Intra–annual height growth of hybrid poplars in Latvia. Results from the year of establishment

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Abstract. Fast growing hybrid poplars (*Populus* spp.) could be successfully used for bioenergy as well as wood production. Productivity of clones had been studied in Baltic States recently, however, little is known about the impact of weather conditions on poplar height growth, thus the potential effect of climate change. Therefore, the aim of this study was to characterize the intra–annual height growth of hybrid poplar clones in Latvia. Height increment of 12 hybrid poplar clones was measured on average with an 11–day interval in the first vegetation season in 2016. Annual shoot height was on average 81.0 ± 6.8 cm, significantly ($p < 0.001$) depending on the poplar clone. Use of long (0.5 m) instead of short (0.3 m) cuttings leaded to larger annual height increment during the year of establishment of the plantation. From June to September the mean growth intensity was 10 to 15 mm day^{-1}. The trend of height growth intensity, described by Gompertz model, indicated that the poplar clones with largest height had relatively fast increase of the growth intensity from June to July. Changes of growth intensity was linked both with the temperature and sum of precipitation. This tendency was not so pronounced for clones with largest height increment, emphasizing the importance of the phenotypic plasticity in selection of clones for plantations.

Key words: *Populus* spp., short–rotation forestry, cutting length, growth intensity.

INTRODUCTION

The importance of short–rotation forestry has been recognized lately in context of carbon sequestration both as a source for the fibre and solid–wood production as well as the fuelwood (Uri et al., 2011; Bronisz et al., 2016; Wang et al., 2016). Poplars (*Populus* spp.), mostly their hybrid clones, are promising tree species for intensive cultivation in boreal climate, considering their productivity, multiple use of the wood and relatively high resistance against biotic and abiotic stresses (Weih, 2004; Ball et al., 2005; Christersson, 2010; Tullus et al., 2013; Kutsokon et al., 2015).

The growth of poplars is determined by genetic properties of clones (Zhang et al., 2003; Mead, 2005), applied management strategies (DeBell et al., 1996; Mead, 2005; Bilodeau–Gauthiera et al., 2011; Wang et al., 2016), and climate (Olivar et al., 2009; Wang et al., 2016; Štícha et al., 2016). Genetics (species, as well as clones) has strong impact on growth traits and wood properties (Zhang et al., 2003), as well tolerance of trees against different stresses: drought, frost etc. (Mazzoleni & Dickmann, 1988; Ilstedt,

1996; Giovannelli et al., 2007; Chhin, 2010; Pollastrini et al., 2013; Lazdiņa et al., 2016), water–use strategy and efficiency (Schreiber et al., 2011). Therefore, effective selection of best genotypes for specific set of conditions (regions) can be carried out and its results applied in praxis promptly due to simple and cheap vegetative propagation (Mead, 2005; Tullus et al., 2013).

The impact of climatic factors such as temperature (Šēnhofa et al., 2016), length of vegetation period (Wang et al., 2016), frequency and severity of drought (Giovannelli et al., 2007; Olivar et al., 2009; Pollastrini et al., 2013) to growth rate of poplars have been studied extensively. However, under changing climate (Kirschbaum, 2000), the knowledge about the environmental stresses affecting poplar growth, is necessary for development of the sustainable short–rotation forestry (Kozlowski & Pallardy, 2002). Since that, the influence of temperature and precipitation might be modified to some extent by management decisions (Kutsokon et al., 2015) and selection of clones with proper adaptation to certain climate (DeBell et al., 1996; Chhin, 2010).

In different ecotypes the poplar growth has been determined by the photoperiod (Howe et al., 1995), although, temperature has been recognised as strong additional environmental factor, which modifies the sensitivity of the day–length signals at growth cessation and influence the duration of growth and bud formation (Rohde et al., 2011). Differences between the frost tolerance of poplar clones (Lazdiņa et al., 2016), as well as regeneration of trees after serious frost damages (Šēnhofa et al., 2017) have been studied also in Latvia. However, little is known about the intra–annual growth patterns and response to weather conditions. Numerous studies regarding effect of water availability on poplar productivity found that the precipitation has large effect of tree growth during the vegetation period (Leonelli et al., 2008; Jules et al., 2010), however, in Nordic countries it has not been recognised as a limiting factor (Messaoud & Chen, 2011). Temperature has been found as primary controlling factor of height growth intensity of a most widely used hybrid aspen (*Populus tremula* L. × *P. tremuloides* Michx.) in our region (Jansons et al., 2014). The impact of diurnal temperature and precipitation to variation of height growth intensity and, cumulatively, to annual height increment has not been widely discussed, however, it can be crucial for achieving growth superiority of poplars in expected changing climate in northern Europe. Therefore, the aim of this study was to characterize the intra–annual height growth of hybrid poplar clones in Latvia.

