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Growth and Yield of 15-Year Plantations of Pine, Spruce and Birch in Agricultural Land

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Abstract. The growth data and the potential returns from 15-year-old plantations of pine *Pinus sylvestris* L. (6 trial sites), spruce *Picea abies* Karst L. (9 trial sites) and silver birch *Betula pendula* Roth (13 trial sites), established in abandoned agricultural lands in a variety of soil types (sod calcareous, anthrosols, podzolic, podzols, gley, podzolic gley, alluvial), using the planting density 2,500 and 3,300 and also 5,000 trees/ha are analysed.

For tree plantations in agricultural soils (alluvial sod-gley, gley-sod podzolic, sod-podzolic gley, typic podzol) at the survival of 80-98% the stock volume for 15-year pine is as high as 102-155 m^3ha^{-1} with the volume growth 5.72-8.94 m^3ha^{-1} per year; the same indices for spruce in agricultural soils (gley sod-calcareous, sod-podzolic, cultivated, sod-podzolic gley, alluvial sod-gley, base-unsaturated brown) are 75-98 m^3ha^{-1} and 10.26-15.76 m^3ha^{-1}, respectively. For 15-year plantation birch the mentioned indices may vary from 61 to 169 m^3ha^{-1} and from 7.54 to 29.82 m^3ha^{-1} per year. The lowest volume growth (4.66 m^3ha^{-1} per year) is for birch in heavy clay soil (gleyic sod-podzolic), the highest (29.72-29.82 m^3ha^{-1} per year) – in cultivated soils and pseudogley soil.

Plantation cultivation of pine, spruce and birch in agricultural lands may by the age of 15 years yield with a profit such forest products as pulpwood, fire wood and woody biomass. The gross income gained from first commercial thinnings of plantation pine, utilizing pulpwood, fire wood and logging residue biomass, may vary from 679-2267 EUR ha^{-1}, for spruce the same indices are 1644-3272 EUR ha^{-1}, for birch - 683-2188 EUR ha^{-1}.
Key words: pine; spruce; birch; growth and yield; stock volume; biomass; gross income.

Introduction

The plantations of ligneous plants and forest stands have been at the center of attention both in economic, ecological, and social sectors for several centuries now (West, 2014). Scientists and practitioners are unanimous: as the population of the world increases, so does the need for timber, wood biomass and its products, and forest plantation industry plays invaluable role in satisfying these needs. The worldwide experience shows that the plantations of ligneous plants are the main source of timber and wood biomass for providing building materials, manufacturing of paper, and energy wood production. Besides, these plantations serve as carbon sinks and give substantial contribution in reducing the greenhouse effect (Carnus *et al*., 2006; Del Lungo, Ball & Carll, 2006; Zanchi *et al*., 2007; Paquette & Messier, 2010; West, 2014; Global Forest Resources Assessment, 2015).

In the boreal and semi-boreal forest zone, as well as in the countries of the northern part of Europe - Norway, Finland, Sweden, the Baltic states - the main coniferous tree species planted in the forest plantations are those of the pine (*Pinaceae*) family - pines (*Pinus* spp.- *Pinus sylvestris*, *Pinus murayana*, *Pinus contorta* a.o.), spruce (*Picea* spp.- *Picea abies*, *Picea sithensis* a.o.), larches (*Larix* spp.- *Larix decidua*, *Larix sibirica*, *Larix x eurolepis* a.o.), as the main deciduous tree species we can mention birch family (*Betulaceae*) species: birches ((*Betula pendula*, *B.pubescens*), alders (*Alnus glutinosa*, *Alnus incana* a.o.), hybrid aspens, poplars (*Populus tremula x P.tremuloides*, *Populus x canadensis* a.o.), osier varieties (*Salix* spp.) a.o. (Global

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Forest Resources Assessment, 2015, Nabuur *et al*., 2014).

Scientists conclude that when selecting areas for plantation establishment not only the choices of the location - soil type, hydrological regime and microclimate must be taken into consideration, but also, depending on those characteristics, the plantation establishment technology, one or several tree species, management regime, and potential future products must be determined. Depending on the type of the plantation (short-rotation - for obtaining biomass, pulpwood, veneer log, sawlog production) appropriate tree species must be selected and establishment density (500-5000 trees/ha or 10 000-25 000, species of ligneous plants - Salix species, willow species, viburnums, elders (Mather, 1993; Johansson, 1996; Savill *et al*., 1997; Brown, 2000; Weber, 2000; Daugaviete *et al*., 2003; Feedman, 2005; Zanchi *et al*., 2007; Halldorsson, Oddsdottir & Eggertsson, 2007; Hynynen *et al*., 2010; Lazdiņš, 2011; Lazdins *et al*., 2011; *Liepiņš*, 2011; West, 2014; Daugaviete *et al*., 2015).

Expierence with afforestation demonstrates that throughout Nordic region of the EU, there has been increased emphasis on the use of native species - pine, spruce and birch (Savill *et al*., 1997; Sedjo & Botkin, 1997; Weber, 2000; Halldorsson, Oddsdottir & Eggertsson, 2007; Zanchii *et al*., 2007; Hynynen *et al*., 2010; Kund *et al*., 2010; Tullus *et al*., 2012; West, 2014). The scientists and practitioners came to the conclusion – in Northen Europe, birch and spruce are comerrcially the most important tree species for plantation forestry (Johansson, 1996; Savill *et al*., 1997; Rytter & Werner, 2007; Haldorsson, Oddsdottir & Eggertsson, 2007; Hynynen *et al*., 2010; West, 2014).

