

Productivity of Different Tree Species in Plantations on Agricultural Soils and Related Environmental Impacts

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Abstract

Fifteen-year research results of afforestation and plantation on abandoned and marginal agricultural lands have been analysed. The annual growth of different tree species has also been determined performing measurements annually in the first five years and later each 2-3 years. The environmental impacts of afforestation have been assessed in terms of changes in the aboveground vegetation and soil chemical properties. The following tree species were included in the studies: Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* (L.) Karst.), silver birch (*Betula pendula* Roth.), common alder (*Alnus glutinosa* (L.) Gaertn.), grey alder (*Alnus incana* (L.) Moench.), pedunculate oak (*Quercus robur* L.), small-leaved lime (*Tilia cordata* Mill.), and wild cherry (*Cerasus avium* (L.) Moench syn. *Prunus avium* L.).

In 15 years tree species such as Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* (L.) Karst.), silver birch (*Betula pendula* Roth.), common alder (*Alnus glutinosa* (L.) Gaertn.), and grey alder (*Alnus incana* (L.) Moench.) have reached maximum standing volume from 100 m³·ha⁻¹ (for conifers) to 248 m³·ha⁻¹ (for broadleaves) on soils with light and medium heavy texture and high density of stocking (2,500- 3,300 trees ha⁻¹). In Latvian climatic conditions lime (*Tilia cordata* L.), pedunculate oak (*Quercus robur* L.), as well as wild cherry (*Cerasus avium* (L.) Moench.) have reached the standing volume of 18-39 m³·ha⁻¹ in 15 years. It implies that their suitability can be evaluated no sooner than after some 40-70 years. Soil chemical properties have changed during 15 years since forest was established on agricultural lands. In general, the humus content in the active root layer (depth 0-30 cm) has increased and the soil reaction has become more acidic. Changes were observed also in the ground cover vegetation. Before afforestation the trial sites were generally dominated by meadow or fallow plant communities. Shifts in ground cover vegetation are faster on dry lean soils, where in plantations of conifers typical forest bryophytes appear rapidly, but various nitrophyte species prevail on sites of fertile and moderately moist soils.

Key words: afforestation of surplus and marginal farmlands, plantation of forest tree species, monocultures, mixed plantations, tree species: *Pinus sylvestris*, *Picea abies*, *Betula pendula*, *Alnus glutinosa*, *Alnus incana*, *Quercus robur*, *Cerasus avium*, *Tilia cordata*

Introduction

Afforestation, widely practiced all over the world, may be regarded as one of the ways of rational and sustainable utilization of surplus and marginal lands (Weber 2000, Karlen et al. 2003, Lambin and Geist 2006, Zanchi and Lindner 2006, Zanchi et al. 2006, Heil et al. 2007, Halldorsson et al. 2008, Terres et al. 2013).

Apart from its positive impacts, researchers also point to a variety of negative effects of afforestation, such as reduced groundwater recharge and decrease in the number of species of vascular plants (Baltodano 2000, Weber 2000, Freedman 2005, Zanchi et al 2006, Heil et al 2007, Halldorsson et al. 2007, Halldorsson et al. 2008, Terres et al. 2013). In many countries, both in Europe and other continents, large-scale national-level afforestation programmes have been launched to address the problems faced by their economies

(Brown 2000, Weber 2000, Cossalter and Pye-Smith 2003, Zanchi et al. 2007, Daugaviete et al. 2013).

From the management perspective, plantations of forest crops on abandoned and marginal lands are established for the following reasons:

- creating multifunctional forest stands;
- producing forest products;
- creating plantations of fast-growing tree species for obtaining forest products after a relatively short period (40–60 years);
- planting of fast-growing woody plants for biomass production (5–10 years);
- planting trees around urban areas and industrial centres;
- afforestation of selected areas (Mather 1993, Weber 2000, Brown 2003, Feedman 2005, Zanchi and Lindner 2006, Zanchi et al. 2007, Halldorsson et al. 2007, Halldorsson et al. 2008).

When choosing areas for establishment of forest, location, soil type, hydrological regime and microclimate must be taken into account, and this knowledge must be combined with the objective of afforestation, the type of future management, the species to be planted, use of pure or mixed stands, etc. Depending on the objective of the plantation cultivation (short-rotation crops or production of wood products, such as pulpwood, veneer logs, constructional timber, etc.), the tree species and planting density are chosen (normally 500–5,000 plants per hectare or 10,000–25,000 plants for shrubs like osiers, viburnum, danewort, etc.) (Mather 1993, Weber 2000, Feedman 2005, Zanchi and Lindner 2006, Zanchi et al. 2007, Halldorsson et al. 2008).

In Latvia, the land use policy favours establishment of forests on abandoned, mainly highly fragmented agricultural lands unsuitable for farming. It implies that the landowners need science-based recommendations on how to obtain a multifunctional, ecologically stable forest or plantation that gives reasonable profit to the owner.

To ensure sustainable management of Latvian land resources and secure economic, ecological and social benefits from land use, already in the early 1990s Latvian State Forest Research Institute (LSFRI) *Silava*, with the help of State Forest Service, Ministry of Agriculture and EU funds (PHARE projects) started developing methods for sustainable management of low-value agricultural lands with plantation cultivation of forest crops and a variety of woody plants in areas unsuitable for agriculture as one of the options (Daugaviete et al. 2013).

Between 2006 and 2011 land area used for farming was reduced by 512,711 ha. A part of abandoned lands were converted by natural regeneration into woodlands or used for plantations of forest crops (totally about 30,000 ha), with about 260,000 ha naturally overgrowing with trees (www.vmd.gov.lv; Lazdins et al. 2011).