MATERIALS AND METHODS

Study area is located in central part of Latvia, near Vecumnieki (56º34′ N, 24º31′ E), on former agricultural land. In the spring of 2016 the plantation of poplars was established on flat area with deep drained fertile peat soil of pH 6.

Monoclonal row–plots in three replications were used; the distance between rows was 4 m, between the trees within a row 2 m. Unrooted 0.3 m and 0.5 m long (further 'short' and 'long', respectively) poplar cuttings of 12 clones were planted leaving 3–5 cm above ground (Table 1).

During the study, 20 ramets per clone and type of cutting were randomly selected (on average 6 per replication) for shoot height measurements. Nine measurements of shoot height with the interval of approximately 11 days (ranging from 5 to 18 days) were taken from the ground level in year of establishment. Eight periods of measurements

were defined: 17.06.–29.06., 30.06.–10.07., 11.07.–21.07., 22.07.–08.08., 09.08.–17.08., 18.08.–29.08., 30.08.–08.09., 09.09.–13.09.. About 50% of poplar shoots during the study period were browsed by cervids and damaged by snails; only undamaged trees were included in data analysis (Table 1).

Table 1. Description of the tested poplar clones

Clone	Number of ramets*	Length of cuttings, m	Species	Origin of cuttings**
OP 42	3	0.3	*P.maximowiczii* × *P.trichocarpa*	Germany
Max 1	6	0.3	*P.maximowiczii* × *P.nigra*	Germany
Max 3	7	0.3		
Matrix 24	6	0.3	*P.maximowiczii* × *P.trichocarpa*	Germany
Matrix 49	7	0.3		
Hybride 275	9	0.3	*P.maximowiczii* × *P.trichocarpa*	Germany
LV 1	3	0.3	Clones from section *Tacahamaca*	Sweden
LV 3	6	0.3		
LV 4	6	0.3		
Baldo	7	0.3	*P.deltoides* clones	Italy
	9	0.5		
Oudenberg	8	0.3	*P.deltoides* × *P.nigra*	Italy
	10	0.5		
Vesten	7	0.5	*P.deltoides* × *P.nigra*	Italy

* undamaged by cervids and snails; ** country from which the cuttings were obtained.

Mean growth intensity (mm day⁻¹) during measurement periods were calculated for individual trees. The mean annual height increment ± 95% confidence interval (CI) and mean growth intensity ± CI for each variant of planting material of poplar cuttings were calculated. At the end of the period of measurements all 'short' poplar clones were grouped depending on the length of annual height increment assessment: 1 – 'short–max' – Hybrid 275, Oudenberg 0.3 m; 2 – 'short–average' – Baldo 0.3 m, Max 1, Max 3, Matrix 24, Matrix 49; 3 – 'short–min' – OP 42, LV 1, LV 3, LV 4. Hourly data of weather parameters (i.e., temperature, precipitation) were obtained from the nearest weather station of Latvian Environmental, Geology and Meteorology Centre from the study site.

Analysis of variance (ANOVA) and the Tukey Honest Significant difference (HSD) test were used to assess the differences of height increment and growth intensity between cuttings of different length, as well as the differences between clones. The non–linear Gompertz model (Eq. 1) was fitted for individual trees to assess the intra–annual growth trend in growing season (Fekedulegn et al., 1999)

$$f(A) = \alpha \exp(-\beta \exp(-kA)) \qquad (1)$$

where α – asymptote parameter; β – displacement parameter; k – growth intensity parameter; A – day since the start of the measurements.

The differences between obtained parameters (α, β, k) were compared using ANOVA to assess the clone effect. The Pearson correlation test was used to assess the relationship between height growth intensity from June till September and values of meteorological factors (i.e., including mean temperature and precipitation sum in the period). The differences in growth intensity and temperature between the measurement

periods were estimated using ANOVA; mean temperature ± CI was calculated from temperatures of each day of a particular period. All statistical analyses were performed using R v.3.3.1 (R Core Team, 2016).