The issue about rational land utilization became topical once more in the mid-90s of the 20th century when, following the agrarian reform, 36.6% of agricultural lands (AL) and 42% of forest land ended up in the possession of private owners[1].

From 1999-2015 the area of AL afforested with improved planting material already constituted 32 357 ha, including 9502 ha of plantation forests (29.4% of afforested areas)[2].

In Latvia, substantial research about the growth and management of pine, spruce, birch, aspen, hybrid aspen, ash, larch stands in AL was done by forest scientists P.Sarma (1949), P.Maike (1953), R.Sacenieks and V.Gaross (1961).

In the 1960s the growth of birch plantations on former AL was studied by P.Maike, who concluded that the plantations in these areas reach the site index of I – Ia and that in 1950s their standing volume has been up to 439 m^3ha^{-1}. Tree trunk form and pruning evaluated as being good, and these plantations have been deemed suitable for obtaining good quality industrial timber (Maike, 1952).

Extensive research on pine and spruce growth on former AL between 50s and 70s of the 20th century has been done by Sarma (1949), Sacenieks, Gaross (1961), a.o. Scientists have concluded that artificially established and natural stands on former AL develop much faster in comparison with natural stands in forest soils. For spruce, the current annual height increment culminates in the age class I, but the standing volume - in the age class II. Plantations on former AL show high site index class: spruce plantations Ia-Ic, pine plantations – Ia site index. Spruce stand mean annual increment reaches 10-12 m^3ha^{-1} per year (Sarma, 1949). 48-year-old spruce pure stand reaches 361-548 m^3ha^{-1}, whereas pine pure stand reaches 291-298 m^3ha^{-1} at the age of 35-40 years.

Since 1995 research has been done on the growth of plantation forests on former AL, assessing the growth of various tree species and stem quality in current and former year plantations (Daugaviete *et al*., 2003; Daugaviete, 2005; Daugaviete, K.Liepiņš & J.Liepiņš, 2011; Daugaviete *et al*., 2015, Lazdiņš, 2011, Liepiņš, 2011). It has been concluded in this research that in age class I (0-20 years) stands on former AL show higher growth indices (mean height, mean diameter, volume current annual increment), but in the following age classes the growth evens out.

The research continues, as the processes in the environment and the plantation establishment technologies have changed significantly. In the last decade in Latvia, due to both climatic changes and rational land management guidelines, introduction of regulations on growing plantation forests, short-rotation plantations and plantations of ligneous plants that allow for the possibility of establishing ligneous plant plantations on agricultural lands - plantations the maximum growth period of which is up to 15 years, without transforming the land into forest land[3], improvement of the volume and quality of the grown planting material, scientists are carrying out in-depth research about the development and productivity of plantations and plantation forests on afforested AL, as well as the assessment of these stands.

The aim of the research: to explain the growth and productivity of 15-year-old plantation-type stands of most widespread tree species - pine, spruce,

1 http://www.csb.gov.lv/statistikas-temas/metodoloģija/lauksaimnieciba-izmantojamas-zemes-izmantošana-38278.htm

2 http://www.vmd.gov.lv/StateForestService.LatvianForest Sector, 2015

3 http://likumi.lv/doc.php?id=87480

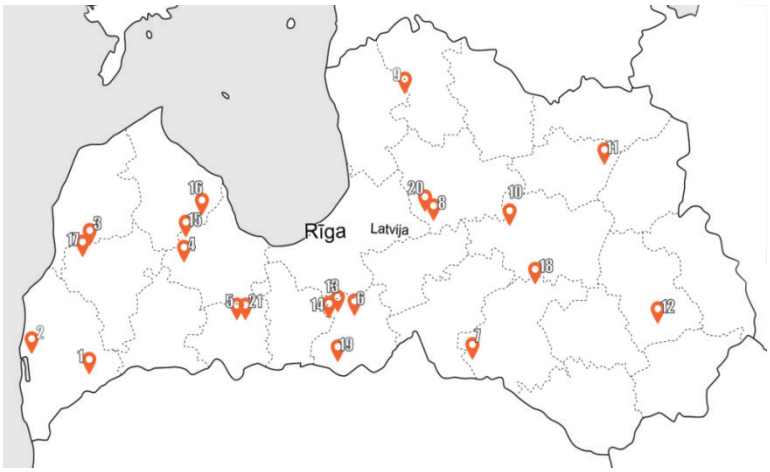

Figure 1. Site location of experimental plots.

birch - in various AL soils, and assess the economic effectiveness of these plantations.

Materials and Methods

The research material has been gathered at 21 established experimental plantations and 150 sample plots in afforestations of AL in the territories of Grobina, Priekule, Kandava, Dobele, Ozolnieki, Bauska, Viesite, Amata, Koceni, Madona, Gulbene and Rezekne municipalities (Table 1; Figure 1).

