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Above ground and below ground biomass in grey alder *Alnus incana* (L.) Moench. young stands on agricultural land in central part of Latvia

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Abstract. Young grey alder stands under 10 years of age that are growing on abandoned agricultural lands in Central Latvian lowlands were selected for this study. In the framework of the research the biomass of the trees was studied and an equation was developed for grey alder stands on abandoned agricultural lands. An allometric equation for the different biomass fractions of grey alder was developed. Tree biomass is characterised by a power model with a single independent variable (DBH), which also indirectly substitutes for the effect of the stand age. The model is adapted to each fraction by changing its ratio values. The determination coefficient of the model is high, varying from $R^2 = 0.89$ to $R^2 = 0.94$, and the confidence level of the model is 95%. The biomass of particular fractions is defined by a power regression, with the tree stem diameter at the height of 1.3 m used as an argument. In young grey alder stands on abandoned agricultural lands the majority, 64%, of root fractions is composed of coarse roots, followed by the stump fraction and fine roots, 28% and 8%, respectively. For aboveground biomass the largest fraction is stem, which constitutes 75% of the total aboveground biomass, while the share of branches is 25%.

Key words: allometric equations, coarse roots, fine roots, stump, stem, branches, power model.

INTRODUCTION

There is a growing interest in the evaluation of biomass in forest lands, as it plays an important role in the turnover cycle of carbon and nutrients. Easy-to-use and precise methods for biomass estimation concerning the aboveground components of the tree have been developed, but what is usually problematic and difficult to assess is the root biomass (Sanford & Cuevas, 1996). It is known that the aboveground tree characteristics, such as tree stem diameter and height, can be used to accurately predict the tree biomass fractions (Ruark & Bockheim, 1987; Lavigne & Krasowski, 2007), but our knowledge of the components of tree biomass and its division into the smallest fractions is incomplete. Biomass calculations are needed mainly for sustainable forest resource planning, as well as for studying energy and substance turnover cycles in ecosystems (Zianis et al., 2005). Biomass evaluation depends on the aboveground tree dimensions and that is why biomass equations are developed to predict it according to a fixed variable (Repola, 2009). To better understand the regularities and influencing factors of biomass division, we need to carry out research on stand structures, biogeochemical cycles and many other aspects related to global climate change (Dixon et al., 1994; Sanford & Cuevas, 1996). A growth in biomass can be observed as the trees get older, but its decrease is observed in very old stands (Peet, 1981). The development of a tree is also affected by the density of the stand, access to nutrients and water, soil temperature, as well as changes in density and oxygen availability (Dobson & Moffat, 1993; Dobson, 1995; Makkonen & Helmissari, 1998; Dieter & Elsasse, 2002; Ehman et al., 2002; Finer et al., 2007). As different factors affect the formation of tree biomass, broad generalizations on tree biomass can be drawn, which means that extensive research is necessary to improve and develop on biomass calculation models (Zianis et al., 2005).

Differences in tree biomass fractions are based on the ability of the tree to adapt to various conditions (Melecis, 2011). On flooded, damp or dried out soils, where the growth of trees and roots is limited, roots may grow thin and reach several metres in depth (10 m or more), as long as there is a sufficient supply of oxygen, water and nutrients. In such areas the trees wither, become similar to shrubs; the roots are weakly developed and make up an insignificant part of the biomass production (Perry, 1982). It is known that the geographical location of woody plants affects their biomass structure and morphological parameters; in general, woody plants adapt to their respective conditions. Various environmental conditions, such as wet, dry or windy environment, low average temperature, soil fertility etc., significantly affect root morphology and the physiology of development as well as root biomass (Kramer & Kozlowski, 1960; Pyatt et al., 2001; Finer et al., 2007).

Biomass equations should be flexible and applicable to biomass calculations for young stands (Repola, 2008). Numerous studies on grey alder biomass equations have been published, but only few of them fulfil the above-mentioned criteria (Repola, 2009). The suitability and precision of biomass equations depend on the collected empirical material as well as the interpretation thereof. Most of the tree fraction biomass equations consist in a power equation (Zianis et al., 2005). In the framework of this study, a power equation suited to Latvian conditions was developed.

