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Productivity of poplar hybrid (*Populus balsamifera* x *P. laurifolia*) in Latvia

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Abstract. Fast growing poplar clones have been widely used for biomass production in Southern Europe; however, there is insufficient information about the growth of poplar in north-eastern Europe that might hamper its wider use. The aim of the study was to assess the productivity of poplar hybrid and its potential for biomass productions. Material for the study was collected in 14 stands (age 54–65 years) located in the central and western part of Latvia (56–57°N, 22–23°E), which were established on fertile drained mineral soil (*Mercurialiosa mel.*) and mineral soil with normal moisture regime (*Oxalidosa* and *Aegopodiosa*). Tree diameter and height were measured and biomass was estimated using equation developed based on 24 sample trees.

Mean tree diameter and height in stands on mineral soil varied greatly (from 29 ± 1.6 cm to 45 ± 3.9 cm and from 24 ± 0.9 m to 31 ± 0.8 m, respectively); however in stands on drained mineral soil mean diameter and height was 42 ± 2.1 cm and 27 ± 0.7 m, respectively. Mean diameter and height of poplar was 16.7–25.1% higher compared with Norway spruce and these differences were statistically significant (p-value < 0.05), differences with common aspen were not significant.

The number of fallen and standing dead trees, reaching up to 14–46% from the number of living trees, indicated aging and intense self-thinning. Mean annual volume increment of all stands was 11.8 m^3 ha^{-1} y^{-1} (in some of stands reaching 21.0 m^3 ha^{-1} y^{-1}), corresponding to 4.2–9.8 t of dry matter per year. Thus, the results suggest that poplar could be an efficient species for production of bioenergy.

Key words: *Salicaceae*, height, diameter, yield.

INTRODUCTION

Poplars are widely used across the Globe and increasingly cultivated in planted stands that in year 2012 reached an estimated total area of 8.6 million hectars (FAO, 2012). Most of the plantations in Europe are located in the southern, south-western part of the continent. So far there is insufficient information about the growth of poplar in the north-eastern Europe that might be one of the factors affecting its wider use.

Productivity of poplar stands is the main driver of its extensive use: at the age of 10–12 years stands accumulate 200 t of wood (Nervo et al., 2011) and reach mean annual volume increment of 29 m^3 ha^{-1} y^{-1} (Zsuffa et al., 1977; Labrecque & Teodorescu, 2005).

Main purpose for the establishment of poplar plantations is industrial roundwood production as well as fuelwood and biomass production. For these uses relative low initial costs, ensured by easy vegetative propagation with cuttings, are crucial. Poplar wood, in particular from plantations, is used for veneer and plywood as well as pulpwood production. Other minor uses are matches, poles, chips for OSB.

High productivity of plantations also ensures contribution to other goals – carbon sequestration, renewable energy production and areas for nature protection without compromising total wood availability. It has been found in Italy that at the age 10–12 years poplar plantation sequesters 50 t of carbon and energy content of its wood is equal to that of 35 t of crude oil (Nervo et al., 2011). Rate of carbon sequestration is higher than in agricultural lands (Rytter, 2006). Already in 1950th in Netherlands was found, that poplar plantation, occupying 2% from the total forest area, ensures 20% of wood yield (Houtzagers, 1952). These findings demonstrate, how wider use of poplar plantation can contribute to European Union goals to ensure 20% of its energy-consumption from renewable sources until 2020 (2009/31/EC) and with aim to continue increasing this share in future and limit net carbon emissions. Use of poplars for energy wood production is also more sustainable than serial agricultural crops, that can be a threat to many areas that have already been fragmented and degraded and are rich in biodiversity and provide habitat for many endangered and endemic species (Beringer et al., 2011).