Legend: Birch (*Betula pendula* Roth.), Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* (L.) Karst.).

In each plantation, the tree growth and productivity monitoring has been conducted, determining the following parameters: tree height, m; tree diameter at breast height, cm; tree stem quality knottiness below 2 m, above 2 m, spike knot - below 2 m and above 2 m, stem, m. Measurements repeated every 1–5 years. The first 5 years after establishment of plantations measurements repeated each year. Total monitoring period was 15 years.

In each sample plot standing volume has been calculated (Liepa, 1996), volume of mean tree, standing volume current annual increment, biomass of each tree components (stem, branches, leaves), and freshly cut biomass was calculated per unit area.

The mean diameter of young stands, the average height of which exceed 9 m, had been calculated by the results of tree diameter measurement - as the basal area weighted mean diameter of diameter classes.

Individual tree stem volume has been calculated with the formula (Liepa, 1996):

$$v = \psi L^{\alpha} D^{\beta lgL+\varphi}; \quad (1)$$

where:

v – stem volume with bark, m^3;

L – stem length, m;

D – stem breast height diameter with bark, cm;

$\psi, \alpha, \beta, \varphi$ – the coefficients dependent on tree species (Liepa 1996).

Using the sample tree data, the stand volume current annual increment has been calculated with the formula (Liepa 1996):

$$Z_M = kG\left[\frac{2Z_D(H-2Z_H+4)}{10D+Z_D} + Z_H\right]; \quad (2)$$

where:

Z_M – current actual stand volume increment, m^3/ha;

H – average stand height, m;

G – stand basal area, m^2/ha;

k – empirical ratio

D – mean breast height diameter of the stand, cm;

Z_D – current increment of DBH of the stand, mm;

Z_H – current increment of the stand height, m.

To determine the volume of the above-ground biomass produced by various tree species, three sample trees were cut down in each plantation at root collar - one Kraft class I and two Kraft class II. After felling the tree height has been measured using tape-measure (with a precision to 1 cm), the stem pruned and cut into meter long sections. The sample tree weight determined on site by weighing separately: stem wood, dry branches, live branches.

Wood samples of each tree were collected for drying in laboratory - dry branch, 3 live branches (from different sections of the crown) and three disks (from various sections of the stem).

To carry out the stem analysis, wood disks have been acquired from each tree - in the middle of 0 m, 1.3 m, and meter long sections (0.5; 1.5; 2.5 etc.). On the bottom of each disk the tree number, cut height and northerly direction has been noted. Wood disks have been analyzed with the computer software

Table 1

Characteristics of experimental plots

Site location/ district/ farm	Latitude N	Longitude E	Soil type (Karklins 2008)	Tree species	Number of trees ha^{-1}
Grobina/ Bērzpurvi (Grob/ Bērz)	56°23’29”	21°07’11”	TP Typical podzol	Birch, Pine	3300 5000
Kandava/ Aizlolas (Kand/ Aizl)	56°55’11”	22°41’30”	/GSC Gley-sod calcareous soil	Birch, Scots pine Norway spruce	3300 5000 2000
Kuldiga/ Rūmnieki (Kuld/ Rūmn)	57°03’3”	21°46’5”	GSP /Gley-sod-podzolic soil	Birch	2000; 2500; 5000
Dobele/ Mezansi (Dob/ Mez)	56°15.465	25°25.470’	/SP Sod-podzolic soil	Birch Norway spruce	3300 3300
Ozolnieki/Medni (Ozol/ Med)	56°33.005’	24°04.212’	SPG Sod podzolic gley soil	Birch Scots pine Norway spruce	3300; 1600 5000 2000
Iecava/ Skujenieki (Iec/Skuj)	56°32.605’	24°19.414’	ASG Alluvial sod-gley soil	Birch Scots pine Norway spruce	3300 5000 3300
Iecava/ Gaiļi (Iec/Gaiļ)	56°34.192’	24°08.863’	CS Strongly altered by cultivation soil	Birch Norway spruce	2500 3300 2500
Viesite/ Palsani (Vies/Pals)	56°15’28”	25°25’23”	BUB Base-unsaturated brown soil	Birch/ Norway spruce	3300 3300
Rezekne/ Bitītes (Rēz/Bit)	56°14.763’	27°17.277’	SP Sod-podzolic soil	Birch Scots pine Norway spruce	2000; 2500 5000 3300
Madona/ Birzes (Mad/Birz)	56°54’55”	25°57’16”	SP Sod-podzolic soil	Birch Scots pine Norway spruce	2000; 2500 5000 3300
Amata/ Laubites (Amat/ Laub)	57°0’15”	25°12’16”	/SP Sod-podzolic soil	Birch Norway Spruce	3300 3300
Gulbene/ Sopuli (Gulb/Sop)	57°09’25	26°58’33”	AHG Alluvial humic-gley soil	Birch	3300
Koceni/ Zarini (Amat/ Zar)	57°39’17”	25°03’22”	TSP Typical sod-calcareous soil	Birch	3300

WinDendro 2007, by determining the annual tree-ring widths and the number of tree-rings in relevant cut heights.

