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Effect of permanent waterlogging on the growth of poplar clones MAX 4, MAX 5 (J-104, J-105) (*Populus maximowiczii* A. Henry × *P. nigra* Linnaeus) and evaluation of wood moisture content in different stem parts – Short Communication

V. Štícha, J. Macků, O. Nuhlíček

Department of Forest Technologies and Construction, Faculty of Forestry and Wood Sciences, Czech University of Life Sciences Prague, Prague, Czech Republic

ABSTRACT: The study deals with differences in the growth of 2-year mix of poplar clones MAX 4, MAX 5 in the first rotation period at a site with the average moisture regime and at a neighbouring site affected by waterlogging. Average diameter at breast height (DBH) at the site without the observable water influence was 19.6 mm (average height 380 cm). Average DBH at the water-affected site was 8.1 mm (height 220 cm). The difference was statistically significant, which corroborates the hypothesis of the adverse influence of waterlogging on the growth of poplar clones. Furthermore, moisture content was ascertained in wood samples. A comparison was made of samples from the butt, middle part and top part of the stem. Differences between the respective stem parts were not statistically significant. Total average wood moisture content at the time of harvest (January 2012) was 59.7%.

Keywords: biomass; fast-growing tree species; effect of site; energy coppicies; short rotation; Japanese poplar

Poplar clones of *Populus maximowiczii* A. Henry × *P. nigra* Linnaeus have gradually spread into many countries of the temperate zone in Europe. They are widely cultivated in central Europe on otherwise difficult-to-use agricultural lands in so-called short-rotation coppice plantations to produce biomass for energy (Mládek 2010) and represent a possibility of utilizing agricultural land for other than food crop growing purposes (Kovářová et al. 2002). The poplar has many physical traits which make it suitable for plantation forestry when compared to other forest species, e.g. fast growth, adaptability to diverse environmental conditions and different silvicultural systems (Fang et al. 1999). Biomass production is a promising alternative for the Czech agricultural sector (Lewandowski et al. 2006). Poplar clones cultivated most frequently in the Czech Republic are those obtained through the intentional hybridization of black poplar and Maximowicz' poplar (*P. nigra* × *P. maximowiczii*) featuring excellent sprouting capacity comparable with willows, which is important for general longevity of the plantation (Strašil, Šimon 2009). Havlíčková et al. (2007) pointed out that a minimum rotation period in the Czech Republic is 3 years. This rotation period can be prolonged in unfavourable localities such as frost pockets, higher elevations or waterlogged soils. Maximowicz' poplars achieve the highest yields within the altitudinal range from 300–600 m a.s.l. Even though they may be cultivated at higher elevations, the yields of harvested wood mass at such elevations are markedly lower. For their optimum growth, Maximowicz' poplars require minimum annual total precipitation amounting to 500 mm. In dry localities Maximowicz' poplars do better than most other clones (Kravka et al. 2012). They are less suitable for sites with soil salinization and summer spells of drought (McIvor et al. 2011). Jules et al. (2010) observed that higher precipitation and cooler summers were positively correlated with the plant growth. Conversely, some studies indicated that on a regional level the temperature can override the influence of precipitation levels. Thanks to its potential, Maximowicz' poplar has gained an increasing attention. In 5 years, it can reach a height of up to 11 m in favourable localities (Trnka 2009). For its high yield (9–12 t DM·ha^{-1}) and the high rooting capacity of cuttings often exceeding 90% (only 10% of cuttings do not produce any roots and die), the species is cultivated on more than 70% of plantations in the Czech Republic (Weger 2012). Poplar is susceptible to soil acidity. It thrives in neutral or acidic soils with extreme minimum pH 5.5 (Kohout et al. 2010). The growth of poplars is greatly affected by calcium and nitrogen (Celjak et al. 2008). In the furniture industry, poplar wood was used for the manufacture of veneers, plywood, barrels and boxes. Today, its wood is mostly used as fuel or in woodcarving (Celjak et al. 2008), and the use of poplar for biomass production appears to be an interesting opportunity for Czech farmers with regard to its modest requirements. The submitted paper aims at a comparison of growth parameters in Maximowicz' poplar cultivated at two neighbouring and – in terms of the water regime – different sites and at a comparison of water content in different parts of the stem at a standard site.