The objective of the given research is to work out guidelines for the choice of tree species suitable for plantations on former agricultural lands in the rural areas.

The research tasks are specified as follows:

1) analysis of the performance of various tree species (pine, spruce, birch, common alder, grey alder, oak, lime, sweet cherry) on former agricultural lands of different soil types;

2) identification of the most promising tree species for plantations;

3) evaluation of the environmental impacts of forest establishment on farmlands and plantation of forest crops (changes in soil chemical properties and above-ground vegetation).

Material and Methods

The field data were gathered in 19 experimental plots and over 150 subplots in all territory of Latvia with a total research area of more than 50 ha (Figure 1).



Figure 1. Locations of experimental plots

Pure or mixed species plantations of different stocking density were established using the following tree species: Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* L. Karst.), silver birch (*Betula pendula* Roth.), common alder (*Alnus glutinosa* L. Gaertn.), grey alder (*Alnus incana* L. Moench.), pedunculate oak (*Quercus robur* L.), small-leaved lime (*Tilia cordata* L.) and sweet cherry (*Cerasus avium* (L.) Moench.) (Table 1).

In each plantation four circular sample plots (500 m², R = 12.62 m) were set up, choosing their location randomly.

The following actions were done on each sample plot:

- numbering of all tree stems;
- measuring DBH of all trees (accuracy 0.1 cm) and determining the Kraft class;
- measuring tree height with *Vertex III* for 15 trees (5 trees in each diameter class: small, average, and large), (accuracy 0.2 cm);
- determining number of decaying and dead trees;
- extracting core samples at breast height from 15 trees to determine exact tree age and annual ring width; core samples were analysed with *WinDendro 2007* software.

Soil properties in the sample plots were examined every 3–5 years taking soil samples at the specified locations. The samples were taken in the active tree root zone at a depth of 0–30 cm (0–10; 10–20; 20–30 cm) in five replications in each sample plot with one averaged sample made for each soil horizon. In this study variations in the soil humus content and acidity in the active root zone of trees (0–30 cm) were analysed before planting and analyses were repeated at specified

Table 1. Characteristics of experimental plots

No of trial	Site location: municipality/parish/property	Site location	Soil type	Year of establishment/thinning	Tree species, kind of plantations
1	Priekule/Gramzda/Ozolbunci	56°23'29" 21°40'35"	TSP-	1997/-	Oak: 1,100 trees ha ⁻¹ Monoculture – European cherry - 2,000 trees ha ⁻¹
2	Grobina/Grobina/Berzpurvi	56°30'43" 21°07'11"	TP	1997/-	Birch, Pine, Spruce - monoculture- 3,300 trees ha ⁻¹ ,
3	Ventspils/Piltene/Piltene rural territory	57°13'60" 21°39'20"	SP	2000/-	European cherry - monoculture - 1,100 trees ha ⁻¹
4	Tukums/ Vane/Aizololas	56°55'11" 22°41'30"	GSC	1997/-	Birch, Pine, Spruce - monoculture 3,300 trees ha ⁻¹ : Oak - 1,100 trees ha ⁻¹
5	Tukums/Rumene/Viesturi	57°03'11" 22°44'21"	SPG	2000/-	Birch, Pine - monoculture - 2,000 trees ha ⁻¹
6	Talsi/Balgale/Zeltini	57°08'50" 22°54'31"	SP	2003/-	Monoculture – European cherry - 10,000 trees ha ⁻¹
7	Kuldiga/Padure/Rumnieki	57°03'3" 21°46'5"	SPG	1997/-	Birch - different spacing: 1,100 - 10,000 trees ha ⁻¹ , European cherry - 3,300 trees ha ⁻¹
8	Dobele/Auri/Mezansi	56°15.465 25°25.470	SP	1997/-	Monoculture: Birch, Spruce, Black alder- 3,300 trees ha ⁻¹
9	Jelgava/Salgale/Medni	56°33.005 24°04.212	SPG	1993-1995/-	Birch - different spacing - 1,600- 3,300 trees ha ⁻¹ Monoculture: Pine, Spruce – 2,000-4,000 trees ha ⁻¹
10	Ozolnieki/Garoza/Meldri	56°36.907 23°58.687	TP	2004/-	Monoculture - Pine - 5,000 trees ha ⁻¹
11	Iecava/Iecava/Skujenieki	56°32.605 24°19.414	ASG	1997/-	Monoculture-Birch, Spruce, Pine- 3,300 trees ha ⁻¹
12	Iecava/Iecava/Gaili	56°34.192 24°08.863	CS	1994-1995/thinning of spruce plantation at the age of 14 yrs.	Different spacing – Spruce - 2,000-3,300 trees ha ⁻¹ Monoculture: Birch- 2,000 trees ha ⁻¹ , Oak - 1,600 trees ha ⁻¹
13	Jēkabpils/Sauka/Palsani	56°15'28" 25°25'23"	BUB	1997/-	Monoculture: Birch, Spruce- 3,300 trees ha ⁻¹ , Oak -2,000 trees ha ⁻¹
14	Krustpils/Mezare/Paki	56°35'12" 26°08'4"	SPG	1993-1997/-	Monoculture: Birch, Spruce- 2,000 trees ha ⁻¹ , Lime - 1,000 trees ha ⁻¹
15	Rezekne/Malta/Bitītes	56°14.763 27°17.277	SPG	1997/-	Birch - different spacing - 1,100- 10,000 trees ha ⁻¹ , Monoculture: Pine, Spruce - 3,300 trees ha ⁻¹
16	Madona/Vestiena/Birzes	56°54'55" 25°57'16"	SPG	1997/ thinning of pine plantation at the age of 9 yrs.	Birch - different spacing – 1,100 - 10,000 trees ha ⁻¹ , Monoculture - Pine, Spruce - 3,300 trees ha ⁻¹
17	Cesis/Zaube/Laubites	57°0'15" 25°12'.16"	TP	1997/-	Monoculture - Birch, Spruce - 3,300 trees ha ⁻¹

