CARBON ACCUMULATION IN OVERGROUND AND ROOT BIOMASS OF GREY ALDER (*ALNUS INCANA* (L.) MOENCH) AEGOPODIOSA

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Abstract

Considering specific role of forest in carbon cycling, the scope of the study is evaluation of assimilation of carbon dioxide in a single grey alder stand. The National statistical forest inventory demonstrates that total area of afforested farmlands is 314 thousands of ha, including 212 thousands of ha are grey alder stands. Empiric data are collected in 2011 in 15 years old grey alder stand representing Aegopodiosa site type, site index II. Dendrometric characteristic of the stand are estimated using a method of 6 sample tree plots. Average height of dominant trees is 9.6 ± 0.14 m, diameter at breast height - 6.7 ± 0.18 cm, volume of stem - 0.02002 ± 0.00673 m^3, number of trees per ha – 5806 ± 560, growing stock - 116.2 ± 20.0 m^3 ha^{-1}. Density of the grey alder stem wood is 411.0 ± 2.2 kg m^{-3}, average relative moisture - 51.6 ± 0.13%. Dry biomass of grey alder in the evaluated stand is 73.4 tons ha^{-1}, including stem biomass - 65.3%, branches - 11.1%, leaves - 2.3%, stump - 6.8% and roots - 14.6%. In average evaluated stands accumulated 36.9 tons ha^{-1} of carbon removing from atmosphere 135.5 t ha^{-1} of CO_2. Wood density is estimated according to ISO 3131:1975 standard, moisture content – according to EN13183-1:2002 standard.

Key words: forest, density, conversion factors, photosynthesis equation.

Introduction

Latvia signed the United Nations Framework Convention on Climate Change (UNFCCC) in Rio de Janeiro in 1992 and ratified it in the parliament of the Republic of Latvia in 1995. The aim of the UNFCCC is reaching stabilization of the concentration of greenhouse gases (GHG) in the atmosphere up to the level to prevent dangerous anthropogenic interference in the climate system. GHG are natural and anthropogenic gaseous compounds in the atmosphere absorbing and re-emitting infrared radiation. They are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6), as well as indirect GHG – carbon oxide (CO), nitrogen oxides (NOx) and non-methane volatile organic compounds (VOC). In accordance with the Kyoto protocol of the UNFCCC (ratified by the parliament of the republic of Latvia in 2002) Latvia, individually or in a joint action with other countries, should reach the level when aggregate anthropogenic direct GHG (CO_2, CH_4, N_2O, HFC, PFC and SF_6) emissions by the years 2008 - 2012 are 8% below emission level of 1990 (LR Vides ministrija, 2010).

During the previous century annual increase of level of anthropogenic emissions was 2.5% on average. One of the factors affecting increase of anthropogenic emissions is reduction of forest area (Nikodemus et al., 2008). Forests cover about 30% of the terrestrial territories of the Earth, and unfortunately there is a tendency of reduction of forest coverage. There are published data, which approve that each hectare of forests sequestrates about 100 tons of organic carbon (Daugaviete et al., 2008).The mount of biomass produced by different tree species is relevant to average density of wood (Miezīte, 2008). Grey alder is fast growing tree specie with high photosynthetic activity and considerably high rate of removals of CO_2 in biomass and soil (Liepa and Gaitnieks, 2002). According to the State forest service data, the area of grey alder stands in Latvia is 192 kilo. ha or 7% of the total forest area, turning this tree specie into one of the most common in Latvia (Gadskārta, 2008). Grey alder is one of the pioneer species, which actively invades abandoned farmlands; therefore, it has an important role in reduction of concentration of GHG in the atmosphere. It should be noted, that ecological role of grey alder is not completely evaluated yet, including the potential of carbon sequestration, especially in relation to quantitative issues of this process on a former farmlands.

The main mechanism securing sequestration of carbon in forest ecosystems is the process of photosynthesis, which uses light energy to convert atmospheric CO_2 into organic compounds, producing woody biomass. Due to this reason biomass method, based on assumption that carbon stock is linearly correlating with biomass, is often used to estimate rate of carbon sequestration. In practice it means, that biomass should be estimated first and then, knowing average concentration of carbon in biomass, the carbon stock can be easily calculated.

The bottleneck of the method is estimation of biomass fractions of the tree and the whole stand. This applies particularly on non-timber fractions of biomass (branches, leaves, stump and roots), which cannot be easily determined directly. This problem is usually solvable by elaboration of the expansion factors, which allow to calculate different biomass fractions from a stem volume or growing stock of a stand.