To achieve the positive impact of poplar plantations an appropriate genetic material has to be used. Therefore active breeding, investigating high number of species and inter-specific hybrids, in southern Europe has been carried out already from the beginning of 20th century (Saliņš, 1971; Cagelli & Lefèvre, 1995; Stettler, 1996). Currently, only tested clones, that can be a result of hybridization for several generations, are used at commercial scale (1999/105/EC (2000)). Poplar breeding in the Nordic and Baltic countries has shorter history (since 1960th), has not been as extensive and has had long periods without any activity (Rytter et al., 2013) as the main tree breeding effort was dedicated to coniferous trees. Main *Populus* species tested in this region are *P.tremula*, *P.tremuloides*, *P.trichocarpa*, *P.maximowiezii*, *P.deltoides, P.nigra* and their hybrids (Rytter et al., 2013) and also *P. balsamifera*. The need to test more clones for selection of those more adapted to the northern climatic conditions has been noted (Christersson, 2006). There are notable areas of abandoned agricultural lands, like 300–500 thousand ha in Sweden (Anonymous, 2006; Larsson et al., 2009), similar areas in Latvia, that could potentially be used for the establishment of poplar plantations. Since the information on growth of poplars in Baltic countries is sparse, but there might be a notable potential of its use, the aim of the study was to assess the productivity of poplar hybrid and its potential for biomass production.

MATERIALS AND METHODS

Material was collected in 14 stands in 3 forest research stations (Fig. 1) located in the central and western part of Latvia (56–57°N, 22–23°E), which were established on a fertile drained mineral soil (forest type, based on classification used in Latvia *Mercurialiosa mel.*) and mineral soil with normal moisture regime (forest type *Oxalidosa* and *Aegopodiosa*).

Figure 1. Locations of studied stands (forest research stations).

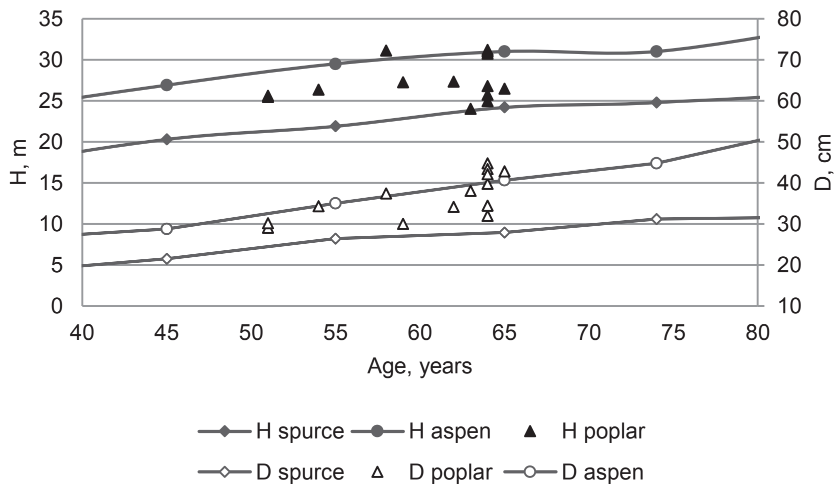
The initial spacing ranged from 5,000 to 7,000 trees per hectar, no commercial thinning has been done before sampling. Stand age at the sampling was 54–65 years. Diameter, height and damages were measured. Information from National Forest Inventory plots from common aspen and Norway spruce stands of the same age and forest type, from the same regions of Latvia were used for a comparison.

Twenty four trees from 3 stands, representing diameter distribution (ranging from 23 cm to 57 cm) were felled for the measurements of biomass components. Five sample disks (first at 1.3 m and one more after each fifth part from the rest of the tree height) from the stems of trees as well as four sample branches from each quarter of the living crown were taken for the assessment of the relative moisture of wood. The stem of the tree was cut into 0.5 m sections and weighted, living branches from each quarter of the living crown and dead branches were weighted separately. Afterwards dry biomass of the components was calculated as weighted average from the acquired relative humidity data using the measured weights of the respective parts of the tree as weights. Data from the dead branches were excluded from the analysis due to large variation both in relative moisture and measured biomass to minimize the error of the estimates. Tested poplar biomass models developed by other authors (Freedman et al., 1982; Zabek & Prescott, 2006) fit to the empirical data poorly, probably due to differences in diameter range. Therefore new model was developed to estimate dry biomass of stem and stem together with green branches (Jansons et al., submitted), demonstrating a good fit to empirical data ($R^2 = 0.96$), and used for calculations.

RESULTS AND DISCUSSION

Mean tree diameter and height in poplar stands on mineral soil varied greatly: from 29 ± 1.6 cm to 45 ± 3.9 cm and from 24 ± 0.9 m to 31 ± 0.8 m, respectively (Fig. 2) and parameters of stands on drained mineral soil were within range of this variation: 42 ± 2.1 cm and 27 ± 0.7 m, respectively.