Legend: Pine – Scots pine (*Pinus sylvestris* L.), Spruce – Norway spruce (*Picea abies* (L.) H.Karst.), Larch – European larch (*Larix decidua* Mill.), Birch – silver birch (*Betula pendula* Roth.), Aspen – (*Populus tremula* L.), Black Alder- (*Alnus glutinosa* L.) Gaertn.), Grey alder – (*Alnus incana* (L.) Moench.), Ash (*Fraxinus pensilvania* L.), Oak – (*Quercus robur* L.), Lime – (*Tilia cordata* L.), Wild cherry – (*Cerasus avium* Moench. (L.) var. *Prunus avium* L.).

TSP is for Typical sod-calcareous soil, GSC is for Gleyic sod-calcareous soil, BUB is for Base-unsaturated brown soil, SP is for Sod-podzolic soil, TP is for Typical podzol, SPG is for Sod-podzolic gley soil, HPG is for Humi-podzolic gley soil, ASG is for Alluvial sod-gley soil, AHG is for Alluvial humic-gley soil, CS is for strongly altered by cultivation soil.

intervals till the age of 15 years. Soil analyses were performed in laboratory of Latvian Environment, Geology and Meteorology Centre following international standards (organic substance content in dry matter – *LVS EN 13039:2003*; pH (KCl) – *LVS ISO 10390:2002*) (www.lvgma.gov.lv).

Afforestation-induced changes in the above-ground vegetation were studied on permanent vegetation survey plots (size 1m²), that were inventoried four times – (1) before the afforestation, (2) in the third year after afforestation, (3) in the eighth year after afforestation and (4) at the age of 15 years. Changes in vegetation were recorded and evaluated depending on tree species, changes in the exposure to light in the course of tree growth, etc.

In each plantation, the stand growth was followed up recording tree height (m), DBH (cm), branch-free stem height (m), and crown height (m).

For each sample a plot following indices were calculated: mean basal area, mean tree volume and standing volume, using formula by I. Liepa (1996):

$$V = \psi \cdot h^{\alpha} \cdot d^{\beta} \cdot g^{h+\varphi}, \quad (1)$$

where: h is the mean height following the height curve, m; d is the mean diameter, cm; ψ , α , β , φ are indices of stem bulkiness for the respective tree species

For young stands with the mean height ≤ 9 m the following formula was used:

$$V = k \cdot G \cdot (H+4), \quad (2)$$

where: V is the standing volume of the respective tree species, m³·ha⁻¹; k is the coefficient depending on tree species (Liepa 1996); G is the stand basal, m² ha⁻¹; H is the mean height, m.

On the afforested sites vegetation was inventoried in 1996 before forest establishment, in 1999 and 2004, and again in 2008-2012 in order to study the changes in ground cover vegetation of the agricultural ecosystems (meadow, fallow land) gradually turning into forest. During the first inventory in 1996, a total of 10 sample plots (1 × 1 m each) were described throughout the whole territory of plantation. In the inventories carried out in 1999 and 2004, three 1 × 1 m sample plots were established in each tree plantation, total number of survey plots is 219. Starting with 2008 inventory, when tree crowns had already closed, the survey plot size was 10 × 10 m instead of three former 1 × 1 m plots, in total 127 survey plots. A full list of flora species was compiled for each site, including the species found next to the survey plot. Vegetation data was stored using TURBOVEG Software (Hennekens and Schaminee 2001). The projective cover of each plant species in the tree, shrub, herbaceous and bryophyte layer was assessed as a percentage of the respective species, using the Braun-Blanquet method (Westhoff and Maarel 1978). Mean indicator values were calculated for each plot from

all present vascular plant species, for which an indicator value according to Ellenberg et al. (1992) was available (Rusiņa et al. 2011).

Data validation and mathematical calculations were performed with *Microsoft Excel 2003*. Summary statistics for DBH, height and basal area were calculated using *SPSS* software (Arhipova and Bāliņa 2006). The formulas of Liepa (1) were used to calculate stem volume for different tree species. One-way analysis of variance (ANOVA) and *t-test* were used in statistical analysis ($p < 0.05$). The mean values in the tables are presented together with standard deviation ($\pm SD$).

Results

After afforestation on various soils the growth rates were determined for eight tree species – pine, spruce, birch, common alder, grey alder, oak, lime and wild cherry. The indices describing stand growth show that there is no single species suitable for all growing conditions. Generally, the growth rates are higher for tree plantations on fertile, nutrient-rich soils with a settled hydro-geological regime.

According to the field data, in agricultural lands the growth rate of young pine (*Pinus silvestris* L.) stands is slow, especially in the first five years, while the trees adapt to the new growing conditions and develop root mycorrhiza. As it follows from Table 2, the standing volume for pine accumulated in 15 years differs according to location and number of trees per unit area. The highest volume growth is found on sites with a higher number of trees (trials 2, 5) while the mean tree volume on these sites is significantly lower than on more fertile soils (ASG, SP) (trial plots 9, 15) or untended plantations (trial plot 16).

