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Carbon content of below–ground biomass of young Scots pines in Latvia

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Abstract. Forest ecosystems play crucial role in global carbon cycling, therefore, increasing afforestation of agricultural land in Europe has been recognized as important contribution of carbon sequestration. In carbon reporting systems, root carbon content (CC) default value has been set to 50%. The study aimed to estimate CC in below–ground biomass and in relation to tree age in young Scots pine stands on forest and former agricultural land. The below–ground CC of young (8 to 40 years) managed Scots pine (*Pinus sylvestris* L.) stands growing on nutrient poor mineral soils in Latvia was carried out. In total 62 sample trees (43 in forest land, 19 in former agricultural land) were randomly selected for destructive sampling to estimate the CC within below–ground biomass. Below–ground biomass weighted mean CC was 49.7 ± 0.4%, being slightly lower than the default CC value used to calculate carbon budgets. Root fractions stump, small roots (diameter 2–20 mm), coarse roots (diameter > 20 mm)) differed ($p < 0.001$) in their CC. Stumps (50.6 ± 0.6%) had highest ($p < 0.001$) CC in the below–ground biomass, followed by coarse (49.5 ± 0.4%) and small (49.1 ± 0.4%) roots, which did not differ from each other in their CC. Results demonstrated age–dependent increase of CC ($p < 0.001$) from 48.2 ± 0.3% to 51.7 ± 0.5%, indicating overestimation of the default value during the first two decades, but underestimation for older trees (24 to 40 years).

Key words: root biomass, coarse roots, stump, abandoned agricultural land.

INTRODUCTION

Forest ecosystems contain the majority of the carbon (C) pool on the Earth and play crucial role in global C cycling both as C sink and source (Dixon et al., 1994; Uri et al., 2012). Increasing afforestation of former agricultural land in Europe also has been seen as important contribution for C sequestration in future (Paul et al., 2002; Vesterdal et al., 2002). Both above– and below–ground biomass is an essential C pool of forest ecosystems (Helmisaari et al., 2002; Karsenty et al., 2003; Tang et al., 2015), however, the uncertainties in below–ground biomass C estimation remains (Varik et al., 2013; Addo–Danso et al., 2016). The importance of below–ground C pool inclusion in total C estimation is recognised thought the Kyoto protocol and Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCC) (Petersson et al., 2012; Merilä et al., 2014). In accordance to both international agreements, member states are required to monitor, report, and reduce greenhouse gas

(GHG) emissions (Frederici et al., 2008) to achieve ambitious climate goals worldwide (Rogelj et al., 2016).

In national and international GHG reporting systems for C stock estimates, the mean carbon content (CC) of tree roots is set 50% of the dry biomass (Lamlom & Savidge, 2003; Martin & Thomas, 2011). This default value is widely used for CC calculations in different forest zones (Saatchi et al., 2011) and in various forest management systems as managed forests, plantations and agro–forestry. However, this approach can lead to an accounting error of approximately 5% (Martin & Thomas, 2011). Partly due to methodological challenges (Finér et al., 2011), the accurate C estimation in forest below–ground biomass and its potential to mitigate global climate change in Europe are not always clearly defined (Addo–Danso et al., 2016; Sochacki et al., 2017). Efforts reducing uncertainty in the below–ground biomass studies on GHG attraction and C turnover cycle in the forest ecosystem recently have grown (Liski et al., 2003; Thomas & Martin, 2012; Sochacki et al., 2017).

Forest sector has high importance in Baltic States. Nearly half of the territory of Baltic States are covered by forests (Eurostat, 2016). According to the Latvian State Forest Service, forests cover 52% of the total land area. The forest area has almost doubled from 1935 till 2015, mostly due overgrowth of agricultural land (Nikodemus et al., 2005). Scots pine (*Pinus sylvestris* L.) is the most common and economically important in Latvia, occupying 34% of the total forest area, of which nearly half are located on dry mineral soils (Baumanis et al., 2014). Despite the intensive forest management practices in region, studies of C accumulation in tree root biomass and their role in C budgets of forests in this region have been scarce.