According to the latest data of the prices of pulpwood (EUR per m^3) and wood waste (EUR/loose m^3) calculated the gross income 15-year-old pine, spruce and birch plantations[4].

Mathematical data processing and credibility calculation was done by mathematical-statistical methods using Microsoft Office Excel 2003 software; mean data, standard deviations and relative error have been calculated using SPSS software (Arhipova & Balina, 2006).

The significance of variance difference determined using a two-way analysis of variance without replication (Anova: Two-Factor without Replication) (Arhipova & Balina, 2006).

Results and Discussion

Six pine (*Pinus sylvestris* L.), nine spruce (*Picea abies* (L.) Karst.), thirteen common silver birch (*Betula pendula* Roth) plantations have been assessed that were established in 1997 on agricultural land using various planting densities – 2500 and 3300, 5000 trees ha^{-1}. During fifteen years, the growth and productivity of these plantations in different soil types have been researched (Table 1).

By assessing the growth of pine plantations in 6 different soil types (TP, SPG, GSC, ASG, SP,) we conclude that in 15-year-old plantations the tree height has reached on average 7.3-7.7 m, except the pines in heavy gley soil (GSC), where their average height is considerably smaller - 6.8 m (Table 2).

Pine has reached breast height (1.3 m) in experimental sites only at the age of 6 years, which indicates that its growth was affected by both agro-chemical and physically-mechanical indices of the soil, and the abundant above-ground herbaceous vegetation (Daugaviete *et al*., 2015).

When comparing the growth of pine in 15-year-old plantations in AL and in forest land, it was concluded that the mean height of pine H=7.5 m is comparable to 17-year-old pine in dominant height site index H_{20}=9 m (H_{100}=28 m)[5].

The largest volumes have been recorded in the trials Grob/Bērz (TP), Iec/Skuj (ASG) and Ozoln/Med (SPG), where in 15-year-old plantations the volumes have been marked as 152 m^3ha^{-1}, 102 m^3ha^{-1} and 115 m^3ha^{-1} respectively (Table 2). It must be noted that in the trial Grob/Bērz (TP) the plantation survival was 98% until the age of 15 years, and this plantation shows the largest current volume increment per year - 8.94 m^3ha^{-1}, despite the fact that the volume of mean tree is comparatively smaller than in lower stocking density plantations.

As indicated by the data of Table 2, significantly smallest stem volume of mean tree in 15-year-old plantations, compared to other plantations, has been

Table 2

Stand data of pine plantations on different soils (age 15 yr.)

Experimental trial	Soil type	Density stems ha^{-1}	D, cm	H, m	Volume of mean tree, m^3	Volume, m^3 ha^{-1}	Average volume increment m^3ha^{-1} per year	Significant difference at *p<0.05*
Grob/Bērz	TP	3774	11,6±2,78	7.7±0.60	0,0404	152	8.94	Except Iec/Skuj *(p>0.05)*
Kand/Aizļ	GSC	2651	13.9±2.6	7.3±0.74	0,0300	79	4.44	Between all
Ozol/Med	SPG	2925	12.9±2.6	7.4±0.95	0,0392	115	4.06	Between all
Iec/Skuj	ASG	1853	12.7±2.2	7.7±0.43	0,0551	102	5.26	Except Ozol/Med *(p>0.05*)
Rēz/Bit	SP	1510	10,3±2.88	8,2±0.90	0,0589	89	5.77	Except Ozol/Med *(p>0.05)*

[4] http://data.csb.gov.lv/pxweb/lv/lauks/lauks__ikgad__mezsaimn/MS080_euro.px/table/tableViewLayout1/?rxid=cdcb978c-22b0-416a-aacc-aa650d3e2ce0; http://www.mezsaimnieks.lv/lv/koksnes_tirgus_apskats/

[5] http://www.vmd.gov.lv/valsts-meza-dienests/statiskas-lapas/normativie-akti-?id=807#jump_MK noteikumi Nr.647 Mežaudzes novērtēšanas kārtība, pieņemti 25.06.2009

Table 3

The average indices of sample tree above-ground biomass (freshly-cut/abs. dry/%) in 15-year old pine plantations

Trials	Total biomass, freshly-cut, kg/abs. dry,kg/%	Stem mass freshly-cut, kg/ abs. dry,kg/ %	Branch mass, freshly-cut,kg/abs. dry kg/%
Grob/Bērz	174.42/106.05/100	143.14/87.03/82.1	31.28/19.02/17.9
Ozol/Med	210.52/128/100	170.1/103.42/80.8	40.42/24.57/19.2
Iec/Skuj	185.52/112.80/100	132.12/80.32/71.2	53.4/32.47/28.8
Average freshly-cut, kg abs. dry,kg %	190.15±15.1 115.61 100	148.45±15.95 90.26 78	41.7±9.1 25.35/ 22

marked in the trial site Kand/Aizļ, in heavy gley soil (GSC).

In the researched pine plantations, the biggest volumes at the age of 15 years have also been registered in the trials with the largest tree amount per unit area, considering that the volumes of mean tree in individual plantations are smaller.

By performing the sample tree analysis, the research of pine plantation above-ground biomass volume dynamics suggests that the above-ground biomass of mean tree in 15-year-old pine plantations constitutes on average 190.15 kg (100%), including stem biomass 148.5 kg (78 %) and crown biomass (branches plus needles) 41.7 kg (22%) (Table 3).