The highest mean volume increment is observed on the trial site on podzolic gley soils (trial plot 16), where at the age of 9 years the number of trees was reduced from 3,300 to 1,300 trees·ha⁻¹ (Figure 2).

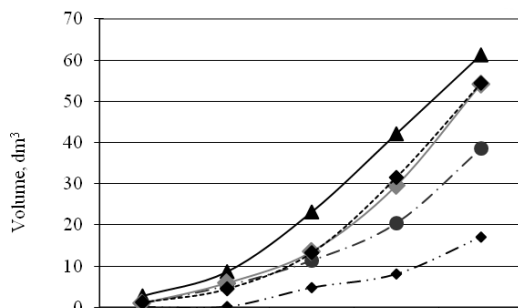
The same phenomenon is also observed on trial plots 11 (AGS) and 15 (SP) where the number of trees is reduced naturally by 44-55 % (initial number of trees 3,300) with the total standing volume relatively low.

Similar growth is observed also in spruce (*Picea abies* L. Karst.) plantations on naturally dry mineral soils (soil types TP, GSC, SPG, SP, ASG and BUB) (Table 3).

For spruce plantations the fastest growth rates are observed in anthropogenic soils, including the cultivated ones, where upper soil layers are rich in mineral nutrients. In such soils mean DBH of trees in a 15-year old plantation is as high as 11 cm and $H = 9.6$ m. In gley sod-calcareous soils the mean DBH is 6.9 cm and H is 5.3 m; and in turf podzolic loamy and sandy loam soils the indices are 9.3 cm and 7.6 m, respectively.

Table 2. Stand data of pine plantations on different soils (age 15 yr.)

No of trial	Soil type	DBH, cm	Average tree height, m	Average volume of tree, m ³	Yield, m ³ ·ha ⁻¹	Number of trees ha ⁻¹	Significant difference at 0.05 level (p < 0.05)
2 Berzpurvi	TP	10.7±3.37	7.4±0.85	0.0404	152	3774	Except No. 11 (p > 0.05)
4 Aizlolas	GSC	9.5±1.96	7.0±0.43	0.0300	79	2,651	Between all
5 Viesturi	SPG	10.3±2.88	8.2±0.90	0.0392	115	2,925	Except No. 11 (p > 0.05)
9 Medni	SPG	14.6±2.34	15.1±0.87	0.139	243	1,750	Between all
11 Skujenieki	ASG	12.7±2.23	7.7±0.45	0.0551	102	1,853	Except No.9 (p > 0.05)
15 Bitites	SP	12.9±2.63	7.4±0.95	0.0589	89	1,510	Except No.9 (p > 0.05)
16 Birzes	SPG	13.9±2.62	7.3±0.74	0.0627	81	1,289	Between all



●— 2Berzpurvi TP	0,96	5,27	11,38	20,45	38,56
◆- - 4Aizlolas VKg	0,06	0,14	4,74	8,06	17,04
▲— 16Birzes PVv	2,8	8,7	23,2	42,2	61,39
■- - 15Bitites PVv	0,96	5,9	13,52	29,59	54,22
◆- - - 11Skujenieki Alv	1,29	4,57	13,32	31,61	54,51

Figure 2. Increment of mean tree volume in different growing conditions in Scots pine plantations (period: 5–15 years), dm³ ($v = \psi \cdot h^\alpha \cdot dv^{\beta \cdot lg h + \varphi}$; $\Psi = 1.6541 \cdot 10^{-4}$; $\varphi = 1.59689$; $\alpha = 0.56582$; $\beta = 0.25924$)

Also in spruce plantations the volume growth depends on site characteristics and tree density. The volume growth is highest on sites with a high number of trees per ha (trial plots 15 and 16) while the mean tree volume is significantly lower on poor soils as compared to the plantations on richer soils (ASG; trial plot 11) or those tended (trial plot 12).

When analysing the mean volume increment, the highest growth is found for spruce on soils strongly altered by cultivation (SC; trial plot 12) and on alluvial sod gley soil (ASG; trial plot 11) (Figure 3).

It is to be noted that on the site 12Gaili at the age of 14 years the number of spruce trees was reduced from 2,500 to 1,300 trees ha⁻¹ (CS). In other spruce sites as 4Aizlolas, 8Mezansi, 11Skujenieki, 13Lone, 15Bitites, 16Birzes, there is a need for thinnings to improve stand performance.

Statistical analyses show that young spruce plantations are significantly less productive on gley sod-calcareous soils (GSC; site 4Aizlolas) and on soils with higher clay content (BUB; site 13Lone). Regarding the latter site, spruce there has a good potential for growth, provided the number of trees per ha is reduced from 3,154 to 1,500 trees per ha (Table 3).

In former agricultural lands, the growth of silver birch plantations on naturally dry mineral soils as sod-podzolic (SPG), sod-calcareous (SC, GSC), alluvial (ASG, AHG), brown (BUB), and anthropogenic soils (CS) is significantly higher than that of conifers (Table 4).

In alluvial and cultivation-altered soils, birch reaches the breast height (h=1.3 m) on average four years after planting. Consequently, cultivating birch we may significantly reduce the expenses for plantation tending and monitoring (Liepiņš 2011).

The growth of birch in plantations show that the first commercial thinnings should be carried out at the age of 15, when birch crowns start to decrease because of high tree density, thereby reducing the surface area of assimilating leaves and as a result slowing down the growth.

