# BELOW-GROUND BIOMASS PRODUCTION IN YOUNG STANDS OF SCOTS PINE (*PINUS SYLVESTRIS* L.) ON ABANDONED AGRICULTURAL LAND

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**Abstract**
Tree roots take up a high proportion of forest biomass, and nowadays we use different methods to estimate the root biomass. Methods vary greatly due to the different studies and different excavation methods used. In the summer 2010, a study of the below-ground biomass of young Scots pine *Pinus sylvestris* L. stands was carried out in central Latvia. In this paper, different below-ground biomass fractions data of 10 sample trees from the abandoned agricultural land plantations were approximated by allometric functions depending on tree stem diameter at breast height 1.3 m (DBH). The main objective was to determine the average below-ground biomass and approximated below-ground biomass fractions by allometric functions depending on tree DBH of young stands of Scots pine on abandoned agricultural land. Our regressions offer good overall approximations of the data. DBH – stump, coarse root and small root and total biomass regressions were highly significant ($p<0.001$). The most substantial part of total below-ground biomass was from stumps (45%). The smallest shares of the biomass were coarse roots 38% and small roots 16%. The largest portion (52%) of the total fine-root biomass of 12- and 14-year-old Scots pine stands was located at a depth of 0–10 cm, decreasing in deeper mineral soil layers. Total dry (DM) below-ground biomass including fine-root biomass was 19.0 ±5.2 t DM ha$^{-1}$.
**Key words:** Scots pine, Root biomass, Agricultural land, Sapling stands, Regression equation.

## Introduction

Root biomass is an important part of the biosphere and can take up to 30% of the total above-ground biomass (Grier et al., 1981; Hoffmann and Usoltsev, 2001). Tree growth in boreal forests is generally limited by the availability of nutrients, especially nitrogen. Therefore, the below-ground compartments are responsible for the acquisition of scarce soil resources. The root systems provide trees with physical support and the ability to capture resources essential for growth and reproduction (Gautam et al., 2003).

Accurate quantification of below-ground carbon stocks in forests is critical for effective predictions of how future climate change will impact global carbon dynamics. However, the development of forest carbon budget models has historically been restricted by the lack of species and site-specific estimates of below-ground biomass (Brassard et al., 2011). Root biomass production is important for modeling carbon cycling, but its calculation has been dependant on the available data.

Gathering data on root biomass distribution is a very drudgery process. It includes root excavation, washing, sieving, separating gathered material into species and diameter classes and also biomass weighing (Polomski and Kuhn, 1998). Root distribution may be very heterogeneous and extensive due to the rocks and impenetrable layers of the soil. It may depend on many factors such as tree species, influence of water supply and ground water table (Hoffmann and Usoltsev, 2001). Very often data is reported per unit of forest area only, making these data unusable for modeling based on individual tree root biomass (Santantonio et al., 1977; Haland and Braekke, 1989).

Relatively few studies are dealing with both root diameter and rooting depth for individual trees. Their findings are often hard to compare due to several reasons (Jenik, 1971; Haland and Braekke, 1989). Stump biomass which is very important part of below-ground biomass is not uniformly defined, separately from total biomass, or ignored completely, and the size of root biomass classes are defined significantly differently (Hoffmann and Usoltsev, 2001).

In this study, the main objective was to determine the average below-ground biomass production in different fractions and develop DBH – stump, coarse root and small root biomass equations for young trees of Scots pine.

## Materials and Methods

*Study area*

The research was carried out in two young stands of Scots pine (*Pinus sylvestris* L.), established in central Latvia, Ozolnieki and Iecavas regions, approximately 25 km east of Jelgava. One of the closest meteorological stations is located in Jelgava. The study area has a temperate climate, moderately warm and dry with 3 to 4 months long vegetation period. The average annual precipitation for Jelgava (period 2000 – 2010) is 584 mm and average annual temperature is 6.9 °C. The prevailing site type of the region is well drained agricultural land.

*Experimental stands*

Our research of below-ground biomass production was carried out in two planted Scots pine stands on abandoned former agricultural land. The average age of the stands was 12 and 14 years. The spacing in plantations was from 1.0 m between rows and from 2.0 m within rows. Stand density was between 2145 and 2925 trees per ha in the plantations (Table 1). One experimental sample plot (500 m$^2$) in each stand was established in the summer 2010. The stem diameter at breast height 1.3 m (DBH) and the height of all trees were measured in each sample plot.

