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The selected biomass properties of *Paulownia tomentosa* strains cultivated for energy purposes in the first two years of vegetation

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Abstract: *The selected biomass properties of* Paulownia tomentosa *strains cultivated for energy purposes in the first two years of vegetation*. The objective of research was to examine usefulness of *Paulownia tomentosa* for cultivation for biomass. Intense growth and calorific value of this species was confirmed. The strains examined varied in terms of growth strength and winter hardiness both internally and externally. There is a base for effective selection of fast-growing genotypes of Paulownia of reduced thermal requirements, adapted to Polish climate conditions.

Key words: *Paulownia tomentosa*, biomass, combustion heat, plant growth

INTRODUCTION

Paulownia tomentosa is a species originating from south-eastern China. Due to its properties, such as intense growth and quick biomass increment, the plant is used as an energy crop and for biomass production. Paulownia is characterized by great ability to regrow from the roots or the shoot base after cutting the aboveground part, without the need to replant it after cutting, which results in reduction of investment costs.

Paulownia plants are characterized by a wide range of uses, from energy industry (incineration, bioethanol, pyrolysis), through furniture, paper and pharmaceutical production, to decorative purposes, beekeeping and as a source of manure and fodder for animals [Rao et al. 1986, Woods 2008, Yadav et al. 2013, Vityi and Marosvölgyi 2014]. Paulownia is also very useful for soil remediation and phytoremediation. It is more tolerant to heavy metals than willows and poplars. Moreover, thanks to well developed root system and high productivity, it collects large amounts of trace elements from the soil [Woods 2008, Azzarello et al. 2012]. Therefore, there has been growing interest in cultivation of Paulownia in many countries of Europe, particularly those with a climate warmer than Poland. Information on growth and yields of Paulownia in Europe is scarce. In particular, there is lack of reliable information on behavior of these plants in Poland. Therefore, the aim of the research conducted was to compare the strength of growth of the selected strains of *Paulownia tomentosa* in the first two years of vegetation and a preliminary assessment of usefulness of this species for cultivation for biomass in south-eastern Poland.

MATERIAL AND METHODS

The research was conducted using generatively propagated *Paulownia tomentosa* plants belonging to 13 strains of varying origin. Most of the strains assessed came from seeds obtained from trees growing in botanical gardens, arboreta and in private possessions in Poland, while three came from abroad. These were grown from seeds received from Hungary, Romania and Crimea.

Field research was conducted in south-eastern Poland – one in Grochowe near Mielec, and one in the vicinity of Świlcza near Rzeszow. Experimental plot I was established in sandy soil of quality class 6, fertilized prior to planting with sewage fertilizer (80 t·ha^{-1}), and plot II – in organic soil (lowmoor peat) of class 3 of quality, fertilized with sewage from a treatment plant between rows in the second year of vegetation. The plots were established in June of 2014, using entirely randomized blocks method. Each strain was represented by 40 (plot I) and 36 plants (plot II). The plants were planted in rows and bands, at spacing of (3 m + 0.75 m) × 0.5 m (plot I) and (6.4 m + 1.5 m) × 0.35 m (plot II); respectively: (distance between bands + distance between two rows in band) × distance between plants in row. The density was approximately 10 and 7 thousand plants per ·ha, respectively.

During and after the vegetation period, assessment of usability properties of *Paulownia tomentosa* was conducted. The basic biometric measurements of the plants were performed, and in the spring of 2015, wintering was assessed. The results obtained were processed statistically using Statistica 10 software. Variance analysis (ANOVA) was applied. The average values were compared using the NIR test, at the significance level $\alpha < 0.05$.