The highest growth rates of birch are found in plantations on anthropogenic (CS- site 12Gaili) and alluvial soils (ASG-site 11Skujenieki) (Figure 4). In such soils, the individual tree growth in 15–16-year plantations is significantly higher than in sites of poorer soils (sites No 2, 4, 5, 7, 8, 9, 15, 16, 17). High mean tree volume growth for birch is also observed on ASG (trial plot 11), SPG (trial plot 9), and AHG soils (trial plot 17); this index is the lowest for sites of GSC soils (trial plot 4).

According to the statistical analysis the growth of young birch plantations is significantly lower in gley sod-calcareous soils (GSC; trial plot 4) and periodically overflowing alluvial soils (trial plot 17).

When evaluating stand and volume growth in birch plantations of different stocking densities (1,100

Table 3. Stand data of spruce plantations on different soils (age 15 yr.)

No of trial	Soil type	DBH, cm	Average tree height-H, m	Average volume of tree, m ³	Yield, m ³ ha ⁻¹	Number of trees per ha	Significant difference at 0.05 level ($p < 0.05$)
4 Aizolas	GSC	6.9±2.471	5.3±1.26	0.01471	27	1,820	Between all
8 Mezansi	SP	9.3±2.87	8±1.91	0.026595	75	2,840	Except Nos. 13;16 ($p > 0.05$)
11 Skujenieki	ASG	12.6±2.31	7.7±0.71	0.05091	72	2,660	Except No. 13($p>0.05$)
12 Gaili	CS	11.0±2.53	9.6±1.06	0.05351	82	1,505	Except No. 11 ($p > 0.05$)
13 Palsani	BUB	9.3±1.75	7.9±0.85	0.03343	59	3,154	Except Nos. 8;16 ($p > 0.05$)
15 Bitites	SP	9.4±2.87	7.4±1.91	0.026595	89	2,957	Except No. 13;16 ($p > 0.05$)
16 Birzes	SPG	9.5±1.80	7.4±0.88	0.03129	97	3,100	Except No. 8;13 ($p > 0.05$)

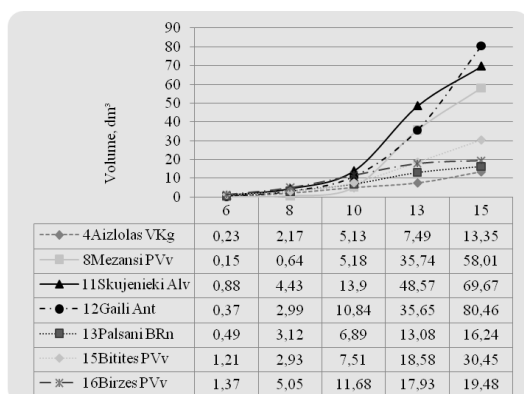


Figure 3. Increment of mean tree volume in various growing conditions in spruce plantations (period 6-15 years), dm³ ($v = \psi \cdot h^\alpha \cdot dv^{\beta \cdot lg h + \varphi}$; $\Psi = 2.3106 \cdot 10^{-4}$; $\varphi = 1.18811$; $\alpha = 0.78193$; $\beta = 0.34175$)

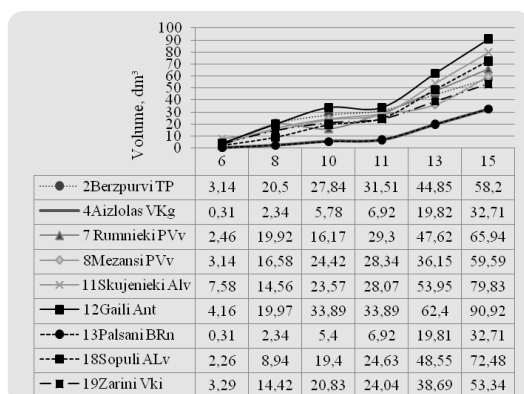


Figure 4. Increment of mean tree volume in different growing conditions in birch plantations (during 6-15 years), dm³ ($v = \psi \cdot h^\alpha \cdot dv^{\beta \cdot lg h + \varphi}$; $\Psi = 0.9090 \cdot 10^{-4}$; $\varphi = 1.75701$; $\alpha = 0.71677$; $\beta = 0.16692$)

(3 × 3 m); 1,600 (2 × 3 m); 2,500 (2 × 2 m); 5,000 (1 × 2 m); 10,000 (1 × 1 m) trees·ha⁻¹) in three trial plots (7, 15, 16), we found significant differences in stem diameter growth. For planting density 1×1m after 15 years of growth the DBH was 7.6 cm, with this index 9.1 cm for 1 × 2 m planting density, 10 cm for 2x2m planting density, 10.4 cm for 2 × 3 m planting density and 12.4 cm for 3 × 3 m planting density. Mathematical data treatment shows significant differences between planting patterns 1 x 1 m and 1 × 2 m, patterns 2 × 2 m, 2 × 3 m and 3 × 3 m (Daugaviete 2005, Daugaviete et al. 2011).

In overstocked stands of birch (10,000 trees·ha⁻¹; 5,000 trees·ha⁻¹) mean tree volume and standing volume (153.9 m³·ha⁻¹; 131.9 m³·ha⁻¹, respectively) are significantly higher compared to those in stands with stocking densities 2,500, 1,600 and 1,100 trees·ha⁻¹ (99.3, 63.7 and 65.3 m³·ha⁻¹ respectively) (Table 5).