Poplars at the same age and forest type on mineral soils were statistically significantly higher than Norway spruce (on average by 16.7%), but non-significantly lower than common aspen (on average by 12.8%). Similarly, also mean diameter of poplars was significantly larger than for Norway spruce (on average by 25.1%), but differences with common aspen were not statistically significant (Fig. 2). Converting the detected differences in units of time: for Norway spruce stands on fertile mineral soils it would take on average additional 30 years to reach similar height and additional 15 years to reach similar diameter as poplar's, but for common aspen it would take on average 10 years less. It can be seen, that in such long rotation period tested poplar hybrid does not have an advantage in tree dimensions (influencing the outcome of sawn-timber) over native common aspen.



H- height, D – breast height diameter

Figure 2. Mean height and diameter of poplars in comparison to Norway spruce and common aspen (NFI data).

Tree height and diameter was significantly influenced by stand age and also by density (height increasing and diameter decreasing with increasing stand density) that is in accordance with other studies in poplar plantations (Ze-Hui et al., 2007). Diameters of trees in our trails were notably smaller than found for poplars in USA at the age of 50 years (67.3 cm), and similar to that found at notably younger age: 20–25 years (von Althen, 1981). Diameter exceeding 20 cm was found in poplar plantations at the age of 20 (26.9 cm) years and 18 years (25.9 cm) in Sweden (Christersson, 2010, 2011) and at the age of 10 years (22.9 cm) in USA (Netzer et al., 2002). Tree height similar to that in our trials was found at the age of 10–15 years in USA (von Althen, 1981) and at the age of 37 years (29.6 m) in Ukraine (Saliņš, 1971). These results suggest that poplars can achieve notably faster growth that could be related both to genetic differences and soil.

For example in Sweden *Populus maximowiczii x P. trichocarpa* hybrid on former agricultural lands reached height of 28 ± 1.5 at the age of 20 years (Christersson, 2011).

Also poplar breeding programs report gains in stem volume while selecting the best-performing hybrids and clones. For example 15% increase in diameter growth as a result of selection has been found in three years old *Populus* × *wettsteinii* experiment in Finland (Yu & Pulkkinen, 2003). While selecting 8% of the best performing clones, 23–89% yield increase has been achieved at the age of six years in USA (Riemenschneider et al., 2001). Selection of the top 10% of a *Populus* × *wettsteinii* clonal distribution evaluated across multiple sites at age nine predicted a 45% increase in stem volume in Sweden (Stener & Karlsson, 2004). Site-specific selection for one third of fastest growing clones of *Populus* × *tomentosa* predicted a 34% improvement in 5th-year stem volume in Canada (Zhang et al., 2008). Best growth can be achieved on former agricultural lands, but also forest lands are suitable for poplars.

Forest type had a statistically significant influence on average height and diameter of trees also when only types on mineral soil with normal moisture regime (*Oxalidosa* and *Aegopodiosa*) were analysed.

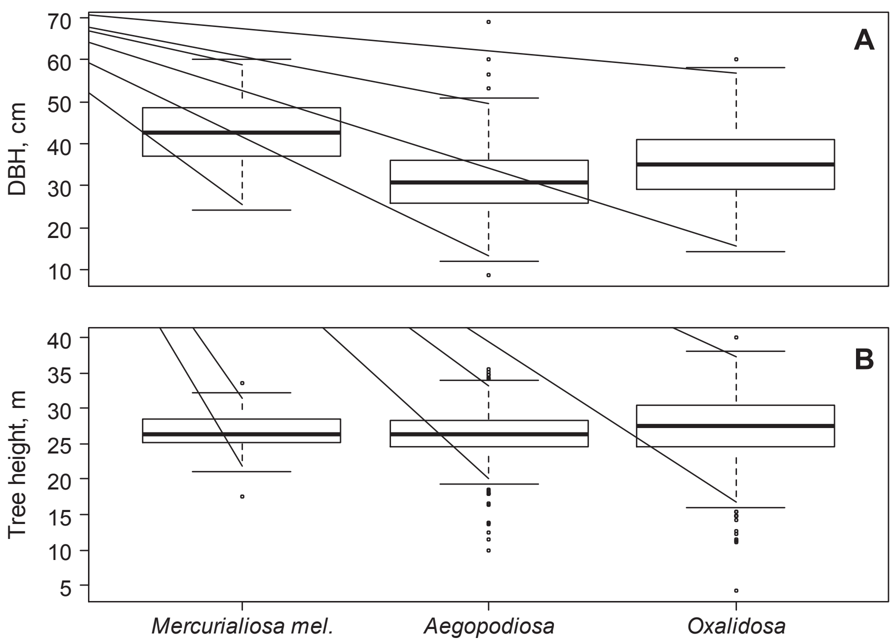


Figure 3. DBH (A) and height (B) of poplars in Mercurialiosa mel., *Aegopodiosa* and *Oxalidosa* forest types.

