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THE GROWTH DYNAMICS OF PAULOWNIA TREES CULTIVATED AS ENERGY PLANTATIONS IN THE FOREST-STEPPE ZONE OF UKRAINE

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Abstract

The main objective of this study was to establish the impact of varietal characteristics of Paulownia trees on growth and productivity depending on the density of planting in the forest-steppe zone of Ukraine. The greatest increasing of Paulownia Clone 112 trees height - 425 cm was fixed in the first year of vegetation at a density of 625 plants/ha. The same tendency observed in the fourth year. The highest height of Paulownia Clone 112 during the vegetation season was observed in June (170 cm), Paulownia tomentosa - 140 cm. The smallest increase in height was achieved in October, 40 cm and 35 cm, and in April, 15 cm and 10 cm, respectively. A first year trunk of a Paulownia tree reaches a diameter of 4-6 cm, a second year trunk - 7-10 cm, a three-year trunk - 11-16 cm, a four-year trunk - 15-23 cm. A linear relationship between the height and diameter of Paulownia trees was established. It is enough to measure one leaf dimension (length or width) to determine the area of the leaf surface.

Key words*: Paulownia, variety, clone, growth parameters, density of plantations*.

INTRODUCTION

An increase in the concentration of carbon dioxide and greenhouse gases in the earth's atmosphere is one of the main causes of climate change on earth (Sinchenko, 2020). These problems lead to the search for new ways of management and effective technologies. Further use of forest resources and existing wood potential in Ukraine is unacceptable, as the average afforestation of the territory of Ukraine is 16.5% (Shvidenko et al., 2017). This is one of the lowest indicators among European countries. Bigger environmental safety from burning biomass is the main advantage compared to fossil fuels (Kraszkiewicz et al., 2020). During the combustion of biofuels based on plant biomass, significantly less sulfur oxide is formed compared to fossil fuels.

Energy plantations based on tree crops in a minimal period provide an opportunity to obtain a significant volume of high-quality wood products. It is necessary to use mainly fast-growing trees to create energy plantations with a short vegetation period 3-5 years (Wang & Shogren, 1992). One of the promising, economically and ecologically justified crops is Paulownia, which is undemanding in maintenance, investments are repaid quite quickly due to intensive growth rates and the volume of final products (Beel, 2005). Planting paulownia is able to restore in the shortest possible time areas of land affected by fire, landslides, flood scour, or other land scarification (Innes et al., 2009). Paulownia trees have shown a high growth rate during the first three years after coppicing (Criscuoli et al., 2022). Growth rate sharply decreased starting from the fourth year because of the need for greater planting spacing. Paulownia trees cultivation can either increase or decrease crop production, depending on the manipulation of the tree density and rotation length (Yin & He, 1997). Economic profits of timber-oriented Paulownia stands with intercrops are greater than those of crop fields with scattered Paulownia trees. The combined net returns of crops and trees are generally higher than those of the control, ranging from 50% to 100% (Jiang et al., 1994). Paulownia tree can develop deep root system (up to 8 m) depending on soil structure (Szabo et al., 2022). Paulownia at least does not consume substantially higher amounts of water than a few other tree species that are commonly utilized in plantations settled in arid and semi-arid conditions (Baier et al., 2021). However, it is necessary to consume up to 2000 litters of water per tree to reach a production of 4.3 t/ha during the first cut (García-Morote et al., 2014). There were shown differences in the Paulownia trees clones growth dynamics regarding to local environmental and climatic conditions (Jakubowski, 2022). Dry biomass production yields in the second year of cultivation range from 1.5 t/ha to 14 t/ha. Areas abandoned for agricultural use and other categories of land that are not suitable for use (low-productivity, waterlogged, eroded, etc.) can serve as energy plantations in the best way (Blanco-Canqui, 2016; Icka et al., 2016). This will also make it possible to significantly increase the efficiency of the use of such areas, significantly improve the ecological state of the environment and create favorable conditions to cultivate energy plantations (Flynn & Holder, 2001). Significant increase in microbial activity of Cambisol was fixed after one year of tree planting (Wozniak et al., 2022). It was proved the prospects of the Paulownia as fast-growing plant for reclamation on abandoned mineland (Fokina et al., 2020). An unusual weather event (freezing temperatures, drought and strong winds) can be the reason of weak performance of Paulownia plantations during the early years of trees growth (Olave et al., 2015; Pástor et al., 2022). Five years after planting only 25% of planted individuals of Paulownia showed signs of crown damage caused by wind (Barton et al., 2007). The rest individuals of *P. cotevisa* in this study were not affected by any other negative environmental factor or biological pest. The clone *Paulownia elongata* x *fortunei in vitro* 112 was selected in Spain to resist temperature extremes (from −25 to +45°C) and to grow at a faster rate compared to other Paulownia species and hybrids (Ayan et al., 2006). It was established that the age of 5 years is the minimum cutting age for the use of this wood for solid fuel, such as pellets, and as solid wood (Esteves et al., 2022). The main prospects of growing Paulownia trees in short cycles is to produce woody biomass for bio-goods (Kalaycioglu et al., 2005; Caparro et al., 2008; Schroder et al., 2018). The fast growing Paulownia trees can serve also for such purposes as mulching and leafy biomass for fodder (Stewart et al., 2018). Leaves of Paulownia have the same as alfalfa nutritious values including fats, sugars and proteins for cattle nourishment to be are suitable as forage used for ruminants, non-ruminants animals and poultry feeding (Alagawany et al., 2022). The β-carotene content in the Paulownia leaves rich 7716 μg/g (Steier et al., 2022).