The stands were situated on a similar site and soil type. In both Scots pine stands there was sandy loam soil, with a relatively thin humus layer, but saturated with nutrients. The site type according to classification is *Hylocomiosa* (Bušs, 1981).

Table 1

**Characteristics of studied plantations**

| Characteristics | Stand age (years) | |
|---|---|---|
| | **12** | **14** |
| Plot area, m$^2$ | 500 | 500 |
| Numbers of trees ha$^{-1}$ | 2145 | 2925 |
| Mean diameter, cm | 11.2 | 10.3 |
| Mean height, m | 7.7 | 8.2 |
| Basal area, m$^2$ ha$^{-1}$ | 21.0 | 24.3 |
| Stand volume m$^3$ ha$^{-1}$ | 92.2 | 115.4 |

*Sample tree selection*

The total root system of 10 sample trees (5 in each sample plot) was excavated, washed, divided into diameter classes and weighed in the summer of 2010. Trees were selected for excavation using systematic random technique. We selected only healthy, undamaged trees within the DBH range (one minimal, three average and one maximal sample tree per each plot) and with average tree height.

*Coarse root, small root and stump sampling*

Root systems were excavated, washed free of soil using high pressure water, and the entire root system was divided into diameter classes and weighed on site using a hand scale. To have more accurate root biomass determination, we divided all roots in two diameter classes:

- small roots (Ø 2 – 20 mm);
- coarse roots (Ø > 20 mm) (Ohashi et al., 2007).

We included also the stump part in below-ground biomass; both the above-ground (beginning of the stem) and below-ground parts. With the latter we understand monolithic part that was not otherwise differentiated (Liepa, 2005).

*Fine root sampling*

Fine root sampling was conducted in August 2010. Fine roots are generally defined as non-woody, small-diameter roots (Nadelhoffer and Raich, 1992), but there is no established convention defining the diameter size range of fine roots (Fogel, 1983). In this study, roots smaller than 2 mm were regarded as fine roots. The soil core sampling method was used to collect the fine roots (diameter ≤ 2.0 mm). Twenty soil cores (volumetric samples 100 cm$^3$ and core diameter 50 mm) per sampling were randomly taken in both sample plots for the determination of fine-root biomass. The soil cores were divided into five layers by depth: 0–10 cm, 11–20 cm, 21–30 cm, 31–40 cm and 51–60 cm of the mineral soil.

*Laboratory analyses*

To determine the dry root weight of each tree root system, we randomly selected fresh root samples for each diameter classes and stump. The samples were placed in polyethylene bags, transported to the laboratory and weighed. In the laboratory, samples were dried to constant mass at 105 °C, and weighed. The fresh to dry weight ratios were then used to calculate dry weight for each below-ground fraction of the tree.

Fine root samples were placed in polyethylene bags, transported to the laboratory, and stored in a refrigerator at 4 °C until the analysis. In the laboratory, fine roots were washed and separated into Scots pine roots and roots of other plants. Roots with diameter greater than 2 mm were excluded from the analysis.

*Data analysis*

Single power regression models that related stump, coarse root, small root and total root biomass to DBH and height were developed for both stands (Eq. 1):

$$Y = b_1 \times X^{b_2} \quad , \tag{1}$$

where Y is root fraction biomass (kg), X is DBH (cm) or height (m), and $b_1$ and $b_2$ are coefficients.

Descriptive statistics were use for all below-ground fractions.

**Results and Discussion**

Brassard et al. (2011) showed that the equations developed on the stand level of several above-ground attributes including DBH allow biomass and carbon budget models to characterize below-ground dynamics more accurately using readily available above-ground metrics. Usoltsev and Vanclay (1993) demonstrated that total root biomass could be approximated by function of diameter at breast height, with coefficients of determination of 0.956. Results of our study give evidence of close correlation between root biomass and DBH (Figure 1), as shown also by Usoltsev and Vanclay (1993). Coefficient of determination for stump biomass in our case was 0.892, for small roots 0.851, for coarse roots 0.939 and for total biomass 0.917. Relationship between DBH and root biomass is clearly strong; therefore, this relation can be used for biomass equations.

The regression coefficients for each model are reported in Table 2. Fitted equations have the form $Y = b_1 * X^{b2}$, were y is root biomass fraction (kg), $X$ is DBH (cm), $b_1$ and $b_2$ *are* coefficients. In Table 2 we presented regression coefficients for allometric equations relating stumps, coarse roots, small roots and total biomass to DBH in young Scots pine stands. DBH – stump, coarse root, small root and total biomass regressions were highly significant (P < 0.001), with correlation coefficient ranging from 0.852 to 0.926.

