POTENTIAL OF PRODUCING WOOD BIOMASS IN SHORT-ROTATION GREY ALDER (*ALNUS INCANA* MOENCH) PLANTATIONS ON AGRICULTURAL LANDS

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Abstract. *The paper describes the potential of producing wood biomass in short rotation tree plantations (rotation period 5, 10 and 15 years) on agricultural lands. The research is focused on managing naturally emerging grey alder (Alnus incana Moench) coppice on agricultural lands, following up its course of growth and estimating the volume of biomass to be recovered. Grey alder as a fast-growing specie is suitable for short-rotation plantation cultivation in sites of nutrient-rich soils (site index H20=12m). Coppice of grey alder between the age of 5 and 15 years may be cultivated as a short-rotation plantation with the biomass yield depending on growing conditions from 20 to 445 loose* m^3 ha^{-1} *and gross income between 189 and 4201 EUR* ha^{-1}. *In grey alder plantations of site index H20=12, H20=16 and H20=20 you may already at the age of 10 to 15 years harvest pulpwood (top diameter 7cm under bark), packaging wood and fuel wood; the amount to be obtained depends on the intensity of thinnings done in age class I. As follows from the results, the average volume of fresh biomass in one year-old untended coppice of grey alder varies from 1.43 t* ha^{-1} *to 11.15 t* ha^{-1} *with the mean shoot height Hv=1.4 m and highly variable number of stems per unit area. In two-year old stands this variation is from 5.27 t* ha^{-1} *to 28.50 t* ha^{-1} *with the mean stem height Hv=2.5 m; in three-year old stands – from 7.95 t* ha^{-1} *to 36.60 t* ha^{-1} *(mean height Hv=3.0 m); in four-year old stands – from 18.83 t* ha^{-1} *to 52.80 t* ha^{-1} *(mean height Hv=4.4 m); in five-year old stands – from 22.91 t* ha^{-1} *to 64.23 t* ha^{-1} *(mean height Hv=4.8 m).*

Key words: *grey alder, naturally moist biomass, average height, number of trees per ha, productivity.*

INTRODUCTION

Over the past decades research on cultivating forest crops for energy wood has received increasing attention mainly due to the need to substitute fossil fuels for those recovered from renewable resources. In the boreal forest zone grey alder (*Alnus incana* (L.) Moench) is one of the fastest-growing species which yields both timber assortments and energy wood. In Latvia, between the 1930s and 2010 the area of grey alder stands has increased significantly because of abandoned farmlands taken over by forest [2]. This process is still ongoing, and according to the 2014 data of the Statistical Bureau the area under grey alder is as high as 210700 ha (stock volume 30.3 million m³), which accounts for 11.4% of the total forest area (www.csp.gov.lv). In the Nordic countries, in 1980-1990s extensive research was carried out on cultivating grey alder and Salix species for wood chips.

In 2005-2009, the Latvian State Forest Research Institute Silava (LSFRI Silava) performed research on the potential of using grey alder coppice for short-rotation cultivation of energy wood (rotation for 5, 10, and 15 years). As proved by the results, grey alder appears to be a superior species for short-rotation plantations: 1) high productivity in a relatively short period; 2) no need for additional soil improvement due to symbiotic nitrogen fixation (actinomyce *Frankia*); 3) high resistance against unfavourable climatic conditions, diseases and pests; 4) coppicing ability which entails considerably less investments in stand regeneration and protection; 5) relatively simple stand management [2], [3].

In Sweden, Finland, Estonia and elsewhere a number of scientists have attempted determining mathematically the amount of biomass produced by grey alder stands, using regression equations with one or two variables – the DBH and tree height, as well as the mean diameter or stand basal area, determined on the basis of sample plots [4],[9]. In Latvia, significant studies on the productivity of grey alder stands have been done by a number of scientists [8], [5], [3]. In the mid-20th century P. Mūrnieks graphically developed the growth and yield tables for grey alder using the traditional methodology based on the data obtained from 80 sample plots measured once [8].

Recently J. Bisenieks and M. Daugavietis proposed mathematical models for determining the growth and yield of Latvian grey alder stands [3].

O. Miezīte has studied the problem of determining the biomass volume of sapling stands by using regression equations with a single variable – DBH, and the stand basal area – for calculating the volume of above-ground biomass in untended grey alder stands [7]. To calculate the biomass volume of sapling stands the LSFRI Silava researchers used regression equations with a single variable – the shoot height [1].

