

Research Article

Carbon Concentration Variability of *Larix olgensis* in North-Eastern China

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Abstract: In order to measure the carbon concentration in different organs of the *Larix olgensis* tree with different ages, eight trees of them, which have the age between 7.5 and 46 years, were measured with dry combustion method by using Vario EL III element analyzer. The errors in estimates of carbon stock were examined by using 0.5 while ignoring ages or intra-specific variations. The results show that: the weighted mean carbon concentration of *Larix olgensis* by biomass was approximately 48.15%. In this study, the carbon concentration of aboveground tree organs is ranked with descending order as living branch>bark>foliage>dead branch>stem; and in the belowground, it is ranked as large roots>stumps>thick roots>medium roots>small roots. The carbon concentration differs significantly between tree organs, while there is no significant difference between trees with different ages.

Keywords: Ages, Carbon (C) concentration, *Larix olgensis*, organs, variability

INTRODUCTION

The temperate forest in North-Eastern China accounts for more than one-third of Chinese forest resources (both by area and stocking volume) and plays a key role in the national and global C budgets and climatic system (Wang, 2006).

Biomass and C concentration are the two key factors in the study of forest C storage and C flux and how to measure and estimate them accurately is the base of regional and national C storage estimation (Ma *et al.*, 2002). Fifty percent in dry wood used to be a C concentration that was widely accepted as a constant factor for the conversion from biomass to C stock (Zhang *et al.*, 2008; Ma *et al.*, 2010; Zhang *et al.*, 2010; Ju *et al.*, 2011; Fang *et al.*, 2003). But with the development of research, it is an oversimplification of estimating C storage and C flux. Their liability of C allocation data in structural functional models can be improved by more accurate C content estimations.

There is no absence of studies on C in species. The research that of all possible sources of variation species was the most important in explaining variation in C concentration, suggest that a better knowledge of species-specific C concentration could reduce the error associated with estimates of C sequestration (Elias and Potvin, 2003), but there were no significant differences in %C content of trees across ecological regions or across tree social classes (Xing *et al.*, 2005). Failing to account for the inter- and intra-specific variations in C concentration will introduce a relative error of -6.7 to +7.2% in estimates of biomass C stock from inventory

data, of which >93% is attributed to ignoring the inter-specific variation in C concentration (Zhang *et al.*, 2009).

The higher C content in conifers agrees with their higher lignin content (~30, versus ~20% for hardwoods) (Lamlom and Savidge, 2003). C concentration was highly correlated with wood specific gravity (Elias and Potvin, 2003; Thomas and Malczewski, 2007). Wood-meal samples drilled from discrete early wood and late wood zones of seven of the forty-one species were also investigated contents of early woods were invariably higher than those in corresponding late woods (Lamlom and Savidge, 2003).

Compared oven-dried wood meal with wood meal dried at ambient temperature over a desiccant. C contents of oven-dried woods were significantly lower (Lamlom and Savidge, 2003). The volatile C fraction was non-negligible, averaging 2.2% and showed high variation among species (Thomas and Malczewski, 2007).

The C concentration varied largely between compartments and showed a quadratic relationship with relative height in the four stem compartments and in branches and buds. It showed a negative exponential relation with root diameter. The C concentration of needles was not related to their age or their relative height in the crown. C concentration variations were in accordance with the tissue chemical composition found in literature (Bert and Danjon, 2006). There was a significant difference between the C concentrations of the tree components, forest floor and understory

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Table 1: The site condition of different age samples

Age	Altitude (m)	Slop direction	Slop location	Grade	Soil type	Soil thickness (cm)
7.5	396	SW	Lower	9°	Dark brown	>50
11.5	266	SW	Lower	0°	Dark brown	>50
19	419	SW	Lower	6°	Dark brown	>50
23	418	SW	Lower	13°	Dark brown	>50
28	456	SW	Lower	6°	Dark brown	>50
33	423	SW	Lower	6°	Dark brown	>50
35	383	SW	Lower	13°	Dark brown	>50
46	466	SW	Lower	9°	Dark brown	>50

SW: Southwest

(Tolunay, 2009). Between and within compartment variations in C concentration should be considered in C content evaluations and in structural-functional models (Bert and Danjon, 2006).