RESULTS AND DISCUSSION

Measurements had been started, when the length of annual shoot ± CI had reached 4.0 ± 1.6 cm; it was significantly ($p < 0.05$) smaller for 'short' Baldo (1.6 cm) and OP 42 (1.8 cm). Contrary, 'short' Oudenberg as well as 'long' Vesten and Oudenberg had significantly ($p < 0.05$) larger shoot height before the measurements, 11.8, 12.1 and 14.2 cm, respectively. The mean height ± CI of poplars at the end of the first growing season (June – September) was 81.0 ± 6.8 cm; it significantly differed ($p < 0.001$) between the poplar clones, ranging from 32 to 102 cm for 'short' cuttings and 73 to 132 cm for 'long' cuttings, respectively (Fig. 1).
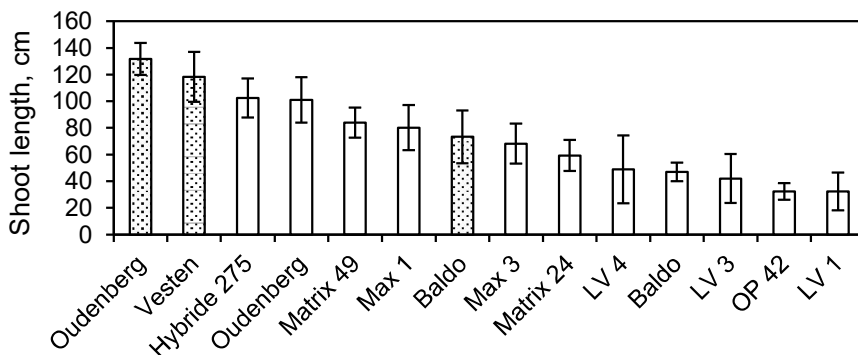

Figure 1. Height increment of poplar clones at the end of the first growing season ± CI. Different fill patterns separate groups of different cuttings length: 'short', (0.3 m) – white columns; 'long', (0.5 m) – dotted columns.

At the end of September, mean height ± CI of 'short' clones was 69.2 ± 6.9 cm. Shoot height of 'short' Hybride 275, Oudenberg and Matrix 49 were significantly higher than 'short' Baldo, LV 3, OP 42 and LV 1 clones. The significantly ($p < 0.05$) smaller height at the end of period of measurements was reached by clones LV 1 and OP 42 with 32 ± 14.1 cm and 32 ± 6.3 cm, respectively. Although clone OP 42 had poor growth, likely due to specific site conditions, it has been widely and successfully used in the south of Sweden, reaching the biomass of approximately 8 t dry mass ha^{-1} yr^{-1} (Christersson, 2008), suggesting that the limited number of replications requires additional studies.

The mean shoot height ± CI of 'long' clones was 107.9 ± 13.4 cm. The 'long' Oudenberg and Vesten clones had significantly ($p < 0.05$) higher shoot height (131.8 cm and 118.3 cm, respectively) compared to 'long' Baldo (73.3 cm) at the end of September, likely due to the differences in the late–summer growth strategy (Devine et al., 2010).

For the clones with two different cutting lengths, Oudenberg and Baldo, shoot height was significantly ($p < 0.001$) influenced both by clone and length of the cuttings, while the effect of the interaction between these two factors was non–significant ($p = 0.74$; $R^2 = 0.75$). The 'long' cuttings of Oudenberg clone exceeded the shoot height

