j.jaridenv.2008.07.007

Huang Jinxue, Huang Limei, Lin Zhichao *et al*., 2010. Controlling factors of litter decomposition rate in China′s forets. *Journal of Subtropical Resources and Environment*, 5(3): 56–63. (in Chinese)

Huang L, Liu J Y, Shao Q Q *et al*., 2012. Carbon sequestration by forestation across China: Past, present, and future. *Renewable and Sustainable Energy Reviews*, 16(2): 1291–1299. doi: 10.1016/j.rser.2011.10.004

IPCC (Intergovernmental Panel on Climate Change), 2007. *Climate Change 2007*: *The Physical Science Basis*. Cambridge: Cambridge University Press.

Jandl R, Lindner M, Vesterdal L *et al*., 2007. How strongly can forest management influence soil carbon sequestration? *Forest Ecology and Management*, 137(3–4): 253–268. doi: 10.1016/ j.geoderma. 2006.09.003

Li X F, Han S J, 2008. Preservation of broadleaf species in Korean pine (*Pinus koraiensis*) plantations affects soil properties, carbon storage, biomass allocation, and available nitrogen storage. *Canadian Journal of Forest Research*, 38(8): 2227–2235. doi: 10.1139/X08-052

Li Xiaohan, Wang Chaohui, 2009. Comparison of two soil organic carbon determination methods. *Analytical Instrumentation*, 40(5): 78–80. (in Chinese)

Liu C, Lu J Z, Yin R S, 2010. An estimation of the effects of China′s Priority Forestry Programs on farmers′ income. *Environmental Management*, 45(3): 526–540. doi: 10.1007/ s00267-010-9433-2

Mo Jiangming, Brown Sandra, Peng Shaoling *et al*., 2002. Role of understory plants on nutrient cycling of a restoring degraded Pine forest in a MAB Reserve of Subtropical China. *Acta Ecologica Sinica*, 22(9): 1407–1413. (in Chinese)

Paul K I, Polglase P J, Nyakuengama J G *et al*., 2002. Change in soil carbon following afforestation. *Forest Ecology and Management*, 168(1–3): 241–257. doi: S0378-1127(01)00740-X

Peichl M, Arain M A, 2006. Above- and belowground ecosystem biomass and carbon pools in an age-sequence of temperate pine plantation forests. *Forest Ecology and Management*, 140(1–4): 51–63. doi: 10.1016/j.agrformet.2006.08.004

Pérez-Cruzado C, Mansilla-Salinero P, Rodríguez-Soalleiro R *et al*., 2012. Influence of tree species on carbon sequestration in afforested pastures in a humid temperate region. *Plant and Soil*, 353(1–2): 333–353. doi: 10.1007/s11104-011-1035-0

Schulp C J E, Nabuurs G J, Verburg P H *et al*., 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. doi: 10.1016/j.foreco. 2008.05.007

Schumacher B A, 2002. *Methods for the Determination of Total Organic Carbon* (*TOC*) *in Soils and Sediments*. Las Vegas: United States Environmental Protection Agency, Environmental Sciences Division National Exposure Research Laboratory.

Shi J, Cui L L, 2010. Soil carbon change and its affecting factors following afforestation in China. *Landscape and Urban Planning*, 98(2): 75–85. doi: 10.1016/j.landurbplan.2010.07.011

Somogyi Z, Cienciala E, Mäkipää R *et al*., 2007. Indirect methods of large-scale forest biomass estimation. *European Journal of Forest Research*, 126(2): 197–207. doi: 10.1007/ s10342-006-0125-7

Toriyama J, Kato T, Siregar C A *et al*., 2011. Comparison of depth- and mass-based approaches for estimating changes in forest soil carbon stocks: A case study in young plantations and secondary forests in West Java, Indonesia. *Forest Ecology and Management*, 262(9): 1659–1667. doi: 10.1016/ j.foreco. 2011.07.027

Verma A, Tewari A, Shah S, 2012. Carbon storage capacity of high altitude *Quercus semecarpifoilia*, forests of Central Himalayan region. *Scandinavian Journal of Forest Research*, 27(7): 609–618. doi: 10.1080/02827581.2012.689003

Wang B, Wei W J, Xing Z K *et al*., 2012. Biomass carbon pools of *Cunninghamia lanceolate* (Lamb.) Hook. Forests in subtropical China: Characteristics and potential. *Scandinavian Journal of Forest Research*, 27(6): 545–560. doi: 10.1080/ 02827581.2012.672585

Wang C K, 2006. Biomass allometric equations for 10 co-occuring tree species in Chinese temperate forests. *Forest Ecology and Management*, 222(1–3): 9–16. doi: 10.1016/j. foreco.2005.10.074

Wang C M, Ouyang H, Shao B *et al*., 2006. Soil carbon changes following afforestation with Olga Bay Larch (*Larix olgensis* Henry) in northeastern China. *Journal of Integrative Plant Biology*, 48(5): 503–512. doi: 10.1111/j.1744-7909.2006.00264.x

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(3–4): 1210–1218. doi: 10.1016/j.foreco.2007.10.026

Wang Q K, Wang S L, Zhang J W, 2009. Assessing the effects of vegetation types on carbon storage fifteen years after reforestation on a Chinese fir site. *Forest Ecology and Management*, 258(7): 1437–1441. doi: 10.1016/j.foreco.2009.06.050

Zhang Q Z, Wang C K, 2010. Carbon density and distribution of six Chinese temperate forests. *Science China* (*Life Sciences*), 53(7): 831–840. doi: 10.1007/s11427-010-4026-0

Zheng H, Ouyang Z Y, Xu W H *et al*., 2008. Variation of carbon storage by different reforestation types in the hilly red soil region of southern China. *Forest Ecology and Management*, 255(3–4): 1113–1121. doi: 10.1016/j.foreco.2007.10.015

Zhou Lei, Wang Shaoqiang, Kindermann Georg *et al*., 2013. Carbon dynamics in woody biomass of forest ecosystem in China with forest management practices under future climate change and rising CO_2 concentration. *Chinese Geographical Science*, 23(5): 519–536. doi: 10.1007/s11769-013-0622-9

Zhou Yurong, Yu Zhenliang, Zhao Shidong, 2000. Carbon storage and budget of major Chinese forest types. *Acta Phytoecologica Sinica*, 24(5): 518–522. (in Chinese)