From the result of research that three of the species sampled in plantations and natural forests, shows that the nature forest individuals had significantly higher C concentration (Elias and Potvin, 2003). Bert also found thinning practices and crown position did not greatly affect C partitioning and tree social class had a weak to non-existent effect on C content (Bert and Danjon, 2006). The study that difference in C content between clones was significant, suggests that the genetic improvement of C content by selection has a small effect on the genetic improvement of C sequestration capacity by selection in *L. kaempferi* (Fukatsu *et al.*, 2008).

For all previous measurements indicated that C concentration had significance various in different species, organs, treatment types, drying temperature, provenance (Natural or plantation), climate and so on. But there are a small number of researches on C concentration of tree components by age in China (Zhang *et al.*, 2009), even in the world.

An accurate estimate of C content is a key element in the life cycle assessment of products (Bert and Danjon, 2006). The Virgin Forests of China remain not much, most of them are the secondary forest or plantation which have been disturbed by human, at the same time, a forestation make sapling take up more than 50% of the China forest (Hang *et al.*, 2008).

Larix olgensis is an nation and one of dominate commercial tree species of china in the Northeast. In order to improve C stock and fluxion assessments, we have now studied the variations in the C concentration of *Larix olgensis* organs by with different ages and then we samples from aerial parts and belowground roots for elemental chemical analysis. The objectives of the research are: to explore the effect of organ and age on the carbon concentration.

MATERIALS AND METHODS

Site description: Our research area is located in the Dongzhelinghe forest center, which is in the east of Langxiang town, Yichun city, Heilongjiang province, rests between 128° 55' 30" and 129° 15' 21" E and 46°

31' 58" and 46° 49' 38" N. This region has a climate with of Temperate Continental Monsoon Climate; annual average temperature and rain fall are 0.36 °C and 618mm, respectively. The average altitude is 420m and average slope is between 6° and 13°. The soil is a dark brown forest soil and its thickness is greater than 50 cm (Table 1). *Larix olgensis* as an important planting species is the dominant species there. Other tree species in plantations are Keyco (*Ulmus davidianavar. japonica*), Manchurian ash (*Fraxinus mandshurica*), White birch (*Betula platyphylla* Suk.) and Macrophylla (*Maackia amurensis* Rupr. et Maxim), etc.

Eight sampling plots (0.06 ha² for each one) were set in typical *Larix olgensis* plantations, which were all experienced human management and natural thinning. Stand ages of the plantations ranged from 7.5 to 46 year including 4 growth stages as young, mid-aged, near mature and mature.

Sampling of tree: Origin data and samples were collected from July to August in 2009 and 2010, respectively. Measurements for every individual tree contained included Height (H), Diameter at Breast Height (DBH), crown width, first living branch height above ground, canopy density. Based on the collected data, average DBH and H were calculated, which helped us to selected a mean tree for each plot.

Measurements and data collection: After the tree fell down, stems were cut into 1m sections and weighed. At the top of each section, a disc about 2~3 cm was cut and weighted without bark, in the middle of each section, 10 cm bark was stripped from the stem and weighted (Wang, 2006). Positions, base diameter, length, status (i.e., live and dead) of branches in each section were recorded. Standard living or dead branches in each section were sampled and then divided living branches into branches and foliage included reproductive tissues (cone, acorn, nut, flower, etc.). Living branches, foliage and dead branches were weighted respectively. Root biomass sampling was performed concurrently with above-ground harvests. For each tree, separated roots into depths: 0-10, 10-20, 20-40, >40 cm and separated them into classes: fine roots (<2 mm), medium (2~20 mm), coarse roots (20~40 cm), large roots (>50 mm), stump. All samples were weighed, sub-sample and took back to lab for moisture content determination and C concentration.

Methods:

C concentration measured: The C concentration of each sample powder was measured in a gas chromatographic elemental analyzer (Vario EL III, Elementar, Hanau, Germany), (Lamlom and Savidge, 2006). For accurate estimates, we made our powdered samples size we used is no more than 0.3 mm (Lamlom and Savidge, 2003).

Error of C stock estimates: In order to accurately quantify in C stock estimates, we defined the relative error in estimates of biomass C stock in three ways (Zhang *et al.*, 2009):

$$E_a = \frac{(C_1 - C) \times 100}{C} \quad (1)$$

$$E_b = \frac{(C_2 - C) \times 100}{C} \quad (2)$$

$$E_c = \frac{(C_3 - C) \times 100}{C} \quad (3)$$

Here E_a , E_b , E_c stand for relative errors in biomass C estimates introduced by using 0.5 (generic C), ignoring the intra-specific variation in C, ignoring the age variation in C, respectively. C_1 , C_2 , C_3 , C stand for biomass C stock estimation in 0.5 (generic C), the C concentration in different tissues, in different ages and in different tissues and ages measured in this study, respectively.

