Forest Ecology and Management 400 (2017) 384–395

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Newly sequestrated soil organic carbon varies with soil depth and tree species in three forest plantations from northeastern China

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ARTICLE INFO

Article history:
Received 29 March 2017
Received in revised form 1 June 2017
Accepted 5 June 2017
Available online 20 June 2017

Keywords:
Soil organic carbon
Carbon sequestration
Soil depth
Tree species
Forestation
^{13}C isotopic tracing

ABSTRACT

To evaluate and improve the ecological benefit of forestation programs, post-forestation estimations of newly sequestrated soil organic carbon (SOC) are necessary. Here, we collected soil samples from three plantations in northeast China and used ^{13}C natural abundance to measure the amount of SOC sequestrated since 1998. Newly sequestrated SOC decreased with the increasing soil depth in the *Larix gmelinii* plantation, but increased with soil depth in the *Populus trichocarpa* plantation. In contrast, newly sequestrated SOC in the *Armeniaca sibirica* plantation peaked at a soil depth of 30–40 cm. With increasing distance from the tree trunk, average newly sequestrated SOC gradually decreased in the *L. gmelinii* plantation, did not vary in the *P. trichocarpa* plantation, and exhibited a gentle unimodal curve in the *A. sibirica* plantation. Overall, the average density of newly sequestrated SOC in the *L. gmelinii*, *P. trichocarpa*, and *A. sibirica* plantations at a soil depth of 0–50 cm was 0.60, 0.70, and 0.61 g cm^{-3}, respectively. Determination of $\delta^{15}N$ and the C/N ratio provided evidence to support the hypothesis that newly sequestrated SOC was primarily regulated by the root-microbial system. Soil depth and tree species should be taken into account when estimating soil carbon sequestration in future studies.

1. Introduction

Recent trends in global warming has generated heightened interest in understanding and increasing carbon sinks, with considerable attention paid to plantation forests as an environmentally friendly way of absorbing CO_2 and beginning ecological restoration (Pan et al., 2011). Currently, China has the largest plantation area in the world, and planted forests are demonstrable carbon sinks, sequestrating 818 Tg C in biomass (Guo et al., 2013). However, most studies evaluating climate-change impact on forest C balance emphasize trees rather than soil (Callesen et al., 2016), despite the latter containing more C than the former (34 Pg versus 7 Pg: Xie et al., 2007; Guo et al., 2013). Indeed, soil organic carbon (SOC) is the world's largest pool of terrestrial C (Scharlemann et al., 2014). In China alone, SOC at 100 cm soil depth is estimated to be 88.5 Pg (Zhou et al., 2016). Due to the relative lack of attention, accurate assessments of SOC sequestration in forests are difficult (Noormets et al., 2015). Estimates of forest SOC fluctuations in China differ considerably across studies (Huang et al., 2010), likely due to the reasons i.e. different management practices applied in different plantations, spatial heterogeneity across sites and variation in time scale (Noormets et al., 2015; Vanguelova et al., 2016). As a result, there remains substantial debate over the nature of SOC changes following forestation (Huang et al., 2012). Some studies of afforested farmland demonstrated that SOC does not change significantly within 10 years post-afforestation (e.g., De Gryze et al., 2004; Li et al., 2005; Arevalo et al., 2009), but significantly increases afterwards (e.g., Martens et al., 2004; Morris et al., 2007; Lemma et al., 2007). However, research in India and southeast China reported a significant SOC increase after only one year of afforestation (Gupta et al., 2009; Lunstrum and Chen, 2014). Still other studies showed that SOC continues to decrease even 30 years post-afforestation (Laganiere et al., 2010), or decreases at the beginning before increasing after 5 years (Zhang et al., 2010). On the other hand, the effect of stand age on the SOC stock varied among different plantations with different management practices application. For example, in the Lei bamboo plantation, the SOC stock increased as the duration under intensive management (including mulching practice) increased (Li et al., 2010), while in the Moso bamboo plantation, the SOC stock decreased as the duration under intensive management (excluding mulching practice) increased (Li et al., 2013).

To improve the accuracy of SOC measurements and thereby address the inconsistencies in existing research, isotope tracer techniques can be used to distinguish between C pools and

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http://dx.doi.org/10.1016/j.foreco.2017.06.012
0378-1127/

determine their contribution to SOC (Pausch and Kuzyakov, 2012). These techniques take advantage of the shifting isotopic composition in C pools as vegetation changes from C_4 to C_3 plants, or from to C_3 to C_4 (Farquhar et al., 1989). Due to their separate photosynthetic pathways, C_3 and C_4 plants exhibit different isotopic ^{13}C fractionation during carbon assimilation and therefore distinct isotopic compositions (Farquhar et al., 1989). These differences allow us to differentiate between older and younger C pools in regions where C_3 plants have replaced C_4 plants or vice versa (Pausch and Kuzyakov, 2012). Furthermore, the younger C pool should reflect SOC sequestration after the vegetation change (i.e., forestation).