If planned to manage this kind of plantation as a roundwood production plantation, it is necessary to do the first thinning of the standing volume. The projected volume of timber and biomass to be felled has been calculated by considering the number of trees to be felled and the standing volume of the

Table 4

The amount of timber, pulpwood plus wood waste biomass (m^3 ha^{-1}; t ha^{-1}) and gross income (EUR) obtainable from 15-year-old pine plantations

Trial	Timber volume obtainable during thinning, m^3 ha^{-1}	Obtainable pulpwood/ fire wood volume, m^3 ha^{-1}	Total obtainable biomass (stem wood + branches) t ha^{-1} (freshly-cut)/abs. dry	Gross income from 1 ha, EUR		Gross income from 1 ha, (pulpwood/ fire wood/ branch biomass), EUR
				Pulp-wood/ fire wood (30/20 EUR m^3)	Stem waste and branch biomass (7.00 EUR (loose m^3)$^{-1}$	
Grob/Bērz	99	50/49	52/11	1500/800	367	2267
Kand/Aizļ	40	20/20	11/9	600/180	297	1077
Rēz/Bit	12	6/6	6/3	180/120	100	400
Iec/Skuj	30	15/15	16/4	450/300	133	883
Ozol/Med	64	32/32	17/7	960/640	233	1833

[6] http://data.csb.gov.lv/pxweb/lv/lauks/lauks__ikgad__mezsaimn/MS080_euro.px/table/tableViewLayout1/?rxid=cdcb978c-22b0-416a-aacc-aa650d3e2ce0

pine mean tree stem wood and branch biomass. Calculations show that the highest pulpwood volume and wood biomass in the first thinning is obtainable from plantations that have retained the initial planting density (Table 4).

According to the latest data, the prices of pine pulpwood currently fluctuate between 29-31 EUR per 1 m^3 and gross income from pulpwood, after thinning of 15-year-old plantations, has been calculated to be 400-2267 EUR ha^{-1}. The net income from the first thinning of the standing volume of a 15-year-old pine plantation will make around 45 % of gross income for pulpwood and woodchips respectively[6].

The assessment of the growth of spruce plantations on AL had been done on 9 sites, and their growth and cumulative productivity been researched in plantations on agricultural lands in naturally dry mineral soils (SP, BUB, CS, ASG and PGx) (Table 5).

The data acquired in experiments show that by carrying out timely agrotechnical tending in sod-podzolic agricultural lands the spruce mean height at the age of 15 years had reached 8.2 m, which corresponds to spruce dominant height of site index I (H_{20}=12 m) in forest stands[5]. Whereas the spruce mean height in soils was strongly altered by cultivation (Iec/Gaiļ) and in plantations at the age of 15 years, where additional fertilization has been done (Amat/Laub), it reaches H = 10.5 m, corresponding to 16-18-year-old site index I spruce dominant height in forest stands, in forest soils[5].

In rich AL (CS, ASG, SPG) the tree mean diameter at breast height in 15-year-old plantations is respectively 8.3-12.6 cm, height H= 7.1-8.9 m, stem volume of mean tree 25.83-53.43 dm^3, and standing volume 51-87 m^3 ha^{-1}. But the current standing volume increment in these trials constitutes 6.57-15.76 m^3 ha^{-1} per year (Table 5).

When determining the spruce plantation above-ground biomass volume, it was found that in 15-year-old plantation the above-ground biomass of mean tree constitutes on average 142.9 kg (100%): including stem biomass 65.7 kg (46 %) and crown biomass (branches plus needles) - 76.9 kg (53.9%), which in

Table 5

The productivity of spruce plantations in AL at the age of 15 years

Trial	Soil type	D, cm	H, m	V, dm^3	Volume, m^3ha^{-1}	N, trees ha^{-1}	Z_M, m^3ha^{-1} per year	Significant difference at 0.05 level (*p<0.05)*
Dob/Mež	SP	9.2±1.98	7.7±0.71	31.85	75	2840	7.42	Except Vies/Pals, Mad/Birz
Iec/Skuj	ASG	12.6±2.31	7.7±0.71	53.43	87	2660	15.76	Except Vies/Pals
Vies/Pals	BUB	7.9±2.39	6.7±0.86	20.49	47	3128	5.51	Except Dob/Mež, Mad/Birz
Amat/ Laub (after tending)	SP	12.3±2.65	10.5±0.91	66.89	98	1400	14.59	Between all
Mad/Birz	SP	10.5±1.48	7.8±0.69	38.92	97	3100	5.29	Except Dob/Mež, Vies/ Pals
Rēz/Bit	SP	9.4±2.87	7.4±1.91	30.45	89	2957	8.66	Except Vies/Pals
Iec/Gaiļ (3300 trees/ha)	CS	10.6±2.87	8.9±1.91	39.60	85	2230	10.26	Except Iec/Skuj
Iec/Gaiļ (2500 trees/ha)	CS	10.9±2.40	9.5±1.12	49.13	75	2165	13.04	Except Iec/Skuj
Ozol/ Med	SPG	8.3±2.12	7.1±1.01	25.83	51	2640	6.57	Between all