For common alder plantations on wet mineral soils with natural water flow the mean height at the age of 15 years was in the range of 12.7 ± 1.45 – 15.3 ± 0.85 m, and DBH in the range of 11.3 ± 2.85 – 12.2 ± 2.64 cm. The standing volume at the stocking density 1,146 – 2,532 trees ha⁻¹ was as high as 81 – 234 m³·ha⁻¹ (Table 6). Mathematical data treatment shows significant differences between tree volume increment in plantations growing on sod-podzolic soil and typical sod –calcareous soil ($p = 0.011 < 0.05$).

It should be mentioned that because of no tending in trial plot 8 on about 50% of common alder stools there were 2-3 young shoots, while in trial plot 19 after tending only one shoot per stool was left.

As seen from the field data, black alder plantations reach high mean tree volume and standing vol-

Site location	Soil type	DBH, cm	Average tree height, H, m	Average volume of tree, m ³	Yield, m ³ ·ha ⁻¹	Number of trees per ha	Significant difference at 0.05 level (p < 0.05)
2 Berzpurvi	TP	10.6±2.71	12.3±1.14	0.0554	79	1426	Except No 11; 13 (p > 0.05)
4 Aizlolas	GSC	7.9±2.21	8.5±1.00	0.0233	67	1590	Between all
5 Viesturi (12 yr)	SPG	7.7±2.97	7.4±1.58	0.0270	55	2040	Except No 4 (p > 0.05)
7 Rumnieki	SPG	11.6±1.71	12.8±0.80	0.0672	87	1294	Except Nos. 2;9;11 (p > 0.05)
8 Mezansi	SP	9.8±2.24	13.9±1.82	0.0408	116	2840	Except Nos. 4;5;13;15;16 (p > 0.05)
9 Medni (16 yr)	SPG	13.2±2.29	14.7±1.04	0.0985	111	1126	Except No.7 (p > 0.05)
11 Skujenieki	ASG	12.2±1.67	14.2±0.91	0.0808	138	1708	Except Nos. 2;7;13;18 (p > 0.05)
12 Gaili (16 yrs)	CS	13.9±2.46	16.2±1.06	0.1188	159	1338	Between all
13 Palsani	BUB	8.2±2.90	12.4±2.28	0.0584	146	2500	Except Nos. 2;11;18 (p > 0.05)
15 Bitites	SP	8.3±3.10	9.9±1.80	0.0298	62	2078	Except Nos. 2;9;11 (p > 0.05)
16 Birzes	SPG	10.7±3.50	12.2±2.5	0.0588	97	1650	Except Nos. 2;9;11 (p > 0.05)
17 Sopuli	AHG	12.5±2.49	12.1±0.55	0.0734	59	1076	Between all
18 Zarini	TSC	10.4±2.35	12.8±1.55	0.0556	131	2354	Except Nos. 2;11;13 (p > 0.05)

Table 4. Stand data of birch plantations on different soils (age 15 yr.)

Table 5. Stand (7 Rumnieki, 15 Bitites, 16 Birzes) medium data in 15-yr.-old birch plantations of different stand density

Planting pattern, m	Soil type	DBH, cm	Average tree height-H, m	Average volume of tree, m ³	Yield, m ³ ·ha ⁻¹	Number of trees per ha	Significant difference at 0.05 level (p < 0.05)
1×1	SPG,SP	7.6±2.4	11.1±2.3	0.0273	155	6581	Except 2×2;2×3;3×3
1×2	SPG,SP	9.1±2.8	11.5±1.6	0.0395	132	3704	Except 2×2;2×3;3×3
2×2	SPG,SP	10.0±3.2	11.6±2.0	0.0483	99	1782	Except 1×1;1×2
2×3	SPG,SP	10.4±2.7	11.6±2.3	0.0518	64	1012	Except 1×1;1×2
3×3	SPG,SP	12.4±2.5	12.7±1.8	0.0792	65	841	Except 1×1;1×2

Table 6. Stand data of black alder plantations on different soils (age 15 yr.)

Site location	Soil type	DBH, cm	Average tree height, m	Average volume of tree, m ³	Yield, m ³ ·ha ⁻¹	Number of trees ha ⁻¹
8 Mezansi	SP	12.2±2.64	15.0 ±1.43	0.0926	234	2,527
19 Zarini	TSP	11.3±2.85	15.3±0.85	0.0778	81	1,042

ume (up to 234 m³·ha⁻¹) already at the age of 15 years. Under suitable growing conditions common alder may be recommended for short-rotation plantations in Latvian climatic conditions (Figure 5).

Between 2005 and 2009 in the framework of a national research programme extensive studies were carried out on the plantations of grey alder (Daugavietis et al. 2011, Bisenieks et al. 2010, Daugaviete et al. 2010, Daugaviete 2011, Daugaviete et al. 2008, Liepiņš and Liepiņš 2010, Bardulis et al. 2010, Zālītis 2010). The research showed that in plantations grey alder can form productive stands, already at the age of 15 reaching mean DBH of 13.8 cm and height of 16.4 m and standing volume up to 220 m³·ha⁻¹ (Daugavietis et al 2011) (Table 7).