RESULTS AND DISCUSSION

Paulownia tomentosa is one of the fastest growing plants in the world [Ayan et al. 2006, Woods 2008]. Under favorable conditions, 10-year-old trees can reach 1,012 m of height and 3,040 cm of the trunk diameter [Vityi and Marosvölgyi 2014]. Annual plant growth can reach even 5 m in length [Rao et al. 1986]. Intensive plant growth allows for biomass harvest even once a year. Information on extraordinarily quick growth of Paulownia plants, known from foreign literature, has been confirmed (Fig. 1, Table 1). In the poor soil, during the first year of vegetation, the plants developed shoots of length exceeding 55 cm and the shoot base diameter of 1.7 cm. During the second year, shoots of non-watered and non-fertilized plants were, on the average, more than 70 cm long and 1.5 cm thick. The total shoot length in the first year of vegetation exceeded 60 cm, and in the second – 120 cm. In fertile soil, Paulownia plants grew much stronger, developing shoots of average length above 80 cm and diameter at the base of 1.7 cm in the planting year. In the following year, after fertilizing with sewage, the average growth reached more than 170 cm in length and almost 3 cm of diameter at the base. The total shoot length in the first year of vegetation exceeded 95 cm, and in the second – 320 cm. In the planting year, the plants were usually characterized by strong apical dominance, and in the following year, they showed a tendency to axillary branching.

The strains of Paulownia differed significantly in terms of growth strength.

FIGURE. *Paulownia tomentosa* plants in the first (to the left) and second vegetation year (to the right). Photos taken 08.09.2014 at Grochowe and 17.09.2015 at Świlcza

TABLE 1. Selected properties of shoots of *Paulownia tomentosa* in the first and second year of vegetation

Analyzed traits	(Grochowe) Poor soil		(Świlcza) Fertile soil	
	1^{st} year	2^{nd} year	1^{st} year	2^{nd} year
Length of shoot [cm]	55.6 (47.2−67.3-We)*** 26% [a]	70.2 (54.5−89.2LuP)*** 35%	85.5 (65.6−95.5-We)*** 25%	173.7 (152.7−227.6-LuP)*** 27%
Total length of shoots [cm]	61.9 (52.8-84.2-LuP)*** 38%	124.1 (70.8−210.6- LuP)*** 67%	96.6 (65.6−111.3-LuP)*** 36%	324.8 (217.8−500.3- LuP)*** 60%
Number of shoots	1.2 (1.0−1.5-LuP)*** 43%	2.3 (1.7−3.2-LuP)*** 50%	1.2 (1.0−1.4-LuP)** 38%	2.3 1.6−3.0-LuD)*** 53%
Diameter at the shoot base [cm]	1.7 (1.5−1.9-We)*** 19%	1.5 (1.3−1.7-LuP)^{ns} 29%	1.7 (1.5−2.0-LuD)** 32%	2.8 (2.4−3.6-LuP)*** 35%
Fresh weight of shoots [g]	99.2 (63.2−145.1-We)* 34%	–	–	464.8 (333.9−812.2- LuP)** 37%
Dry weight of shoots [g]	29.2 (19.3−43.5-We)^{ns} 35%	–	–	176.6 (136.7−293.5- LuP) 27%
Dry mass content in the shoots [%]	29.4 (27.6−30.5-Bd)^{ns} 5%	–	–	38.2 (35.0−43.9-Bl) 6%

[a]Average (minimum and maximum values – the symbol of the strain); significance level of differences among strains (ns – not significant – p >0.05, * p <0.05, ** p <0.01, *** p <0.001), coefficient of variation.

In both plots, in the second year of vegetation, the "LuP" strain plants could be easily distinguished (Table 1). After two years, the plants of this strain, growing in dry and sandy soil, developed shoots of the total length of more than 2 m, and in fertile soil, about 5 m. Thickness of the base of the strongest shoot was close to 2 and 4 m. A similar shoot growth strength was shown by plants of strains "We" and "LuD". The remaining strains were characterized by visibly poorer growth. Variability of the examined biometric properties (that is, length and diameter of increments and leaf size) among the best strains usually exceeded 20%.