Over the past decade the economic situation has changed drastically in Latvia. Large areas of agricultural land have been left unmanaged, and at present more than 310,000.0 ha of these lands have been afforested or have become afforested naturally, mainly with birch and grey alder. The majority of these forest stands have reached the age of 5 to 15 years, and a significant amount of biomass and carbon has been accumulated both in the aboveground and underground tree parts. Grey alder is a wide-spread tree species throughout Latvia (Forestry-key indicators, 2013), and commercially important for Latvian forestry (Millers & Magaznieks, 2012). Ever since the inventory of forest resources, information concerning the aboveground part, including tree stem diameter and height, is widely accessible in Latvia. By using metrical values relating to the estimation of the aboveground part, it is possible to develop precise formulas for calculating tree biomass fractions as well as carbon accumulation models (Brassard et al., 2011). Tree biomass is an important part of forest ecosystems as it stimulates various economic and biological processes and performs an irreplaceable function in carbon attraction. To calculate the amount of the attracted carbon, a method for establishing the amount of the biomass is used, taking into account a number of recalculation factors (Jenkins et al., 2003). The aim of this study is to investigate the aboveground and root biomass of young grey alder stands on abandoned agricultural lands.

Studying the amount of biomass in young grey alder stands will allow to predict the amount of wood fuel, as well as to calculate the accumulation of carbon both in aboveground and underground biomass. Until now, little research has been conducted in Latvia on the development of grey alder biomass, especially root biomass (Gaitnieks et al., 2007; Daugaviete et al., 2008; Bardulis et al., 2009). This pilot study focused on the calculation of both root and aboveground biomass production in young grey alder stands. The results of the study are essential for a better understanding of grey alder biomass production on abandoned agricultural lands.

The aim of the study is to investigate root biomass and to develop equations for the calculation of different aboveground and underground biomass fractions. The study poses the following hypothesis: The relationship between the components of tree biomass is biologically determined, and the biomass can be calculated as a function of the dendrometric parameters of the tree.

MATHERIALS AND METHODS

The material was collected from 4 similar young grey alder *Alnus incana* (L.) Moench. stands (Table 1) in abandoned agricultural lands located in the central part of Latvia (Fig. 1). The empirical material was collected in 2011 and 2012 after the vegetation period (from September to October), when all the leaves had fallen. The average parameters and characteristics of the selected stands are given in Table 1.

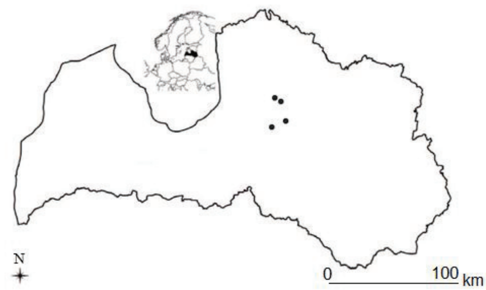

Figure 1. Locations of the studied stands.

The estimation methods for the aboveground part of the stand are based on dendrometric measurements carried out on circular sample plots with a horizontal radius of 12.62 m and area of 500 m^2. All types of tree measurements were carried out in the experiment and seven sample plots were established in each stand.

Table 1. Characteristics of grey alder experimental stands

No.	Coordinates		Age, years	Height, m
	N	E		
1	57°28.410	024°42.690	4	3.7
2	56°56.421	024°40.300	6	4.5
3	57°31.484	024°36.119	7	5.8
4	57°31.510	024°34.190	9	7.1
No.	Growing stock, m^3 ha^{-1}	Basal area, m^2 ha^{-1}	Stand density, stems ha^{-1}	Site class
1	17.8	5.6	7,700	1a
2	25.0	11.0	11,900	3
3	15.8	12.1	2,000	1
4	39.8	12.4	7,200	3

For the establishment and analysis of tree biomass, the sample trees were selected by considering their stem diameter at the height of 1.3 m (DBH) and the average height, including the average stand parameters where possible. Each sample tree was evaluated according to quality criteria – only healthy, vital sample trees with a single top were used in the study. Twenty sample trees from 4 stands were selected, representing a variety of different diameters (ranging from 1.9 cm to 6.8 cm) and heights (ranging from 3.1 m to 7.8 m), and felled for the measurement of aboveground and root biomass components.

For the calculation and analysis of the root biomass of the sample trees selected for this study, tree root system was divided into three fractions: coarse roots Ø > 5 mm; fine roots Ø < 5 mm, and stump. The stump fraction was included in the root biomass – in the aboveground (5–8 cm above the root neck) and underground fractions, the latter being a monolithic, non-differentiated part in some roots.

The grey alder tree stump and coarse root biomass was established for 20 sample trees by unearthing their root system, separating soil particles from the roots, washing the latter under a water jet and weighing them with the precision of ± 0.02 kg.