Hoffmann and Usoltsev (2001) stated that height turned out to be a better prediction than DBH for tree roots, resulting in the allometric equations. In our

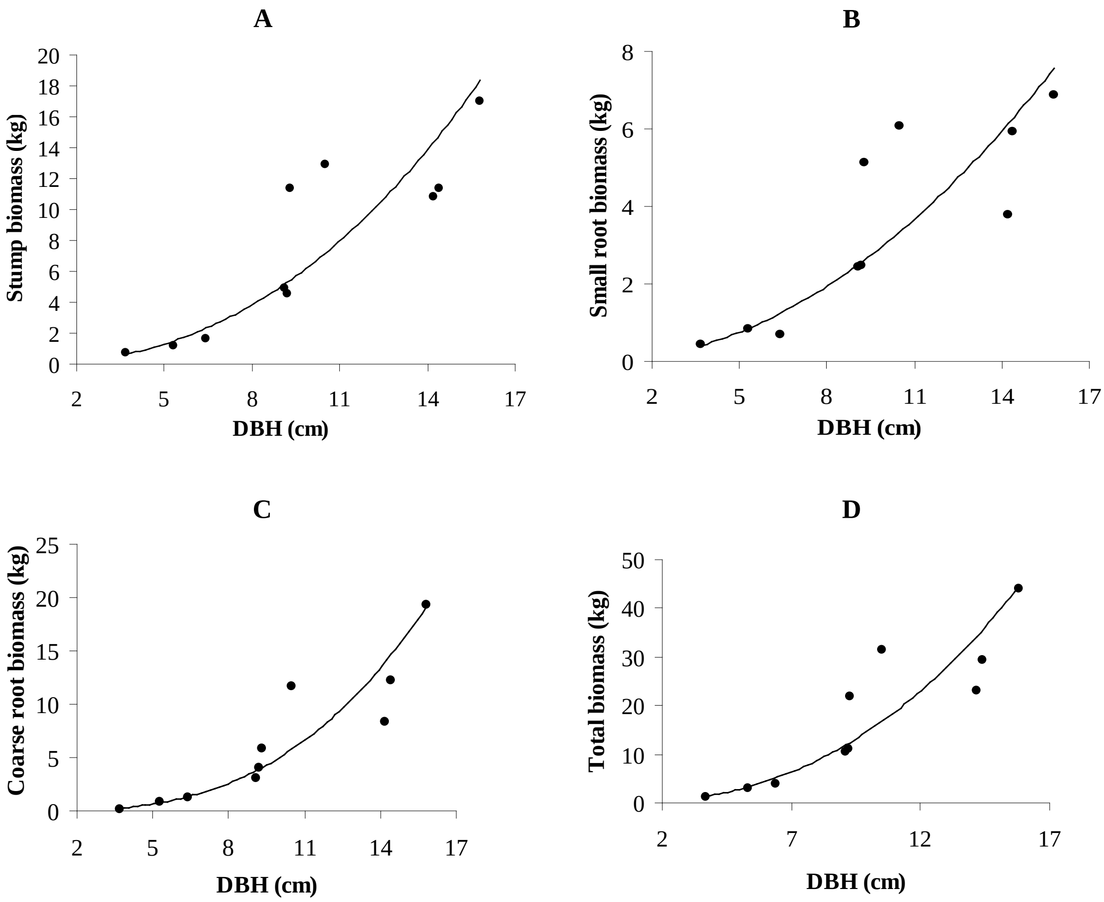


Figure 1. Relationship between DBH and (A) fresh stump biomass, (B) fresh small root biomass, (C) fresh coarse root biomass, and (D) fresh total biomass.

