

Assessment of Carbon Content in Root Biomass in Scots Pine and Silver Birch Young Stands of Latvia

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Abstract

The Scots pine and silver birch young stands (under 40 years of age) were selected in Central Latvian Lowland in the forest land as well as in afforested agricultural land. Sample trees were selected and the root system was excavated in order to collect empirical material. For the study of carbon (C) content, the root biomass of the selected sample trees was divided in four fractions: coarse roots; small roots, fine roots and stump. The average content of carbon in the root biomass of Scots pine and silver birch differed within ~2.5%. The average content of carbon in Scots pine root biomass in forest land was $48.9 \pm 0.1\%$ and in afforested abandoned agricultural land it was $49.5 \pm 0.1\%$. For birch stands in afforested abandoned agricultural land it was $47.3 \pm 0.1\%$. Statistically the average carbon content in root biomass was essentially different among species, land use, different root fractions and age of stands (multifactor variance analysis, $p < 0.05$). The changes in C content for a single species in different root fractions (stump, coarse roots and small roots) can be attained to the rootwood density characterised by close negative correlation between the wood density and C content in the root biomass. The content of C in root biomass fractions is higher for sample trees with larger diameter dimensions, $r = 0.82$ ($\alpha = 0.05$).

Key words: carbon content, *Pinus sylvestris*, *Betula pendula*, forest land, abandoned agricultural land, coarse roots, small roots, fine roots, stump.

Introduction

The main mechanism ensuring the influence of greenhouse effect gases in the forest land is the process of photosynthesis – sunlight affects the CO₂ present in the air, which then accumulates CO₂ in organic compounds in plant biomass (Kluwer Academics 2004, Fonseca et al. 2011). The method for establishing the amount of carbon (C) is based on the conclusion that the C content is proportional to the amount of biomass (Pettersen 1984). Therefore, it is essential to calculate the biomass of stand primarily. It means that these calculations are based on the summary equation of the given tree species photosynthesis, which allows the calculation of the accumulated biomass and its growth in CO₂ and C mass (Pettersen 1984, Christensen and Goudriaan 1993, Brown 1997, FAO 2001, Liepa 2005).

When the wood is being burned, as well as when organic compounds are decomposing, C is drawn out and it enters the atmosphere in the form of CO₂. The larger is the amount of greenhouse-effect-causing gases entering the atmosphere the warmer the climate of the Earth is getting (Jain et al. 2010). Different fractions of the tree (leaves, roots, seeds, branches, bark and CO₂) is the biggest and most dynamic component of the greenhouse effect gases (GHG) in the atmosphere of this planet. Recent studies show a rapid growth of CO₂ content over the last centuries. This tendency has a tight correlation to the warming of the planet and the

frequency and intensity of different natural excesses, as well with other important phenomena (NASA 2001).

Natural variation can be observed in carbon content in wood, but it is indicated in scientific research works that smaller trees have lower content of lignin, which has an essential effect on C accumulation (Sean and Adam 2012), and, respectively, after establishing the average wood humidity, and the values of the aboveground and root biomass ratios, the amount of C accumulated in forest land can be calculated. By establishing such connection, it would be possible to calculate the C accumulation amounts in forest lands in practice, by using simply definable taxation values.

Information on C accumulation in forest ecosystem, including the aboveground and root biomass of woody plant, allows understanding the C accumulation and cycle in the forest. Precise knowledge of the wood carbon content is needed to evaluate the carbon reserves in the forest biomass (Sean and Adam 2012). When calculating the C content in the wood of different species and forest types, it is important to understand the C accumulation and storage potential (Lamlom and Savidge 2003). Research indicates that there are major differences in C content between different species, which significantly affects the C accumulation calculations (Elias and Potvin 2003, Lamlon and Savidge 2003). In most cases on a local, regional and global level it is assumed that the C content is 50% of the tree biomass (Sean and Adam 2012). This value is widely used in C calculations

in natural tropical (Saatchi et al. 2011) and temperate forests (Kauppi et al. 1995, Fang et al. 2011), as well as in managed forests (Blanc et al. 2009), tree plantations (Beets et al. 2011) and agro-forestry (Soto-Pinto et al. 2010). Nevertheless, the data from latest research show, which assuming the average wood C content as 50%, there is an error of approximately 5% (Thomas and Malczewski 2007, Martin and Thomas 2011, Melson et al. 2011) in C accumulation in the forest. That is why new methods and knowledge are required to evaluate the changes in the amount of accumulated C in the forest ecosystems (Brunner and Godbold 2007).