Table 6

The average indices of sample tree above-ground biomass (freshly-cut/abs. dry) in 15-year-old spruce plantations

Trial	Total biomass, kg/ %	Stem biomass, kg/ %	Tree crown biomass		
			Live branches, kg/%	Incl., needles	
				kg	% of stem biomass
Iec/Gaiļ	176.5/100	85.3/48.3	91.0/51.5	44.1	25.0
Iec/Skuj	142.9/100	65.7/46.0	76.9/53.8	38.1	26.7
Mad/Birz	152.7/100	66.5/43.5	85.8/56.2	46.3	30.3
Vies/Pals	122.1/100	50.1/41.0	72.0/59.0	34.6	28.3
Dob/Mež	134.5/100	60.8/45.2	73.4/54.6	36.6	27.2
Ozol/Med	128.7/100	65.9/51.2	62.3/48.4	28.8	22.4
Average freshly-cut,kg /abs. dry,kg %	142.9/ 65.73/ 100	65.7/ 30.22/ 46	76.9/ 35.37/ 54	38.1 19.05	26.7

turn splits into branch biomass - 31.6 kg (41%), and needle biomass – 45.30 kg (59 %) (Table 6).

To calculate the potential gross income from spruce plantations after the thinning - first thinning - sample trees have been taken out and analyzed in most characteristic plantation trials: Mad/Birz, Vies/Pals, Dob/Mež, Iec/Gaiļ and Iec/Skuj, where thinning had not been done before. Based on sample tree data, the volume of obtainable products - pulpwood, branch biomass and raw biomass (needle and non-ligneous shoots) - has been calculated. According to the latest data, the prices[5] of spruce pulpwood currently fluctuate between 29-30 EUR per 1 m^3 and gross income from pulpwood, after thinning of 15-year-old plantations, comprise 472-973 EUR ha^{-1}, but income from branch biomass - 312-1015 EUR ha^{-1}.

The net income from the first thinning of the standing volume of a 15-year-old spruce plantation will make around 40 % of gross income[6]. Thus, it was concluded that the net income from the total stem

Table 7

The potential timber volume to be felled during thinning of 15-year-old spruce plantations, the volume of obtainable green crown biomass and gross income (m^3 ha^{-1}, t ha^{-1}, EUR ha^{-1})

Spruce plantations	Timber volume obtainable during thinning, m^3 ha^{-1}	Obtainable pulpwood/ fire wood volume, m^3 ha^{-1}	Total obtainable biomass (stem wood + branches), t ha^{-1} (freshly-cut/abs. dry)	Including raw biomass (needles plus new shoots), t ha^{-1}	Gross income from 1 ha, EUR			Gross income (pulpwood/ fire wood/ felling waste and branch biomass), EUR ha^{-1}
					Pulpwood/ fire wood (29.5/20 EUR per m^3), EUR	Abs. dry branch biomass, (7.00 EUR loose m^3), EUR	Raw needle and new shoot biomass (130 EUR t^{-1}), EUR	
Mad/Birz	54	27/27	66/39	8	737/480	1015	1040	3272
Iec/Gaiļ	33	16/17	40/23	4	472/340	312	520	1644
Vies/Pals	36,5	18/18	45/26	4.6	531/360	342	598	1831
Iec/Skuj	67	33/34	82/48	7.8	973/680	507	1014	3174
Dob/Mež	46	23/23	56/33	5.3	678/460	436	689	2263

volume to be felled in 15-year-old spruce plantations, including the raw needle mass, is on average 1.5 times greater when compared to the scenario where only pulpwood and branch biomass is sold (Table 7).

The research on the growth of birch and productivity on former AL, in naturally dry mineral soils, it is suggested that overall, compared to conifers, the growth of birch in these plantations is more dynamic (Daugaviete *et. al*. 2015, Daugaviete and Liepiņš 2014).

The greatest birch height recorded exactly in plantations in fertile agricultural soils - in soil

Table 8

Birch plantation characterizing parameters in various agricultural land soils at the age of 15 years