Carbon sequestration and amount of root biomass in forest are dependent on tree species, site types, soil properties, environmental factors and forest management practices (Haynes & Gower, 1995; Gill & Jackson, 2000; Pregitzer et al., 2000; Brassard et al., 2011). Moreover, previous studies suggest that CC in below–ground biomass has been strongly influenced by the stand age (Peichl et al., 2006; Jain et al., 2010; Uri et al., 2012; Bijak et al., 2013). With the increase of forest harvesting in Europe for the substitution of fossil fuels in energy production (Levers et al., 2014; Merilä et al., 2014), due to slow decomposition and life–cycle features, roots and stump may play essential role for long term C input in soil (Bardgett et al., 2014; Kaarakka et al., 2016). Therefore, due to changes in forest age–structure, it is crucial to understand the contribution of young tree root biomass growth to C fluxes in forest and woodland (Pajtík et al., 2008; Finér et al., 2011; Fonseca et al., 2011).

The aim of this study was to estimate CC in below–ground biomass and in relation to tree age in young Scots pine stands on forest and former agricultural land (FAL).

MATERIALS AND METHODS

Site characteristics

The study was carried out in young Scots pine stands in Latvia (Table 1). Latvia is located in the north–western edge of the East European Plain within hemiboreal forest zone with mixed broad–leaved and coniferous forests (Ahti et al., 1968; Hytteborn, 2005). The climate of Latvia is moderate. According to data from the Latvia Environment, Geology and Meteorology Agency, mean annual temperature is around 6 °C. January is the coldest month with mean temperature –5.3 °C, but warmest month is July when mean temperature is 17.2 °C. The mean annual precipitation is 645 mm, though half of annual precipitation is recorded during summer period May–September.

Table 1. Characteristics of Scots pine experimental stands

Land type	Stand location	N	Stand age	Tree height (m)	dbh (cm)	Tree below–ground dry–mass (kg)	Basal area (m^2 ha^{-1})	Stand density (trees ha^{-1})
Forest land	56°50 N 24°38 E	5	8	2.7	2.4	0.7	2.3	3,600
	56°50 N 24°38 E	7	8	2.4	2.2	1.0	4.6	8,800
	56°34 N 25°01 E	3	12	4.0	6.6	7.5	7.3	2,145
	56°24 N 25°01 E	6	13	4.6	5.2	4.1	4.8	2,215
	56°51 N 24°35 E	6	14	4.8	5.3	4.8	7.2	3,200
	56°41 N 24°27 E	10	24	10.0	11.0	17.4	13.2	1,385
	56°43 N 24°34 E	3	40	17.7	18.8	38.9	18.0	583
	56°43 N 24°34 E	3	40	17.1	18.6	41.6	16.2	570
FAL	56°34 N 24°08 E	5	12	7.7	11.2	14.7	21.1	2,145
	56°32 N 24°04 E	5	14	8.2	10.3	21.8	24.3	2,925
	56°41 N 26°01 E	3	38	17.3	14.4	19.6	28.9	1,680
	56°41 N 26°09 E	6	38	17.0	14.4	19.3	18.6	1,260

FAL – former agricultural land; N – number of sampled trees; dbh – tree diameter at breast height.

All sampled stands were on dry sandy nutrient poor mineral soils, representing typical Scots pine forest growth conditions in Latvia. The study material was collected in 8 Scots pine stands on forest land and 4 stands on FAL at the age of 8 to 40 years. Except one naturally regenerated 8 years old Scots pine stand, all studied stands was planted after soil preparation with 2 years–old bare–rooted or containerised seedlings.

One circular sample plot was established in each stand: in stands younger than 15 years the area of sample plot was 100 m^2 (R = 5.64 m), in older – 500 m^2 (R = 12.62 m). In each plot tree diameter at breast height (dbh) (± 0.1 cm), tree height (h) (± 0.1 m) and age was measured.

Sampling

In total 62 sample trees (43 in forest land, 19 in FAL) were randomly selected for destructive sampling of the root biomass to estimate the CC allocation in root fractions (Table 1). The sample trees, 3–10 trees per plot, were selected based on quality criteria (health, vitality, single tree top) from different size classes. Samples were collected during the vegetation period from June to August. The dbh and h of sample trees ranged from 1.2 to 26.5 cm and 1.9 to 20.8 m, respectively on forest land. In FAL at age of 12 to 38 years the dbh and h corresponding figures were 3.7 to 26.0 cm and 5.9 to 20.8 m (Fig. 1).

Figure 1. Tree diameter at breast height and height of the sample trees.

For CC analysis, the sample tree root biomass was divided into fractions: small roots (diameter 2–20 mm), coarse roots (diameter > 20 mm) (Fujii & Kasuya, 2008; Finér et al., 2011) and stump. Stump biomass included both the above–ground (5–8 cm above the root collar) and below–ground monolithic part.