The Kyoto Protocol plays a major role in the context of forestry as a factor of climate change mitigation (Bert and Danjon 2006) stating that the countries shall reduce the amount of greenhouse effect causing gas emissions that has been agreed by the countries on accepting the strategy. This strategy calls for development of specific activities for carbon absorption, including afforestation and forest renewal activities. Therefore, the climate changes and increasing amount of CO₂ emissions in the atmosphere have caused global scale interest in the studies on CO₂ attraction including the possibilities of increasing C accumulation, where wood biomass and soil are of great importance (Parresol 1999, Dieter and Elsasser 2002, Porte et al. 2002, Liski et al. 2003, Brunner and Godbold 2007).

The analysis of information on C accumulation shows that forest ecosystems perform an important function in C cycle. Forests are C absorptive ecosystems (Schimel et al. 2001, FAO 2005) ensuring the accumulation of C and at the same time producing renewable and environmentally friendly raw materials for the power industry and other sectors. Only in the European temperate climate zone, on average, 110 t ha⁻¹ C is accumulated in the biomass produced by forests, and approximately 27 t ha⁻¹ of which is accumulated by root biomass (Perruchoud et al. 1999). In accordance with the statistical Forest inventory data, forests cover 3,221 thousand ha or 50.9% of the territory of Latvia and is a significant storage of carbon. After establishing the average humidity of wood, aboveground and root biomass ratio

values, the amount of attracted carbon in forest stands can be calculated. At the moment, Latvia lacks data on carbon circulation and accumulation, especially in root biomass in forest stands and naturally afforested or planted forest stands in abandoned agricultural land. The information on C accumulation in forest ecosystems, including tree root biomass, provides understanding of C accumulation and circulation cycle in the forests. In order to answer the question on the amount of carbon being attracted in pine root biomass, particularly in the recent years, when there has been a significant growth in forest regeneration and propagation activities, the aim of the research was to study the content of carbon in root biomass in Scots pine and birch young stands.

Materials and Methods

For this research the *Pinus sylvestris* L. and *Betula pendula* Roth. young stands of different density and age were selected in the forest land and abandoned agricultural land in Central Latvia Lowland (Table 1). The stands selected for this research are under 40 years of age. The empirical material for the research was collected during the vegetation period (from June to August) in the years 2009 to 2013. The average parameters and characteristics for the selected stands are given in Table 1.

The taxation methods for the aboveground part of the stand are based on the dendrometrical measurements, which were carried out by constructing round experimental fields with horizontal radius of 5.64 m in stands of under 15 years of age, and with radius of 12.62 m in stands over 15 years of age. All types of tree measurements were carried out in the experimental fields – tree records, measurements of diameter at the height of 1.3 m, height, as well as the age of tree.

73 sample trees in the experimental fields had their root system excavated to establish the C content and analysis. Only healthy and vital sample trees with a single top were used in this research. The sample trees selected for the research for establishing C content in their root biomass had

Tree species	Stand age	Stand location		Tree height (m)	DBH (cm)	Basal area (m ² ha ⁻¹)	Number of sample trees	Density (tree ha ⁻¹)	Land use	Forest type
		North	East							
P	8	50°50.58	24°38.21	2.6	2.0	2.1	12	6200	F	Ln
P	12	56°34.58	25°01.21	4.0	6.6	7.3	4	2145	F	Sl
P	13	56°24.58	25°11.21	4.6	5.2	4.8	6	2215	F	Sl
P	14	56°51.34	24°35.01	4.8	5.3	7.2	6	3200	F	Ln
P	24	56°41.00	24°27.43	10.0	11.0	13.2	10	1385	F	Mr
P	40	56°43.00	24°34.62	17.5	19.5	17.1	6	575	F	Sl
P	12	56°34.21	24°08.87	7.7	11.2	21.1	5	2145	AAL	-
P	14	56°32.98	24°04.16	8.2	10.3	24.3	5	2925	AAL	-
P	38	56°41.25	26°01.17	17.3	14.3	23.8	9	1470	AAL	-
B	13	56°45.59	24°48.19	8.5	10.3	13.3	6	1600	AAL	-
B	40	57°53.25	24°74.31	25.8	27.1	21.2	4	255	AAL	-

