Chapter

Plantation Forests: A Guarantee of Sustainable Management of Abandoned and Marginal Farmlands

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Abstract

The chapter summarises the research data on cultivating forest crops in abandoned and marginal farmlands (AL). The course of growth and productivity of different tree species in the local climatic conditions is clarified in a variety of agricultural soils. The research results show the most appropriate tree species for short-rotation or special end-use monoculture or mixed plantations, using Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* (L.) Karst.), silver birch (*Betula pendula* Roth.), pedunculate oak (*Quercus robur* L.), grey alder (*Alnus incana* (L.) Moench), alder (*Alnus glutinosa* (L.) Gaertn.), wild cherry (*Cerasus avium* (L.) Moench syn. *Prunus avium*), aspen (*Populus tremula* L.), hybrid aspen (*Populus tremula x tremuloides*), and small-leaved lime (*Tilia cordata* Mill.). At the same time, research results show sustainability of management of plantation forests—positive impact on soil agrochemical properties, proportionate changes on above-ground vegetation, and improvement of economic benefits of farmlands.

Keywords: plantation forest, abandoned, marginal farmlands, forest tree species, soil agrochemical properties, above-ground vegetation, productivity, yield, biomass

1. Introduction

The issue of rational and sustainable management of land has been the focus of the countries of the world for several centuries, but the term sustainable was coined in the 1990s of the twentieth century. The term implies that the issue must be addressed as a set of issues:

- Quality of the surrounding environment.
- Economic sustainability.
- Social viability [1–19].

Meanwhile, the quality of the surrounding environment is characterised by the quality of soil, water, and air that forms the basis for ecosystems and sustainability [1–19].

Scientists and practitioners have unanimously recognised that, as the population of the planet increases, the demand for wood, wood biomass, and their products is increasing, and therefore the importance of plantation farms in the meeting of these needs is considerable [1–19]. Large-scale afforestation projects are developed in many countries of the world to resolve the economic problems of the national economy starting from the 1960s of the previous century in European countries: Germany, France, the UK, Denmark, Poland, Ireland, Spain, Italy, Portugal, Greece, Sweden, Norway, Finland, etc. [19].

Currently, large afforestation projects are being implemented in the USA, Canada, countries of South America, African countries, China, Indonesia, New Zealand, Japan, and countries of Southern Asia [19]. Woody plants were already planted as one of the main sources of human existence (food, timber, medicinal plants, etc.), thousands of years ago [15]. One of the first woody plants that was planted in large areas for food purposes was the olive tree (*Olea europaea*). Initially, the plantations occupied large areas in Romania, Greece, and China. About a thousand years ago, the selection of the best specimens of various tree species was commenced, and plantations for obtaining high-quality timber and other products were developed. From 1500 onwards, the selection and propagation of the best specimens of eucalyptus, pine, and other woody plant species were performed in Western Europe with the purpose of obtaining high-quality plantations. Furthermore, woody plants were used for landscaping purposes, the creation of parks, etc. The development of teak, balsa, eucalyptus, various species of pine, and other plantations has been practised in the Southern Hemisphere—Africa, Asia, South America, Australia, etc., since 1950. Meanwhile, in Europe, extensive afforestation of unused agricultural land commenced in the 1960s—in Europe: Sweden, Finland, Denmark, Germany, etc.; in North America: the USA and Canada; and in South America: Brazil, Chile, etc.

The plantations are subdivided into industrial and protective plantations, plantations of various technical crops, plantations for the improvement of low-yielding agricultural lands, short-rotation technical biomass production plantations, and other plantations. The scope of development of these types of plantations is growing worldwide [2].

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 murrayana*, *Pinus contorta* a.o.), spruce (*Picea* spp.: *Picea abies*, *Picea sitchensis* a.o.), and 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 and poplars (*Populus tremula x P. tremuloides*, *Populus x canadensis* a.o.), and osier varieties (*Salix* spp.) a.o. [1, 5, 7–12, 14, 18, 20–23]. 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 plantation, short rotation for obtaining biomass and roundwood plantations for obtaining pulpwood, and veneer log and sawlog productions, appropriate tree species must be selected and density established (500–5000 trees/ha or 10,000–25,000; species of ligneous plants—*Salix* species, willow species, viburnums, and elders [1, 7–12, 14, 18, 20–34]). Experience with afforestation demonstrates that throughout the Nordic region of the EU, there has been an increased emphasis on the use of native species—Scots pine, Norway spruce, and silver birch [1, 2, 5, 8, 10, 11, 17, 27, 30, 31]. The scientists and practitioners came to the conclusion—in Northern Europe, silver birch and Norway spruce are commercially the most important tree species for plantation forestry [2, 11, 14, 20–34].

Energy wood plantations intended for the production of wood biomass, which are also serving as reducers of large amounts of atmospheric carbon dioxide (CO_2) and reduce the salinity of soils by enabling the use of sewage water sludge for the increase in wood biomass, have been becoming increasingly important over recent decades [2, 35, 36].

Today, more than 287 million hectares worldwide are occupied by plantation forests, which ensure 1/3 of forest industry production, which mainly produces timber for the needs of construction and the paper industry [2, 6]. According to the data of the FAO, the areas of plantation forests have increased by about 5 million hectares per year [19]. The management of plantation forests contributes to the conservation of natural forests, where the harvesting of timber has significantly decreased taking into account the productivity of plantation forests, [2, 5, 14, 16]. According to the data of the FAO, timber produced by plantation-type stands ensures approximately 15% of the worldwide demand for timber [19].

The first record of the establishment of forests in low-fertility agricultural land in the territory of Latvia dates back to the nineteenth century, but the extensive afforestation of low-value and unused agricultural land started in the 1920–1930s of the twentieth century, i.e. after the declaration of the independence of Latvia [37]. To promote the economic growth of the country, particular attention was paid to the development of forestry as a very important sector of the economy, especially to the increase in forest areas [38, 39]. However, experts of forestry admitted that significant mistakes were made while planting trees in agricultural fields, primarily soil types that were inappropriate for tree species were selected [38, 39]. First of all, it refers to pine, which was extensively planted in any type of soil. Examples include plantations of pine in former agricultural lands of middle regions of Latvia, resulting in the loss of 39% of the plantations by the late nineteenth century, meanwhile during the 1910–1920s of the twentieth century, approximately 80% of pine plantations in former agricultural lands were lost [38].

The second tree species that was most commonly used in the afforestation of agricultural land was oak, as well as, slightly later, Norway spruce. Both common oak and red oak (*Quercus rubra*) were used. Extensive plantations of oak were developed in the entire territory of Latvia. Some of these plantations have survived to date, and now they have reached the age of 90–110 and more years.

The main measures for the increase of forest areas in Latvia from the eighteenth century to the first half of the twentieth century were as follows:

- Reinforcement and afforestation of dunes.
- Afforestation of low-value agricultural soils, mainly with common pine, less—Norway spruce (*Picea abies*). The most commonly used deciduous tree was oak (*Quercus robur*). Later on, the planting or preservation of naturally afforested areas with the stands of deciduous species—birch (*Betula pendula*) and common ash (*Fraxinus excelsior*)—was permitted.
- Development of plant nurseries for the growing of plantlets.

- Improvement of planting methods [38, 39]. One of the recommended methods was sowing of tree seeds together with cereal crops or in beds, by sowing 40 kg of seeds per 1 ha, and then rolling the field, because the cereal crop protects the young birch trees from excessive sunlight [43]; the other method involved the use of turf plantlets—young forest trees that were removed with a ball of soil [39, 43]; cylindrical shovels were used for this method. Usually, 3–4-year-old forest plantlets or plants were chosen [43].

If in 1923 the forest area of Latvia amounted to 1472 thousand ha (forest covered area—22.8%), then already in 2018, the area of forests increased to 3383 thousand ha (forest covered area—52%) (**Figure 1**) [1, 40–42].

In Latvia the issue about rational land utilisation once again became topical in the mid-1990s of the twentieth 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 2000 to 2017, the area of AL afforested with improved planting material already constituted 61,693 ha, including 18,018 ha of plantation forests (29.4% of afforested areas), of which 18,000 ha have been reported as plantations (**Figure 2**) [41]. During the same period, 233,000 ha of uncultivated agricultural land have been naturally afforested [42].

In the time period from 1993 to 2013, the ratio of tree species in naturally afforested areas and plantation-type cultivated stands reached 233,000 ha, of which birch was registered in 91,000 ha, white alder 47,000 ha, pine forest 25,000 ha, aspen 14,000 ha, spruce 13,000 ha, black alder 11,000 ha, and other species (oak, ash, walnut, elk, maple, linden, grasshoppers, willow) 32,000 ha (**Figure 3**) [25, 42].

In Latvia, substantial research about the growth and management of Scots pine, Norway spruce, silver birch, aspen, hybrid aspen, ash, and European larch stands in AL was performed by forest scientists after the Second World War [43–45]. In the 1960s the growth of silver birch plantations on former AL shows that the plantations in these areas reach the site index of I–Ia and that in the 1950s their standing volume was up to 439 m^3 ha^{-1} [44]. Extensive research on Scots pine and Norway spruce growth on former AL between the 1950s and 1970s of the twentieth century has been performed by Latvian scientists [43–45]. Plantations on former AL

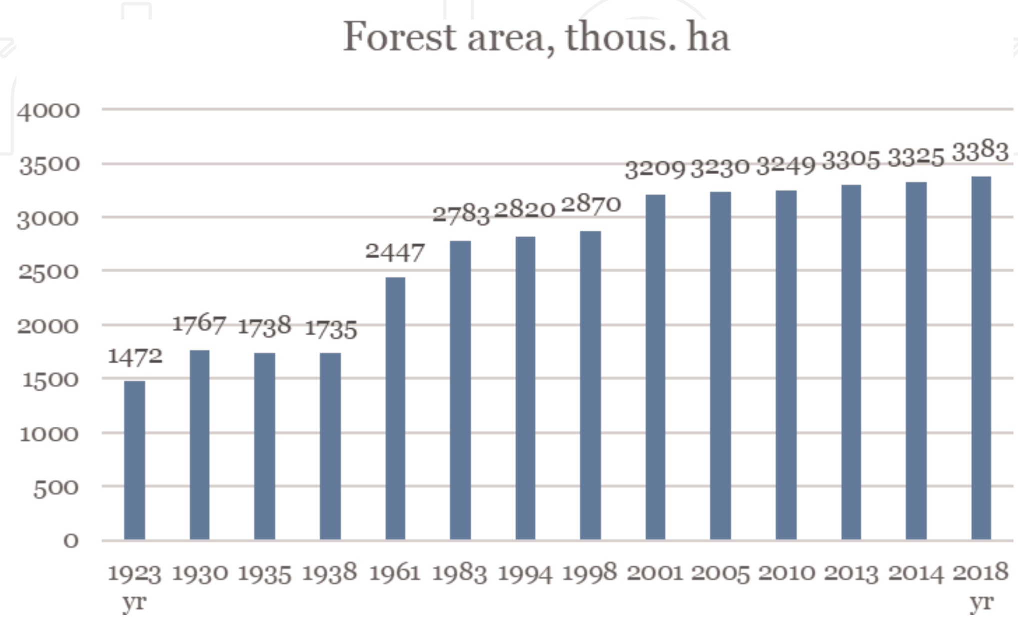

Figure 1.
Forest area dynamics in Latvia 1923–2018 (thousand ha) [1, 40, 41].