Biomass stock in a tree or stand depends from content of water in wood; these parameters are closely correlating (Līpiņš and Liepa, 2007). Therefore, it is important to note moisture content which applies to specified biomass figures. The most important are 2 moisture levels – fresh biomass (SB) and absolutely dry biomass (SM), which is determined by drying until constant weight. The SM multiplied by carbon content in absolutely dry biomass is used to estimate carbon stock. Carbon content in biomass csan be determined using chemical methods, which combines analyzes of different fractions of biomass and statistical evaluation of obtained results (Daugaviete et al., 2008). Note, that there is another method of estimation of carbon stock, which is based on summarized equation of photosynthesis (Liepa, 2005; Bārdulis, 2010).

Studies on carbon sequestration potential of grey alder in Latvia, in spite of broad distribution of this specie, is limited. The scope of our study is to estimate carbon accumulated in above- and below-ground biomass of the grey alder in 15 years old stand representing fertile (Aegopodiosa) growth conditions. According to the aim specific tasks of the project are: 1) evaluation of dendromethric characteristic of the grey alder stand; 2) estimation of above- and below-ground biomass of the stand; 3) elaboration of expansion factors for different biomass fractions of the grey alder and calculation of sequestrated carbon and CO_2 in the grey alder stand.

Materials and Methods

The study material was collected in August, 2007 in unmanaged 15 years old grey alder stand growing on fertile dry soil (Aegopodiosa site type) in Jelgava municipality Vilces parish, Eižāti – Mežsargi property. The stand originated due to natural afforestation of abandoned farmland.

Dendromethric characteristics of the stand are obtained using so called 6 trees sample plot method (Kramer and Akca, 1982). Fifteen sample plots are established in the stand, measuring 90 trees in total. The applied measuring approach belongs to a group of methods of rounded sample plots with variable radius. The radius of sample plot is determined by distance from center of the sample plot to the center of the sixth closest tree. This is considered during calculation of the stand dendromethric characteristics (Miezīte, 2008). Diameters at the breast height and G. Kraft classes of least 6 trees are determined in every sample plot. Manual caliper is used to determine diameter at the breast height of the trees. Accuracy of the measurement – 0.1 cm. Height of 15 trees in the stand was determined using VERTEX height meter with the accuracy of 0.1 m.

Site index of the stand is determined using growth tables of the grey alder elaborated by P. Mūrnieks (Mūrnieks, 1963). Data obtained in the sample plots were used to calculate basal area, growing stock and number of trees in the stand as well as the basal area, diameter, height and volume of average tree (Miezīte, 2008). Stem volume (V, m^3) is calculated using equation No. 1 (Liepa, 1996):

$$V = ø \times L^{á} \times D^{â \lg L +} \quad (1),$$

where
L – height of tree, m;
D – diameter of tree with bark, cm;
$\Psi, \alpha, \beta, \varphi$ – empiric coefficients (grey alder: ψ=0.7450 $\cdot 10^{-4}$; α=0.81295; β=0.06935; φ=1.8546).

Above- and under-ground fractions of biomass of the grey alder is calculated using sample tree method. Selected trees were cut down with chainsaw Husqvarna – 254 XP. After cutting the trees were split into fractions – stem, branches and leaves, and all fractions were separately weighted. Below-ground biomass consists of stem and joined underground part of the trees. The root system of each sample tree was extracted separately. After extraction soil particles were washed down from the roots, then the below-ground part was dried for a short time and weighted. Weighting of fractions of the sample trees were done in the field using KERN scales (accuracy ± 0.02 kg). Samples for determination of dry mass SM of all fractions were taken in 3 repetitions and dried in laboratory to constant weight in 80 °C temperature (Uri et al., 2002).

Density of wood in this study is determined according to ISO 3131 (1975) standard, and moisture of wood – according to EN 13183 – 1 (2002) standard.

Seven sample trees as possible equally distributed across the range of the tree diameters at the breast height stand (4.5 - 9.3 cm) were used for evaluation of distribution of different biomass fractions in the studied stand. Height distribution of sample trees is 8.0 - 12.4 m. Trees representing different G. Kraft classes were used for the evaluation. Studies by foreign authors as well as our former investigations approve, that total biomass as well as distribution of biomass between different fractions is determined by the diameter at the breast height. This relation follows to a power regression equation (Liepa, 2005). In our study this regression is used for quality assurance of the field works.