Some pilot experiments of initial fertilization of grey alder plantings as SRF (short rotation forestry) started at 2011 demonstrate, that fertilization of grey alder with wood ash could decrease increment [6].

The 2009 Cabinet Regulations No. 139 with amendments of 12.03.2013 provide for EU fund-supported short-rotation plantation cultivation of *Salix*, *Populus* and *Alnus* species in agricultural lands without undergoing the procedure of land use transformation (www.lad.gov.lv). The 2014 amendments in the Law on Rural Development define the concept of the plantation of woody plants as a definite-purpose establishment in regular patterns and longer-term cultivation of woody plants (except fruit tree orchards, tree nurseries and ornamental planting) in agricultural lands with the maximum rotation period of 15 years, followed by the crop regeneration or cultivation of farm crops other than woody plants. The above statutory provisions prove that Latvia is determined to pursue the course of using renewable resources for energy.

The goal of the research is to determinate the productivity of grey alder stands with and without tending and to develop a practical method for obtaining the source data necessary for calculation of the biomass of uncultivated grey alder stands aged 1 to 5 and 5 to 15 years.

MATERIALS AND METHODS

To determine the biomass yield in 10-15 year-old grey alder coppice stands sample plots were established and the related measurements made using the methods practiced in forest statistical inventory. Depending on the number of stems in the stand, three types of circular sample plots were set up: 100 m^2 with all stems measured; 500 m^2 with all stems measured; and 500 m^2 with the stems measured in three sectors depending on stem diameter. In all sample plots following measurements were made: diameter of all stems; height of 15-20 stems for calculating the height curve; width of the last 5 annual growth rings by using increment cores from 20 sample stems. In each sample plot increment cores were also taken from 10-12 sample stems for determining the stand age. Totally 42 sample plots were established and measured. For data processing and calculating the stand parameters, three mathematical models were developed and used in the *Excel* format – one for each type of sample plots. The formulas of I. Liepa were used for calculating of stem volume and the reduced current stand volume increment (1),(2):

$$v = 0.7450 \cdot 10^{-4} L^{0.81295} d^{0.06935 \lg L + 1.85346}, \qquad (1)$$

where: v – grey alder stem volume (m^3) with bark;
L – stem height, m;
d – DBH, cm.

$$Z'_M = 12732.4 \Psi H^{\alpha} D^{\beta \lg H + \varphi - 2} \left[\frac{Z_H(\alpha + \beta \lg D)}{H} + \frac{Z_D(\varphi + \beta \lg H)}{10D}\right], \qquad (2)$$

where: Z'_M – reduced current actual stand volume increment, m^3 $(m^2)^{-1}$;
H – average height, m;
D – average diameter, cm;
Z_H – current increment of average height, m;
Z_D – current increment of DBH, mm;
$\psi = 0.7450 \cdot 10^{-4}$, $\alpha = 0.81295$, $\beta = 0.06935$, $\varphi = 1.85346$.

For determination of the above-ground biomass of young grey alder stands, 15 stands of grey alder aged 1-5 years were selected, and the biomass of 3 stands in each age group with an area of at least 1 ha was measured.

In young grey alder stands after every 10 m a circular sample plot (radius 1m; size 3.14 m²) was established following the transect method with the sample plots accounting for 3% of the area. A total of 145 sample plots were established, in which all stems were measured, determining the root collar diameter $D_{root\ collar}$ (cm) of each grey alder stem, and the height H (m); the diameter was measured with a caliper (HAGLOF, Sweden; accuracy ±0.1 cm), the height – with a measuring pole (SK SENSHIN Japan; accuracy ±1 cm). Each stem was cut down, defoliated and weighed using the KERN sales (accuracy ±2g), thus obtaining the biomass (stem + branches) of each stem.
The number of tree stems per 1 ha was calculated using the following formula (3):

$$N = \frac{n1 + n2 + n3}{npl} \cdot 3185, \quad (3)$$

if the sample plot radius R = 1 m,

where: $n1, n2, n3 ... nx$ – number of tree stems in individual sample plots,
npl – number of sample plots.