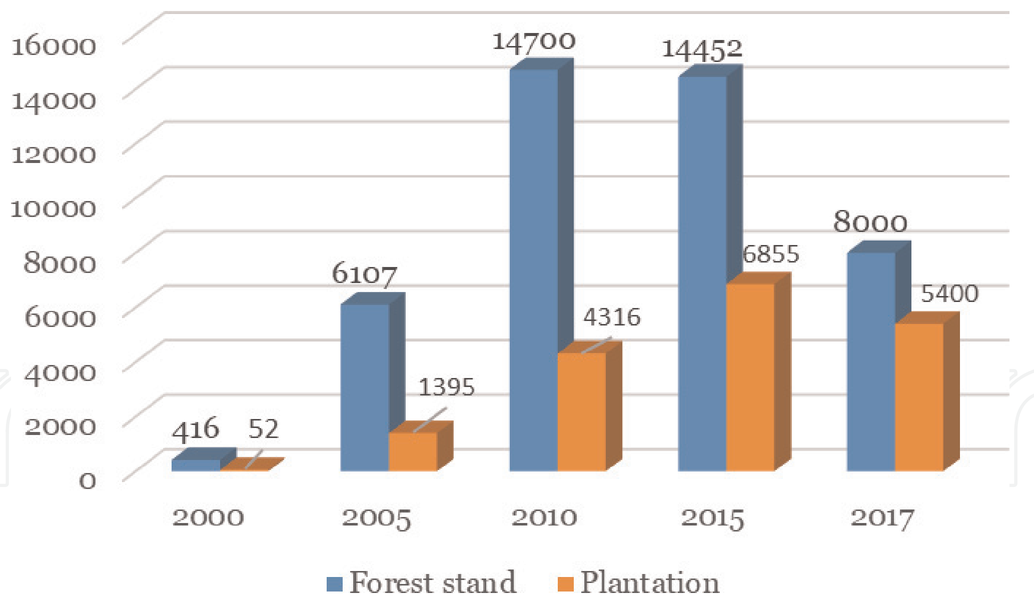

Figure 2.
Afforested abandoned farmland in Latvia during the period 2000–2017 (ha).

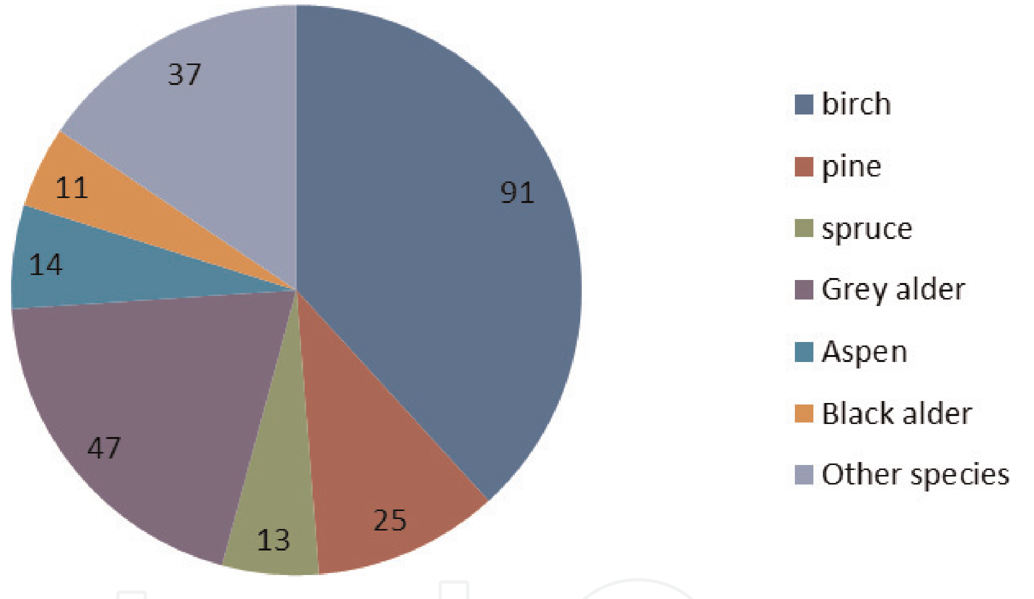

Figure 3.
Area on a per-species basis for natural and planted tree stands in abandoned farmlands, 1993–2013 (thous. Ha) [25, 41].

show a high site index class: Norway spruce plantations Ia–Ic and Scots pine plantations—Ia site index. Since 1995 research has been carried out 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 [1, 21, 27, 28, 31, 33]. 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, scientists are carrying out in-depth research about the development and productivity of plantations and plantation forests on afforested AL, improvement of the volume and quality of the grown planting material, as well as the assessment of these stands. The introduction of regulations on "long term plantings" that allow for the possibility of establishing tree plantations on AL, the maximum growth period of which is up to 15 years, without transforming the land into forest land also increase interest of fast growing tree cultivation [1]. Statistics show that research on the cultivation of different tree species in plantation-type stands is required, since only 29% of plantation-type stands have been reported.

The aim of the research is (1) to explain the growth and productivity of plantation-type stands of the most widespread tree species—Scots pine, Norway spruce, silver birch, alder, grey alder, aspen, hybrid aspen, small-leaved lime, pedunculate oak, and wild cherry—in various AL soils, (2) changes in soil agro-chemical properties, and (3) changes in above-ground vegetation and (4) assess the economic effectiveness of these plantations.

2. Material and methods

The research material has been gathered at 21 established experimental plantations and 150 sample plots in plantations of AL on different soil types: typical sod-calcareous soil (TSC), sod-podzolic gley soil (SPG), gleyic sod-calcareous soil (GSC), sod-podzolic soil (SP), typical podzol (TP), alluvial sod-gley soil (ASG), leached sod-calcareous soil (LSC), base unsaturated brown soil (BUB), strongly altered by cultivation soil (CAS), and humi-podzolic gleyic spoil (HPG) (**Table 1**; **Figure 4**).

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.), alder (*Alnus glutinosa* L. Gaertn.), grey alder (*Alnus incana* L. Moench.), pedunculate oak (*Quercus robur* L.), small-leaved lime (*Tilia cordata* L.) and European syn. Sweet cherry (*Cerasus avium* (L.) Moench syn. *Prunus avium* L.), aspen (*Populus tremula* L.), and hybrid aspen (*Populus tremula x tremuloides* Michx.) (**Table 1**).

In each plantation four circular sample plots (500 m^2, R = 12.62 m) were set up, choosing their location randomly. The following actions were performed on each sample plot:

- Measuring the 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 the number of decaying and dead trees.

- Extracting core samples at chest height from 15 trees to determine the exact tree age and annual ring width; core samples were analysed with WinDendro 2007 software.

In each plantation, tree growth and productivity monitoring has been conducted, determining the following parameters: tree height (H), m; tree diameter at breast height (D), cm. Measurements repeated every 1–5 years. The first 5 years after the establishment of plantation measurements are repeated each year. The total monitoring period was 15 years. In each sample plot, the standing volume has been calculated [46] and the volume of mean tree, standing volume current annual increment, biomass of each tree component (stem, branches, leaves), and freshly cut biomass were calculated per unit area.