From the point of view of easiness of the biomass calculations, it is reasonable to split a tree or a stand into 2 fractions – stem and non-stem fractions, because besides the method of biomass expansion factors the method of basic wood density P_{red}, characterizing the amount of absolutely dry biomass per volume unit of fresh biomass (for instance, tons m^{-3}), can be used to estimate the biomass. According to literature, basic density of grey alder is usually assumed similar to spruce – $P_{red} = 0.365$ (Боровиков, 1989). According to our studies, basic density of the grey alder stem wood $P_{red} = 0.4110 \pm 0.0022$ tons m^{-3}.

Respectively stem biomass SM_{st} expressed in tons can be calculated by equation No. 2:

$$SM_{st} = ñ_{red} \times V \quad (2),$$

where
V – stem volume or sum of stem volumes (growing stock), m^3.

Non-stem part of trees (branches, leaves, stump and roots) can be estimated only using the expansion factors based on easily acquirable arguments – the stem volume or growing stock. Thus multiplication of the expansion factors with the stem volume or growing stock will produce biomass of particular fractions. The expansion factors are calculated using statistical methods on the base empiric data (Liepa, 2005). Expansion factor c_i of fresh material SB expressed in tons m^{-3} can be calculated with equation No. 3:

$$c_i = \frac{m_i}{v} \quad (3),$$

where
m_i – biomass of the sample tree fraction i, tons;
v – volume of sample tree, m^3.

Expansion factor ca_i of dry material SM can be calculated using equation similar to the formula No. 3, putting absolutely dry biomass in place of m_i.

Note that expansion factors c_i and ca_i can be estimated also for the stem biomass and used for quality control of the calculations.

The fact that carbon stock is proportional to the biomass stock is utilized to calculate carbon stock in biomass. It is approved that independantly from the tree species carbon content in wood varies in considerably narrow range (Brown, 1999; Saliņš, 2002). M. Daugavietis (2006) found that absolutely dry biomass of the grey alder characterizes with the following average values: ash 0.3%, carbon 50.3%, hydrogen 6.3% and oxigen 43.1%. A. Bārdulis (2010) add, that leaves of the grey alder contain 52.5% of carbon. Multiplication of the SM and the carbon content results in accumulated carbon M_C. Carbon is 27.27% of atomic weight of CO_2 molecule, therefore CO2 removed from the atmosphere M_{CO_2} can be calculated using the following equation:

$$M_{CO_2} = 3.667 M_C \quad (4)$$

Statistical processing of empiric data was done with Microsoft Excel 2007 using descriptive statistics, correlation and regression analysis (Arhipova, Bāliņa, 2003).

Results and Discussion

Dendrometric characteristics of trees and stands are correlating and depend on many factors. While growing, trees are affected by several factors and character as well as intensity of the effects depends on the age of the stand (Liepa et al., 1991). Dendrometric characteristics of the studied stand were calculated data of all 90 measured trees. The stand corresponds to 2.8 site index quality class (Mūrnieks, 1963). Average diameter at the breast height $D = 6.7 \pm 0.18$ cm, but average height of trees calculated according to the height curve equation (5) H=9.6 m with R^2=0.99, ($p<0.05$) and $3.8 \leq d \leq 10.4$ cm.

$$H = 5.176 \ln(d) - 0.216 \quad (5)$$

Number of trees in the stand is 5806 ± 560 per ha^{-1}, coefficient of variation 37.3%. Average stem volume (1) is 0.02002 ± 0.00673 m^3 (coefficient of variation 38.8%), basal area – 21.82 ± 2.4 m^2 ha^{-1}, growing stock – 116.2 ± 20 m^3 ha^{-1} with average net increment 7.7 m^3 annually, which is a bit less than values obtained in Swedish studies (8.4 m^3 annually) about increment in sixteen 4 to 36 years old grey alder stands on former farmlands (Johansson, 2000). Dominant stand consists of 76% of all trees and undergrowth – of 24% of trees.

Distribution of fractions of fresh and dry biomass in studied stand is estimated by extraction of sample trees and weighting of each fraction separately. Weighting results of fresh biomass SB are shown in Table 1. Fractions are distributed in the following order: stem – 64.6%, branches – 11.3%, leaves – 3.8%, stump – 6.7% and roots – 13.6% (relative moisture of wood 51.6 ± 0.13%). Ratio of above-ground (leaves+branches+stem) and below-ground (stem+roots) biomass is 3.9:1, which is contrasting with findings of other authors (Uri et al., 2008). According to these studies ration of above-ground and below-ground biomass is 3:1. Note the different variability of data characterizing different biomass fractions – the smallest variability found in root biomass (coefficient of variation s%=46.9%), the largest – in biomass of leaves (s%=80.6%). It is possible, that these values characterize competition of sample trees and their neighbour trees, in other words – difference in density of the stand in places, where sample trees were extracted. Empirical data about dry biomass SM are summarized in Table 2.