The average stand height was calculated using the following formula (4):

$$Hv = \frac{h1 + h2 + h3 .... hn}{h1 * n + h2 * n + h3 * n + ... hn * n}, \quad (4)$$

where: Hv – average stand height, m
$h_{1,} h2, h3 .... hn$ – height of saplings measured in sample plots, m
n – number of repetitions.

The biomass of grey alder per 1 ha M (kg ha^{-1}) was calculated using the following formula (5):

$$M = 0.0536 \cdot Hv^{2.2516} \cdot N, \quad (5)$$

where: Hv – average grey alder height, m;
N – number of trees per 1 ha [1].

The data processing and confidence calculations were done following the methods of mathematical statistics by using the *Microsoft Office Excel 2013*, and calculating the parameter mean values, standard deviations and relative errors – by using the SPSS software.

RESULTS AND DISCUSSION

As the field data show, the growth of grey alder differs depending on the growing conditions. In nutrient-rich and adequately drained soils (site index H20=20) the growth of gray alder in age class I is only slightly behind that of hybrid aspen.
For grey alder on the sites of higher site index the standing volume differs considerably. As it follows from Table 1, in higher site index sites (H20=12-20) the yield of stem wood already at the age of 15 years may be as high as 77-178 m^3 ha^{-1} [1].
It is to be noted that in unfavorable growing conditions (site index H20=8) the performance of gray alder is poor and there is no reason for cultivating it on such sites especially as a short rotation crop.
Previous and current studies on the natural regeneration of grey alder show that it coppices abundantly on the sites felled in winter [5],[2].
Depending on the site type, the number of stems in coppice growth varies from 33 360 per ha^{-1} (*Oxalidosa* site type) to 220 000 per ha^{-1} (*Mercurialiosa mel*). In *Aegopodiosa* and *Oxalidosa* site types grey alder stems account for 67% of the total with this index up to 95% in *Hylocomiosa* site type. With stem dimensions increasing their number per unit area decreases and the competition among them declines with age. In two-year grey alder coppice the number of stems declines in *Aegopodiosa* by 16% on average, in *Mercurialiosa*

mel – by 46 %, in *Hylocomiosa* – by 30%, in *Oxalidosa* – by 25% [2]. In subsequent years the number of grey alder stems in three-, four- and five-year stands falls compared to the previous year by 15-20% on average, while in adequate ambient conditions (light, moisture, etc.) it continues to develop basal shoots (Table 2).

Table 1

Productivity of Grey alder stands per ha

Age, years	Tree stem height, m	DBH, cm	Number of tree stems per ha	Volume of medium tree stem, m^3	Yield, $m^3 \cdot ha^{-1}$	Biomass, loose m^3 (0.4 t naturally fresh)
Site index H_{20}=8						
5	2.7	2.3	10000	0.0008	8	20
10	4.8	4.1	5192	0.0038	20	50
15	6.5	5.7	3539	0.0096	34	85
Site index H_{20}=12						
5	4.1	3.4	8000	0.0024	19	47.5
10	7.2	5.9	4251	0.0108	46	115
15	9.8	8.2	2937	0.0262	77	192.5
Site index H_{20}=16						
5	5.4	4.5	6000	0.0050	30	75
10	9.7	7.8	3302	0.0230	76	190
15	13.1	10.8	2328	0.0554	129	322.5
Site index H_{20}=20						
5	6.8	5.8	4000	0.0097	39	97.5
10	12.1	10.0	2339	0.0436	102	255
15	16.4	13.8	1709	0.1041	178	445

Table 2

Average number of stems, growth parameters and biomass in cutovers in 1 to 5 years after logging

Age of grey alder saplings, years	Number of trees per 1 ha	Diameter of root collar, cm	Height of trees, m	Weight of trees, kg
1-year	70 000	0.91±0.21	1.38±0.45	0.066±0.058
2-year	56 000	1.67±0.42	2.5±0.58	0.33±0.13
3-year	44 100	2.49±0.59	3.04±0.64	0.72±0.35
4-year	38 500	2.94±0.63	4.38±0.64	1.32±0.61
5-year	35 000	4.07±0.53	4.81±0.54	2.09±0.72

When comparing the data obtained in the given research with those of Swedish and Estonian [9] scientists, it is concluded that the number of grey alder stems decreases by an average of 20% in the second year, and by 37% in the third year, compared to the initial number of stems per hectare.