Broadleaved hardwood species (oak, cherry) in

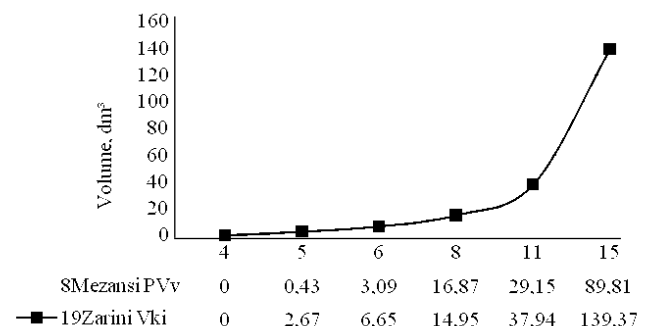


Figure 5. Increment of mean tree volume in different growing conditions in black alder plantations (during 4-15 years), dm³ ($v = \psi \cdot h^\alpha \cdot dv^{\beta-1} e^{h+\varphi}$; $\psi = 0.7950 \cdot 10^{-4}$; $\varphi = 1.80715$; $\alpha = 0.77095$; $\beta = 0.13505$)

Table 7. Stand data and annual increment of grey alder (Site index 20)*

Age, year	Height, m	DBH, cm	Number of trees per ha	Basal area, m ²	Volume, m ³	Volume increment			Total production, m ³
						current, m ³ (m ²) ⁻¹ ×	current, m ³	mean, m ³	
5	6.8	5.8	4,000	10.5	45	1.33	-	9.0	
10	12.1	10.0	2,300	18.2	114	1.12	17.6	11.4	133
15	16.4	13.8	1,700	25.4	200	1.00	23.1	13.3	248

* Daugavietis, Bisenieks and Daugaviete 2011

plantations on agricultural lands with naturally dry mineral soils, sod-podzolic, sod-calcareous, alluvial, and brown soils by the age of 15 years show the following mean parameters: for oak - height $2.6 \pm 0.83 - 6.0 \pm 2.4$ m, DBH $2.8 \pm 1.64-6.6 \pm 3.9$ cm; for wild cherry - height $5.5 \pm 0.81-7.8 \pm 0.53$ m, DBH $5.2 \pm 1.72-11.4 \pm 2.62$ cm. At this stage it is not yet possible to evaluate the performance of these plantations (Table 8).

According to the field data, oak in plantations on agricultural lands slowly adapts to site conditions with the annual height growth in the first 5–7 years no higher than 0.25–0.35 m per year; on average oak plantations reach the breast height level (h = 1.3 m) 7–9 years after planting.

The height curves for 15-year old oaks show that it grows significantly slower on sites with rich above-ground vegetation (GSC, AHG soils) compared to sites

Table 8. Stand data of lime (*Tilia cordata* L.), oak (*Quercus rubra* L.) and wild cherry (*Prunus avium* L.) plantations on different soils (age 15 yr.)

No of trial, site location	Soil type	DBH, cm	Average tree height – H, m	Mean increment of tree volume, m ³	Yield, m ³ ·ha ⁻¹	Number of trees per ha
Lime						
4 Aizlolas	GSC	4.0±2.3	3.3±1.10	0.0042	5	1,200
13 Palsani	BUB	11.8±2.73	8.8±0.73	0.0506	49	860
14 Mezare	SPG	11.5±3.80	7.0±1.48	0.0420	50	1,000
Oak						
2 Berzpurvi	TP	4.9±2.49	4.0±2.16	0.0048	7.60	1,580
4 Aizlolas	GSC	2.9±2.41	2.8±1.32	0.0005	0.63	1,189
7 Rumnieki	SPG	5.1±3.49	4.3±1.47	0.0057	11.00	1,920
12 Gaili	CS	5.9±2.67	4.9±1.73	0.0078	12.90	1,650
13 Palsani	BUB	6.6±3.90	6.0±2.4	0.0095	18.00	1,887
18 Sopuli	AHG	2.8±1.64	2.6±0.83	0.0004	0.40	909
Wild cherry						
3 Piltene	SP	5.3±2.40	5.6±0.67	0.0086	13	1,550
6 Balgale	SP	8.8±2.51	7.1±0.81	0.0206	116	5,600
7 Rumnieki	SPG	5.2±1.72	5.5±0.81	0.0074	15.00	2,038
1 Ozolbunci	TSC	11.4±2.62	7.8±0.53	0.0437	39.00	892

with less grass or intensively tended plantations (SP, SPG, TSP, CS).

Experiments with lime plantations (*Tilia cordata* L.) as pure stands and mixed with oak and spruce show good growth of lime, when intensively tended and protected, similar to that of spruce with DBH = 11.2 ± 3.6 cm and H = 8.6 ± 1.1 m by the age of 15 years at the standing volume $97 \text{ m}^3 \text{ ha}^{-1}$ and density of stocking $2,000 \text{ trees} \cdot \text{ha}^{-1}$ (Daugaviete et al 2013).

In case of mixed plantations (spruce + birch; spruce + oak; spruce + lime) with the same stocking density as in pure stands, the growth of both birch and oak at the age of 15 years is significantly slower than in single-species plantations; the same is true for the mix of spruce and lime with the latter growing slower.

Variation in proportion of soil organic matter and acidity in the active root zone at the depth from 0 to 30 cm over a period of 15 years since forest establishment on the respective site were chosen as indicator to evaluate the impact of afforestation on soil agrochemical properties. The amount of soil humus has changed on sites with a high volume of above-ground vegetation biomass, both trees and ground cover vegetation (trial plots 1, 2, 4, 8, 9, 11, 13 and 19). No significant changes in soil humus content are recorded for sites with relatively small volume of above-ground biomass (trial plots 6, 7, 15, 16, 18) (Table 9). It is to be noted that in the latter case forest was established on old fallows or meadows.