Considering labor intensity of collection of empiric data number of sample trees is minimal – only 7. These trees represent equal range of dimensions of trees growing in the stand and regression analysis is used for mathematical evaluation of empirical material; however, taking in account the key role of obtained data in development of the expansion factors, additional evaluation of representativeness of the sample trees was done. Practically it was implemented by comparison of average dendrometric characteristics of the sample trees (PK) and all measured trees (PL). Results of comparison: PL h = 9.6 m, PK h = 9.8 m; diameter at the breast height – PL d = 6.7 cm, PK d = 6.9 cm; stem volume – PL v = 0.02002 m^3, PK v = 0.01966 m^3. Difference in all cases was less than 3%, which approves the representativeness of the sample trees; in other words – they can be used to develop biomass expansion factors.

Table 1

Dimensions of trees and fresh biomass (SB)

No	d, cm	h, m	V, m^3	Total biomass, kg	Stem, kg	Branches, kg	Leaves, kg	Stump, kg	Roots, kg
4	4.5	8.0	0.0072	10.14	6.56	0.42	0.18	0.60	2.38
3	4.7	8.4	0.0082	11.50	7.04	1.94	0.36	1.08	1.08
6	6.0	11.0	0.0165	22.84	13.90	2.80	0.70	1.04	4.40
7	7.0	12.4	0.0245	29.16	20.16	2.68	0.80	1.72	3.80
5	7.9	11.9	0.0300	40.48	26.09	4.63	1.42	2.52	5.82
2	9.0	11.9	0.0386	46.95	31.36	5.20	2.06	2.86	5.47
1	9.3	12.3	0.0423	56.37	35.30	6.90	2.80	4.68	6.69
X	6,9	11.0	0.0217	31.06	20.06	3.51	1.19	2.07	4.23
S	28.1	17.2	58.5	56.9	57.1	62.4	80.6	68.2	46.9
S_x	0.73	0.70	0.0053	6.68	4.33	0.83	0.36	0.53	0.75

Note: X – mean; *S* – relative standard deviation; S_x – standard error of mean.

Table 2

Dry biomass of sample trees (SM)

No.	Total biomass, kg	Stem, kg	Branches, kg	Leaves, kg	Stump, kg	Roots, kg
4	4.92	3.2	0.2	0.06	0.29	1.17
3	5.47	3.4	0.9	0.11	0.53	0.53
6	10.98	6.8	1.3	0.22	0.51	2.16
7	14.15	9.9	1.3	0.25	0.84	1.86
5	19.53	12.8	2.2	0.44	1.23	2.85
2	22.62	15.4	2.5	0.64	1.4	2.68
1	27.04	17.3	3.3	0.87	2.29	3.28
X	14.96	9.83	1.67	0.37	1.01	2.08
S	46.9	28.1	57.3	63.0	80.2	68.2
S_x	0.37	0.73	2.13	0.40	0.11	0.26

Quality of field works is also evaluated according to strong correlation between diameter at the breast height and total biomass, which can be expressed as a power regression equation. This finding is approved in several studies (Liepa, 2005; Miezīte, 2008) including this research (Fig. 1). Taking into account that empirical points are grouped closely around the power regression curve (R^2=0.902, p<0.05), it can be considered that empirical data are acquired correctly, consequently following to the methodology and can be utilized in the following calculations.

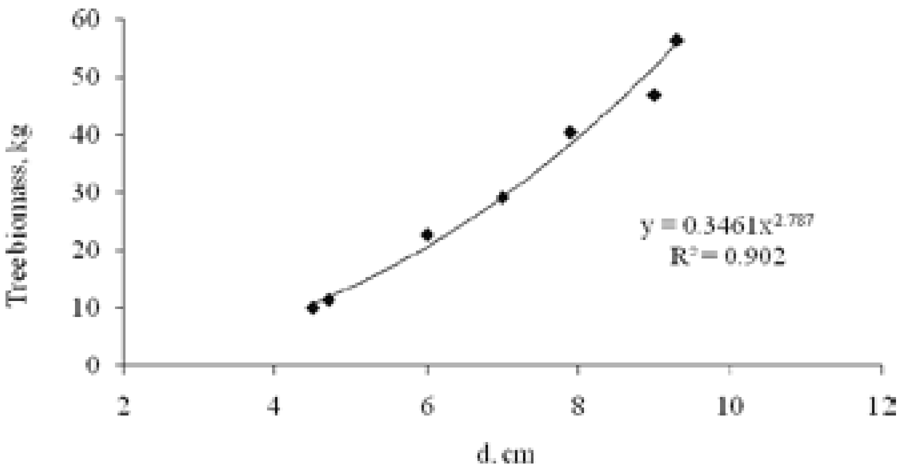

Figure 1. Regression characterizing relation between diameter at breast height and tree biomass.