Analysis methods: For C analysis, the Weighted Mean C Concentration (WMCC) was calculated as (Tolunay, 2009):

$$WMCC = \frac{\sum (B_i \times C_i)}{\sum B_i} \% \quad (4)$$

where,

B_i : The biomass of tree organs

C_i : The C concentration of tree organs

One Way ANOVA was used to test significant differences among tree components and at different ages. The statistical analyses were carried out using SPSS 16.0 statistical software.

RESULTS AND DISCUSSION

C concentration in the aboveground: The C concentration variation of the *Larix olgensis* organs in the aboveground with the different ages is presented in Fig. 1. According to the Fig. 1, the C concentration change trend of various organs is different. The maximum change is in the foliage, over the period 11 to 28 year it has a trend of increasing in the C concentration and there was a dramatic fall from 28 year, foliage C concentration ranged from 46.92 to 51.10%, the mean C concentration of foliage was 48.34%. Living branches C concentration ranged from 48.29 to 49.71% and was found to have the highest mean C concentration which was 48.88%. Dead branches C concentration ranged from 46.34 to 48.57% and the mean C concentration of dead branch was

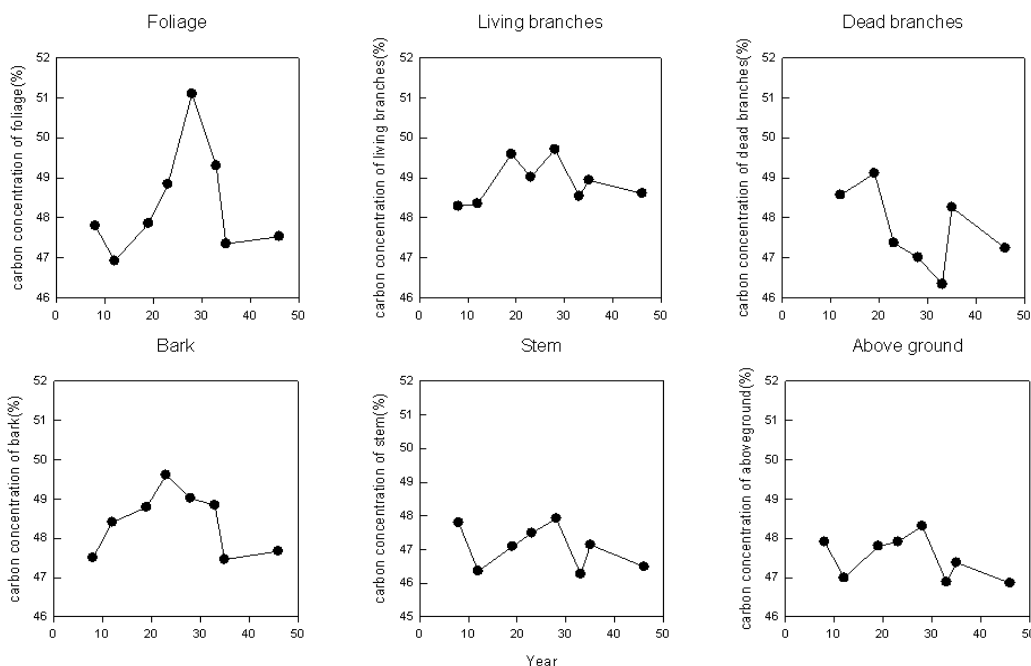


Fig. 1: The C concentration variation of the *Larix olgensis* organs in the aboveground (dead branches have not 7 year's value)