No. of trial	Site location: municipality/ parish	Site location	Soil type	Year of establishment/ thinning	Tree species, kind of plantation
1	Priekule/ Ozolbunci (Priek/ Ozolb)	56°23′29″ 21°40′35″	TSC	1997/—	Pedunculate oak: 1100–10,000 trees ha^{-1} Wild cherry: 2000 tree ha^{-1}
2	Grobina/ Berzpurvi (Grob/ Berz)	56°30′43″ 21°07′11″	TP	1997/—	Silver birch, Scots pine, Norway spruce: 3300 trees ha^{-1}
3	Kuldiga/Rumnieki (Kuld/Rumn)	57°03′03″ 21°46′05″	SP	1997/—	Silver birch, different spacing: 1100–10,000 trees ha^{-1} Pedunculate oak: 1,600 trees ha^{-1} European cherry: 3300 trees ha^{-1}
4	Kandava/Aizlolas (Kand/Aizl)	57°55′11″ 22°42′30″	GSC	1997/—	Scots pine, Norway spruce, Silver birch: 3300 tree ha^{-1} Pedunculate oak: 1100 trees ha^{-1}
5	Dobele/Mezansi (Dob/Mez)	56°15.465′ 25°25.470′	SP	1997/—	Norway spruce, Silver birch, Alder: 3300 trees ha^{-1}
6	Iecava/Skujenieki (Iec/Skuj)	56°32.605′ 24°19.414′	ASG	1997/—	Monoculture: Scots pine, Norway spruce, Silver birch—3300 trees ha^{-1}
7	Viesīte/Palsani (Vies/Pals)	56°15′28″ 25°25′23″	BUB	1997/thinning of birch plantation at the age of 15 years	Monoculture: Silver birch, Norway Spruce—3300 trees ha^{-1} Pedunculate oak: 2000 trees ha^{-1}
8	Amata/Laubites (Amat/Laub)	57°00′15″ 25°12′16″	TP	1997/—	Monoculture: Norway spruce, Silver birch—3300 trees ha^{-1}
9	Koceni/Zarini (Koc/Zar)	57°39′17″ 25°03′22″	LSC	1997/—	Monoculture: Silver birch, Alder —3300 trees ha^{-1}
10	Madona/Birzes (Mad/Birz)	56°54′55″ 25°57′16″	SPG	1997/ thinning of pine plantation at the age of 9 years	Silver birch, different spacing —1100–10,000 trees ha^{-1} Monoculture: Scots pine, Norway spruce—3300 trees ha^{-1}
11	Gulbene/Sopuli (Gulb/Sop)	57°09′25″ 26°58′33″	ASG	1997/—	Pedunculate oak: different spacing —1100–10,000 trees ha^{-1} Monoculture: Silver birch, Aspen —3300 trees ha^{-1}
12	Rezekne/Bitites (Rez/Bit)	56°14.768′ 27°17.277′	SPG	1997/—	Silver birch, different spacing —1100–10,000 trees ha^{-1} Monoculture: Scots pine, Norway spruce—3300 trees ha^{-1}
13	Iecava/Gaili (Iedc/Gail)	56°34.192′ 24° 08.863′	CAS	1994–1995/ thinning of spruce plantation at the age of 14 years	Different spacing, Norway spruce —2000–3300 trees ha^{-1} Silver birch—2000 trees ha^{-1} Pedunculate oak—1600 trees ha^{-1}
14	Ozolnieki/Medni (Ozol/Med)	56°36.005′ 24°04.212′	SPG	1993–1995/—	Silver birch, different spacing: 1600–3300 trees ha^{-1}, Monoculture: Scots pine, Norway spruce—2000–4000 trees ha^{-1}
15	Kandava/Viesturi (Kand/Viest)	57°03′11″ 22°44′21″	SPG	2000/—	Scots pine, Norway spruce, Silver birch—2000 trees ha^{-1}
16	Talsi/Zeltini (Kand/Zelt)	57°08′50″ 22°54′31″	SPG	2003/—	Wild cherry—1000 trees ha^{-1}
17	Kuldiga/Berzi (Kuld/Berz)	56° 59′49.474″	SP	1997/—	Wild cherry—10,000 trees ha^{-1}; 2000 trees ha^{-1}

No. of trial	Site location: municipality/ parish	Site location	Soil type	Year of establishment/ thinning	Tree species, kind of plantation
		21° 41′13.965″			
18	Krustpils/Paki (Krust/Pak)	56°35′12″ 26°10′04″	SPG	1993–1997/–	Monoculture: Norway spruce Silver birch—2000 trees ha^{-1}, Small-leaved lime—1100 trees ha^{-1}
19	Bauska/Ziedini (Bausk/Zied)	56°23′01″ 24°10′48″	SP	2009/–	Wild cherry, clone 'Trust', Denmark —1100 trees ha^{-1}
20	Malpils/ Dizavotini (Malp/ Diz)	57°01.998 24°54.538	SP	1995/–	Monoculture: Silver birch—2000 trees ha^{-1}
21	Dobele/Ezernieki (Dob/Ezer)	57° 35′34.85″ 23°15′ 21.27″	GSC	2011/–	Monoculture: Wild cherry, Sweden clone—2000 trees ha^{-1}

Scots pine (Pinus sylvestris L.), Norway spruce (Picea abies (L.) Karst.), European larch (Larix decidua Mill.), silver birch (Betula pendula Roth.), aspen (Populus tremula L.), alder (Alnus glutinosa L.), grey alder (Alnus incana (L.) Moench), pedunculate oak (Quercus robur L.), small-leaved lime (Tilia cordata L.), wild cherry (Cerasus avium Moench (L.) syn., Prunus avium L.).
TSC—typical sod-calcareous soil, GSC—for gleyic sod-calcareous soil, BUB—base unsaturated brown soil, SP—sod-podzolic soil, TP—typical podzol, SPG—sod-podzolic gley soil, HPG—humi-podzolic gleyic soil, ASG—alluvial sod-gley soil, and CAS—strongly altered by cultivation soil.

Table 1.
Characteristics of experimental plots.

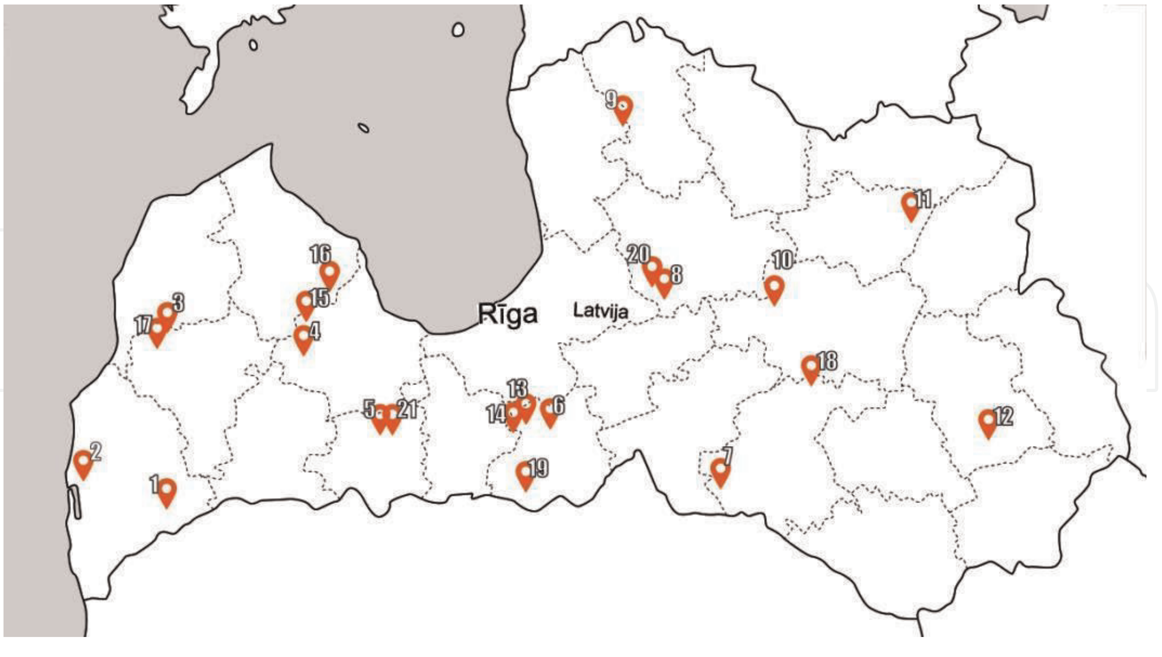

Figure 4.
Locations of experimental plantations.

Individual tree stem volume has been calculated with the formula [46]:

$$v = \psi L^{\alpha} D^{\beta \lg L + \varphi} \tag{1}$$

where v is stem volume with bark, m^3; L is stem length, m; D is stem breast height diameter with bark, cm; and ψ, α, and β are coefficients dependent on tree species [46].

Using the sample tree data, the stand volume current annual increment has been calculated with the formula [46]:

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

where ZM is the current actual stand volume increment, $m^3\ ha^{-1}$; H is the average stand height, m; G is the stand basal area, $m^2\ ha^{-1}$; k is the empirical ratio; D is the mean breast height diameter of the stand, cm; ZD is the current increment of D of the stand, mm; and ZH is 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 the root collar—one Kraft class I and two Kraft class II. After felling the tree height has been measured using a tape measure (with precision to 1 cm), and the stem is pruned and cut into metre-long sections. The sample tree weight is determined on site by weighing separately: stem wood, dry branches, and live branches.

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

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

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 0–40 cm (0–10, 10–20, 20–30, 30–40 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 (0–40 cm) were analysed before planting, and analyses were repeated at specified intervals till the age of 15 years. Soil analyses were performed in the laboratory of the 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) [47].

On the afforested sites, vegetation was inventoried before forest establishment and then after each 3 years 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, a total of 10 sample plots (1×1 m each) were described throughout the whole territory of plantation. In the inventories carried out after each 3 years, three 1×1 m sample plots were established in each tree plantation, and the total number of survey plots is 219. 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 [1, 48]. The projective cover of each plant species in the tree, shrub, and herbaceous and bryophyte layer was assessed as a percentage of the respective species, using the Braun-Blanquet method [49]. The mean indicator values were calculated for each plot from all present vascular plant species, from which an indicator value was calculated according to Ellenberg et al. [50].

Data validation and mathematical calculations were performed with Microsoft Excel 2016. Summary statistics for D, H, and basal area were calculated using SPSS software [51]. The formulas of (1) and (2) were used to calculate the stem volume for different tree species [46]. One-way analysis of variance (ANOVA) and a t-test were used in the statistical analysis ($p < 0.05$). The mean values in the tables are presented together with the standard deviation (±SD).

3. Changes in agrochemical properties of soil

Changing the type of land use causes changes in the ecosystem, as a result of the changes in biotic factors (the impact of microorganisms on other organisms of the biological community), as well as changes in abiotic factors (temperature, light, humidity, soil, acidity of the soil, amount of salts, amount of minerals, etc.).

As we know, the most important parameters of growth conditions are determined by the interaction of several factors—physical, chemical, and biological soil properties—as well as climate, which ensure soil fertility. The analysis of Holubik et al. reviewing 43 afforestation studies found the key factors to be (in the order of importance) (i) previous land use, (ii) climate, and (iii) the type of forest [52]. The research indicates that basic properties of the soil are comparatively stable; they have developed over a long period of soil formation processes under the influence of climate, terrain, geological substratum, flora, and fauna and are characterised by their granulometric composition, ion exchange capacity, depth of geological substratum, and drainage. Human economic activity has a minor effect on this or no effect at all [53, 54]. However, a series of soil characteristics exist that can change significantly over a short period of time: content of soil organic matter, soil structure, bulk density, water infiltration capacity, reaction, plant nutrient resources, etc. Changes in these characteristics are mainly determined by human economic activity: type of land use, soil tillage technology, and cultivated crops or trees. According to the assessment of scientists, organic matter in soil is one of the main indicators of soil quality and productivity [53–59]. The accumulation of organic carbon in the soil occurs in forest and grassland ecosystems. European forests annually capture an average of 124 g $(m^2)^{-1}$ C, 70% of which is accumulated in tree biomass of trees and 30% in the topsoil and soil. Furthermore, the biomass of the forest ecosystem accumulates more carbon than crops grown on agricultural land, thus reducing the concentration of carbon dioxide in the atmosphere and improving the global environment.