Field measurements show that the distribution of grey alder stems in young, naturally regenerated and untended coppice stands is highly uneven as, due to the effect of various factors (light, density, competition by grass and other tree species, skidder routes, etc.), the grey alder shoots up in groups, and therefore the number of stems in biomass measurement sample plots (size 3.14 m²) varies considerably – from 0 to 30 or more stems.

The study results show that the biomass of young grey alder stands (1-5 years old) can be calculated with sufficient confidence by measuring the mean height and the number of stems per unit area, as in one- and two-year old stands we cannot determine the DBH at the stem height of 0.8-1.3 m [1].

The results of calculation of the biomass of young grey alder stands are summarized in Table 3.

As research data shows, the average volume of fresh biomass in one year-old untended sapling stands of grey alder varies considerably from 1.43 t ha^{-1} to 11.15 t ha^{-1} with the mean stem height Hv=1.4 m and a highly variable number of stems per ha (Table 3). In two-year old stands this variation is from 5.27 t ha^{-1} to 28.50 t ha^{-1} with the mean stem height Hv=2.5 m; in 3-year old stands – from 7.95 t ha^{-1} to 36.60 t ha^{-1} (mean height Hv=3.0m); in 4-year old stands – from 18.83 t ha^{-1} to 52.80 t ha^{-1} (mean height Hv=4.4m); in 5-year old stands – from 22.91 t ha^{-1} to 64.23 t ha^{-1} (mean height Hv=4.8m (Table 2).

Table 3

Above-ground biomass fresh of young grey alder stands (age 1-5 yr.), t·ha^{-1}

		Number of trees per ha				
age of stand, years	**average height of trees, m**	**10000-15000**	**30000-40000**	**50000-60000**	**65000-70000**	**95000-100000**
1-year	1.4	1.43	3.39	6.58	7.72	11.15
2-year	2.5	5.27	13.49	24.27	28.50	
3-year	3.0	7.95	22.29	36.60		
4-year	4.4	18.83	52.80			
5-year	4.8	22.91	64.23			

It may be concluded from the research data that in order to achieve a high biomass volume in grey alder coppice thinnings ought to be done no later than at the age of two years, thinning high density groups of saplings to achieve an even distribution of stems over the site and taking out undesired undergrowth trees and shrubs (especially aspen, and also bird cherry, willow, buckthorn).

Taking into account the current market prices of wood chips www.csb.gov.lv), gross income from one ha of grey alder short rotation plantation at the age of 15 years may be as high as 4 201 EUR ha^{-1} (Table 4).

Table 4

Cost-efficiency of Grey alder plantations

Age of stand, year	**Grey alder**		**loose m³ (0,4 t dry matter)**	**Gross income, EUR (8+VAT EUR·b.m³)**
	V, m³ha^{-1}	SM, t.ha^{-1}		
5	8-30	3.4-12.9	20-75	189-708
10	20-102	8.6-43.9	50-255	472-2407
15	34-178	14.6-76.5	85- 445	802-4201

The research data also show that by cultivating grey alder on nutrient-rich sites (site index H20=12; H20=16 and H20=20) already at the age of 15 years it is possible to obtain not only wood chips but also fuel wood and pulpwood assortments (top diameter under bark 7cm) (www.kronospan-riga.lv/, http://www.db.lv).

In Latvia, the 2014 price level for grey alder pulpwood varied between 17 and 31.80 EUR ha^{-1}, and for grey alder fuel wood – from 15.63 to 25 EUR EUR ha^{-1}. In lower site index stands grey alder could be cultivated for wood chips (price level for chips 8.00+VAT EUR per loose m^3).

CONCLUSIONS

Grey alder as a fast-growing tree species is suitable for short-rotation plantation cultivation in sites of nutrient-rich soils (site index H20=12m).

5-15 years old grey alder coppice may be cultivated as a short-rotation plantation with the biomass yield depending on growing conditions from 20 to 445 loose m^3 ha^{-1} and gross income between 189 and 4 201 EUR ha^{-1}.

In grey alder plantations of site indices H20=12, H20=16 and H20=20 it is possible already at the age of 10 to 15 years to recover such assortments as pulpwood (top diameter 7 cm under bark), packaging wood and fuel wood; the amount to be obtained depends on the intensity of thinnings done in age class I.

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