The soil core sampling method was used for collecting fine roots. Twenty soil cores (volumetric samples of 100 cm^3 and core diameter of 50 mm) per sampling were randomly taken from each sample plot for the determination of fine-root biomass. The soil cores were divided into four layers by depth: 0–10 cm, 10–20 cm, 20–30 cm and 30–40 cm of the mineral soil. The samples were placed in polyethylene bags, transported to the laboratory, and stored in a refrigerator at 4 °C prior to the analysis. In the laboratory, the roots were washed of soil and separated into grey alder roots and the roots of other plants. The separated fine roots were dried until they reached constant weight. They were then weighed to determine the dry biomass.

For the calculation and analysis of the aboveground biomass of the sample trees selected for this study, the aboveground parts were divided into two fractions: stem and branches. Two samples from the stem and branches of the living part were taken for the assessment of relative wood moisture. The stem of the tree was cut and weighed, while living branches from the living crown and dead branches were weighed separately. The dead branches were not included in the calculations. The dry biomass of the components was then calculated as weighted average from the relative humidity data using the measured weights of the respective parts of the tree.

To establish the specific weight of dry biomass (DM), tree fraction samples of an appropriate bark sector were collected for analysis and dried out at 105 °C until constant weight (Uri et al., 2002).

Allometric relationships between tree DBH, height and root biomass including the stump were tested. A frequently used model for such relationships is the following power model:

$$Y = \alpha \cdot X^{\beta} \quad (1)$$

where Y is the dependent variable (e.g., tree biomass fraction, kg dry mass), X is the independent variable (e.g., tree DBH, cm), and α and β are, respectively, the scaling coefficient (or allometric constant) and scaling exponent derived from the regression in accordance with empirical data.

The normality of the variables was verified with the Kolmogorov-Smirnov test. To analyse the effect of the qualitative factor on the response variables, One-Way ANOVA was applied. The LSD test was used for a multiple comparison of the mean values if the criteria were satisfied.

When the data did not follow a normal distribution pattern, or when inhomogeneity of group variance occurred, the nonparametric Mann-Whitney test was used for variance analysis. In all cases the level of significance $\alpha = 0.05$ was accepted. For data analyses the software SPSS Statistics 17.0 was used.

RESULTS AND DISCUSSION

As shown by scientific research, the growth of any tree species, including grey alder, is determined by soil fertility. The growth rate is established by examining the site index, which is expressed by the stand height at a given age. However, the site index shows the effect of lengthwise growth, but does not describe the stand biomass (Uri et al., 2007). The biomass of different parts of the twenty harvested sample trees ranges from 1.9 to 6.8 cm in diameter and from 3.1 to 7.8 m in height. The average tree height varies from 3.1 to 7.8 m, with the mean DBH ranging from 1.9 to 6.8. The average total dry biomass was 7.0 ± 0.4 kg, ranging from 2.2 ± 0.1 kg in a 4-year-old stand to 13.5 ± 0.5 kg in a 9-year-old stand (Fig. 2). As seen from Fig. 2, the average ratio of aboveground to root biomass is 3 : 1. Similar distribution patterns of aboveground and root biomass in grey alder plantations were found by scientists in Estonia on abandoned agricultural lands (Uri et al., 2002; Uri et al., 2007). In living plants, the root biomass plays an important part in carbon storage and makes up around 20% (Santantonio et al., 1977) to 26% (Cairns et al., 1997), or 19% to 28% according to Xiao & Ceulemans (2004), of the total tree biomass. The results of this study point to a similar proportion, 28% ± 1%.