Studies conducted by the Latvian State Forest Research Institute (LSFRI) *Silava* indicate that the concentration of nutrients in soil, as well as physical properties of soil, have great importance in ensuring the optimum growth of new stands of different tree species in mineral soils of former agricultural lands [1]. The research of the researchers of Latvia University of Life Sciences and Technologies A. Kārkliņš and I. Līpenīte also bears evidence that after afforestation of former agricultural lands, the physical and chemical properties of the soil have changed: the bulk density of topsoil has decreased, and its total porosity and relative water retention potential has increased [54, 55]. Trials suggest that it is advisable to choose naturally dry mineral soils or soils with a controlled moisture regime to create productive plantations.

According to the studies of LSFRI Silava, aeration, temperature, and humidity regime deteriorate significantly in compacted soils [56, 57]. The scientists have concluded that the optimal soil density for the development of trees, especially at an early stage, is 1.25–1.35 g $(cm^3)^{-1}$ [56, 57]. In dense, heavy soils (exceeding 1.80 g $(cm^3)^{-1}$), the introduction and development of any tree species are difficult without additional soil tillage (continuous ploughing, deep digging, soil structure improvement, etc.). However, as the trees grow, the ability of their roots to penetrate into the denser layers of bedrock increases, and, already at the age of a

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maturing stand (at the age of around 30–40 years), productive plantations can be grown in heavy clay soils [56, 57]. An important parameter for ensuring the successful growth of trees is soil pH, which does not always conform to the optimum. Scientists have found that mildly acidic soils (pH 5.5–6.5) are the most suitable for normal tree development, except for pines growing on acidic soils (pH 4.5–5), but tree species like sweet cherry, oak, ash, etc. are the most productive growers in neutral and even alkaline soils (pH 6.5–7.5 and above) [56–60]. An important condition to ensure optimal tree growth is the selection of a suitable site with appropriate hydrological conditions for planting to ensure that the groundwater table in spring and autumn does not rise above the average depth of 30 cm from the ground surface [61, 62]. Coniferous, as well as many deciduous, species, such as silver birch, oak, and sweet cherry can tolerate flooding of active roots for a period that is no longer than 5 days; after this period, growth disorders may develop. In contrast, tree species like black alder and downy birch are more suitable for wet areas and can withstand 7–9 days of root flooding, even though the largest growth in these species is registered in medium wet loam and sandy loam soils [61, 62].

The optimal soil temperature, which regulates the processes of uptake of available minerals by the plants, as well as the activity of microorganisms, and fluctuates at an average of 15–20°C in our climatic conditions, ensuring the optimum mode of woody plant nutrition provided that the amount of soil moisture is sufficient, is also important for successful tree growth [63]. Soil temperature is largely determined by the mass of herbaceous vegetation: soil temperature in dense and thick grass will be 3–5°C lower than in an open area [63]. Therefore, soil preparation and further plantation care are required to ensure the introduction of trees and faster initial growth. Agrochemical soil properties are equally important prerequisites for the successful cultivation of trees: content of organic substance, amount of minerals (phosphorus, potassium, nitrogen, calcium), and trace elements (magnesium, manganese, boron, iron, copper, sulphur, zinc, etc.) in the soil water solution. Since the leaves of deciduous trees are decomposed quickly, the stands of these trees are predominantly characterised by accumulative processes of soil formation: the build-up of humus results in a content of organic matter in the upper horizons of soil that exceeds 10%, and the amount of potassium and calcium is sufficient, while a deficiency of nitrogen and phosphorus may occur, especially in heavy clay soils, as well as alkaline soils [1, 60, 64, 65]. As scientists report, afforestation of agricultural land leads to considerable changes in processes that occur in the soil, including the circulation of plant nutrients: depending on the species of trees cultivated, biomass that is accumulated in the soil differs in terms of quantity and chemical composition. The rate of soil mineralisation, which is affected by the C and N ratio, as well as the presence of lignin and other secondary carbon compounds, determines the circulation and supply of nitrogen and other plant nutrients in the soil [56–60, 64, 65]. According to the studies of Sanborn[62], soil acidity pH and total N, available to plants P, Ca, Mg and K, have considerably increased 23 years after the afforestation of agricultural land, where mixed stand of paper birch (*Betula papyrifera* Marsh.) and Rocky Mountain lodgepole pine (*Pinus contorta* var. latifolia Dougl. ex Loud.) were developed, while the C:N ratio has decreased, as it is in forest soils [65]. The trials on changes in soil properties after the afforestation of agricultural lands conducted in Latvia have indicated that the physical and agrochemical properties of soil have changed—the bulk density of topsoil has decreased, and its total porosity and relative water retention potential have increased [55–59]. After 15 years of accumulation of the humus in the soil horizon caused by afforestation, the acidification of soil and an increase in the content of organic matter have occurred in comparison with arable soil, while the proportion of total nitrogen in organic matter has decreased, and the amount of phosphorus and potassium in the soil under the pine stands that is available to plants has been higher than in the nearby non-afforested agricultural land [55–59].

To explain the changes in the agrochemical properties of soil under the influence of afforestation, the monitoring of soil agrochemical properties was performed in different soil types of the afforested areas: TSC, GSC, SPG, CAS, SP, TP, ASG, LSC, and BUB. Soil agrochemical properties (N, P, K changes) were evaluated prior to the establishment of tree plantations and then in year 4 and year 15 after the establishment of plantations [1]. In all objects, the plantations were set up in uncultivated agricultural land—fallow land that has not been cultivated for 1–3 years, with the dominant species being creeping thistle and couch grass.

Variation in the proportion of soil organic matter and acidity in the active root zone at a depth from 0 to 40 cm over a period of 15 years since the establishment of the plantation forest on the respective site were chosen as the indicators 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 1–12, 14, and 16). No significant changes in soil humus content are recorded for sites with a relatively small volume of above-ground biomass (trial plots 3, 10, 11, 12, and 16) (**Table 2**).

Similar results are also quoted by researchers of other countries [52, 64, 65]. As concluded in a number of studies, forest floor humus on the soil surface is completely new [65].

The field data show that 15 years after the establishment of plantation forest 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 in most cases was close to neutral (trial plots 2, 4, 6, 10, 16) and in the 15 years had reduced by 1.15 units on the pH scale on average (**Table 2**).

Investigations show that 15 years after afforestation, the content of organic matter in active root layer (0–40 cm) increases by 22.5% average in all experimental trials (**Table 2**, **Figure 5**).

No. of trial	Soil type [52]	Humus content, %		PH_{KCl}	
		Before establishment	After 15 years of establishment	Before establishment	After 15 years of establishment
1 Priek/Ozolb	TSP	1.4	4.56	5.92	5.19
2 Grob/Berz	TP	2.42	3.82	6.52	6.48
3 Kuld/Rumn	SPG	3.06	2.68	6.17	5.41
4 Kand/Aizl	GSC	2.13	4.01	6.60	5.75
5 Dob/Mez	SP	2.62	3.54	5.27	5.70
6 Iec/Skuj	ASG	2.19	2.53	6.7	5.20
7 Vies/Pals	BUB	3.22	3.45	5.15	4.26
9 Koc/Zar	LSC	3.86	3.95	5.45	5.30
10 Mad/Birz	SPG	3.24	2.40	7.02	5.61
11 Gulb/Sop	ASG	2.95	3.07	6.00	5.72
12 Rez/Bit	SPG	3.05	2.46	6.3	4.21
14 Ozoln/Med	SPG	2.71	3.78	5.55	5.08
16 Tals/Zelt	SPG	3.86	3.2	6.9	5.70

Table 2.
Changes in soil chemical properties in the active root layer (0–40 cm) in the 15-year plantations.

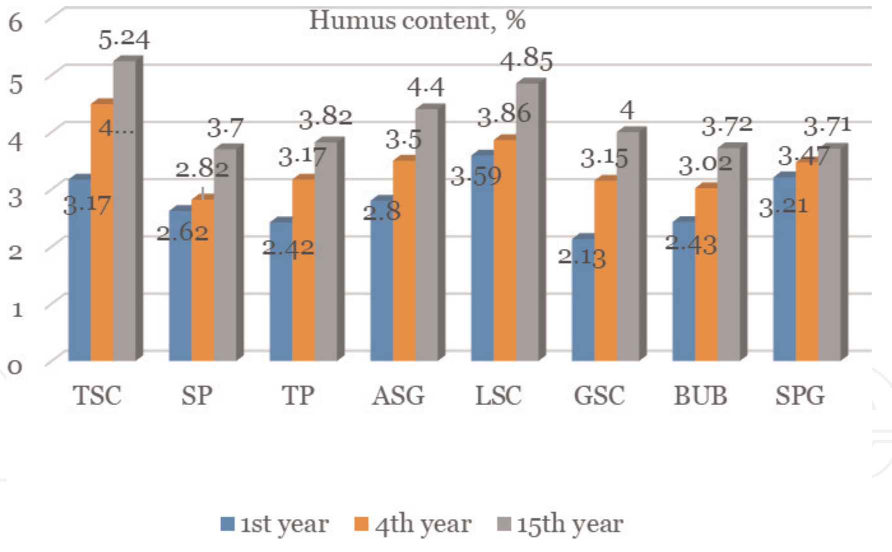

Figure 5.
Dynamic changes in humus content after afforestation in different soil types: Average indicator for all tree species (%).

4. Changes in above-ground vegetation

In all afforested objects, 247 species of vascular plants, 32 species of moss, and 1 species of lichens were listed during the latest inventories. The following trends of changes in ground cover have been observed: the occurrence of grassland and fallow land grass species has decreased, while at some sites, the introduction of up to 20 new ground-cover species has been observed. In fertile soils, meadow species have been replaced by eurybiont nitrophytes *Anthriscus sylvestris*, *Artemisia vulgaris*, and *Urtica dioica*. However, grassland specific grasses have still been present at almost all research sites: *Agrostis gigantea*, *A. tenuis*, *Deschampsia cespitosa*, *Festuca rubra*, and *Phleum pratense*, as well as other meadow and set-aside fallow land plants: *Campanula patula*, *Galium album*, *Leucanthemum vulgare*, and *Taraxacum officinale*. Mosses have disappeared—species colonising bare soils *Barbula unguiculata*, *Pleuridium subulatum*, and *Pohlia wahlenbergii*. The flora of mosses is still most widely represented by species that are common in forests, as well as grasslands, *Sciuro-hypnum curtum*, *Plagiomnium affine*, and *P. undulatum*, but the cover of mosses under the thick layer of herbaceous plants is usually negligible. Introduction of typical boreal coniferous forest cover species *Pleurozium schreberi* and *Hylocomium splendens* occurs faster at the objects where dry and low-fertility fallow lands have been afforested, while dwarf shrubs *Vaccinium myrtillus* and *V. vitis-idaea* that are typical for coniferous forests have not been detected at any object to date.