The stumps and roots were excavated and washed using high pressure water jet. The entire root system was weighted (± 0.02 kg), divided into fractions and each root fraction was weighted (± 0.02 kg). CC analysis were performed for small roots, coarse roots and stump samples. For 16 sample trees (12 trees at age of 8 years and 4 trees at the age of 14 years) coarse roots were not detected, suggesting that coarse roots are developed later. All root components were dried to constant mass at 105 °C temperature and weighted. The mean total below–ground biomass of the sampled trees varied between 0.1 and 155.3 kg with an average of 17.1 kg on forest land. The mean total below–ground biomass of the sampled trees on FAL was 27.3 kg and ranged from 1.3 to 104.2 kg. For CC analysis of individual tree, small roots and coarse roots were divided on 3 diameter classes. In each diameter class, from randomly selected roots on average 2 cm long cuts of boths ends and centre of the root were collected in one homoginised sample (150–200 g) for each root fraction. Whole stump (if it was less than 200 g) or two 2 cm samples from the radial cut zone were obtained. Air–dried samples were milled and 0.25–0.50 g samples for carbon determination were taken.

Data analysis

Carbon content was analysed with an LECO CR–12 Carbon analyser set at 900 °C and the CC was assessed directly by measurement of the CO_2 using infrared radiation (LECO Corporation, 1987). The instrument was calibrated using calibration substance – carbon powder containing 64.8% C and an empty test without a sample was performed.

The mean CC of sample tree below–ground biomass was calculated as weighted average of total CC.

All statistical analyses were performed using R v.3.3.1 statistical environment (R Core Team, 2016). Analysis of covariance ANCOVA was used for estimating the effect of the land type and different root fractions on the root CC. Stand age was added as a numeric covariate in analyses (Peichl & Arain, 2006; Seedre et al., 2015). The Turkey Honest Significant difference (HSD) test was employed to perform multiple post hoc comparisons between CC for different root fractions.

RESULTS AND DISCUSSION

Below–ground biomass CC was compared in each root fraction among and within forest land and FAL (Fig. 2). Mean CC of below–ground parts of young Scots pine trees was 49.7 ± 0.4%. In forest land and FAL the mean below–ground CC was 49.4 ± 0.4% and 50.4 ± 0.7%, respectively. The observed mean root CC of young Scots pine showed slight differences (0.3%) from generally accepted CC of 50%, as shown for other conifers (Ritson & Sochacki 2003, Thomas & Martin, 2012). Such differences have been related to ecological factors (e.g. stand density, tree dimensions, forest type) effecting the assimilation of C as well as sampling methodology of studies (Vucetich et al., 2000; Lamlom & Savidge, 2003; Jain et al., 2010, Thomas & Martin, 2012).

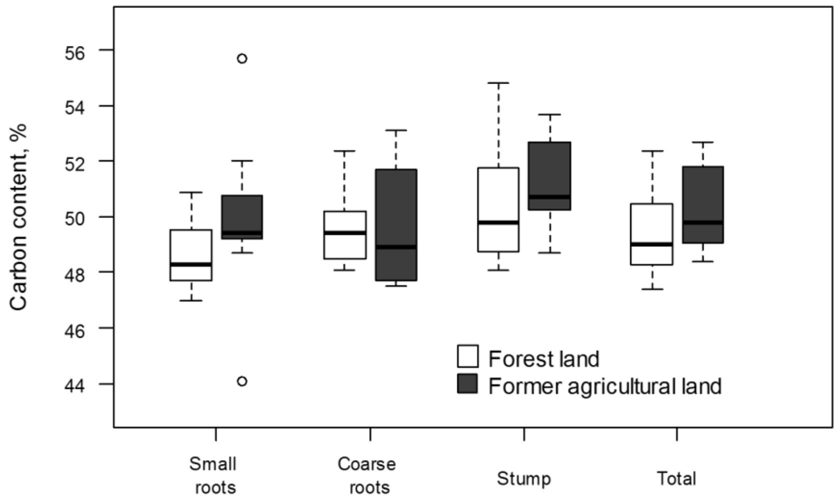

Figure 2. Carbon content in different root fractions in afforested former agricultural land and forest land. Total is carbon content of weighted means based on the weights of different components (stumps, small roots, coarse roots). Line shows the median of dataset, box represents 1st and 3rd quartile, whiskers mark range (not exceeding 150% of interquartile distance) and circles indicate outliers of the datasets.