DBH = diameter at breast (1.3 metre) height; Ln = *Myrtillus*; Sl = *Cladinosa-callunosa*; Mr = *Vacciniosa*; P = *Pinus sylvestris* L.; B = *Betula pendula* Roth.; AAL = abandoned agricultural land

Table 1. Characteristics of Scots pine and silver birch experimental plantations

their root system divided in three fractions: coarse roots – $\varnothing > 20$ mm; small roots – $\varnothing 2-20$ mm and stump.

The samples used for estimating carbon content in fine root ($\varnothing < 2$ mm) biomass were taken with core sample method (*Eijkelkamp* 100 cm³ cylinder). Soil samples were taken 20 times in each experimental field in the depth of 0–10, 10–20, 20–30, 30–40, 40–50 and 50–60 cm. The fine roots samples were washed in laboratory conditions, separating soil particles from the fine roots. The fine roots were carefully separated from small roots and roots of other plants.

For estimating the total content of C the carbon analyser *LECO CR-12* was used, the construction of which consists of burning cameras (measurement and reference cameras). The method is based on CO₂ detection with infrared radiation (*LECO Corporation* 1987). Before initiating analysis the carbon analyser *LECO CR-12* was calibrated with a standard calibration substance – carbon powder containing 64.8% C and an empty test without a sample was performed.

To estimate the density of root fractions a method was used that estimates specific weight of mass and volume of root wood with bark. The volume is measured by placing a specific root fraction in a container filled with water. The volume of the root is equivalent to the amount of extracted water.

Results

This research tested if the carbon content corresponds to the regular division, by using the Kolmogorov-Smirnov test. It was shown that the average C content in root biomass corresponds to the regular division for Scots pine sample trees in the forest land, as well as for Scots pine and birch sample trees in abandoned agricultural land (AAL) ($p > 0.05$).

The average C content in Scots pine root biomass in the forest land was $48.9 \pm 0.1\%$, but in afforested abandoned agricultural land $49.5 \pm 0.1\%$, whereas for birch it was $47.3 \pm 0.1\%$ in afforested abandoned agricultural land. Within the framework of this research, the average carbon content

in Scots pine and birch root biomass differed within $\sim 2.5\%$. Statistically the average carbon content in root biomass was essentially different for Scots pine and birch sample trees, as well as for forest land and AAL (Figure 1), different root fractions (Figure 2) and age of stands (Figure 3) (multifactor dispersion analysis, $p > 0.05$). The carbon content in Scots pine sample tree biomass on AAL was significantly higher than it was in birch sample trees (multifactor dispersion analysis, $p < 0.05$). Whereas the average C content in Scots pine root biomass in forest lands was lower than it was in sample trees in AAL (single-factor variance analysis, $p < 0.05$). This connection can be explained by high content of lignin in coniferous wood: pulp ratio and therefore may be differences in C content (Zaķis 2008).

As previously stated, there are numerous factors affecting the C content in root biomass. It is shown in Figure 1 that the species of the tree and the type of previous land usage create statistically significant differences in C content in root biomass (multifactor dispersion analysis, $p < 0.05$). Differences in carbon content can even be observed in different root fractions of trees of the same species (Figure 2), and they are statistically significant (variance analysis, $p < 0.05$). The highest content of C in Scots pine sample trees in forest land was observed in stump fraction and coarse roots, accordingly $50.3 \pm 0.1\%$ and $49.5 \pm 0.1\%$, but in small roots $49.7 \pm 0.1\%$ and fine roots $46.8 \pm 0.2\%$. Whereas the highest amount of C in Scots pine sample tree in AAL was in stump $52.1 \pm 0.1\%$, small roots $49.9 \pm 0.2\%$ and coarse roots $49.6 \pm 0.1\%$, but for fine roots $47.2 \pm 0.1\%$. The highest C content in birch sample trees in AAL was in small roots $49.5 \pm 0.1\%$, stump $49.4 \pm 0.1\%$ and coarse roots $47.9 \pm 0.1\%$, and the lowest amount, the same as for Scots pine, was in fine roots $45.2 \pm 0.1\%$. The carbon content in fine roots in forest land, as well as in AAL is relatively low ($45.2-47.2\%$), and is statistically different from all other root fractions. After comparing the C content in Scots pine and birch root fractions, it can be observed that it was higher in Scots pine root fractions than in birch root