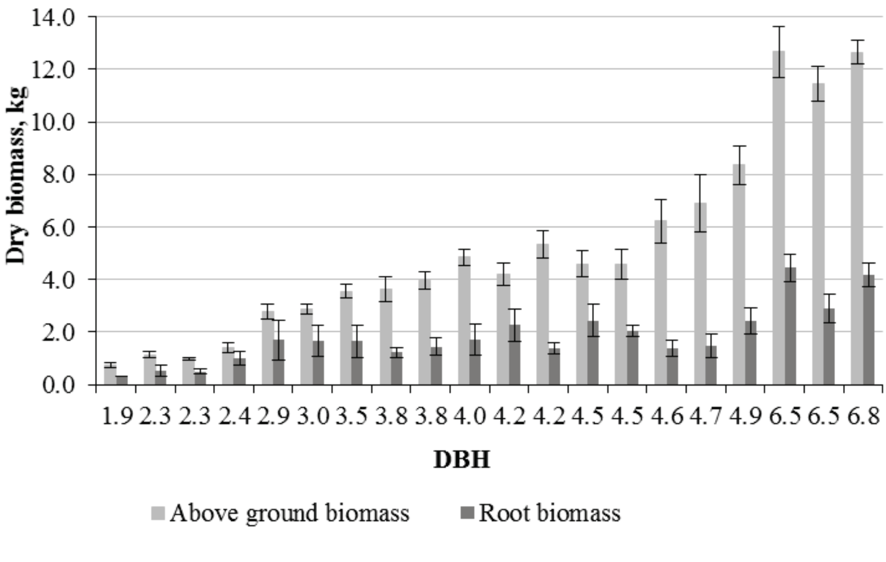

Figure 2. Dry aboveground and root biomass distribution ratio. Confidence interval ± 95% indicated in the error bars.

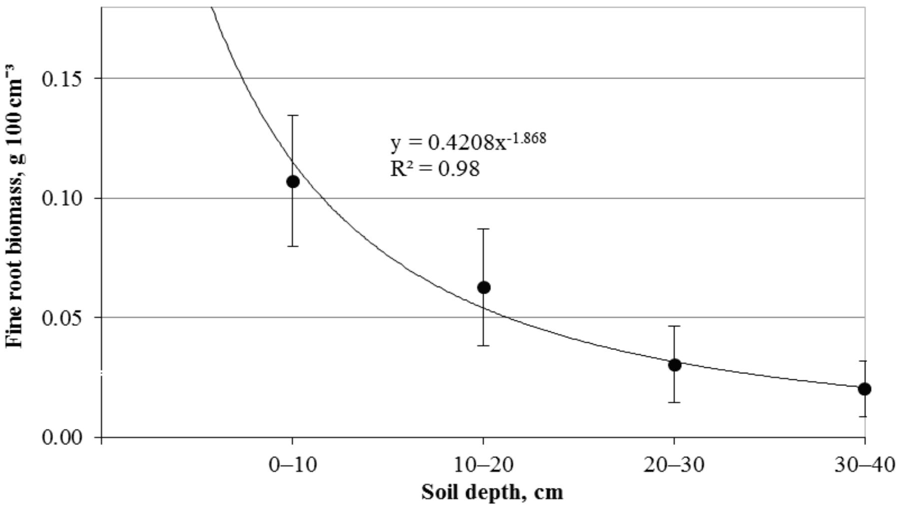

Figure 3. Average fine root biomass and its changes in the soil layer of young grey alder stands. Confidence interval ± 95% indicated in the error bars.

Scientists have developed a number of different biomass equations; however, new equations are needed that could be compared to the present ones, thus improving the biomass calculation models (Zianis et al., 2005). Scientific literature provides different equations for the calculation of root biomass fractions. The most common ones are regression equations with a single effective indicated value. In Europe, simple linear-type logarithmical equations are widely used for calculating root fraction biomass, although non-logarithmical power and straight-line equations are also employed – these use tree height, DBH or the product of squared diameter and height as an independent variable (Zianis et al., 2005). In the framework of this study, a common root biomass equation was developed. Several models were tested and the most precise one was the linear regression model (Formula 1), which included DBH as the single independent variable.

As shown in Fig. 4, tree height and DBH characterise the root biomass non-linearly. The determination ratios of the regression equation are high or moderately high. The data point to a high regression equation determination ratio with the total biomass values for the dependent variable – the tree DBH, or total predicted root biomass ($R^2 = 0.94$). Tree height also exhibits a high regression equation determination ratio with the parameter values, but less than the tree diameter at the height of 1.3 m, especially for total predicted root biomass ($R^2 = 0.66$). The determination ratio in the calculation and prediction of total grey alder root biomass is higher for tree diameter at the height of 1.3 m ($R^2 = 0.80$) than it is if for tree height ($R^2 = 0.31$), as well as for aboveground predictions, especially $R^2 = 0.89$ and $R^2 = 0.64$. Researchers point out that biomass equations should be flexible, multifunctional and applicable to biomass calculations for different tree stands (Repola, 2008).

Consequently, the relationship between tree diameter at the height of 1.3 m, tree height and total root biomass is characterised by a strength correlation, expressed by a correlation coefficient (r) equal to 0.97 ($\alpha = 0.05$) and 0.80 ($\alpha = 0.05$. Biomass is better described by a regression, with tree diameter at the height of 1.3 m as an independent variable.