In the land plot on the poor soil, fresh mass of one-year shoots of strain "We" per plant was 0.14 kg, and dry mass – 0.04 kg, which, for density of 10 thousand plants per ha, would give 1.4 and 0.4 t of biomass per ha, respectively, in the first year of cultivation. In the following year, the strongest strain ("LuP") in Świlcza gave about 0.8 kg fresh mass (0.3 kg dry mass) of shoots per plant. Approximately, at a density of 7 thousand plants per ha, this would produce 5.6 t of fresh (2.1 t of dry) biomass per ha in the second year.

Paulownia plants developed very large leaves (Fig., Table 2). After less than 3 months of vegetation, the average leaf length was close to 25 cm, and width – to 30 cm (plot 1). Fresh leave mass was about 18 g, a dry mass – about 5 g. In the second year of functioning of the plantation in Grochowe, the plants developed much smaller and lighter leaves in comparison with the first year, which was mainly due to a long draught period. In the second year of vegetation in Świlcza (fertile soil), the average leaf length was about 29 cm, and their width was about 37 cm, fresh leaf mass exceeded 30 g, and dry mass – 7 g. In both experimental

TABLE 2. Selected properties of *Paulownia tomentosa* shoots in the first and second year of vegetation

Analyzed traits	(Grochowe) Poor soil		(Świlcza) Fertile soil	
	1st year	2nd year	1st year	2nd year
Length of leaf blade [cm]	24.5 (22.1–27.4-We)*** 16% [a]	15.0 (13.3–19.2- LuP)*** 29%	–	29.2 (25.9–38.2- LuP)*** 23%
Width of leaf blade [cm]	30.1 (26.4–33.5- We)*** 19%	19.3 (16.0–24.4- LuP)*** 29%	–	36.9 (33.7–46.8- LuP)*** 24%
Fresh weight of leaf [g]	18.2 (15.2–21.8-We)ns 17%	7.9 (5.3–10.6-LuP)ns 40%	–	31.0 (26.9–42.4- LuP)ns 19%
Dry weight of leaf [g]	5.1 (4.2–6.3- We)* 15%	1.7 (1.2–2.4-LuP)ns 41%	–	7.4 (6.5–9.6- LuP)ns 22%
Dry mass content in the leaves [%]	28.2 (26.0–30.7-LuD)ns 11%	22.6 (18.3–26.8-Po)ns 24%	–	23.9 (22.1–25.7- We)ns 9%

For explanations see Table 1.

plots, the dimensions and mass of leaves of the strongest strains (“We”, “LuP”) was more than 20% greater than the average for all strains.

According to Rao et al. [1986], the biomass of Paulownia is characterized by relatively low moisture content upon harvest (about 21%), and it dries quickly. The dry mass content in the shoots was usually higher than in the leaves (Tables 1 and 2). Combustion heat of one-year Paulownia shoots was 14.8 to 18.2 $MJ \cdot kg^{-1}$, and leaves – 15.9 to 18.7 $MJ \cdot kg^{-1}$. In the case of most strains (12 out of 13 examined), the value of this property was close to the value quoted in literature for energy willow [López et al. 2012]. It can be stated that the leaves of Paulownia are as valuable as a source of biomass as the sprouts; however, they fall after the first frost, and earlier harvest may be troublesome and unprofitable.

In the available literature, there is no information on winter hardiness of *Paulownia tomentosa* under our climate conditions. Among the Paulownia genus, the species *Paulownia tomentosa* is characterized by the highest resistance to frost. The plants are nevertheless able to survive if temperature drops to about –25°C [Rao et al. 1986]. In the spring of 2015, assessment of wintering of Paulownia plants was conducted. The strains examined differed significantly in terms of winter hardiness. In the experimental plot I, the number of plants that died due to frost damage was, on the average, 19.2%, and in plot II – 15.8%. This property was characterized by great variability. In both plots, significantly more resistant to low temperatures were the plants of the fastest growing strains “LuP”, “LuD’, and “We”, for which the number of fallen plans did not exceed 8% in Grochowe and 14% in Świlcza. In the case of the most sensitive strains, the number of fallen plants exceeded 35%.