Similar results are quoted also by researchers of other countries (Hagen-Thorn et al. 2004, Kacalek et al. 2011, Kacalek et al. 2013). As concluded in a number of studies, forest floor humus on the soil surface is a completely new layer (Wall ad Hytonen 2005, Wall and Westman 2006, Olszewska and Smal 2008, Kacelek et al. 2013).

The field data show that after forest establishment on farmlands the soil tends to become more acidic. On sites, where trees were planted on arable land right after harvesting the previous crops, the soil acidity was in most cases close to neutral (trial plots 4, 6, 7, 11, 15, 16, 18) and in 15 years had reduced on average by 1.15 units on the pH-scale.

Our findings reveal that afforestation of arable soils in some 7-10 years acidifies the topsoil layer (by 0.1 – 1.5 units at the depth 0-30 cm) agree with studies in other countries (Ritter et al. 2003, Wall and Hytonen 2005, Wall and Westman 2006, Kasparinskis et al. 2011).

In all survey plots, a total of 247 vascular ground cover plants and 32 bryophyte species were recorded during the recent inventories. The number of species (herbaceous plants and bryophytes) found in different plots ranged from 56 to 112 and from 4 to 21, re-

Table 9. Changes in soil chemical properties in the active roots layer (0-30 cm) in the plantations, 1996-2012

No of trial	Soil type	Humus content, %		PH _{KCl}	
		1996	2012	1996	2012
1 Ozolbunci	TSP	1.4	4.56	5.92	5.19
2 Berzpurvi	TP	2.42	3.82	6.52	6.48
4 Aizlolas	GSC	2.13	4.01	6.60	5.75
6 Zeltini	SP	3.86	3.2	6.90	5.70
7 Rumnieki	SPG	3.06	2.68	6.17	5.41
8 Mezansi	SP	2.62	3.54	5.27	5.70
9 Medni	SPG	2.71	3.78	5.55	5.08
11 Skujenieki	ASG	2.19	2.53	6.7	5.20
13 Palsani	BUB	3.22	3.45	5.15	4.26
15 Bitites	SPG	3.05	2.46	6.3	4.21
16 Birzes	SPG	3.24	2.40	7.02	5.61
18 Sopuli	AHG	2.95	3.07	6.00	5.72
19 Zarini	TSP	3.86	3.95	5.45	5.30

*TSP is for Typical sod-calcareous soil, GSC is for Gleyic sod-calcareous soil, BUB is for Base-unsaturated brown soil, SP is for Sod-podzolic soil, TP is for Typical podzol, SPG is for Sod-podzolic gley soil, HPG is for Humi-podzolic gley soil, ASG is for Alluvial sod-gley soil, AHG is for Alluvial humic-gley soil, CS is for Strongly altered by cultivation soil.

spectively. Following trends in the dynamics of ground cover vegetation may be pointed out: the meadow and fallow grass species are declining, while in some plots up to 20 new different ground cover species have appeared. In fertile soils the meadow species are replaced by benthic eurytopic nitrophytes like *Urtica dioica*, *Anthriscus sylvestris*, *Dactylis glomerata*. Bryophytes colonizing bare soil have disappeared (*Barbula unguiculata*, *Pleurozium subulatum*, *Pohlia wahlenbergii*) and instead we find common forest ground cover species like *Plagiomnium affine*, *P. undulatum*, *Sciuro-hypnum curtum*, etc. Forest ground cover vegetation emerges faster in the sites on dry lean soils (trial plots 15 and 16), with typical forest bryophytes like *Pleurozium schreberi*, *Hylocomium splendens*, *Polytrichum juniperinum* etc. appears in conifer plantations. In sites with nutrient-rich and moderately moist soils (trial plots 1, 4, 8, 11, 12, 18) the moss layer is dominated by nitrophytes like *Brachythecium rutabulum*, *Cirriphyllum piliferum*, *Oxyrrhynchium hians*, *Plagiomnium affine*, *P. cuspidatum*, which are found in various biotopes.

Conclusions

In studied plantations on former agricultural lands, Scots pine (*Pinus sylvestris* L.), Norway spruce (*Pi-*

cea abies (L.) Karst.), silver birch (*Betula pendula* Roth.), common alder (*Alnus glutinosa* (L.) Gaertn.), and grey alder (*Alnus incana* (L.) Moench.) reach a standing volume of maximum 100-248 m³ ha⁻¹ in 15 years, the lowest for conifers and the highest for broadleaves. To ensure potentially high volume growth in similar plantations in the future, number of trees per unit area should be reduced.

According to our results, silver birch, common alder, grey alder and Norway spruce are most suitable for short rotation (25-40 years) plantations in naturally dry mineral soils of light and medium heavy texture in Latvian climatic conditions. The stands of increased stocking density could be useful for producing energy wood while those of lower density - for economically feasible production of commercial timber.

In Latvian climatic conditions, small-leaved lime (*Tilia cordata* L.), pedunculate oak (*Quercus robur* L.) and wild cherry (*Cerasus avium* (L.) Moench. syn. *Prunus avium* L.) have reached the standing volume of 18-39 m³ ha⁻¹ 15 years after plantation establishment; accordingly we cannot evaluate their suitability for use in plantations before some 40-70 years.

After forest establishment on farmlands, the soil tends to become more acidic. Characteristic meadow and fallow grass species are declining, while species typical to forest vegetation appear. In fertile soils, the meadow plant species are replaced by benthic eurytopic nitrophytes like *Urtica dioica*, *Anthriscus sylvestris*, *Dactylis glomerata*. Forest ground cover vegetation emerges faster in the sites on dry lean soils.

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