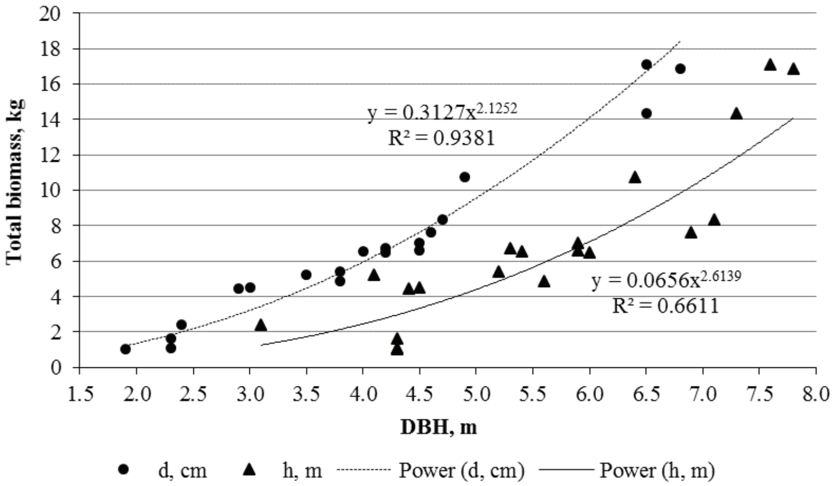

Figure 4. Relationship between the tree diameter and total root biomass.

Diameter at chest height was an effective predictor of all fractions of tree biomass in young grey alder stands, with the coefficient of determination R^2 values ranging from 0.89 to 0.94 ($p < 0.05$ for all models; Table 2). Therefore, the variation in total root biomass can be explained with a 94% model reliability by the developed non-linear regression model. Scientists point out that the developed tree biomass equations are of high value if the determination ratios are high or moderately high (R^2 = 0.63–0.99), allowing to predict the biomass with high precision (Zianis et al., 2005). We discovered that trees with a larger diameter exhibited greater error variance than smaller trees. However, plots of the residuals of coefficients demonstrated that there was no large or systematic bias toward over or underestimation of biomass at any DBH within the range used to develop the models.

Table 2. Allometric models for predicting root biomass in individual specimens taken from young grey alder stands

Biomass fraction	Equation parameter	Value of parameter	SE	p -value	R^2
Aboveground	α	0.163	0.009	0.041	0.92
	β	2.373	0.513	0.001	
Root biomass	α	0.418	0.005	0.009	0.89
	β	1.310	0.768	0.041	
Total biomass	α	0.241	0.002	0.032	0.94
	β	2.324	0.216	0.000	

Note: The models for all dependent variables follow the form $Y = \alpha * X^{\beta}$ where Y is the dependent variable (kg dry weight for root biomass fractions), X is the predictor variable (DBH, cm) and α and β are parameters of the equation. SE is the asymptotic standard error of the parameter estimate. All models were statistically significant ($p < 0.05$).

In conclusion, this study provides some of the first allometric biomass equations for grey alder stands in Latvia's conditions, and as expected, stem DBH was highly correlated with root biomass fractions.

CONCLUSIONS

An equation for calculating grey alder biomass was developed in the framework of this study. The equation remains the same for different tree fractions (coarse roots, stump, stem branches) and for trees of different age in abandoned agricultural lands. The amount of tree biomass in the above-mentioned fractions is characterised by a non-linear power model with one independent variable (DBH), which implicitly includes the effect of the stand age. The model is adapted to each fraction by modifying the numerical values of the ratio. The coefficient of determination of the model for total tree biomass is high at $R^2 = 0.94$.

In grey alder stands, the main part of the root fraction is made up of coarse roots (68% of the total root biomass), followed by the stump fraction (32%). The majority of the aboveground biomass fraction is made up of stem (75%), followed by branches (25%). The biomass of each of these tree fractions is established by a power regression with tree DBH used as an argument. The specific average value of dry biomass in grey alder stands in abandoned agricultural lands is 27.1 ± 2.3 t DM ha^{-1}.

The dry fine root biomass in young grey alder stands is 1.2 ± 0.4 DM t ha^{-1} in the mineral soil layer of 0–40 cm. Fine roots play a key role in tree ecosystems and make up 2.6 ± 0.8% of the total root system, but 8.6 ± 0.9% of the total tree biomass.

The study confirmed the hypothesis that the root fraction biomass can be calculated with high credibility as a function of easily measured tree parameters, i.e. tree DBH.

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