Trial	Soil type	D, cm	H, m	V, dm^3	M, m^3 ha^{-1}	N, trees ha^{-1}	Z_M, m^3 ha^{-1} per year	Significant difference at 0.05 level *($p<0.05$)*
Grob/Bērz	TP	10.6±2.71	12.3±1.14	53.43	82	1758	14.33	Except Iec/ Skuj, Vies/Pals
Kuld/Rūm	GSP	11.6±1.71	12.8±0.80	65,94	101	1952	12.17	Except Grob/ Bērz, Ozol/Med, Iec/ Skuj
Kand/Aizļ	GSC	7.9±2.21	8.5±1.00	21,93	36	2165	4.66	Between all
Dob/Mež	SP	10.5±2.60	14.2±1.82	59,59	128	2650	13.49	Except Ozol/ Med, Kuld/Rūm, Rēz/Bit
Iec/Skuj	ASG	10.3±2.80	12.5±2.3	51,26	138	2500	21.69	Except Kand/ Aizl, Kuld/ Rūmn, Vies/ Pals,
Vies/Pals	BUB	10.9±1.96	14.3±1.06	64,49	145	2928	25.11	Except Kand/ Aizl, Iec/Skuj
Amat/Laub	SP	9.7±2.60	13.3±1.83	50,46	112	2214	15.72	Except Kand/ Aizl, Rēz/Bit, Ozol/Med
Koc/Zar	TSP	10.4±2.35	12.8±1.55	53,34	131	2354	20.97	Except Grob/ Bērz, Iec/Skuj, Vies/Pals
Mad/Birz (2500 trees/ha	SP	10.8±3.3	13.0±2.18	58,20	135	1650	12.07	Except Grob/ Bērz, Ozol/ Med, Iec/Skuj
Gulb/Sop	ASH	12.5±2.49	12.1±0.55	72.47	60	861	8.30	Between all
Rēz/Bit	SP	8.8±3,6	10.0±3,0	43.91	61	1400	3.72	Except Grob/ Bērz, Ozol/ Med, Iec/Skuj
Iec/Gaiļ	CS	13.9±2.46	16.2±1.06	90.92	169	1675	29.82	Between all
Ozol/Med (initially 3000 trees per ha)	SPG	12.6±2.06	14.0±1.53	48.86	143	2765	29.72	Except Iec/Gaiļ
Ozol/Med (initially 1600 trees/ha)	SPG	13.2±2.29	14.7±1.04	98.53	122	1480	24.97	Except Iec/Gaiļ

strongly altered by cultivation in the trial Iec/Gaiļ, and in podzolic pseudogley soil in the trial Ozol/Med; the mentioned soils had been extendedly used in agricultural production (Table 8), here the mean height of birch at the age of 15 years marked as 15.3 m.

In the plantations in sod-podzolic soils, the mean height of birch varies from 11.7 m to 14.2 m, in alluvial soils (Iec/Skuj) from 12.2 m to 12.5 m, in brown soil (Vies/Pals) - 13.6 m, and in gley-sod calcareous soil (Kand/Aizļ), on heavy gley base material - 8.5 m (Table 8).

In the plantations in sod-podzolic soils (Ozol/Med, Rez/Bit, Mad/Birz), the mean diameter at breast height of birch fluctuates from 9.5 cm to 10.8 cm, in alluvial soils (Iec/Skuj, Gulb/Sop) - from 10.5 cm to 12.7 cm, in brown soil (Vies/Pals) - 10.9 cm, and in gley-sod calcareous soil (Kand/Aizļ), on heavy gley - 7.9 cm (Table 8).

The productivity of birch plantations at the age of 15 years in different soils vary from 62 to 169 m^3 ha^{-1} (Table 8).

The current standing volume increment in birch plantation experimental trials varies from 7.54 to 29.82 m^3ha^{-1} per year: the smallest increment – 4.66 m^3ha^{-1} per year – in 15-year-old plantations has been registered in heavy gley soil (Kand/Aizļ), but the largest –29.72-29.82 m^3ha per year – in soil strongly altered by cultivation (Iec/Gaiļ), and in pseudogley soil (Ozol/Med) (Table 8).

The data statistical analysis indicates that the productivity of birch plantations at young stand age is significantly smaller ($p \leq 0.05$) also in heavy gley soils (Kand/Aizļ).

The largest cumulative volumes of mean tree for birch are in pseudogley extendedly cultivated soil (Ozol/Med)–96.04 dm^3 and in soil strongly altered by cultivation (Iec/Gaļ) –90.92 dm^3, in alluvial sod-gley soil (Iec/Skuj)–79.83 dm^3 (Table 8).

The smallest cumulative volumes of mean tree have been recorded in heavy gley soil in the trial Kand/Aizļ–21.93 dm3 (Table 8).

Research on the volume of the birch plantation above-ground biomass indicate that the biomass of a 10-year-old birch constitutes on average 64.93±12.81kg (100%), of which the stem takes up 47.95±9.49 kg or 74% of the total tree biomass, but the crown biomass (branches plus leaves) –16.97±4.35 kg or 26% of the total tree biomass. A 15-year-old birch biomass constitutes on average 158.41±31.72 kg (100%), including the stem biomass –121.1±22.8 kg or 76% of the total tree biomass, but the crown biomass (branches and leaves) –37.31±14.35 kg or 24% of the total tree biomass (Table 9).

In the research trials the first round tending or thinning is needed to ensure the further growth, by reducing the number of trees and thus obtaining the pulpwood to be sold (Table 10). Its volume calculation has been done by the methodology of modelling roundwood assortment yield in thinning birch plantations (Prindulis *et.al*., 2013). These investigations show the number of trees after first thinning must be no more than 1100 trees per ha (Zālītis, Dreimanis & Daugaviete, 2003; P. Zālītis, 2006; T. Zālītis, 2008; Daugaviete, K.Liepiņš & J.Liepiņš, 2011; Prindulis *et al*., 2013; Daugaviete *et al*., 2015).

According to the latest data, the prices of birch pulpwood[4] currently fluctuate between 29-30 EUR per 1 m^3 and gross income from pulpwood[5], after first thinning of the standing volume of 15-year-old plantations, constitute 221-1003 EUR ha^{-1}, but income from stem and branch residues biomass - 1365-4123 EUR ha^{-1}. Therefore, the net income from the first thinning of the standing volume of a 15-year-old birch plantation will make around 30-10 % of gross income for pulpwood and woodchips respectively (Table 10).