Herbaceous vegetation has changed as a result of afforestation at all objects: the replacement of original ground cover of grassland and fallow land species with forest-specific plants has begun. Most species belong to native flora; however, certain garden escaping plants and adventive species have been registered: *Lupinus polyphyllus*, *Oxalis stricta*, *Sambucus racemosa*, *Solidago canadensis*, *Symphytum asperum*, and *Heracleum sosnowskyi*. Among the aforementioned species, only *Lupinus polyphyllus* plays a significant role in the phytocoenosis of some objects. Some indicator species of natural grasslands can still be found: *Agrimonia eupatoria*, *Linum catharticum*, *Pimpinella saxifraga*, *Polygala vulgaris*, and *Primula veris*. Rare and protected species are represented by individual orchid specimens—*Dactylorhiza* sp. and *Platanthera* sp. [1, 17, 66].

5. Growth and development of Scots pine (*Pinus sylvestris* L.) plantations in agricultural land

By assessing the growth of Scots pine plantations in four different soil types (TP, SPG, GSC, ASG), we conclude that the growth of pine in farmlands differs from that in forestlands. So, the diameter of the mean tree of 15-year plantation pine is comparable to that of 25–28-year forest pine of site index I, with the mean height corresponding to that of 16–18-year forest pine of site index I (**Table 3**) [67].

The stock volume of well-growing plantation pine may by the age of 15 be as high as 80–155 $m^3\ ha^{-1}$ and by 22 years reach even 243 $m^3\ ha^{-1}$. Pine plantations produce the highest stock volume in podzol, cultivated, and soddy-podzolic soils, where the stock volume for 15–16-year pine is 112–155 m3 ha^{-1}, with the current volume growth of 5–8 m3 ha^{-1} per year (**Table 3**).

When evaluating the growth of above-ground biomass of plantation pines by analysing sample trees, the biomass weight for a single tree is found to be on average 136.6–190.15 kg (100%), of which stem biomass is 69.8–148.5 kg (51.1–78.1%) and crown biomass (branchwood and foliage) 66.8–41.7 kg (48.9–21.9%). To gain an appreciable stock volume of plantation pine already by the age of 40, purposeful and properly timed tending, including the pruning of future crop trees, should be started no later than at the age of 14–15 (**Table 4**).

It is to be noted that in fertile agricultural soils (cultivated, alluvial, calcareous), the plantation pines develop twin stems and thick branches that adversely affect the potential height and diameter growth and, consequently, the mean stem volume, quality, and the stock volume anticipated. When tending pine in similar growing conditions, the emphasis should be on removing all low-quality stems or using the plantation for short-rotation (15–20 years) cultivation of pinewood biomass.

To get high-quality sawlogs from pine plantations, branches of the lowest whorl should be pruned no later than at the age of 5–7 years, followed by removing in each ensuing year the branches of the next whorl. After the first pruning, the length of the remaining crown should be 2/3 of the tree height, reducing in each subsequent pruning the crown length to ½ of the stem height, so that by the age over 30 years the crown length should be 1/3 of the tree height.

Experimental trial	2Grob/Berz	4Kand/Aizl	14Ozol/Med	6Iec/Skuj	12Rez/Bit
Soil type	TP	GSC	SPG	ASG	SPG
Density stems ha^{-1}	3774	2651	2925	1853	1510
D, cm	11.6 ± 2.78	13.9 ± 2.6	12.9 ± 2.6	12.7 ± 2.2	10.3 ± 2.88
H, m	7.7 ± 0.60	7.3 ± 0.74	7.4 ± 0.95	7.7 ± 0.43	8.2 ± 0.90
Volume of mean tree, m^3	0.04	0.03	0.04	0.06	0.06
Volume, $m^3\ ha^{-1}$	152	79	117	111	91
Average volume increment $m^3\ ha^{-1}$ per year	8.94	4.44	4.06	5.26	5.77
Significant difference at $p < 0.05$	Except 6 (p > 0.05)	Between all	Between all	Except 14 (p > 0.05)	Except 14 (p > 0.05)

Table 3.
Stand data of scots pine plantations on different soils (age 15 years).

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/%
2Grob/Berz	174.42/106.05/100	143.14/87.03/82.1	31.28/19.02/17.9
14Ozol/Med	210.52/128/100	170.1/103.42/80.8	40.42/24.57/19.2
6Iec/Skuj	185.52/112.80/100	132.12/80.32/71.2	53.4/32.47/28.8
Average			
Freshly cut, kg	190.15 ± 15.1	148.45 ± 15.95	41.7 ± 9.1
Abs. dry, kg	115.61	90.26	25.35
%	100	78	22

Table 4.
The average indices of sample tree above-ground biomass (freshly cut/abs. Dry/%) 15-year-old pine plantations.

In highly productive pine plantations, the protection of trees against the damage of artiodactyls is a must. For this purpose we may use repellents and stem protection tubes or fence the site in.

6. Growth and development of Norway spruce plantations on agricultural land

The assessment of the growth of spruce plantations on AL had been performed on nine sites, and their growth and cumulative productivity has been researched in plantations on AL in naturally dry mineral soils (SP, BUB, CAS, ASG, and PGx) (**Table 5**).

Investigations show that Norway spruce may be successfully cultivated in open farmland areas. Its rooting and growth in intensively managed (additional fertilisation and soil liming in case of need) and duly tended sites should be evaluated as good and excellent. However, spruce as a shade-tolerant species adapts itself much slower to the growing conditions of open farmlands. As it follows from the field data, the growth in height of spruce in the first 5–6 years after planting is stunted (on average 0.10–0.15 m.year^{-1}), and only in optimum growing conditions it reaches the height of DBH (1.3 m) by the said age (**Table 5**).

The data acquired in experiments show that by carrying out timely agrotechnical tending in sod-podzolic agricultural lands, the (exp. trials 5, 8, 10, 12) Norway spruce mean height at the age of 15 years had reached 8.3 m, which corresponds to the Norway spruce dominant height of site index I (H = 12 m) in forest stands [67], whereas the Norway spruce mean height in soils' CAS (13Iec/Iec2) and in plantations at the age of 15 years, where additional fertilisation has been performed (8Amat/Zaube), reaches H = 9.5–10.5 m, corresponding to the 18-year-old site index I spruce dominant height in forest stands, in forest soils [67].

In AL of soil types CAS, ASG, and SPG without fertilisation, the tree mean diameter at breast height in 15-year-old plantations shows a greater difference: 8.3–12.6 cm, tree height H = 7.1–8.9 m, and standing volume 68–142 m^3 ha^{-1}. The current standing volume increment in these trials constitutes 6.57–15.76 m^3 ha^{-1} per year (**Table 6**).

When determining the Norway spruce plantation above-ground biomass volume, it was found that in a 15-year-old plantation, the above-ground biomass of mean tree constitutes 143 kg (100%) on average, including stem biomass 66 kg (46%) and crown biomass (branches plus needles) 77 kg (54%), which in turn splits

Experimental trial	5Dob/Mez	6Iec/Skuj	7Vies/Pals	8Amat/ Laub	10Mad/Birz	12Rēz/Bit	13Iec/Gaili 3300 trees ha^{-1}	13 Iec/Gaili 2500 trees ha^{-1}	14 Ozol/ Med
Soil type	SP	ASG	BUB	TP	SPG	SPG	CAS	CAS	SPG
Density, stems ha^{-1}	2840	2660	3128	1400	3100	2957	2230	2165	2640
DBH, cm	9.2 ± 1.98	12.6 ± 2.31	7.9 ± 2.39	12.3 ± 2.65	10.5 ± 1.48	9.4 ± 2.87	10.6 ± 2.87	10.9 ± 2.40	8.3 ± 2.12
H, m	7.7 ± 1.91	7.7 ± 0.71	6.7 ± 0.86	10.5 ± 0.91	7.8 ± 0.69	7.4 ± 1.92	8.9 ± 1.90	9.5 ± 1.12	7.1 ± 1.01
Volume of mean tree, dm^3	0.0318	0.0534	0.0205	0.0669	0.0389	0.0304	0.0396	0.0491	0.0258
Volume, m^3 ha^{-1}	90	142	64	98	97	90	88	106	68
Average volume increment, m^3 ha^{-1}/year	7.42	15.76	5.51	14.59	5.29	8.66	10.26	13.04	6.57
Significant difference at $p > 0.05$	Except 7Vies/Pals 10Mad/Birz	Except 7Vies/Pals	Except 5Dob/Mez 10 Mad/Birz	Between all	Except 5Dob/Mez 7Vies/Pals	Except 7Vies/Pals	Except 6Iec/Skuj	Except 6Vies/ Skuj	Between all

Table 5.
Growth and productivity of Norway spruce plantations on agricultural lands.

Trial	Total biomass, kg/%	Stem biomass, kg/%	Tree crown biomass		
			Live branches, kg/%	Incl., needles	
				kg	% of stem biomass
13Iec/Gail	177/100	85/49	91/51	44	25
6Iec/Skuj	143/100	66/46	77/54	38	27
10Mad/Birz	153/100	66/43	86/56	46	30
7Vies/Pals	122/100	50/41	72/59	35	28
5Dob/Mez	134/100	61/45	73/55	37	27
14Ozol/Med	129/100	66/51	62/48	29	22
Average freshly cut, kg /abs. Dry, kg %	143/ 66/ 100	66/ 30/ 46	77/ 35/ 54	38 19	27

Table 6.
The average indices of sample tree above-ground biomass (freshly cut/abs. Dry) in 15-year-old Norway spruce plantations.

into branch biomass 32 kg (41%) and needle biomass 45 kg (59%) (**Table 6**). The profitability of plantation cultivation of spruce may be raised by delivering foliage biomass to the manufacturers of medicinal preparations and food additives.