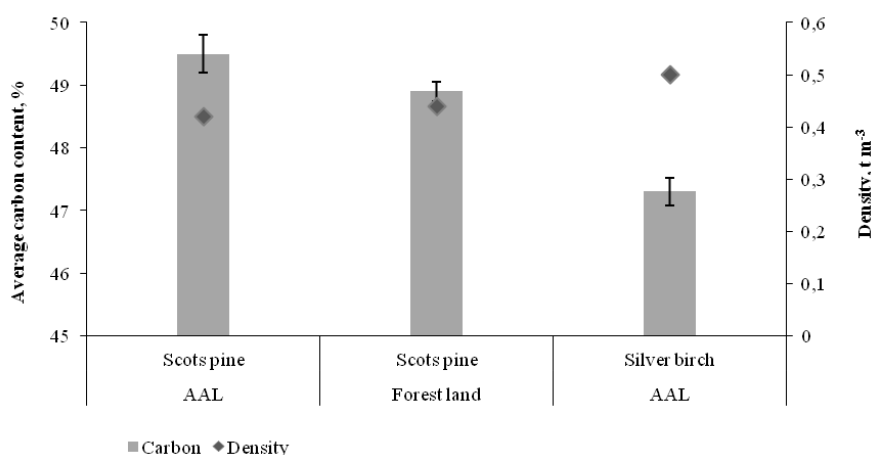


Figure 1. Comparison of carbon content and density in Scots pine and silver birch sample tree root biomass in abandoned afforested agricultural land (AAL) and forest land

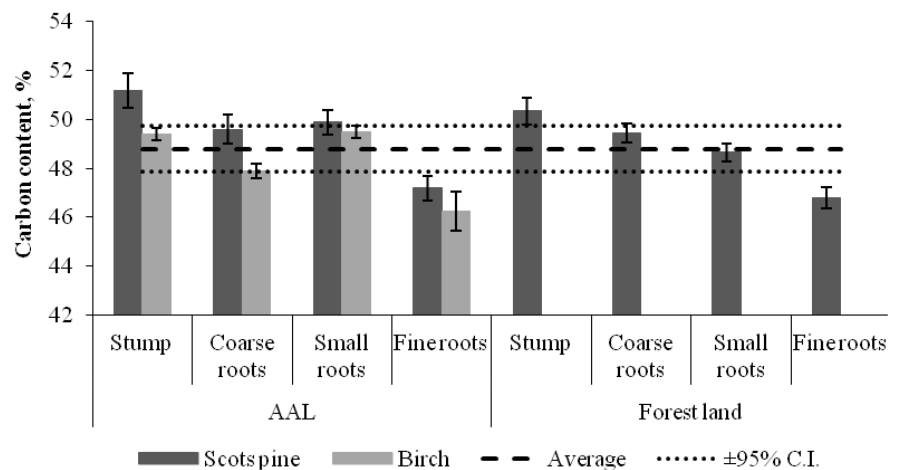


Figure 2. Comparison of carbon content in different root fractions in afforested abandoned agricultural lands and forest lands

fractions, although the difference was not statistically significant (variance analysis, $p < 0.05$).

In the course of this research, the differences in C content within the root fractions (stump, coarse roots and small roots) of trees of single species can be explained by rootwood density (Figure 1), which is defined by a strong negative correlation between the density and C content in root biomass, accordingly the correlation ratio for Scots pine sample trees in forest land was $r = -0.65$ ($\alpha = 0.05$) and in AAL $r = -0.62$ ($\alpha = 0.05$). Whereas for birch sample trees in AAL the C content in root fractions and root fraction density create a stronger negative connection than it was for Scots pine in forest land and AAL, accordingly the correlation ratio was $r = -0.81$.