These findings could be related to differences in soil fertility, since poplars have been found to be very responsive to increase in soil nutrient (especially nitrogen) content (Brown & van den Driessche, 2002, 2005; Guillemette & DesRochers, 2008) as it has been studied in a number of fertilization experiments (Coleman et al., 2006; Guillemette & DesRochers, 2008; Lteif et al., 2008; Patterson et al., 2009; Pearson et al., 2010).

Significant differences in mean annual height and diameter increment between stands on mineral and drained mineral soil were found: 0.45 ± 0.004 m y^{-1} *vs.*

0.41 ± 0.010 m y^{-1} and 0.6 ± 0.01 cm y^{-1} *vs.* 0.7 ± 0.02 cm y^{-1}, respectively. However, due to differences in stand density and limited number of sample stands on drained mineral soils (peat layer up to 20 cm deep), no clear conclusions can be drawn on their suitability for the establishment of poplar plantations in comparison to sites on mineral soil with normal moisture regime. Also in literature different opinions can be found on suitability of soils with high peat content for poplar plantations: Klasa (2008) states that such sites shall be avoided, but Christersson (2010) finds a high productivity (23 m^3 ha y^{-1} at the age of 17 years) of polar stands on peat soils with pH > 6.

Table 1. Characteristics of poplar hybrid (*Populus balsamifera* x *P. laurifolia*) sample plots

Forest type	Stand age	Species	Number of trees	H, m	M, m^3 ha^{-1}	V, m^3	Stem biomass, t_{dry} ha^{-1}	Total biomass, t_{dry} ha^{-1}
Oxalidosa	59	Polar	158	27.3	442	1.01	209	232
		Total	328	22.7	613	0.67		
Aegopodiosa	51	Polar	136	25.5	385	0.94	191	212
		Total	266	20.0	449	0.57		
Aegopodiosa	51	Polar	22	25.6	566	1.00	279	312
		Total	38	21.7	641	0.66		
Oxalidosa	64	Polar	25	31.2	915	2.48	353	416
		Total	61	21.3	1011	1.12		
Oxalidosa	64	Polar	43	25.0	609	1.03	315	353
		Total	90	19.8	702	0.57		
Oxalidosa	64	Polar	25	31.0	1347	2.25	537	624
		Total	37	25.4	1417	1.60		
Oxalidosa	64	Polar	41	30.8	-	1.89		
Oxalidosa	63	Polar	141	24.0	-	1.41		
Oxalidosa	62	Polar	239	27.4	-	1.28		
Oxalidosa	64	Polar	211	25.7	-	1.22		
Oxalidosa	58	Polar	119	31.1	-	1.75		
Aegopodiosa	54	Polar	107	26.4	-	1.24		
Mercurialiosa mel.	65	Polar	40	26.5	-	1.87		
Mercurialiosa mel.	64	Polar	47	26.8	-	1.89		

Species: Poplar – poplar hybrid (*Populus balsamifera* x *P. laurifolia*); Total – including admixture of other species (Norway spruce, Silver birch) found in some of the sample plots; H – height; D – diameter at breast height; M – yield; V – stem volume; Total biomass – total above-ground biomass.