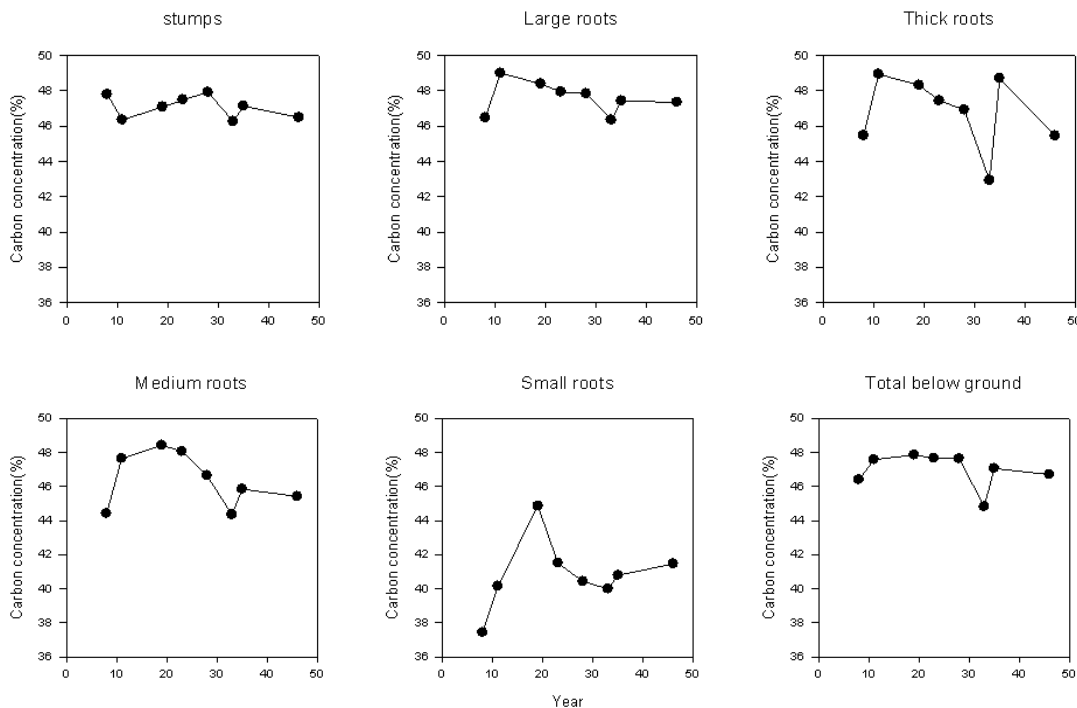


Fig. 2: The C concentration variation of the *Larix olgensis* organs in the belowground

47.49% without 7 years value. Bark C concentration ranged from 47.46 to 49.61%, except 7 years, all the values of bark C concentration were higher than that in the stem without bark, the mean C concentration of bark was 48.20%. The stem without bark C concentration ranged from 46.27 to 47.92%, the mean C concentration of stem without bark was 47.52%. We found that the variation of aboveground WMCC was similar to the C concentration in stem (Fig. 1), for the highest stem biomass allocation in the total tree.

C concentration in the belowground: The C concentration variation of the *Larix olgensis* organs in the belowground with the different ages is presented in Fig. 2. The value of the stumps C concentration is same as that in stems for the stump was part of the stems. According to the Fig. 2, the small roots C concentration had the biggest change between different ages and lower than that in other organs. Small roots C concentration ranged from 37.44 to 44.86% and the mean C concentration was 40.83%. We found that the C concentration of large roots, thick roots and medium roots have the similar change trend. There was an upwards trend from 7 to 11 years and a gradual reduction after 19 years. Yet a dramatic fall from 28 years in thick roots. At the 33 year, the C concentration reached a trough and then increased, after 35 year declined slightly. The mean C concentration of stumps, large roots, thick roots, medium roots and small roots were 47.07, 47.6, 46.77, 46.35 and 40.83%, respectively. The C concentration of tree organs in the

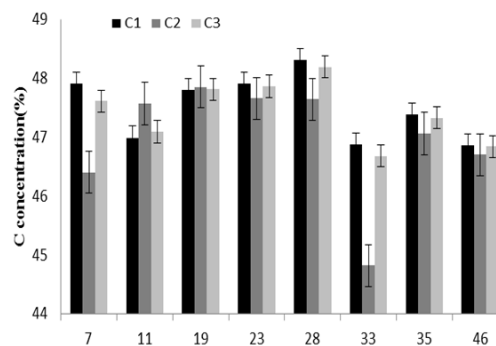


Fig. 3: Weighted Mean Carbon Concentration (WMCC) of *Larix olgensis* organs at different ages
C₁: Above WMCC; C₂: Below WMCC; C₃: Total WMCC; The error bars represent standard deviations

belowground was ranked in descending order as large roots>stumps>thick roots>medium roots>small roots.

Weighted mean C concentration: Figure 3 shows Weighted Mean Carbon concentration of *Larix olgensis* organs at different ages, the Above WMCC, Below WMCC and Total WMCC of *Larix olgensis* varied from 46.88-48.31%, 44.82-47.85% and 46.68-48.19%, respectively. There is no significant differences in WMCC between aboveground and belowground (the correlation coefficient is 0.524, Sig. = 0.000).