The average amount of carbon content in root fractions creates a clear correlation with the age of the stand described by Pearson's correlation factor $r = 0.93$ ($\alpha = 0.05$). A tight correlation of the stand age with C accumulation can be observed individually for each fraction ($r = 0.81-0.95$). Accordingly, older stands have higher carbon content in their root biomass fraction (Figure 3). A natural variation in root biomass fraction carbon content can be observed, which depends on the wood density. Figure 3 shows that the stand age explains nonlinearly the changes of C content in different root fractions. In forest land the Scots pine stand age most accurately explains the changes in C content in stump biomass ($R^2 = 0.92$), coarse roots ($R^2 = 0.79$), but most poorly in small roots ($R^2 = 0.63$). Scots pine and birch sample trees in AAL had a similar tendency to Scots pine in forest land, because the stand age most accurately describes the C content changes in stump fraction. Within the framework of this research the changes in carbon content in fine roots of Scots pine in forest land, as well as Scots pine and birch in AAL, had no significant effect from the age of the stand, which is described by correlation ratio $r < 0.3$ ($\alpha = 0.05$).

The content of carbon greatly varied in Scots pine and birch stands of the same age, and there was a tight correlation with the sample tree dimensions (Figure 4), because a

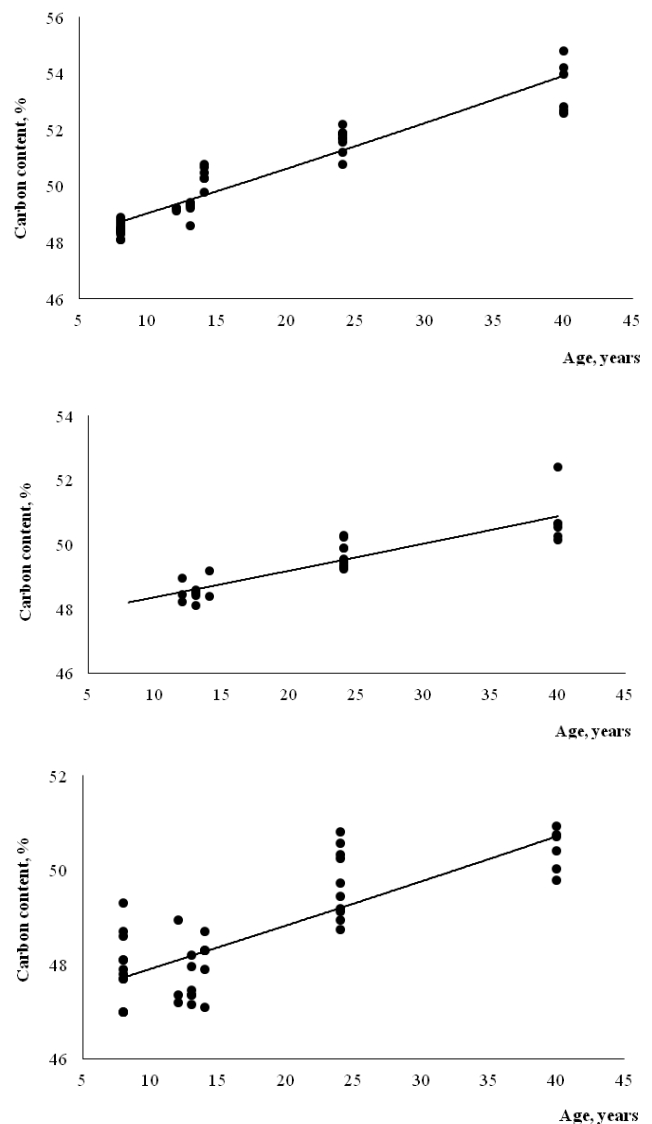


Figure 3. Changes of carbon content in Scots pine sample trees in forest land in different root fractions depending on the age of the tree

tight correlation between the sample tree diameter at breast height at 1.3 m (DBH) and average carbon content in root wood was observed, which is described by the Pearson's correlation ratio $r = 0.82$ ($\alpha = 0.05$).