The observed difference in the mean CC between land types was non–significant ($p > 0.05$) (Table 2), however, higher variations of CC at the individual tree level were observed in FAL (Fig. 2) likely due to physical and biological features, such as content of lignin, different age and composition of root fraction (Lamlom & Savidge, 2003; Peichl & Arain, 2006; Bennett et al., 2014; Seedre et al., 2015).

Table 2. The effect of root component and growing conditions on CC in roots according to the results of ANCOVA; the age of the stand have been added as covariate in analysis

Model Anova (Type II test)					
	Variable	Sum of Square	Degree of freedom	F value	*p*–value
	Root fraction	93.91	2	45.389	< 0.001
	Land type	1.85	1	1.789	0.183
	Age	269.55	1	260.549	< 0.001
	$R^2 = 0.69$ (Adjusted R^2=0.68)				
Multiple Comparisons of Means of Tukey HSD Test					
	Root fraction	Difference	Standard Error	*t*–value	*p*–value
	Coarse roots – Stump	–1.51	0.20	–7.566	< 0.001
	Small roots – Stump	–1.57	0.18	–8.608	< 0.001
	Small roots – Coarse roots	–0.06	0.20	–0.302	0.951

Root fraction differed in their CC (Table 2). The CC were estimated to be 49.5 ± 0.4% and 49.1 ± 0.4% in the coarse roots and small roots, but there were not statistically significant ($p > 0.05$) difference observed between both root fractions. The CC of both root fractions is also comparable to earlier study (cf. Janssens et al., 1999; Bert & Danjon, 2006). Stumps had significantly ($p < 0.001$) higher CC (50.6 ± 0.6%), that might be explained by the differences in length of the life cycle of different root fractions (Palviainen et al., 2010; Uri et al., 2012), hence lignification of tissues (Bert & Danjon, 2006).

At the age from 8 to 40 years, mean below–ground biomass CC increased significantly ($p < 0.001$) from 48.2 ± 0.3% to 51.7 ± 0.5%, approving our hypothesis that CC is age dependent, as it has been previously observed for other *Pinus* species by Ritson & Sochacki (2003), Peichl &Arain (2006,) Jain et al. (2010). Steeper increase of mean below–ground CC was observed for younger trees, reaching 50.6 ± 0.3% at the age of 24 years (Fig. 3).

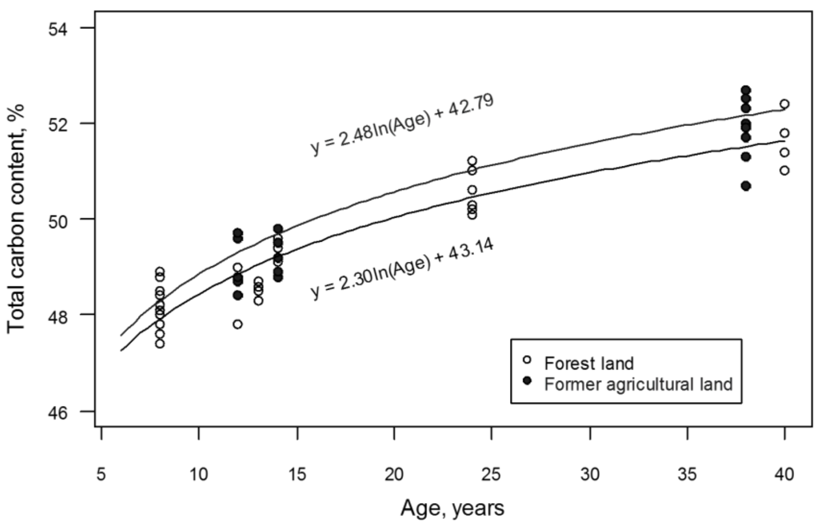

Figure 3. Effect of stand age on the total root CC on forest land and former agricultural land.

The age–dependent increase of root CC followed logarithmic curve (Fig. 3), indicating overestimation of the default value during the first two decades of tree life, but underestimated CC at older age 24 years). Considering that, the below–ground biomass CC could be determined as a function of stand age to improve C estimation within reporting systems for climate change mitigation (Bert & Danjon, 2003; Lamlom & Savidge, 2003). Further studies shall address older trees and other tree species in order to improve overall accuracy of below–ground C assessment.

CONCLUSIONS

Below–ground CC was age dependent, but was not affected by land type. More accurate below-ground biomass CC values for young trees had been established.

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