MATERIAL AND METHODS

Study area. The plantation in Vráž near Písek in the South Bohemian Region was established on April 20, 2010 and its size is 1 ha. In this area, 8,000 cuttings of Maximowicz' poplar were planted. The study area is situated at an altitude of 435 m a.s.l. and its geographic coordinates are 49°22'45"N latitude and 14°7'37"E longitude. It represents the classified soil-ecological unit No. 74702 with a mean annual precipitation amount of 565 mm. Such a soil-ecological unit is defined as deep (> 60 cm), with the skeleton part lower than 25%. The structure is partly crumbed, deeper horizons are polyhedric. Plot 1 is without apparent influence of water and Plot 2 is significantly affected by water (a terrain depression without precipitation water runoff, as can be seen in the terrain analysis application developed by the Czech Office for Surveying, Mapping and Cadastre, available at http://ags.cuzk.cz/dmr/). The ground level in the middle of Plot 1 is more than 1 m higher than the ground level in the middle of Plot 2. Water on the ground surface was observed repeatedly and regularly in Plot 2 during the vegetation period, while there was not always

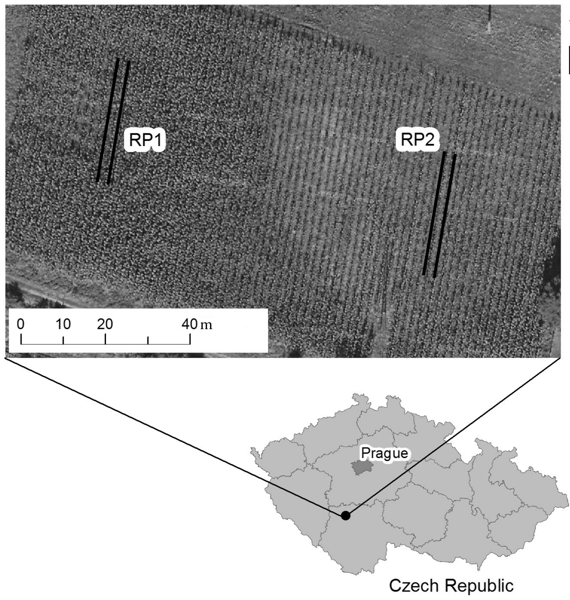

Fig.1. View of the study area (www.mapy.cz), localization of the plots within the Czech Republic

observed any water in Plot 1. The difference in the character of the two stands is also shown in the aerial photograph taken in 2011 (Fig. 1).

Data collection. In January 2012, the plantation was divided into two research plots. 40 individual trees were chosen on each plot. To eliminate side light, border effect etc., individuals were picked out from the middle part of the plot surrounded by a 10-m "buffer" border zone. In this middle part, two central transects 1.8 m apart were chosen, and every second individual in a row was picked out. This systematic approach was preferred as the number of individuals to choose from was relatively small and any randomizing aspect could lead to the opposite effect than covering the heterogeneity of this middle part which was approximately 30 m long. Further identification of the collection area is in Fig. 1, where two pairs of transects are shown as lines. The number of 40 individuals proved to be sufficient for statistical evaluation considering variation. Diameter at breast height and tree height were measured in all individuals using digital calliper and telescopic lath. Samples for the determination of moisture content were taken only from Plot 1 – in the butt part, in the middle of the stem and at 1 m from the top. The reason was that the site is of standard character with the standard water regime. The length of all samples was 2 cm, the thickness varied according to the stem diameter. Immediately after having been taken, the samples were marked and inserted into polypropylene bags. Subsequently, they were weighed with a digital scale PBS/PBJ (Kern & Sohn GmbH, Balingen, Germany) to the nearest one hundredth of gram in the laboratory of

Table 1. Average values of tree heights and mean diameters at breast height (DBH) from 40 individuals from each of the compared plots

Plot	Average tree height (m)	Standard deviation	Average DBH (mm)	Standard deviation
1	3.7998	59.9	19.58	4.84
2	2.1980	38.9	8.10	2.30

the Faculty of Forestry and Wood Science, dried in a furnace at 103°C and repeatedly weighed. Results of measuring were recorded and moisture content in the samples was calculated.

Data processing. A hypothesis of the growth parameters of poplar being fundamentally affected by waterlogging was tested by comparing DBH and tree height values measured in the individuals chosen on the two plots. The null hypothesis was that there are no differences between the measured characteristics (H_0: $P_1 = P_2$), i.e. mean P_1 of the supposedly affected population is equal mean P_2 of the control population. The difference between variances of the respective data sets was established first by Fischer's *F*-test (Eq. 1):

$$F = \frac{\text{higher of the variances } (s_1^2, s_2^2)}{\text{lower of the variances } (s_1^2, s_2^2)} \qquad (1)$$

where:

s_1^2, s_2^2 – sample variances of two plot populations represented by the individuals in transects.

Mean tree height values were compared using Welch's *t*-test.