Table 2

**Regression coefficients for allometric equations describing relation between below-ground fractions and tree DBH**

| Below-ground fractions | Number of tree | DBH range | $b_1$ | $b_2$ | $R^2$ | P | MSE | SEE |
|---|---|---|---|---|---|---|---|---|
| Stumps* | 10 | 5.3 – 15.8 | 0.032 | 2.300 | 0.892 | < 0.001 | 0.157 | 0.396 |
| Coarse roots* | 10 | 5.3 – 15.8 | 0.060 | 2.943 | 0.939 | < 0.001 | 0.137 | 0.370 |
| Small roots* | 10 | 5.3 – 15.8 | 0.030 | 2.004 | 0.851 | < 0.001 | 0.171 | 0.414 |
| Total* | 10 | 5.3 – 15.8 | 0.060 | 2.392 | 0.971 | < 0.001 | 0.127 | 0.356 |

MSE = mean square of the error
SEE = standard error of the estimate of the regression
* fresh biomass

Table 3

**Regression coefficients for allometric equations describing relation between below-ground fractions and tree height**

| Below-ground fractions | Number of tree | Height range | $b_1$ | $b_2$ | $R^2$ | P | MSE | SEE |
|---|---|---|---|---|---|---|---|---|
| Stumps* | 10 | 5.9 – 10.3 | 0.005 | 3.281 | 0.236 | > 0.05 | 2.744 | 1.053 |
| Coarse roots* | 10 | 5.9 – 10.3 | 0.0001 | 4.924 | 0.342 | > 0.05 | 6.180 | 1.218 |
| Small roots* | 10 | 5.9 – 10.3 | 0.009 | 2.640 | 0.091 | > 0.05 | 1.777 | 0.966 |
| Total* | 10 | 5.9 – 10.3 | 0.006 | 3.562 | 0.173 | > 0.05 | 3.234 | 1.059 |

MSE = mean square of the error
SEE = standard error of the estimate of the regression
* fresh biomass

study we obtained different results than Hoffmann and Usoltsev, and we must conclude that DBH was a better predictor of different below-ground biomass fractions than height in our study (Table 3). DBH – below-ground biomass models had consistently higher $R^2$ than height – below-ground biomass models for all biomass fractions. Height – stump, coarse root and small root and total biomass regressions were not significant ($p>0.05$), with correlation coefficient ranging from 0.242 to 0.301.

The largest share (around 45%) of total below-ground biomass in young Scots pine stands was from stumps. The smallest shares of the biomass were in coarse roots and small roots - 38% and 16%, respectively. Total dry root biomass on abandoned agricultural lands in young stands of Scots pine is 14.6±5.1 t ha$^{-1}$, including stump biomass 6.6±2.2 t DM ha$^{-1}$, coarse root biomass 5.6±1.0 t DM ha$^{-1}$ and small root biomass 4.9±0.7 t DM ha$^{-1}$ (Figure 2). Results showed that all root fractions were developed evenly, and such root biomass structure development model is normal for young stands. Comparing our data with the literature data on grey alder (*Alnus incana* (L.) Moench), which is one of the most typical tree species on abandoned agricultural land in Latvia, we found out that DM below-ground biomass production in 10-year-old grey alder stands is more than 1.6 times less (Uri et al., 2008) than results from our study.

Comparing both stands, no significant differences (Table 4) between below-ground biomass parts were detected. Older stand produced more biomass than the younger one, but statistically the difference was not significant and for calculations both stands can be combined together.

Table 4

**Average below-ground biomass of 12- and 14-year-old Scots pine stands**

| Stand age | Biomass $\bar{x} \pm s_{\bar{x}}$ | | |
|---|---|---|---|
| | Stumps* | Coarse roots* | Small roots* |
| 12 years | 5.7 ±2.9 | 5.7 ±3.5 | 2.6 ±1.2 |
| 14 years | 9.4 ±2.1 | 7.8 ±2.1 | 4.3 ±1.0 |
| p-value | 0.32 | 0.60 | 0.27 |

*fresh biomass

The amount of fine-root biomass varies between soil layers. The largest part of the Scots pine fine roots

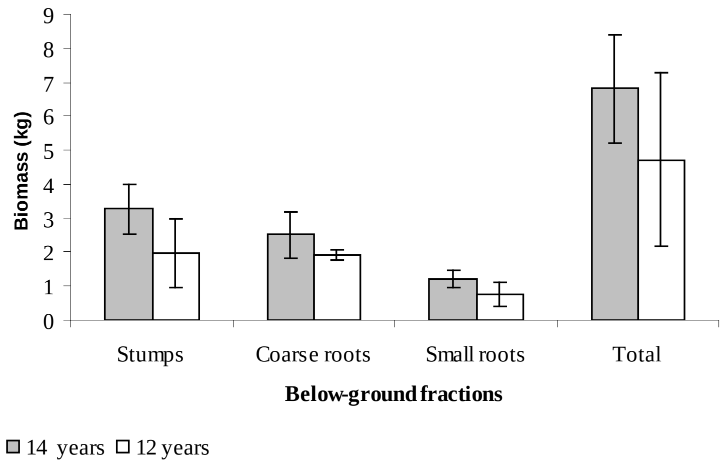


Figure 2. Mean dry biomass in different below-ground fractions. Standard error values are shown in error bars.