by 30% compared to 'short' cuttings, 132 ± 12.0 cm and 101 ± 17.1 cm, respectively. For Baldo, the 'long' cuttings exceeded the shoot height of 'short' cuttings by 50% (73 ± 20.0 cm and 47 ± 7.0 cm, respectively), suggesting that the 'long' cuttings resulted in largest height and biomass production (depending from the clone); it is in accordance to findings of other studies (Burgess et al., 1990; DeBell et al., 1996; Rossi, 1999; Camp et al., 2012). Such tendency can be explained by larger nutrient reserves for shoots of longer cuttings (Buhler et al., 1997; Marino & Gross, 1998). Moreover, the higher shoot height of 'long' cuttings may have occurred due to higher ability to reach the capillary flow of ground water compared to 'short' cuttings, considering the planting depth (Bloomberg, 1963; Vigl & Rewald, 2014). The mean growth intensity in all periods was 10 to 15 mm day^{-1}. Some of the clones (e.g., OP 42, LV 1, LV 3) did not show the height increment greater than 10 mm day^{-1} in any period of measurements – contrary the 'long' Vesten, 'long' and 'short' Oudenberg, as well as 'short' Hybride 275 exceeded 15 mm day^{-1} at least in two measuring periods. It suggests, that clones have different intra–annual growth trends (Devine et al., 2010).
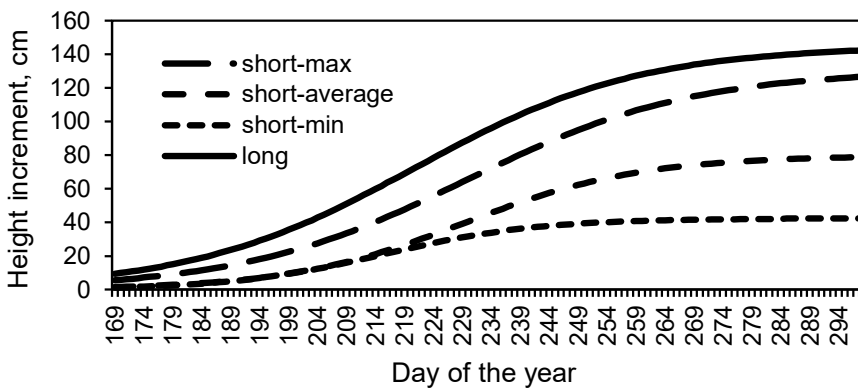

Figure 2. Gompertz model for groups of poplar clones. Clone groups of poplar: 'short–max' – Hybride 275, Oudenberg 0.3 m cuttings; 'short–average' – Baldo 0.3 m, Max 1, Max 3, Matrix 24, Matrix 49; 'short–min' – OP 42, LV 1, LV 3, LV 4; 'long' – Oudenberg 0.5 m, Vesten 0.5 m.

The non–linear Gompertz model was fitted to height growth intensity data for 4 clone groups of poplars after the mutual growth trend analysis: 'short–min', 'short–average', 'short–max', and 'long' (clone Baldo was excluded from this group due to significantly ($p < 0.05$) lower height compared to Oudenberg and Vesten) (Fig. 2). Model parameter α, showing the maximum value of the height increment, significantly ($p < 0.05$) differed between all 'short–' clone groups, although, parameter β, describing the initial phase of the growth, was similar. Significant ($p < 0.05$) differences between the slope (parameter k) of 'short–min' and 'short–max' groups indicated the sharper increase of height increment at the beginning of July for poplars with largest annual height increment at the end of the September. Obtained model parameters (α, β, k) revealed that the growth dynamics was similar between 'long' and 'short–max' poplar clones, showing that weather conditions (primarily temperature) play a significant role in their growth (Ilstedt, 1996; Šēnhofa et al., 2016). Generally, clones with largest height increment at the end of growing season showed the highest growth intensity in the beginning of growth and relatively fast increase during first part of the season; that partly

might be a result of genetically determined differences in leaf flushing (Jansons et al., 2014).