Table 9

The average indices of sample tree above-ground biomass (freshly-cut) in 10 to 15-year-old birch plantations

Sample tree age, years	Total biomass kg/%	Stem mass kg/%	Branch mass, kg/%
10 y.o.	64.93±12.81/ 100	47.95±9,49/ 74	16.97±4.35/ 26
12 y.o.	98.23±7.25/ 100	70.83±3.92/ 72	27.40±3.45/ 28
15 y.o.	158.41±31.72/ 100	121.1±22.88/ 76	37.31±14.35/ 24

Table 10

The potential timber volume to be felled during thinning of 15-year-old birch plantations, the volume of obtainable green crown biomass and gross income (m^3 ha^{-1}, t ha^{-1}, EUR ha^{-1})

Trial	Timber volume obtainable during thinning, m^3 ha^{-1}	Obtainable pulpwood/ firewood production, m^3 ha^{-1}	Total obtainable biomass/ t ha^{-1} (freshly-cut/ abs. dry)	Gross income from 1 ha, EUR		Gross income from 1ha, EUR
				Pulp-wood / fire wood (29.5 /20.0 EUR per m^3)	branch biomass (7.00 EUR per loose m^3	
Grob/ Bērz	36	18/18	104/65	531/360	175	1066
Kuld/ Rūmn	57	28.5/28.5	64/47	841/570	240	1651
Kand/ Aizļ	25	7.5/17.5	22/18	221/ 350	112	683
Dob/Mež	63	19/44	69/52	560/880	264	1704
Iec/Skuj	77	23/54	84/74	678/1080	324	2082
Vies/Pals	58	29/29	63/48	855/580	243	1678
Amat/ Laub	56	17/39	49/37	501/780	91	1372
Koc/Zar	70	21/49	61/47	619/980	294	1883
Mad/ Birzes	33	10/21	29/22	295/420	112	827
Iec/Gaiļ	68	34/34	74/56	1003/680	285	1968
Ozol/Med	81	24/57	88/67	708/1140	340	2188

Therefore, the net income from the first thinning of the standing volume of a 15-year-old birch plantation will make around 40 % of gross income and are forecast to be in the amount of 273-875 EUR ha^{-1}.

Our research indicates that for acquisition of energy wood higher stocking density (10000 and 5000 trees per ha) birch plantations can be established, the rotation period of which could be 15 years (Daugaviete *et al*., 2011). It must be noted that despite the decreasing the number of trees by 26-34%, the total biomass (number of trees x medium tree mass, kg), reaches about 530-942 t ha^{-1} (Table 8, Table 9).

Similar conclusions have also been published in Finland and Sweden (Niemisto, 1995; Hynhynen & Niemisto, 2009), where it has been noted that dense birch plantations must be managed for obtaining energy wood, but sparse plantations must be designated for acquisition of assortment.

Conclusions

1. The establishment of pine, spruce and birch plantation type forests on former agricultural land secures the acquisition of the first production and net income within 15 years.
2. In AL (ASG, PGx, SPG, TP) the standing volume of 15-year-old pine plantations reaches 102-155 m^3ha^{-1} and the current standing volume increment reaches 5.72-8.94 m^3ha^{-1} per year, under the condition that the plantation survival rate is within 80-95%.
3. The above-ground biomass of 1 tree in 15-year-old pine plantations constitutes on average 190.15 kg (100%), including stem biomass 148.5 kg (78 %) and crown biomass (branches plus needles) 41.7 kg (22%).
4. In rich AL (ASG, CS, SPG) the standing volume of 15-year-old spruce plantations reaches 75-98 m^3ha^{-1} and the current standing volume increment reaches 10.26-15.76 m^3ha^{-1} per year, under the condition that the plantation survival rate is within 80-98%.
5. In 15-year-old spruce plantation the above-ground biomass of 1 tree constitutes on average 142.9 kg (100%): including stem biomass 65.7 kg (46.0 %) and crown biomass (branches plus

needles) - 76.9 kg (53.9%), which in turn splits into branch biomass - 31.6 kg (41%), and needle biomass – 45.30 kg (59 %).

6. 15-year-old birch plantation standing volume depends on soil fertility and varies from 61 to169 m^3ha^{-1}. The current standing volume increment in birch plantations varies from 7.54 to 29.82 m^3ha^{-1}per year.
7. 15-year-old birch average biomass comprises 158.41±31.72 kg, of which the stem mass is 121.1±22.88 kg or 76%, but the crown biomass (the mass of branches and leaves) - 37.31±14.35 kg or 24% of the total tree biomass.
8. The first thinning of the standing volume in pine, spruce and birch plantations must be done not later than at the age of 15 years if the plantation survival rate varies within 80-95%. Gross income from the first thinning of the standing volume in pine plantations varies from 400 to 2267 EUR ha^{-1}, under the condition that pulpwood and felling waste biomass is prepared, in spruce plantations –1644-3272 EUR ha^{-1} if the spruce needles biomass is utilized, in birch plantations –683-2188 EUR ha^{-1}.

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