7. Growth and development of silver birch plantations on agricultural land

The research on the growth of silver birch and productivity on former AL, in naturally dry mineral soils, it is suggested that overall, compared to conifers, the growth of silver birch in these plantations is more dynamic [1, 17, 27, 28, 31, 33].

The greatest silver birch height is recorded exactly in plantations in fertile agricultural soils—in soil CAS in the trial 13Iec/Gail and in SPG soil in the trial 14Ozol/Med; the mentioned soils had been extensively used in agricultural production (**Table 8**), here the mean height of silver birch at the age of 15 years marked as 15.3 m.

In the plantations in SPG soil (trials No 3, 8, 10, 12, 14), the mean height of silver birch varies from 12.8 to 14.7 m, in ASG soil (trial No 6) from 12.1 to 12.5 m, in BUB soil (trial no 7) 14.3 m, and in GSC soil (4Kand/Aizl), on heavy gley base material, 8.5 m, but the mean diameter at breast height in these trials fluctuates from 9.7 to 13.2 cm, from 10.3 to 12.5, 10.9, and 7.9 cm, respectively (**Table 8**).

The productivity of silver birch plantations at the age of 15 years in different soils varies from 62 to 169 m^3 ha^{-1} (**Table 7**).

The current standing volume increment in silver birch plantation experimental trials varies from 7.54 to 29.82 m^3 ha^{-1} per year: the smallest increment—4.66 m^3 ha^{-1} per year—in 15-year-old plantations has been registered in heavy gley soil (4Kand/Aizl), but the largest, 29.72–29.82 m^3 ha per year, in CAS soil (13/Gail) and in pseudogley soil (14/Med) (**Table 7**).

The data statistical analysis indicates that the productivity of silver birch plantations at the young stand age is also significantly smaller ($p \leq 0.05$) in heavy gley soils (4Kand/Aizl).

Experimental trial	**1Grob/ Bērz**	**3Kuld/ Rūmn**	**4Kand/ Aizl**	**5Dob/Mez**	**6Iec/Skuj**	**7Vies/Pals**	**8Amat/ Laub**	**9Koc/Zar**	**10Mad/ Birz**	**11Gulb/ Sop**	**12Rez/Bit**	**13Iec/Gail**	**14Ozol/Med (initially 3000 trees ha^{-1}**	**15Ozol/Med (initially 1600 trees ha^{-1}**
Soil type [53]	TP	GSP	GSC	SP	ASG	BUB	SP	TSP	SPG	ASH	SPG	CAS	SPG	SPG
N, trees ha^{-1}	1758	1952	2165	2650	2500	2928	2214	2354	1650	861	1400	1675	2765	1480
D, cm	10.6 ± 2.71	11.6 ± 1.71	7.9 ± 2.21	10.5 ± 2.60	10.3 ± 2.80	10.9 ± 1.96	9.7 ± 2.60	10.4 ± 2.35	10.8 ± 3.3	12.5 ± 2.49	8.8 ± 3.6	13.9 ± 2.46	12.6 ± 2.06	13.2 ± 2.29
H, m	12.3 ± 1.14	12.8 ± 0.80	8.5 ± 1.00	14.2 ± 1.82	12.5 ± 2.3	14.3 ± 1.06	13.3 ± 1.83	12.8 ± 1.55	13.0 ± 2.18	12.1 ± 0.55	10.0 ± 3.0	16.2 ± 1.06	14.0 ± 1.53	14.7 ± 1.04
V, dm^3	0.0534	0.0659	0.0219	0.0595	0.0512	0.0645	0.0505	0.0533	0.0582	0.0725	0.0439	0.0909	0.0489	985
M, m^3 ha^{-1}	82	101	47	128	138	145	112	131	135	62	61	169	143	122
Z_M, m^3 ha^{-1} per year	14.33	12.17	4.66	13.49	21.69	25.1	15.72	20.97	12.07	8.30	3.72	29.82	29.72	24.97
Significant difference at 0.05 level ($p < 0.05$)	Except trials 6, 7	Except trials 2, 6, 14, 15	Between all	Except trials 3, 12, 14, 15	Except trials 3, 4, 7	Except trials 4, 6	Except trials 4, 10, 14, 15	Except trials 2, 6, 7	Except trials 2, 6, 14, 15	Between all	Except trials 2, 6, 14, 15	Between all	Except 13 Iec/ Gail	Except 13 Iec/ Gail

Table 7.
Growth and productivity of birch (Betula pendula Roth) plantations on agricultural lands.

Experimental trial	Soil type	Mean tree volume, m^3				
		Variants, planting schema				
		1 × 1 m	1 × 2 m	2 × 2 m	2 × 3 m	3 × 3 m
3Kuld/Rumn	SP	0.0272	0.0356	0.0516	0.0603	0.0802
10Mad/Birz	SPG	0.0353	0.0530	0.0605	0.0592	0.1025
12Rez/Bit	SPG	0.0194	0.0298	0.0327	0.0360	0.0550
Average		0.0273	0.0395	0.0483	0.0518	0.0792

Table 8.
Variations in the mean tree volume of a 15-year birch depending on planting density at trial sites.

The largest cumulative volumes of mean tree for silver birch are in SPG extendedly cultivated soil (14Ozol/6Med) 0.0960 m^3, in CAS soil (13Iec/Gail) 0.0909 m^3, and in ASG soil (6Iec/Skuj) 0.0798 m^3, but the smallest cumulative volumes of mean tree have been recorded in GSC heavy gley soil in the trial 4Kand/Aizl, 0.0219 m^3 (**Table 7**).

The growth of birch plantation, especially in the young age, depends on such factors as soil fertility, relief, microclimate, hydrological regime, and the method of establishing and tending the plantation. In terms of growth and yield, the best performance by the age of 15 years is shown by birch plantations (stock volume 112–169 m^3 ha^{-1}) in fertile agricultural soils with stable moisture regime (cultivated, sod-podzolic, unsaturated brown, sod-gley alluvial soils).

It should be noted that the significant differences for the tree volume growth of birch plantation in 15 years depend on planting density (**Table 8**) [1, 26, 27].

Investigations show the same results than Estonian and Scandinavian researchers [24, 29, 30]; that higher density birch plantations (10,000 and 5000 trees ha^{-1}) are profitable as short-rotation plantations of energy wood, but plantations with lower density (1600, 1100 trees ha^{-1}) could be used for cultivating birch timber.

Research on the volume of the silver birch plantation above-ground biomass indicates that the biomass of a 10-year-old silver birch constitutes 65 $\pm$ 12.81 kg (100%) on average, of which the stem takes up 48 $\pm$ 9.5 kg or 74% of the total tree biomass, but the crown biomass (branches plus leaves) 17 $\pm$ 4.3 kg or 26% of the total tree biomass. A 15-year-old birch biomass constitutes 158.41 $\pm$ 31.72 kg (100%) on average, including the stem biomass 121 $\pm$ 22.8 kg or 76% of the total tree biomass, but the crown biomass (branches and leaves) 37.3 $\pm$ 14.3 kg or 24% of the total tree biomass (**Table 9**).

8. Growth and development of alder (*Alnus glutinosa* (L.) Gaertn.) plantations

Recent research indicates that alder occupies an important place in plantation forestry as well, since it grows vigorously in periodically wet areas or in areas with high groundwater levels and develops deep and broad root systems even under anaerobic conditions thanks to the absorption of oxygen through the lenticels of its trunk above the surface of the water; furthermore, alder is also capable of excreting toxic gases through the cells of its parenchyma [65]. Plantation cultivation of alder offers a high yield of wood in a relatively short period of time. It should be grown in fertile, sufficiently moist soils, where the groundwater level stays fairly high; these

Sample tree age (years)	Total biomass kg/%	Stem mass kg/%	Branch mass, kg/%
10 years old	65 ± 12.8/ 100	48 ± 9.5 74	17 ± 4.3/ 26
12 years old	98 ± 7.2/ 100	71 ± 3.9/ 72	27 ± 3.4/ 28
15 years old	158 ± 31.7/ 100	121 ± 22.9/ 76	37 ± 14.3/ 24

Table 9.
The average indices of sample tree above-ground biomass (freshly cut) in 10–15-year-old silver birch plantations.

Experimental trials	5 Dob/Mez		9Koc/Zar	13Iec/Gail
	1st floor	2nd floor		
Soil type [53]	SP	SP	LSP	CAS
N, trees ha^{-1}	Total 3345/1st floor 2532	813	1146	700
D, cm	12.2 ± 2.64	6.2 ± 1.44	11.3 ± 2.85	14.5 ± 3.42
H, m	15.4 ± 1.43	10.9 ± 1.56	15.3 ± 0.85	10.9 ± 1.12
V, dm^3	0.0898	0.0184	0.0769	0.0923
M, m^3 ha^{-1}	Total 249/1st floor 234	15	88	66
$Z_{M,\ m}$^{3} ha^{-1} per year	26.16	—	10.77	13.07
Significant difference at 0.05 level ($p < 0.05$)	Between all		Except 5Dob/Mez	Except 5Dob/Mez

Table 10.
Growth and productivity of alder (Alnus glutinosa (L.) Gaertn.) plantation in agricultural land.

are cultivated, soddy-podzolised, alluvial, podzolised gley, semi-hydromorphic, and peaty soils of high and transitional bogs with no stagnant groundwater [65].

The objective of the research project carried out by LSFRI Silava is to find out the productivity of alder in plantation-type stands in former agricultural lands. The research of alder stands is conducted at three objects: on SP soil (Dob/Mež), on LSC soil (Koc/Zar), and humus rich CAS soil (13Iec/Gaiļ). Typically, the alder reaches DBH level during the second or third year after planting (**Table 10**).

Trials show that alder plantations in Sp, LSp, and CAS soils reach an average height of 10.9 ± 1.12–15.4 ± 1.43 m and diameter at the level of the chest of 11.3 ± 2.85–14.5 ± 3.42 cm at the age of 15. The wood volume of the plantation, with the density of plantation being 1146–3345 trees ha^{-1}, amounts to 81–234 m^3 ha^{-1} (**Table 10**).