between the C content in the heartwood and sapwood, respectively in *Pinus sylvestris* stands 52.3% and 45.3% (De Aza et al. 2011), which marks out the effect of the wood density, in addition, it is indicated that C content in conifer-

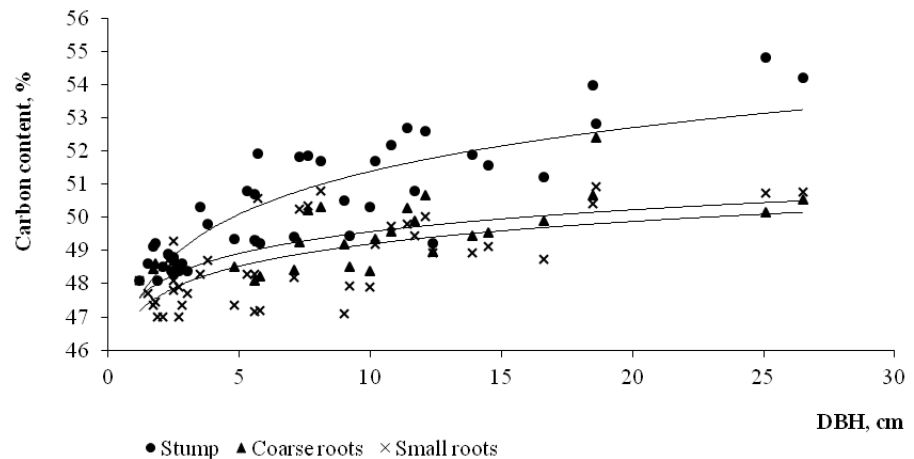


Figure 4. Interrelation between Scots pine sample tree DBH and carbon content in different root fractions

Also the C content in each root fraction was strongly correlated with the sample tree diameter at breast height (Figure 4), accordingly the C content in coarse roots and DBH correlated with $r = 0.68$ ($\alpha = 0.05$), the C content in small roots and DBH with $r = 0.67$ ($\alpha = 0.05$), as well as the C content in stump and DBH with $r = 0.86$ ($\alpha = 0.05$).

Discussion

In order to evaluate the carbon content in tree biomass, precise study of its different components is required. Usually, on a local, regional or global level it is assumed that the carbon content in tree biomass is 50% (Kauppi et al. 1995, Fahey et al. 2005, Redondo-Brenes and Montagnini 2006, Chave, Condit, Muller-Laundan et al. 2008, Blanc et al. 2009, Buermann, Lewis, Hagen et al. 2011). However, the data obtained in Lithuania showed that mean C contents in the needles, living and dead branches, and stemwood were similar, 49.0–51.9 g kg⁻¹, but still with the significantly lowest C content in stemwood of Scots pine stands (Armolaitis et al. 2013). It was found out that, by using the value of 50% C content in tree biomass, an error of about 5% is present at calculating the carbon reserves in stands (Sean and Adam 2012) or significantly higher than the default value of 50% (Jones and Hara 2012). The results of this research showed a similar tendency, and mark out significant C content differences between different root fraction and stand age as well as species. After comparing the results of C content calculation in stands, when generally accepted C content (50%) has been used and the C content in different root biomass fractions established during our research, an error of $5.2 \pm 0.3\%$ was found. The cited literature provides useful information on the fact that there are significant differences

ous wood (on average $50.8 \pm 0.3\%$) is about ~3% higher than that in deciduous tree wood (on average $47.7\% \pm 0.3\%$) (Sean and Ada 2012). Additionally, researchers have found changes in C content in different forest litterfall fractions in Scots pine stands, where the average carbon content ranges from $52.5 \pm 1.5\%$ in branch fractions to $41.9 \pm 1.7\%$ in needle fractions (Bārdule et al. 2012), and in different biomes, where the C content varies from 41.9 to 51.6% in tropical tree species, from 45.7 to 60.7% in tree species of sub-tropical and temperate zone forests, and from 43.4 to 55.6%, in tree species growing of boreal forests (Sean and Ada 2012).