The water content in the samples was calculated on the basis of the difference between the mass of the fresh sample and the mass of the sample dried out in furnace. The proportion of water was expressed as a percentage of the fresh sample mass, i.e. as relative moisture content (MC_{wet}) (Eq. 2):

$$MC_{wet} = 100 \times ((Wt_{wet} - Wt_{dry})/Wt_{wet}) \qquad (2)$$

where:

Wt_{wet} – mass of the fresh sample,

Wt_{dry} – mass of the sample dried out in furnace.

Subsequently, differences between the variances of the respective data sets were ascertained using the *F*-test again, and differences between the means of all three data sets were established by Welch's *t*-test. The data were processed by the MS Excel 2007 programme (Microsoft Co., Redmond, USA).

RESULTS

Average DBH at the site unaffected by waterlogging was 19.6 mm (average tree height 3.7998 m). Average DBH at the waterlogged site was 8.1 mm (average tree height 219.8 cm) (Table 1). In the DBH, a significant difference was revealed by the *F*-test between the variances of data sets ($P = 9.42 \times 10^{-6}$). Subsequently, the hypothesis of the equality of these data set means was rejected by Welch's *t*-test at a very high level of significance ($P = 4.95 \times 10^{-19}$). The comparison of tree height variances by the *F*-test did not show any significant difference between the variances of the data sets ($P = 0.0083$), and using Welch's *t*-test, the hypothesis of the equality of the data set means was rejected at a high level of significance again ($P = 1.43 \times 10^{-21}$). This indicates that the growth of Maximowicz' poplar (expressed by means of DBH and tree height) at the waterlogged site reached significantly lower values than at the site unaffected by water.

The same method was employed to compare moisture content in samples from the butt part of the stem, from the middle part of the stem and from the top stem part. Differences between the respective stem parts were statistically insignificant. Total mean moisture content at the time of harvest (January 2012) was 59.7% (Table 2).

DISCUSSION

The effect of water on the production of poplar was studied e.g. by Christersson (2006), who claimed that excessive waterlogging was not ideal for poplar. Similarly, Čížek (2007) characterized the root system of poplars on waterlogged sites to be only superficial, and poplar trees tending to be wind thrown. Moreover, poplar roots cannot penetrate the waterlogged

Table 2. Comparison of moisture content in individual parts of the stem taken from 40 individuals on first plot

Stem part	Average moisture content in the sample (%)	Standard deviation
Base	59.3	2.06
Middle	60.4	1.58
Top	59.4	2.24

horizons properly (Celjak et al. 2008). Studies with the seedlings of two poplar clones (NL-80105, NL-80351) and willow show that under soil waterlogging, the root number was decreased, root length was shortened, root activity was declined, height growth became slow, and correspondingly, the biomass was decreased. Leaf stomata showed a strong response to waterlogging stress, which affected the activity of nitrate reductase in leaves. Willow had a stronger waterlogging resistance than poplar, no matter on growth or on physiological properties (Luozhong 1998). On the other hand, water deficiency is one of the most common external factors affecting biomass production with moderate water deficiency resulting in a considerably reduced biomass production in a majority of genotypes (Felix et al. 2008). By contrast, clones of *P. deltoides* Bartram ex Marshall exhibit considerably suppressed photosynthesis, growth of leaves and stomatal conductivity already after one day of flooding. Nevertheless, responses to excessive water are different for each genotype as shown for example by a study of three different genotypes the results of which were contradictory (Bassman 2001). Pliura et al. (2007) blamed insufficient drainage to be responsible for the decreased production of poplars in Canada. On the other hand, drought during the growing season suppresses increment as well, which was demonstrated for example by a research from Canada (Hogg et al. 2005).

Research values of relative wood moisture in poplar hybrids in the winter period range from 53 to 58% in dependence on the specific genotype (Tha-rakan et al. 2003; Verlinden et al. 2013). Results of our study are in good agreement with them.

CONCLUSIONS

The above presented results of our study demonstrate that the effect of waterlogging on the growth of Maximowicz' poplar is highly profound and negative. Therefore, the factor should be considered at the first place in choosing a site suitable for the establishment of poplar plantation, together with the other most important factors. The established wood moisture content corresponds with the results of other authors. The tested differences show that the wood moisture content is practically identical in various parts of the stem. This is an important fact for measuring the mass and volume of timber from various stem parts when larger diameters can be used as piece fuel and smaller diameters can be processed for wood chips.

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Corresponding author:

Ing. Václav Štícha, Ph.D., Czech University of Life Sciences Prague, Faculty of Forestry and Wood Sciences, Department of Forest Technologies and Construction, Kamýcká 1176, 165 21 Prague 6-Suchdol, Czech Republic; e-mail: sticha@fld.czu.cz