Mean annual increment in studied poplar stands ranged between 7.5 m^3 ha^{-1} y^{-1} and 21 m^3 ha^{-1} y^{-1} and were on average 13.1 m^3 ha^{-1} y^{-1} in *Oxalidosa* and 9.31 m^3 ha^{-1} y^{-1} in *Aegopodiosa* forest type. It was in range of the estimates reported by other authors: 18–22 m^3 ha^{-1} y^{-1} at the age of 9–12 years (Karacic et al., 2003), 21–23 m^3 ha^{-1} y^{-1} at the age of 18–20 years (Christersson, 2010, 2011), however, also higher estimates can be found: 28 m^3 $ha^{-1}y^{-1}$ in *P.trichocarpa* stand in Sweden (Christersson, 2010) and even 39.6 m^3 ha^{-1} y^{-1} for hybrid poplar clone in riparian buffer strips (nutrient rich, well-drained soil) in southern Québec (Fortier et al., 2011). Comparisons might be influenced by stand density: in plantations outside the forests with aim to produce saw-log or veneer logs, density of the plantation usually is lower, thus increasing diameter increment of each tree, but not maximizing yield per hectar. Also stand age is of importance: in our trials number of fallen and standing dead trees, reaching up to 14–46% from the number of living trees, indicated intense self-thinning and stands had long-passed the peak of mean annual volume increment that is reported for poplars from age 6 to 15 years (von Althen, 1981; Netzer et al., 2002). Nevertheless, for most of the poplar trials annual volume increment is still higher than that at the peak for Norway spruce: 14 m^3 ha^{-1} y^{-1} (Eriksson, 1976), silver birch: 8–10 m^3 ha^{-1} y^{-1} (Elfving, 1986; Sonesson et al., 1994), grey alder and common aspen: ~9 m^3 ha^{-1} y^{-1} (Granhall & Verwijst, 1994; Johansson, 1999b). It exceeds also that found on average for Norway spruce, silver birch and common aspen stands at the age 51–60 years in Latvia (4.71, 4.52 and 7.12 m^3 ha^{-1} y^{-1} respectively), however, the numbers for those common tree species do not include volume of trees cut in commercial thinnings.

Absolute dry biomass in poplar trials ranged from 212 to 624 t per ha (Table 1), corresponding to 4.2–9.8 t ha^{-1} y^{-1}. Results are close to those achieved in plantations with sparse initial spacing (1,000 trees ha^{-1}) on former arable land at the age of 9 years: 9.2 t ha^{-1} y^{-1} and at the age of 11–12 years: 8.2-13.6 t ha^{-1} y^{-1} (Karacic et al., 2003; Zabek & Prescott, 2006). Slightly denser plantations on fertile former agricultural lands reached productivity of 18 t ha^{-1} y^{-1} (Zsuffa et al., 1977; Labrecque & Teodorescu, 2005). Plantations with dense spacing (10000 trees ha^{-1}) ensure notably faster accumulation of biomass: already at the age of four years mean annual biomass productions reaches 11.4 t ha^{-1} y^{-1} (Laureysens et al., 2004) and even figures as high as 35 t ha^{-1} y^{-1} have been reported (Scarascia-Mugnozza et al., 1997).

Stem biomass in our trials reaches on average 88% from total above-ground biomass that is slightly higher than observed in Sweden: 75.3% (Johansson & Karacic, 2011) most likely due to differences in stand age and density.

Above-ground biomass increment of poplar stands is notably higher than that of Norway spruce at the age of 40 years: 5.5 t ha^{-1} y^{-1} (Johansson, 1999a), but comparable with very dense (17–42 thousand trees ha^{-1}) young (7–15 years) stands of silver birch, common aspen, black and grey alder (7.2–8.6 t ha^{-1} y^{-1}) as well as coppice of hybrid aspen and salix at the age of 4 years: 9.0 t ha^{-1} y^{-1} and 4.9 t ha^{-1} y^{-1} respectively (Johansson, 1999b, 1999c, 2000; Rytter, 2006; Smaliukas et al., 2007).

CONCLUSIONS

1. Poplar hybrid (*Populus balsamifera* x *P. laurifolia*) planted with density 5,000–7,000 trees ha^{-1}, at the age of 54–65 years on mineral soils reached mean height 27.0 ± 0.23 m and breast height diameter 34.3 ± 0.47 cm, significantly exceeding that of Norway spruce at similar age. Both of these parameters were statistically significantly influenced by forest type.

2. Mean annual volume increment after its peak age in studied poplar stands (7.5–21 m^3 ha^{-1} y^{-1}) was in range of that reported by sparser plantations on former arable land, suggesting that growth conditions are suitable for this poplar hybrid in Latvia.

3. Total above-ground dry biomass increment (on average 88% of it – stem biomass) reached 4.2–9.8 t ha^{-1} y^{-1}, exceeding that of several other tree species and suggesting that poplars could be a viable alternative for biomass production in Latvia.

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