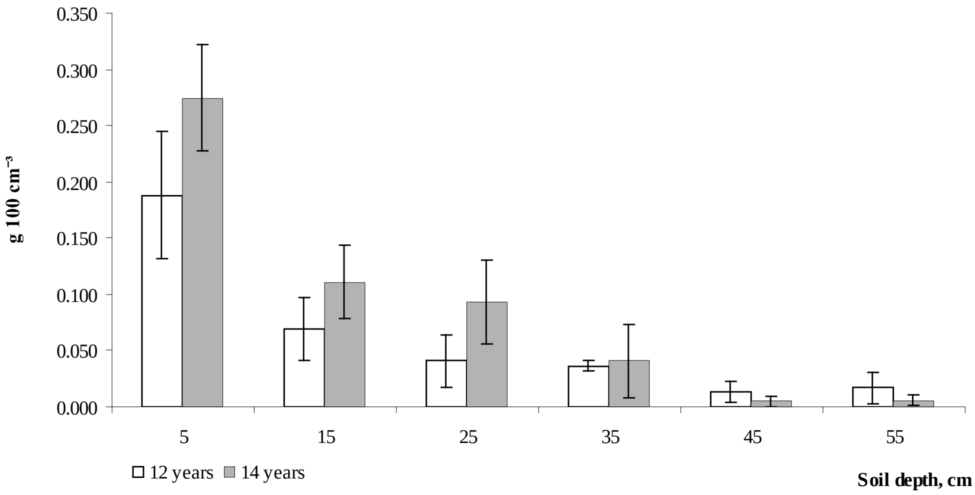


Figure 3. Comparison of fine-root biomass in different soil depths of 12- and 14-year-old Scots pine stands. Standard error values are shown in error bars.

(46%) is reported to be found in the upper mineral soil layer (Helmisaari et al., 2002). There is normally a significant distribution of fine-root biomass in the top soil layers, decreasing at greater soil depth (Claus and George, 2005; Makkonen and Helmisaari, 1998; Helmisaari et al., 2002).

In our study the value of fine-root biomass was 1.8 ±0.5 t $ha^{-1}$ (52%) in 12-year-old and 2.7 ±0.4 t $ha^{-1}$ in 14-year-old (52%) stand in the upper mineral soil (0–10 cm), which is nearly equal to the fine root biomass range reported by other authors (Trettin et al., 1999). Results showed a clear relation between fine-root biomass and the depth of the mineral soil layer, coefficient of determination $R^2$ being equal to 0.89. The largest part of fine-root biomass was located at a depth of 0–10 cm and decreased in deeper soil layers (Figure 3).

Between the soil layers and average fine-root biomass in the Scots pine stands there were significant differences ($p<0.05$). The largest distribution of fine-root biomass in soil layer 0–60 cm was found in the older stand (14-year-old) – 5.3 ±1.6 t DM $ha^{-1}$, but in the younger stand (12-year-old) the value was 3.6 ±1.5 t DM $ha^{-1}$. The studied stands were of the same age class but with different densities (see Table 1). The amount of biomass correlates with tree density per ha and describes its significant differences between both stands.

In our study, the object's total below-ground biomass including fine-root biomass was 19.0 ±5.2 t DM $ha^{-1}$. Regarding our results, we must agree with the other researchers who state that below-ground biomass is an important part of the tree, and plays a significant role for carbon budget modelling and tree development (Brassard et al., 2011).

## Conclusions

1. Below-ground biomass fractions were approximated by function of DBH, with coefficients of determination for stump biomass 0.892, small roots 0.851, coarse roots 0.939 and total biomass 0.917, respectively.
2. DBH is a better predictor for different below-ground biomass fractions than tree height.
3. The vertical distribution of fine root biomass in the studied Scots pine stands decreased with increased soil depth.
4. The largest part (52%) of the fine-root biomass was located in the upper mineral soil layers (0–10 cm).
5. Total below-ground biomass including fine-root biomass was19.0 ±5.2 t DM $ha^{-1}$.

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