Link between growth intensity and meteorological parameters (i.e., temperature and precipitation) was observed (Fig. 3). In second period (30.06.–10.07.) the mean diurnal temperature decreased (from 19.3 °C to 17.6 °C) causing the growth intensity decrease by on average 2.2 mm day^{-1} for all trees, although, the precipitation sum was 69 mm (Fig. 3). The maximum growth intensity was recorded when the precipitation reached the maximum (108 mm; 19.2 °C) at the end of July (22.07.–08.08.), increasing to an on average 12.7 mm day^{-1}. The growth intensity in fourth period varied greatly between the poplar clones, ranging from 4.6 mm day^{-1} (LV 1) to 18.5 mm day^{-1} ('long' Oudenberg). In the mid–August (09.08.–17.08.) temperature and precipitation felled to 14.9 °C and 60 mm, respectively, caused the growth intensity decrease to on an average of 10.2 mm day^{-1}. Although, the temperature increased in the next period (18.08.–29.08), the growth intensity remained approximately the same as in the previous period (10.3 mm day^{-1}). This suggests different late–summer growth strategy (Devine et al., 2010) for analysed poplar genotypes, confirming that weather conditions have a strong influence on growth and inwintering of poplars during the last month of growing season (Ilstedt, 1996). Further, the growth intensity decreased gradually with the decrease of temperature and precipitation as sum until the end of measuring.
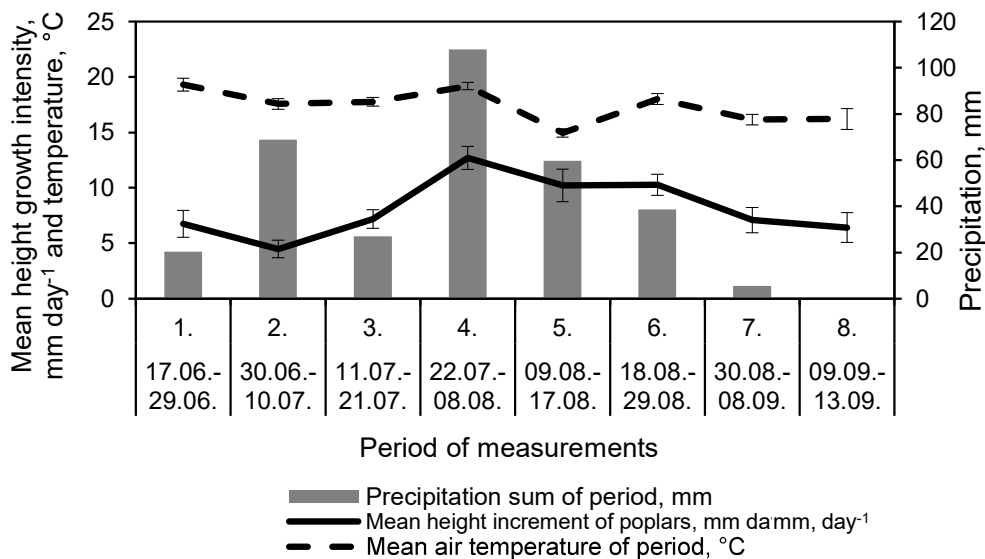
Figure 3. Mean height growth intensity (mm day^{-1}) of poplar ± CI in relation to meteorological parameters. The temperature for the period of measurements has been calculates as mean value of the recorded diurnal temperatures ± CI.

Growth intensity of the poplar clones had notable ($p > 0.05$) positive correlation with the precipitation sum, weaker – with the mean diurnal temperature, mean $r = 0.60$ and $r = 0.17$, respectively. Clones with longest annual height ('long' Vesten and 'long' Oudenberg) during the unusually cold period (09.08.–17.08.) continued their growth, when other poplar clones reduced it (Figs 1, 3). This suggested the robustness of fast–growing genotypes to weather conditions, as previously shown by Jansons et al. (2014).

Despite non–significant correlation, the temperature effect on poplar growth was evident by the notable differences of the height growth intensity between the periods with the prompt changes of mean diurnal temperature (Fig. 3), i.e.: between the first and second, the third and fourth, the fourth and fifth, as well as the sixth and seventh periods. It may indicate the short term acclimatization of poplars to environmental signals, showed by Rohde et al. (2011). However, at the first part of the growing season (i.e., between the second and third period) temperature was not deciding factor to ensure significant growth intensity increase (Fig. 3). It might be due to interaction with other environmental factors, like precipitation (Leonelli et al., 2008; Chhin, 2010). Also towards the end of the growing season (between the fifth and sixth period), sharp increase of temperature was not followed by notable rise of growth intensity, suggesting that other factors, e.g., photoperiod (Howe, 1995; Rohde et al., 2011; Soolanayakanahally et al., 2015) may have reduced the importance of temperature.

CONCLUSIONS

Mean annual shoot height of poplar clones was 81.0 ± 6.8 cm; it was significantly affected by genotype (clone). Slightly longer (0.5 vs. 0.3 m) cuttings (Baldo, Oudenberg) ensured notably (30–50%) larger annual shoot length. Intra–annual height curves, described by Gompertz model, indicated that the poplar clones with largest annual shoot height ('long' Vesten and 'long' Oudenberg) had relative sharp increase of the growth intensity from June to July. Link between growth intensity and temperature, precipitation was observed; it was weaker for the clones with largest annual height increment.

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