The use of residues generated in the forest biomass industry (pine bark and biomass ash) as a soil amendments had a positive effect on the soil microbial activity (Moreno et al., 2017). Extending the length of the fertilization period to 10 years in a Paulownia plantation can be an effective management practice and tool to provide efficient carbon sequestration in the soil carbon pool and for rational application of organic fertilizer in Paulownia plantations (Wu et al., 2022). An significant positive effect of the slurry application in plantation of Paulownia was established in the diameter at breast height and total stand height (Menino et al., 2022).

The main objective of this study was to establish the impact of varietal characteristics of Paulownia trees on growth and productivity depending on the density of planting in the forest-steppe zone of Ukraine.

MATERIALS AND METHODS

The research was carried out during 2018-2021 at the field experimental station of the Institute of Bioenergy Crops and Sugar Beet of the Ukrainian National Academy of Sciences. The analysis of the dynamics of the weather conditions during the season of vegetation was made for 2018-2021 (Figure 1).

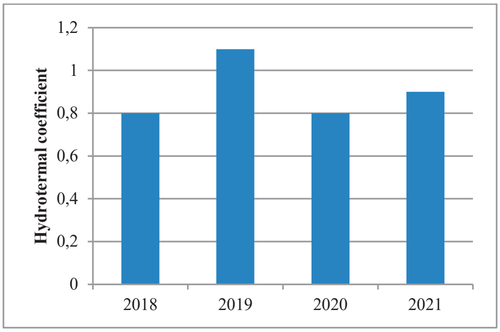

Figure 1. Hydrothermal coefficient for 4 years

According to the analysis of changes in the hydrothermal coefficient (HTC), the conditions for growing paulownia in the forest-steppe zone of Ukraine are optimal.

The soil of the experimental field - sod - podzolic sandy loam had the following parameters of the topsoil: pH - 5.3-5.5, total humus content 0.50-0.62%; mobile phosphorus and potassium - 160-180 and 50-65 mg/kg of soil, respectively; hydrolyzed nitrogen according to Kornfield - 39-45 mg/kg of soil. In general, the soil has low fertility.

Paulownia plantations were established according to tree planting scheme 4 x 4 m with a density: A - 500, B - 625, C - 833 and D - 1050 pcs/ha.

Deep plowing of the soil was done in autumn along with the introduction of herbicides. Soil cultivation was done in the spring. Holes for planting seedlings were made with a motor drill with a diameter of 60 cm and a depth of 40 cm. Mineral and organic fertilizers were applied before the same time. Seedlings grown in vitro were subjected to a two-week adaptation to natural lighting and daily temperature changes before planting in open ground to a permanent place. The tested cultivars were Paulownia Clone - 112 and Paulownia Tomentosa P. Annual growth, trunk diameter, and leaf surface area were determined annually (Figures 2 and 3).