In the general opinion, Paulownia trees are not demanding, they grow relatively well even in poor soils [Rao et al. 1986, El-Showk and El-Showk 2003, Woods 2008]. Nevertheless, they are not tolerant of very dry, excessively firm and waterlogged soil [Woods 2008]. This has been partially confirmed by the results of experiments conducted. Understandably, Paulownia plants grew better in fertile soil in comparison with very poor soil. Good plant growth was observed in light grow upon moderate precipitation in the vegetation period (2014) and its substantial slowing down in the subsequent year, under the conditions of long-term drought. Perhaps, weaker growth was also associated with the fact that fertilization ceased as the area was included in the zone of “Natura 2000”. This effect was not observed in the second experimental plot, established on fertile land with high level of groundwater content. It seems that Paulownia plantations can be recommended in sandy soils under the condition of provision of an irrigation system and proper fertilization.

CONCLUSIONS

1. Cultivation of *Paulownia tomentosa* can become a valuable and efficient source of biomass in south-eastern Poland.
2. The examined Paulownia plants differed in terms of growth strength and winter hardiness, which should allow for selection of strong genotypes, better adapted to Polish climate conditions.

3. Biomass of Paulownia is characterized by good energy characteristics, that is, combustion heat value comparable to willow and poplar and a relatively low moisture content.
4. In the case of establishment of Paulownia plantations in sandy soils, it is necessary to provide an irrigation system and proper fertilizing.

REFERENCES

AYAN S., SIVACIOGLU A., BILIR N. 2006: Growth variation of Paulownia Sieb. and Zucc. species and origins at the nursery stage in Kastamonu-Turkey. Journal of Environmental Biology 27: 499–504.

AZZARELLO E., PANDOLFI C., GIORDANO C., ROSSI M., MUGNAI S. 2012: Ultramorphological and physiological modifications induced by high zinc levels in Paulownia tomentosa. Environmental and Experimental Botany 81: 11–17.

El-SHOWK S., El-SHOWK N. 2003: The Paulownia tree an alternative for sustainable forestry. Retrieved from http://www.cropdevelopment.org/docs/PaulowniaBrochure.pdf [Accessed: 23.08.2016].

LÓPEZ F., PÉREZ A., ZAMUDIO M.A.M., De ALVA H.E., GARCÍA J.C. 2012: Paulownia as raw material for solid biofuel and cellulose pulp. Biomass and Bioenergy 45: 77–86.

RAO A.N. (Ed.) 1986: Paulownia in China: Cultivation and utilization. By Chinese Academy of Forestry Staff. Asian Network for Biological Sciences, Singapore.

VITYI A., MAROSVÖLGYI B. 2014: New tree species for agroforestry and energy purposes. Proceedings of International Conference on Energy, Environment, Biology and Biomedicine, 2–4.04.2014, Prague: 82–84.

WOODS V.B. 2008: Paulownia as a novel biomass crop for Northern Ireland? A review of current knowledge. Occasional publication of Agri-Food and Biosciences Institute 7.

YADAV N.K., VAIDYA B.N., HENDERSON K., LEE J.F., STEWART W.M., DHEKNEY S.A., JOSHEE N. 2013: A Review of Paulownia Biotechnology: A Short Rotation, Fast Growing Multipurpose Bioenergy Tree. American Journal of Plant Sciences 4: 2070–2082.

Streszczenie: *Wybrane cechy biomasy rodów paulowni puszystej uprawianej na cele energetyczne w dwóch pierwszych latach wegetacji.* Celem badań jest ocena przydatności roślin paulowni puszystej do upraw z przeznaczeniem do produkcji biomasy. Potwierdzono informacje o intensywnym wzroście i wartości energetycznej tego gatunku. Badane rody różniły się pod względem siły wzrostu oraz zimotrwałości zarówno między sobą, jak i w ich obrębie. Istnieją więc podstawy do skutecznego wyselekcjonowania szybko rosnących genotypów paulowni o zmniejszonych wymaganiach termicznych, dostosowanych do warunków klimatycznych Polski.

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