Biomass expansion factors are calculated for fresh (SB) and dried (SM) biomass. According to the methodology, they are expressed in tons m^{-3} as ratio of particular fraction of biomass and the stem volume (3). Results of calculations of the expansion factors are shown in Table 3 and can be utilized for calculation of biomass fractions of the grey alder. A particular biomass fraction can be calculated by multiplication of the stem volume or growing stock in m^3 and the expansion factor of specified fraction. For instance, biomass of fresh branches in the studied stand can be calculated using the following approach: $SB_{branches} = V \cdot c_z = 116.5\ m^3\ ha^{-1} \cdot 0.1468\ tons\ m^3 = 17.1\ tons\ ha^{-1}$. SB and SM expansion factors are calculated as weighted average. The weighting was done: for stem fraction – against stem volume, for other fractions – against diameter at the breast height. This procedure is considered useful to reduce effect of number of sample trees to evaluate expansion factors.

Table 3

Parameters of calculation of evaluated grey alder stand in Aegopodiosa growth conditions

Parameter	Biomass fraction				
	stem	branches	leaves	stump	roots
Expansion factors of fresh biomass SB c_i, t m^{-3}	0.8388	0.1468	0.0469	0.0872	0.1873
Fresh biomass in the stand, t ha^{-1}	97.7	17.1	5.5	10.2	21.8
Share of the SB fraction, %	64.2	11.2	3.6	6.7	14.3
Expansion factors of dry biomass SM ca_i, t m^{-3}	0.4110	0.0697	0.0146	0.0426	0.0919
Stock of dry biomass in the stand, t ha^{-1}	47.9	8.1	1.7	5.0	10.7
Share of the SM fraction, %	65.3	11.1	2.3	6.8	14.6
Carbon content in dry biomass SM, kg C per kg of biomass	0.503	0.503	0.525	0.503	0.503
Accumulated carbon C, t ha^{-1}	24.1	4.1	0.9	2.5	5.4
Accumulated carbon C, t m^3	0.2067	0.0351	0.0077	0.0214	0.0462
Sequestrated CO_2, t ha^{-1}	88.3	15.0	3.3	9.2	19.7
Expansion factors of carbon cc_i, t m^{-3}	0.2067	0.0351	0.0077	0.0214	0.0462

The sum of expansion factors of different biomass fractions and a tree diameter at the breast height (1.3 m) have an insignificant correlation ($R^2=0.217$, $p<0.05$) due to dendromethric diversity of sample trees (different trees are selected advisedly to represent different G. Kraft classes and diameters). This correlation, pointing at the necessity to calculate expansion factors as the weighted average, allow to estimate SB and SM fractions of a stand or bunch of stands using only weighted values of the expansion factors of particular species, which considerably simplify estimation of the biomass stock, as it is necessary to know only one value – the growing stock, to estimate total biomass or specific fractions of biomass in the stand.

Carbon accumulated in the studied stand can be expressed as a product of two values – expansion factor of specific biomass fraction ca_i and carbon content in biomass, CO_2 can be calculated by using equation No. 4. In order to calculate carbon stock, expression of carbon content in tons per m^3 of fresh wood is more handy approach. In this case carbon stock can be calculated directly by multiplication growing stock with the content of carbon per m^3. Results of calculations of carbon stock and accumulated CO_2 are shown in Table 3.

Conclusions

The study data on non-stem biomass fractions of trees are obtained from 7 sample trees growing in Jelgava forest district, in 15 years old grey alder stand characterized by Aegopodiosa growth conditions, site index 2, growing stock $116.2 \pm 20\ m^3\ ha^{-1}$, number of trees 5806 ± 560 per ha^{-1} ($p<0.05$).

Expansion factors c_i of non-stem biomass fractions (branches, leaves, stump and roots) of the particular grey alder stand can be calculated as ratio between biomass of the biomass fractions and the stem volume, the application is restricted to the trees having diameter at breast height 4.5…9 cm.

Carbon stock in the grey alder stands can be expressed as a product of expansion factor of particular biomass fraction ca_i and carbon content in this fraction, but in case if carbon content should be calculated directly from volume units (m^3) of fresh wood, then carbon stock can be estimated by multiplication of the expansion factor with timber volume or growing stock.

The results of the study approves that the evaluated method can be applied to elaboration of biomass and carbon expansion factors for grey alder stands on regional or national scale.

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