The numerous afforested regions in China are ideal for the study of newly sequestrated SOC following forestation. Since the 1980s, the Chinese government has launched several major ecological engineering programs to address widespread environmental degradation. Among them, the Sloping Cropland Conversion Program had afforested 1.47×10^7 ha of abandoned farmland and 1.73×10^7 ha of wasteland (Zheng et al., 2016). However, the knowledge about newly sequestrated SOC under forestation in these regions is scare, including how it may be affected by basic properties such as soil depth and tree species (Huang et al., 2012; Vesterdal et al., 2013; Han et al., 2016). Therefore, natural

Table 1
The main properties of the experimental plantations.

Species	Tree height (m)	Diameter of breast height (cm)	Soil bulk density (g cm^{-3})	Surface soil carbon content (%)	Surface soil nitrogen content (%)	Surface soil C/N	Surface soil $\delta^{15}N$ (‰)	Surface soil $\delta^{13}C$ (‰)	Root $\delta^{13}C$ (‰)	Fractionation between root and SOC (‰)
Larix gmelinii (Rupr.) Kuzen	6.4	6.1	1.50	1.20	0.14	8.70	2.66	−24.26	−26.34	−2.08
Populus trichocarpa L.	10.5	10.5	1.44	1.21	0.13	8.88	3.19	−24.40	−26.41	−2.02
Armeniaca sibirica L.	–	–	1.46	1.05	0.14	7.99	0.74	−25.36	−26.37	−1.02

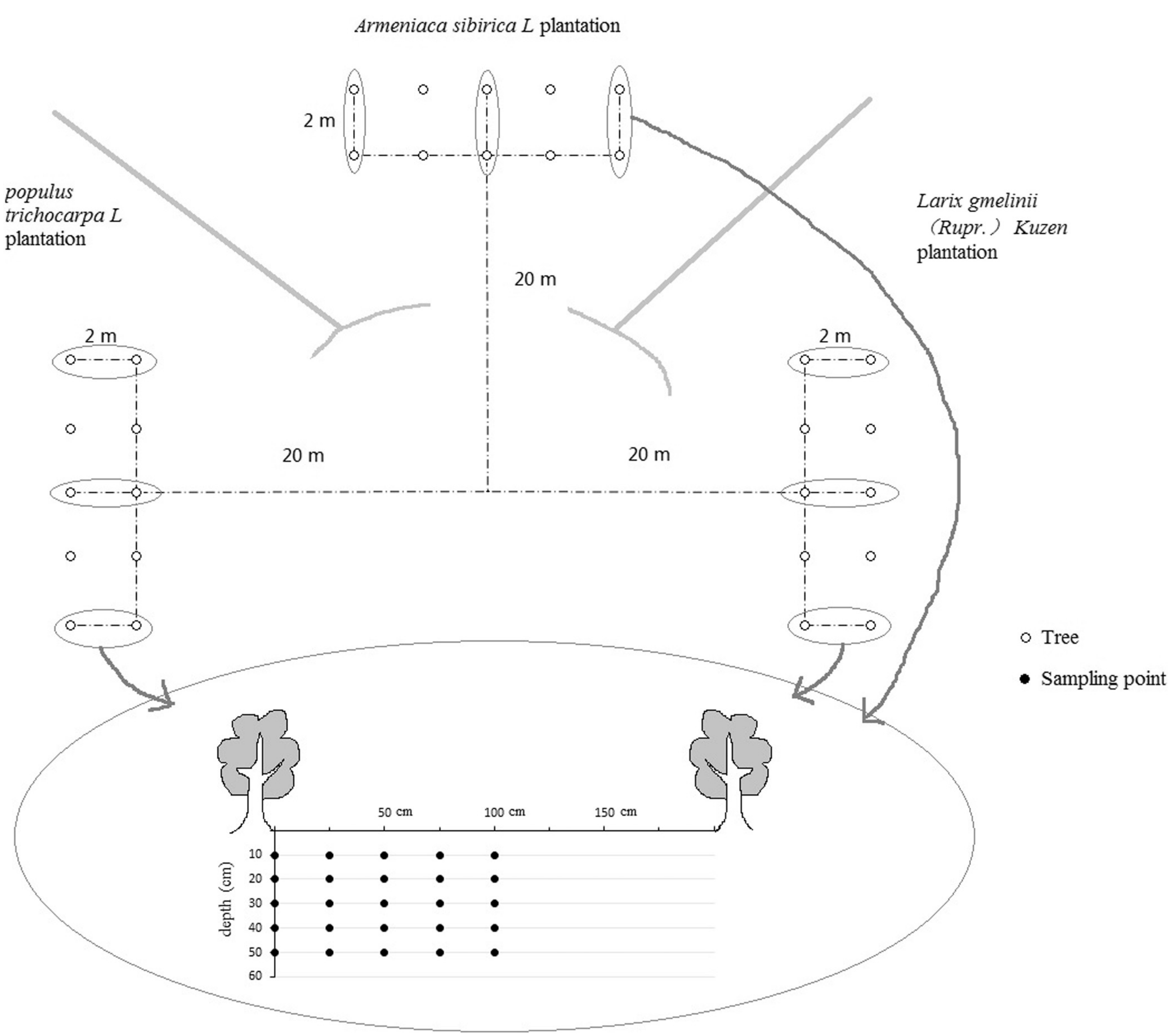

Fig. 1. Sketch map of sampling sites.