Relative error in biomass C estimates: In order to avoid the errors caused by biomass estimate, C estimates should use the sampling single biomass and,

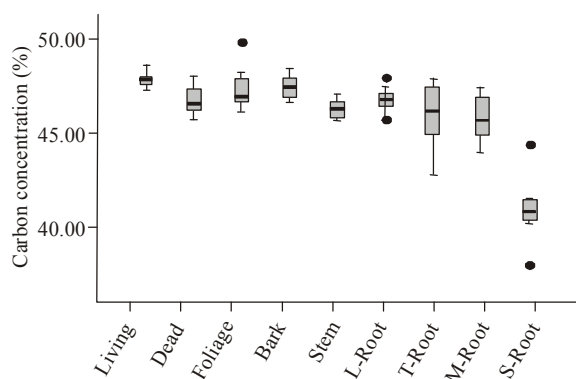


Fig. 4: C concentration of different organs of a *Larix olgensis* tree

The filled circles represent outliers; The vertical bars represent data ranges defined as 5*the inter-quartile range; the horizontal lines within the boxes represent median values; The upper and lower bounds of the boxes represent the 3rd and 1st quartiles, respectively; L-Root: Large root; T-Root: Thick root; M-Root: Medium root; S-Root: Small root

calculated the site conditions in similar circumstances, used by the formula (1) (2) (3), we found that E_c (ignore age) is 0.48%, E_b (ignore organ) is 2.97%, while the use of generally accepted 0.5, the estimation error E_a caused by as much as 10.07%.

C concentration variation among different parts of the tree: The mean weighed C concentration in living branches, dead branches, foliage, bark, stems and small root, medium root, thick root and large root for all sites are (\pm S.E.) 48.88 \pm 0.5, 47.7 \pm 1.0, 48.34 \pm 1.4, 48.41 \pm 0.8, 47.07 \pm 0.6, 40.83 \pm 2.1, 46.35 \pm 1.6, 46.77 \pm 2.1 and 47.60 \pm 0.9, respectively (Fig. 4). The highest C concentration was found in living branches, which is in accordance with the result of Tolunay (2009) and Li *et al.* (2010), while the lowest was found in small roots.

The C concentration differed significantly between *Larix olgensis* tree components (single-factor ANOVA: F9, 82 13.71, $p < 0.0001$, within group Degrees of Freedom (DF) = 82, Mean Square variance (MS) = 4.497 and between group DF = 9, MS = 61.653). The value of small root is far less than the other organs, probably because the error is caused by the sampling, on the other hand the small root is difficult to clean. In this study, the stem without bark C concentration ranged from 46.27 to 47.92%, less than previous studies (Qi *et al.*, 2011; Thomas and Malczewski, 2007), probably because we sampled stem without bark, in our study the C concentration in bark is larger than that in stem without bark, or dry the samples in 105° which was higher than kiln-dried, C concentration in kiln-dried conifers from 47.21 to 55.2% (Lamlom and Savidge, 2003), but our results is higher than 43.51% in the stem of Yu *et al.* (2012). In this study, the C

concentration of tree organs in the aboveground was ranked in descending order as living branch>bark>foliage>dead branch>stem, which is accordance with the previous results (Tolunay, 2009).

C concentration variation among different ages of the tree: Our finding revealed a range from 46.68 to 48.19% in the C concentration of *Larix olgensis* by ages. There was no statistically significant difference in C concentration depending on the age, (single-factor ANOVA: F10, 81 = 1.006, $p = 0.445 > 0.05$, within group Degrees of Freedom (DF) = 81, Mean Square variance (MS) = 10.142 and between group DF = 10, MS = 10.208) and the difference ignored ages caused by error is 0.48%. In this study, we found that there is no statistically significant difference in C concentration fitted to the *Larix olgensis*, a nation tree species. The influence of age on other species should be study in the future.

C concentration research is an important part of estimating C storage, a 1% difference in C concentration conceivably could have a significant impact on wood and pulp industries in relation to allocation of C credits within the Kyoto Protocol (Lamlom and Savidge, 2003). In our study, the estimation error caused by using the generally accepted 0.5 was as much as 10.07%. And for the different of geographical, tree species, regions and sites and so on, C concentration is different in different species and the different organs in the same species. Ignoring the difference will cause greater error. In forest ecosystem C reserves estimation However, there were few people pay attention to C concentration study, the conversion factor which we used to calculate C stock doesn't have unified standard and confusion. Therefore, we should pay more attention to C concentration study in the future for more accurately estimate of C stock.