Figure 2. Measurement of Paulownia plants height

It was necessary to make a technical cut after the first year of vegetation at a height of 2-3 cm from the ground and remove young, newly formed shoots (stepchildren). The diameter of the trunk was measured at a height of 1 m.

Figure 3. Measurement of Paulownia plants leaf area

The height and number of leaves on the selected plants in the research plot of paulownia were measured. Then the plants were cut and the total leaf surface area and the mass of each stem with leaves were determined. The research was intended to establish the stochastic dependence of the leaf surface area of paulownia plants on its morphometric indices. The circle modeling was used for this. The correlation and regression analyses of the dependence of leaf surface area on leaf size were carried out using the "Pitiole" software application.

RESULTS AND DISCUSSIONS

The density of plants is related to the area of their nutrition. The greatest of Paulownia Clone 112 trees height - 425 cm was fixed in the first year of vegetation at a density of 625 plants/ha. The same tendency observed in the fourth year (Figure 4). The similar results were obtained in other case study when growth indices after the third year were significantly reduced for plants located in the interior portion of the stands because of the competition between trees (Criscuoli et al., 2022). The need for a larger planting spacing confirmed after the third year.

The greatest development of Paulownia Clone 112 during the vegetation season was observed in June (170 cm), *Paulownia tomentosa* - 140 cm. The smallest increase in height was achieved in October, 40 cm and 35 cm, and in April, 15 cm and 10 cm, respectively (Figure 5). A first year trunk of a Paulownia tree reaches a diameter of 4-6 cm, a second year trunk - 7-10 cm, a third year trunk - 11-16 cm, a fourth year trunk - 15-23 cm (Figure 6).

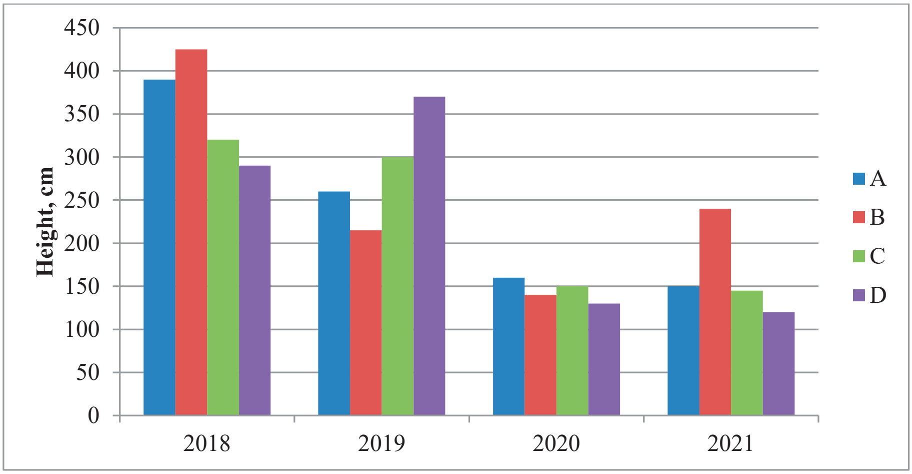

Figure 4. The growth dynamics of Paulownia Clone 112 trees for 4 years, cm

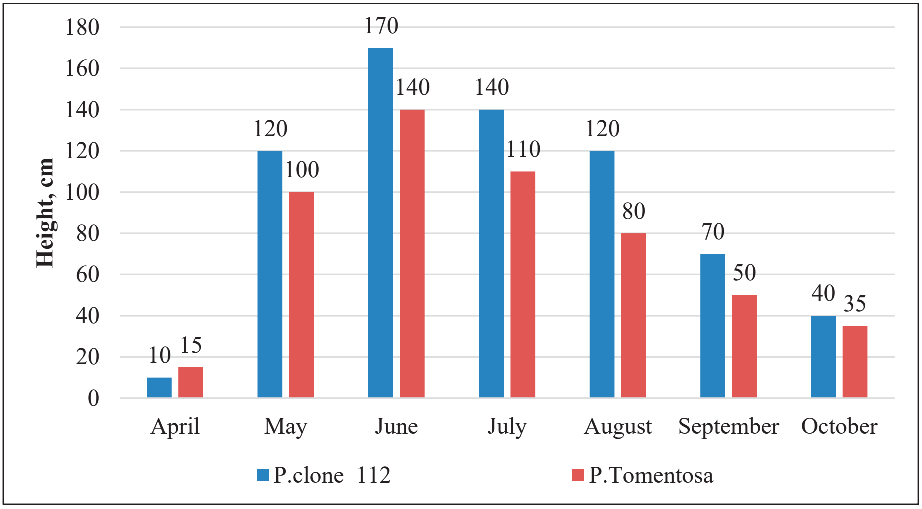

Figure 5. Average monthly growth of Paulownia Clone 112 and *Paulownia tomentosa* by month