It should be noted that the removal of several root suckers has not been performed at the object 5Dob/Mez and in 50% of the cases two to three root suckers were left at each trunk, while at the object 9Koc/Zar, all suckers have been removed (**Table 10**).

Plantation cultivation of common alder offers a high yield of wood in a relatively short period of time. It should be grown in sufficiently fertile moist soils, where the groundwater level stays fairly high; these are cultivated, sod-podzolic, alluvial, podzolic-gley, semi-hydromorphic, and peaty soils (CAS, SP, LSP, AHG, SPG, ASG, BUB, etc.) of high and transitional bogs with no stagnant groundwater.

9. Growth and development of grey alder (*Alnus incana* (L.) Moench) plantations on agricultural lands

Research indicates that grey alder is a promising species of trees in the climate zone of Latvia, as the volume of appropriately managed grey alder stands can reach 250–400 m^3 ha^{-1} within as few as 25–30 years, with 50–70% of the trunk timber conforming to roundwood requirements [1, 17, 68].

Research has confirmed that grey alder is particularly suitable for the development of plantations and short-rotation plantations.

It has been found that the growth rate of grey alder varies considerably in different growth conditions. In soils rich in mineral nutrients, as well as in humidity-controlled areas, the growth of grey alder in young stands and within the framework of first age class is only slightly behind the growth rate of hybrid aspen (see the section Growth Rate of Aspen and Hybrid Aspen Plantations) (**Table 12** [1, 17, 22, 69]).

The volume of grey alder in high-quality stands (H20 = 12–20 m) is also considerable, and as soon as within 15 years, the volume of harvested trunk timber amounts to 77–178 m^3 ha^{-1} (**Table 12**). Meanwhile, the yield of timber obtained from well-cultivated high-quality stands (H20 = 20 m) of grey alder at the age of 25 years amounts to 359 m^3 ha^{-1} (**Table 11**).

Investigations show that grey alder as a fast-growing species is suitable for plantation cultivation in sites with fertile soils and stable moisture regime. In high site index plantations (H_{20} = 16–20 m), the stock volume of 10–15-year grey alder may reach even 180 m^3 ha^{-1} (**Table 12**). Depending on the intensity of thinning at the early age, we may recover a definite volume of such assortments as roundwood, case timber, and firewood or wood chips. A 5–15-year grey alder coppice should be managed as short-rotation plantation, yielding 75–455 loose m^3 ha^{-1} of wood chips.

Development of broadleaved species: pedunculate oak (*Quercus robur* L.), wild cherry (*Cerasus avium* Moench. syn. *Prunus avium),* and small-leaved lime *(Tilia cordata* L.*)* plantations on agricultural lands.

Broadleaved species pedunculate oak, wild cherry, and small-leaved lime plantations on agricultural lands with naturally dry mineral soils (TSC, SP,GSC, BUB, ASG, CAS) show different growth rate than common tree species: for oak, tree height fluctuated from 2.6 ± 0.83 to 6.0 ± 2.4 m and breast height (DBH) from 2.8 ± 1.64 to 6.6 ± 3.9 cm; for wild cherry, tree height fluctuated from 5.5 ± 0.81 to 7.8 ± 0.53 m and DBH 5.2 ± 1.72–11.4 ± 2.62 cm; and for small-leaved lime, tree height fluctuated from 7.1 ± 0.84 to 8.8 ± 2.14 m and DBH from 8.8 ± 2.14 cm to 13.6 ± 2.80 cm. At this stage it is not yet possible to evaluate the performance of these plantations (**Table 12**).

Research shows that, under the climatic conditions of Latvia, the growth rate of tree species like pedunculate oak (*Quercus robur* L.), small-leaved lime (*Tilia cordata* L.), and wild cherry (*Cerasus avium* (L.) Moench syn. *Prunus avium* L.) is slower than the local tree species (Scots pine, Norway spruce, silver birch, etc.) and 15-year-old plantations present with comparatively minor tree dimensions and thus the productive volume. This means that considerably different plantation management must be scheduled compared to the plantation management of native tree species.

Plantation cultivation of common oak proves right only in the case there is a suitable site for it: relief elevation; calcareous rock in lower soil horizons; sufficiently moist and fertile soils like soddy calcareous, soddy-podzolised, and alluvial soils with a stable moisture regime, cultivated soils with sandy loam, and loam as the parent rock; soil acidity pH -6-7-8; and liming in case of need. In

Parameters	5 years old	10 years old	15 years old	20 years old	25 years old
Site index H_{20} = 8 m					
N, trees ha^{-1}	10,000	5192	3539	2696	
D, cm	2.7	4.8	6.5	8.0	
H, m	2.3	4.1	5.7	7.3	
V, m^3	0.0008	0.0038	0.0096	0.0178	
M, m^3 ha^{-1}	8	20	34	48	
Z_M, m^3 ha^{-1} per year	1.7	2.0	2.2	2.4	
Site index H_{20} = 12 m					
N, trees ha^{-1}	8000	4251	2937	2259	1843
D, cm	4.1	7.2	9.8	12.0	13.9
H, m	3.4	5.9	8.2	10.4	12.5
V, m^3	0.0024	0.0108	0.0268	0.0491	0.0803
M, m^3 ha^{-1}	19	46	77	111	148
Z_M, m^3 ha^{-1} per year	3.7	4.6	5.1	5.5	5.9
Site index H_{20} = 16 m					
N, trees ha^{-1}	6000	3302	2328	1817	1499
D, cm	5.4	9.7	13.1	16.0	18.5
H, m	4.5	7.8	10.8	13.7	16.4
V, m^3	0.0050	0.0230	0.0554	0.1040	0.1688
M, m^3 ha^{-1}	30	76	129	189	253
Z_M, m^3 ha^{-1} per year	6.1	7.6	8.6	9.4	10.1
Site index H_{20} = 20 m					
N, trees ha^{-1}	4000	2339	1709	1368	1151
D, cm	6.8	12.1	16.4	20.0	23.2
H, m	5.8	10.0	13.8	17.3	20.6
V, m^3	0.0097	0.0436	0.1041	0.1930	0.3119
M, m^3 ha^{-1}	39	102	178	264	359
Z_M, m^3 ha^{-1} per year	7.9	10.2	11.9	13.2	14.3

Table 11.
Grey alder plantation characterising parameters in various agricultural land soils at the age of 5–15 years (site index H20 = 8 m to H20 = 20 m) [69].

adequately tended plantations, common oak in favourable growing conditions may by the age of 15 years reach the mean height of 6.0 m and the mean diameter of 6.6 cm. To ensure 80–85% survival of the oaks planted out, the plantation should be properly and timely tended, as well as protected against the pest, disease, and wildlife damage (use of repellents, protection tubes for tree stems, etc.). Wild cherry should be cultivated on fully lighted relief elevations, suitable for the given species. Preferably, the site should be protected from the north and east winds and have well-aerated sandy loam and loamy soils with calcareous rock underneath (soil reaction pH 6.5–8). Wild cherry cannot be planted in terrain depressions, where it may suffer from night frosts. Site preparation is by

			Pedunculate oak			
Experimental trials	**1Priek/ Ozol**	**3Kuld/ Rumn**	**4Kand/Aizl**	**7Vies/ Pals**	**11Gulb/Sop**	**13Iec/ Gail**
Soil type	TSC	SP	GSC	BUB	ASG	CAS
N, trees ha^{-1}	1580	1950	1190	1887	818	1650
D, cm	4.9 ± 2.49	5.1 ± 3.49	2.9 ± 2.35	6.6 ± 3.90	2.8 ± 1.64	5.9 ± 2.67
H, m	4.0 ± 2.16	4.3 ± 1.47	2.8 ± 1.32	6.0 ± 2.40	2.6 ± 0.83	4.9 ± 1.73
V, dm^3	0.0048	0.0118	0.0005	0.0095	0.0019	0.0078
M, m^3 ha^{-1}	7.6	23.0	0.6	18.0	1.6	12.9
Z_M, m^3 ha^{-1} per year						
Significant difference at 0.05 level ($p < 0.05$)	Except 3Kuld/ Rumn	Except 7Vies/ Pals, 13Iec/Gail	Except 1Priek/Ozol, 3Kuld/Rumn, 7Vies/Pals, 13Iec/Gail	Except 13Iec/Gail	Except 1Priek/Ozol, 3Kuld/Rumn, 7Vies/Pals, 13Iec/Gail	Except 7Vies/ Pals
Small-leaved lime						
Experimental trials	1Priek/ Ozol	7Vies/Pals	18Krust/Paki			
Soil type	TSC	BUB	SPG			
N, tree ha^{-1}	1000	900	1000			
D, cm	13.6 ± 2.80	11.8 ± 2.73	8.8 ± 2.14			
H, m	8.6 ± 0.95	8.8 ± 0.73	7.1 ± 0.84			
V, dm^3	0.0145	0.0141	0.0149			
M, m^3 ha^{-1}	64	49	42			
Z_M, m^3 ha^{-1} per year						
Significant difference at 0.05 level ($p < 0.05$)						
Wild cherry						
Experimental trials	1Priek/ Ozol	3Kuld/ Rumn	16Tals/Zelt			
Soil type	TSC	SPG	SP			
N, tree ha^{-1}	1580	1920	5600			
D, cm	11.4 ± 2.62	8.5 ± 1.72	11.5 ± 3.80			
H, m	8.5 ± 0.53	8.2 ± 0.81	7.0 ± 1.48			
V, dm^3	0.0437	0.0251	0.0205			
M, m^3 ha^{-1}	69	48	115			
Z_M, m^3 ha^{-1} per year	4.6	3.2	13.49			
Significant difference at 0.05 level ($p < 0.05$)	Except 3Kuld/ Rumn	Between all	Except 3Kuld/ Rumn			

Table 12.
Development of lime (Tilia cordata L.), oak (Quercus robur L.), and European cherry (Prunus avium L.) plantations on agricultural lands.

continuous or strip ploughing 30–40-cm deep; careful tending and stem protection are critical requirements; initial planting density is 900–1600 trees ha^{-1}.

10. Development of aspen (*Populus tremula* L.) and hybrid aspen (*Populus tremula x tremuloides* Mich.) plantations on agricultural lands

Correct selection of the site of planting is important for the establishment of productive conventional and hybrid aspen plantations, since aspen is a light-demanding tree species and its vegetation period is long. Well-drained, fertile loam, and sandy loam soils that are rich in minerals, sod-podzolic, soddy-gley alluvial, and gley soils and agricultural land soils, where the groundwater is running and its level is comparatively high, are the most suitable soils for the cultivation of aspen [1, 70–72].