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REFERENCES

- Bert, D. and F. Danjon, 2006. Carbon concentration variations in the roots, stem and crown of mature *Pinus pinaster* (Ait.). *Forest Ecol. Manage.*, 222: 279-295.
- Elias, M. and C. Potvin, 2003. Assessing inter- and intra-specific variation in trunk carbon concentration for 32 neotropical tree species. *Can. J. Forest Res.*, 33: 1039-1045.

- Fang, Y.T., J.M. Mo, S.L. Peng and D.J. Li, 2003. Role of forest succession on carbon sequestration of forest ecosystems in lower subtropical China. *Acta Ecol. Sinica*, 23: 1685-1694.
- Fukatsu, E., Y. Fukuda, M. Takahashi and R. Nakada, 2008. Clonal variation of carbon content in wood of *Larix kaempferi* (Japanese larch). *J. Wood Sci.*, 54: 247-251.
- Hang, Y., G.S. Zhou, J.S. Wu and X.D. Yan, 2008. Modeling Carbon Budgets of Terrestrial Ecosystems in China. Chapter 1, Science Press, China.
- Ju, W.Z., X.J. Wang and Y.J. Sun, 2011. Age struce effects on stand biomass and carbon storage distribution of *Larix olgensis* plantation. *Acta Ecol. Sinica*, 31: 1139-1148.
- Lamloom, S.H. and R.A. Savidge, 2003. A reassessment of carbon content in wood: variation within and between 41 North American species. *Biomass Bioenerg.*, 25: 381-388.
- Lamloom, H.S. and R.A. Savidge, 2006. Carbon content variation in boles of mature sugar maple and giant sequoia. *Tree Physiol.*, 26: 459-468.
- Li, X., M. Yi, Y. Son, P. Park, K. Lee, Y. Son, R. Kim and M. Jeong, 2010. Biomass and carbon storage in an age-sequence of Korean pine (*Pinus koraiensis*) plantation forests in central Korea. *J. Plant Biol.*, 54(1): 33-42.
- Ma, Q.Y., X.L. Chen, J. Wang, 2002. Carbon content rate in constructive species of main forest types in northern China. *J. Beijing Forest. Univ.*, 9(24): 5-6.
- Qi, G., Q.L. Wang, X.C. Wang, L. Qi, Q.W. Wang, Y.J. Ye and L.M. Dai, 2011. Vegetation carbon storage in *Larix gmelinii* plantation in great xing'an mountains. *Chinese J. Appl. Ecol.*, 22(2): 273-279.
- Thomas, S.C. and G. Malczewski, 2007. Wood carbon content of tree species in Eastern China: interspecific variability and the importance of the volatile fraction. *J. Environ. Manag.*, 85: 659-662.
- Tolunay, D., 2009. Carbon concentrations of tree components, forest floor and under storey in young *Pinus sylvestris* stands in north-western Turkey. *Scand. J. Forest Res.*, 24: 394-402.
- Wang, C., 2006. Biomass allometric equations for 10 co-occurring tree species in Chinese temperate forests. *Forest Ecol. Manag.*, 222: 9-16.
- Xing, Z.S., C.P.A. Bourque, D.E. Swift, C.W. Clowater, M. Krasowski and F.R. Meng, 2005. Carbon and biomass partitioning in balsam fir (*Abies balsamea*). *Tree Physiol.*, 25: 1207-1217.
- Yu, Y., W.Y. Fan, M.Z. Li, 2012. Forest carbon rates at different scales in northeast china forest area. *Chin. J. Appl. Ecol.*, 23: 341-346.
- Zhang, Q.Z., C.K. Wang, X.C. Wang and X.K. Quan, 2009. Carbon concentration variability of 10 Chinese temperate tree species. *Forest Ecol. Manag.*, 258: 722-727.
- Zhang, G.B., S.R. Liu, Y.D. Zhang, Z. Wang and N. Miao, 2008. Biomass carbon density of sub-alpine dark coniferous forest in the upper reaches of Minjiang River. *Sci. Silvae Sinicae*, 44: 1-6.
- Zhang, J., Y. Ge, B. Jiang, J. Chang, W. Yuan, J. Zhu and L. Qi, 2010. Carbon storage efficiency of *Cunninghamia lanceolata* ecological service forest in Zhejiang. *Sci. Silvae Sinicae*, 46: 22-26.