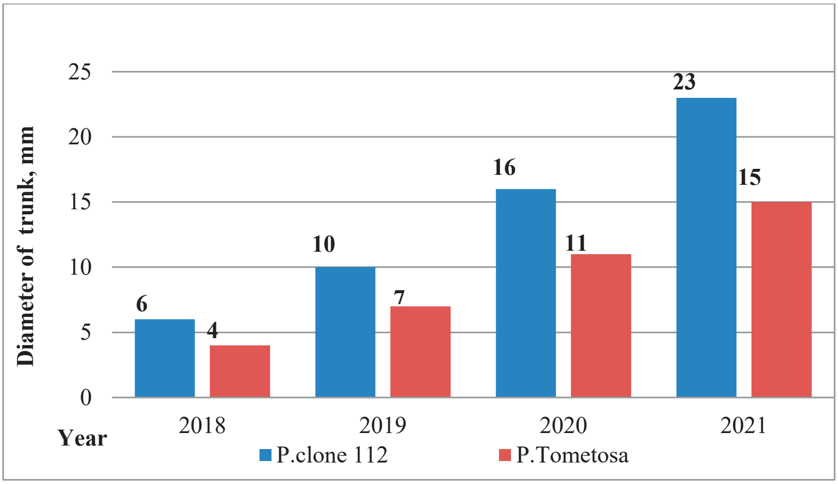

Figure 6. The average diameter of the trunk of Paulownia Clone 112 and *Paulownia tomentosa* by years of vegetation

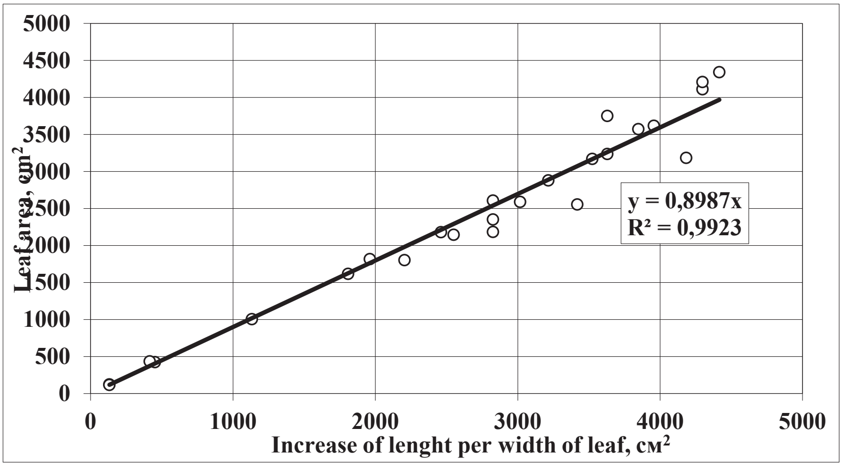

Figure 7. The average diameter of the trunk of Paulownia Clone 112 and *Paulownia tomentosa* by years of vegetation

The results of determining the dependence of the leaf surface area of paulownia plants on the increase of the length of the leaf and its width are shown in the Figure 7. It is enough to measure one leaf dimension (length or width) to determine the area of the leaf surface.

CONCLUSIONS

The greatest increasing of Paulownia Clone 112 trees height - 425 cm was fixed in the first year of vegetation at a density of 625 plants/ha. The same tendency observed in the fourth year. A first year trunk of a Paulownia tree reaches a diameter of 4-6 cm, a second year trunk - 7-10 cm, a third year trunk - 11-16 cm, a fourth year trunk - 15-23 cm. The growth of leaves was especially large in the first and second year of plant vegetation.

Based on the results of research, it was established that the dynamics of the number of trees per hectare, with a square layout of 4x4 m, should be 625 trees per hectare.

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