After the analysis of different studies concerning the C content in root biomass of different tree species, differences were observed. Janssens et al. (1999) reports that in Scots pine stands the coarse roots contain from 49.4% to 52.2% C, fine roots – from 52.6% to 51.6% C. Bert and Danjon (2006) performed the analysis of maritime pine stands (*Pinus pinaster*) and came to a conclusion that the entire root system on average contains 51.7% C. Daugaviete et al. (2008) point out that an absolutely dry root biomass on average contains 50.9% C in birch stands in Latvia. The above-mentioned C content calculation results are similar to the results obtained in this research, and they range widely depending on the tree species and root fractions, but on average have a low C content, 49.1% in Scots pine root biomass and 48.2% in birch root biomass, respectively.

Natural variation can be observed directly in roots wood C content, and scientific literature sources indicate that trees with smaller dimensions have lower lignin content, which is also reflected in C accumulation (Sean and Adam 2012). The research results can be compared to the research of the above-mentioned authors, and mark out the tight connection of C content with the diameter. Sample trees with larger

diameter have higher C content. The research results should be introduced in the national report in the context of Kyoto Protocol in order to define more precisely the amount of attracted C in forest stands.

The highest carbon content in Scots pine and birch is in the stump fraction, because this fraction is an extension of the tree trunk axis. As the sample tree root fraction diameter decreases, the C content gets lower too. Such connection is also observed in *Pinus pinaster* stand, and the researchers stated that the coarse roots contain 52.3% C, but fine roots 50.4% (Bert and Danjon 2006).

The researchers have concluded that the amount of accumulated C in forests varies greatly depending on the climate zone and species (Brunner and Godbold 2007). Accordingly, in this research, on average, young stand root biomass accumulates 42.2 ± 7.9 t ha⁻¹ carbon, which is similar to the conclusions of the above-mentioned authors on boreal forest regions. According to these researchers, on average, the amount of accumulated carbon in root biomass in boreal forest regions is 12–25% of the total amount of accumulated carbon per ha (Trumbore and Gaudinski 2003, Majdi et al. 2005, Brunner and Godbold 2007). Research on C accumulation in Central European forests shows that the amount of accumulated C in root biomass is 110 t C ha⁻¹, including 26 t C ha⁻¹ in coarse roots and 1.2 t C ha⁻¹ in fine roots (Brunner and Godbold 2007), and the emissions from the root biomass are relatively low, accordingly fine roots emit 0.9 t C ha⁻¹ per year, whereas coarse roots 0.8 t C ha⁻¹ per year (Perruchoud et al. 1999). Carbon accumulation is more intensive in tropical and temperate zones, and on average range from 21 to 22 t C ha⁻¹ (Dixon et al. 1994, Jackson et al. 1997, Brunner and Godbold 2007). Scientists have established that ~48.8% of C accumulated in the root is located in the living roots of the tree (Brunner and Godbold 2007). Within the framework of this research, on average, 14.1 ± 2.5 t C ha⁻¹ is accumulated in Scots pine young stands, and 20.6 ± 2.8 t C ha⁻¹ in silver birch young stands, but Scots pine and birch fine roots accumulate, on the average, 3.2 t C ha⁻¹. For example, in comparison to other carbon reservoirs, soil accumulates 195 t C ha⁻¹ in the depth of 0–80 cm (Bārdule et al. 2009), i.e. significantly higher.

Very little research has been done in Latvia on the amount of accumulated C in root biomass, but there is information available on carbon storage and accumulation in Scots pine, spruce and birch young stands and stands in agricultural land (Daugaviete et al., 2008). Daugaviete et al. (2008) note that in a 12-year-old Scots pine stand, the average amount of accumulated carbon is 33 t C ha⁻¹, 65.4% of which is accumulated in the aboveground part, 23% in stump and coarse roots and 11.6% in fine roots. The authors of this research found that an absolutely dry Scots pine root biomass on average contains 50.9% C. They pointed out that the amount of accumulated C in a spruce stand of the same age is 26.5 t ha⁻¹ on average; 19% of the total amount of accumu-

lated C is in stump and coarse roots and 15% is in fine roots. On the average, 49.9% C is accumulated in spruce stand root biomass. In a 10-year-old birch stand root biomass, on average, 49.7% C is accumulated (Daugaviete et al., 2008). It can be concluded that compared to the results obtained in this research, the content of accumulated C in root biomass is similar, hence for calculations of C content no significant differences can be observed.

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