Research has demonstrated that, in order to obtain optimum volume, the plantation must contain no less than 1000–1400 trees per 1 ha until the felling of the plantation at the age of 25 while retaining the initial density of the plantation [69, 70].

The conducted trials indicate that at the age of 15–16, the plantations of aspen, at 2500 trees ha^{-1}, produce 150 m^3 ha^{-1} stock volume and current volume growth of about 7 m^3 ha^{-1} per $year^{-1}$, meanwhile plantations of hybrid aspen of the same age at the density of 950 trees ha^{-1} reach 309 m^3 ha^{-1} in volume with the current volume growth of 25 $m^3 \cdot ha^{-1}$ $year^{-1}$ (**Table 13**).

The average height of trees at the age of 15 years in a common aspen plantation is H = 12.4 m and the average diameter at chest height D = 11.8 cm, while the annual current volume growth is 6.97 m^3 ha^{-1} $year^{-1}$ (**Table 14**). In contrast, the average height of trees at the age of 16 years in the hybrid aspen plantation is H20 = 20 m, and the average diameter at breast height is D = 18.9 cm, while the annual current growth of the stock volume is 24.67 m^3 ha^{-1} $year^{-1}$ (**Table 14**). Similar current growth data for hybrid aspen plantations have also been recorded by Swedish researchers, provided that the first thinning is performed at the age of 10–11, leaving 800–900 trees ha^{-1}; the second at the age of 15–16, leaving 500–600 trees ha^{-1}; and the third at the age of 20, leaving about 350–400 trees ha^{-1} [26, 72].

Highly productive plantations of common and hybrid aspen are possible in fertile sites of loamy and sandy loam soils with a stable moisture regime (soddy-podzolised,

Experimental trials	Common aspen 11Gulb/Sop	Hybrid aspen 13Iec/Gail
Soil type	ASG	CAS
N, trees ha^{-1}	2504	950
D, cm	11.8 ± 2.93	18.9 ± 3.12
H, m	12.4 ± 1.42	20.0 ± 2.05
V, dm^3	0.0599	0.325
M, m^3 ha^{-1}	150	309
Z_M, m^3 ha^{-1} per year	6.97	24.67
Significant difference at 0.05 level ($p < o.05$)	Significant difference with 13Iec/Gail	Significant difference with 11Gulb/Sop

Table 13.
Dendrometric parameters for a 15-year aspen (Populus tremula L.) and hybrid aspen (Populus tremula x tremuloides mill.) at the plantations of agricultural land.

Plantations	Scots pine plantation, age 15 years	Norway spruce plantations, age 15 years	Silver birch plantations, age 15 years
Number of trees ha^{-1}(average)	1510–3774	1400–3128	1400–2650
Timber volume obtainable during thinning, m^3 ha^{-1}	12–99	33–67	25–81
Obtainable pulpwood/firewood volume, m^3 ha^{-1}	6/6–50/49	16/17–33/34	7.5/17.5–24/57
Total obtainable biomass (stem wood + branches) (freshly cut)/abs.dry, t ha^{-1} (**Tables 4, 6, 10**)	5.2/3.1–43/25.5	40/23–82/48	22/18–88/67

Table 14.
The amount of timber and pulpwood plus wood waste biomass (m^3 ha^{-1}; t ha^{-1}) (EUR) obtainable from 15-year-old scots pine, Norway spruce, and silver birch plantations.

soddy-gley, gley, podzolised gley, cultivated soils). To obtain an appreciable stock volume, the planting density should be no less than 1100 trees ha^{-1} at the 85–100% survival of the stock initially planted. The stock volume of a 15-year common aspen plantation may reach 150 m^3 ha^{-1}, while hybrid aspen 300 m^3 ha^{-1}. The first thinning should be done no later than at the age of 9–10 years, reducing the number of trees to 900 trees ha^{-1}. The rotation period for hybrid aspen is 20–25 years, while for common aspen 30–35 years. In managing aspen plantations, sufficient attention should be given to tree protection against the damage of artiodactyls and rodents, let alone the pest and disease control (Plantskids, Cervacol Extra, Wobra; Tubex and Vertex plastic protection tubes; plastic entanglements; fences).

11. Predictable productivity of plantation forests in Latvia

If it is planned to manage this kind of plantation as a roundwood production plantation, it is necessary to perform 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 tree species mean tree stem wood and branch biomass. According to the Latvian forest legislation, the optimal number of tree in pine young stands with average H = 7 m is 1300 trees ha^{-1}, in Norway spruce young stands with H = 8 m are 1100 trees ha^{-1}, and in silver birch young stands with H = 11 m are 900–1100 trees ha^{-1} [73].

Calculations show that the highest pulpwood volume and wood biomass in the first thinning are obtainable from plantations that have retained the initial planting density (**Table 14**) [73].

In the silver birch experimental trials, the first round tending or thinning is needed to ensure further growth, by reducing the number of trees and thus obtaining the pulpwood to be sold. Its volume calculation has been performed by the methodology of modelling roundwood assortment yield in thinning birch plantations [74, 75]. These investigations show that the number of trees after the first thinning must be no more than 1100 trees per ha [74, 75].

Our research indicates that for the acquisition of energy wood higher stocking density (10,000 and 5000 trees per ha) silver birch plantations can be established, the rotation period of which could be 15 years [1]. It must be noted that despite 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 15**).

Experimental trial site	Age (years)	Number of trees per ha/ obtaining cutting out number of trees ha^{-1}	Obtainable volume during thinning, m^3 ha^{-1}	Obtainable pulpwood/ firewood (50% pulpwood, 50% firewood), m^3 ha^{-1}
5Dob/Mez	15	3345/2230	145	72.5/72.5
9Koc/Zar	15	1146/–	0	0
13Iec/Gaili	15	700/–	0	0

Table 15.
Available volume of wood in common alder plantations at experimental trial sites.

Similar conclusions have also been published in Finland and Sweden, 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 the assortment [14, 24, 29].

By the age of 15, the annual volume growth of the alder plantation is 10.77–26.16 m^3 ha^{-1} year with the stock volume up to 249 m^3 ha^{-1}, provided one, two, or even three root suckers are left at each stem. The first thinning, with the roundwood yield of 70–100 m^3, could be performed by the age of 10–12 years, retaining only good quality stems. By careful and proper management of alder plantations, it is possible to get assortments such as veneer logs and sawlogs by the age of 30–40 years (**Table 15**).

According to the recommendation of Swedish researchers, if the plantations of hybrid aspen are developed for the production of chipped wood, thinning should not be performed at all and the rotation cycle is 25 years. Meanwhile, if the plantation is intended for the production of roundwood, the recommended cultivation technology is as follows: the number of original plants is 1100–1200 trees ha^{-1}; the first thinning is performed at the age of 10–11, leaving 700 trees ha^{-1}; and the last thinning is done at the age of 16–17, leaving about 400 trees ha^{-1} [26, 69].

Calculations indicate that the volume of felled timber at the plantation of aspen is expected to average at 102 m^2, while the output of pulpwood is estimated to amount to approximately 50% of the total timber yield, while 50% of the timber will be valued as firewood (**Table 16**).

The investigations show that to obtain an appreciable stock volume, the planting density should be no less than 1100 trees ha^{-1} at the 85–100% survival of the stock initially planted. The rotation period for hybrid aspen is 20–25 years, while for aspen 30–35 years. In managing aspen plantations, sufficient attention should be given to tree protection against the damage of artiodactyls and rodents, let alone the pest and disease control (Plantskids, Cervacol Extra, Wobra; Tubex and Vertex plastic protection tubes; plastic entanglements; fences) [1].

Trial site	Age (years)	Number of trees per ha/ obtainable number of trees cutting out during thinning, trees ha^{-1}	Obtainable volume during thinning, m^3 ha^{-1}	Obtainable volume: roundwood (50–80%)/firewood (50–20%), m^3 ha^{-1}
11Gulb/Sop (aspen)	15	2504/1704	102	51/51
13Iec/Gail (hybrid aspen)	15	950/550	179	143/36

Table 16.
Available volume of wood in aspen and hybrid aspen plantations at the age 15 years.

12. Conclusion

In studied plantations on former agricultural lands, Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* (L.) Karst.), silver birch (*Betula pendula* Roth.), alder (*Alnus glutinosa* (L.) Gaertn.), grey alder (*Alnus incana* (L.) Moench.), aspen (*Populus tremula* L.), and hybrid aspen (*Populus tremula x tremuloides* Mill.) reach a standing volume of maximum 100–300 m^3 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, the number of trees per unit area should be reduced.

Spruce, in terms of growth rates and productivity, performs best in naturally dry nutrient-rich soddy-podzolised, soddy-gley alluvial, and cultivated soils with sandy loam and loam as a parent rock. In the sites like that, spruce with its shallow root system is sufficiently supplied with nutrients and protected from sharp groundwater-level fluctuations in the spring and autumn seasons with heavy precipitation.

Properly timed thinning of spruce plantations, done no later than at the age of 12–15 years, is of special importance for achieving a significant growth of stock volume and having top-quality stems. Pruning of crop trees is desired; it could be done in the localities with no threat of bark stripping by the artiodactyls.

When cultivating spruce in farmlands, protection measures should be taken against potential infection by parasitic fungi. In the case thinning is done during the growing season, the stumps of the trees removed should be treated by some fungi-suppressing agent (Rotstop, etc.) to avoid the spread of root rot, caused by the fungus *Heterobasidion annosum*. In plantation tending care should be taken to avoid mechanical damage of tree stems. To get branch-free spruce stems, pruning up to the height of 2 m should be started no earlier than at the age of 12–15 years and continued in subsequent years.

According to our results, silver birch, alder, grey alder, and Norway spruce are the 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 the economically feasible production of commercial timber.

In the climatic conditions of Latvia, 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 m^3 ha^{-1} in 15 years after plantation establishment, except for the stand volume of wild cherry with 5600 trees per ha; accordingly we cannot evaluate their suitability for use in plantations before some 30–40 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*, and *Dactylis glomerata*. Forest ground-cover vegetation emerges faster in the sites on dry, lean soils.

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