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The estimate of the required amount of water on the growth of five species of Paulownia at the first year of cultivation in a Central Europe

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Abstract

Needed precipitation or supplied water is not known for mostly hybrids. Therefore, we chose one species Paulownia tomentosa and four hybrids - P. bellissia®, P. Clon in vitro 112®, P. Shan Tong and P. Hybrid 9502. We found out how three types of watering affect their height and thickness increment, amount of leaf biomass and leaf area and if the reaction of plants of these species/hybrids to the amount of water is different. We planted 30 plants of each species/hybrids into plant pots under a shelter. At the end of the growing season, we measured the total heights of the plants, the lengths of the current-year shoots, the stem thicknesses of the current-year shoots, and the distances of the ends of the leaves furthest from the stem in the directions of all four cardinal points. We determined leaves area and their weighed (calculated the projection area of the crown and the leaf area index). Our results showed that, generally, the mean precipitation 50 mm per month in vegetation season seems to be insufficient for optimal growth of Paulownia plants in the first years after planting. Depending on the species, Paulownia Shan Tong seems to grow better under 100 mm per month in vegetation season; Paulownia tomentosa seems to grow better under 150 mm (and more) per month in vegetation season; and the plants of Paulownia Hybrid 9502, P. bellissia® and P. Clon in vitro 112® did not achieve optimal growth (values), no matter which type of watering we used.

Introduction

Plants can contain up to 70% of water, whose functions in the plant are: participation in chemical reactions, the transportation of substances, thermoregulation, etc. (Vyskot et al. 1971). A simplified form of water regime comprises intake of water, conduction of transpiration flow and water release in the plant. The plant primarily receives water through its fine roots, and conduction of water is ensured via tracheae and tracheids. The plant releases water by evaporation from the leaves, or even from the non-woody parts of the stem and branches (Švihra et al. 1981). The ratio between water intake and output is called water balance. If the water output is greater than the intake, then the water balance is disrupted, thus bringing about a water deficit, which can occur either due to a reduced water intake caused by a lack of water or high salt concentration in the soil (Švihra et al. 1981), or a higher water output caused by higher temperatures, higher irradiance, faster air flow, lower air humidity, etc. (Kaufmann 1985). The water deficit, among other things, increases the content of abscisic acid in the leaves, closes the stomata and reduces photosynthetic activity, which decelerates cell growth, reduces the growth increment of the above-ground parts, thus accelerating cell ageing or even, in extreme cases, causes plant death (Aspinall 1980; Heitholt et al. 1991; Ludwig and Matthews 1993; Udomprasert et al. 1999; Udomprasert et al. 2005).

When there is an excess of water in the soil, the plants are also stressed (Barickman et al. 2019). First, the hydraulic conductivity of the root drops (Tournaire-Roux et al. 2003), the production of high-energy phosphate compounds (Gibbs and Greenway 2003) and the speed of photosynthesis (Kang et al. 2009) decrease. As a result, the water intake (Tournaire-Roux et al. 2003) and oxygen availability (Armstrong 1979) are limited. Finally, hypoxia occurs when only the above-ground part of the plant has access to oxygen (Mustroph and Albrecht 2003). The plants respond to the excess water in the soil by slowing down physiological performance, which reduces growth and yield (Armstrong 1979; Mustroph and Albrecht 2003; Barickman et al. 2019).

Sorting of Paulownia is very complicated, because number of species in genus Paulownia spp. Siebold & Zucc. consists of 6-to-17 species according to taxonomy classification (Ates et al. 2008; Woods 2008) and moreover, there have been cultivated many hybrids until present. Therefore, species and newly cultivated hybrids are divided into three types, according to the degree of breeding, namely: wild, semi-wild and art (Chinesepaulownia 2016; Maľová et al. 2016; Paulownia Slovakia 2018). Wild Paulownia species are not suitable for growing in plantations because they do not have good growth characteristics (Zhao-Hua et al 1986; Zhegyi et al. 1994; Maľová et al. 2016). Semi-wild Paulownia species (*Paulownia fortunei* (Seem) Hemsl, *P. elongata* S.Y. Hu, *P. catalpifolia* Gong Tong, *P. tomentosa* (Thunb.) Steud., etc.) have better growth characteristics, higher resistance to disease, and can therefore be grown in smaller plantations (Zhao-Hua et al 1986; Zhegyi et al. 1994; Maľová et al. 2016). However, art Paulownia species (also as hybrid) have been bred to maximize the yield of energy wood and saw-timber (Maľová et al. 2016; Chinesepaulownia 2016; Paulownia Slovakia 2018; Paulowniamoravia 2013; Ipaulownia 2018; Bio tree 2021). There are dozens of art Paulownia species on the market and they differ in their growth characteristics and ecological demand for example: Paulownia Shan Tong (hybrid of *P. fortunei* and *P. tomentosa*), P. Shan Dong (hybrid of *P. fortunei* and *P. tomentosa*), P. Bellissia® (hybrid of *P. elongata* and *P. fortunei*), P. Hybrid 9501, P. Hybrid 9502 and P. Hybrid 9503 (hybrids of *P. fortunei* and *P. tomentosa*), P. Pao Tong Z07 (hybrid of *P. fortunei*, *P. tomentosa* and *P. kawakamii*), or P. Clon *in vitro* 112® (hybrid of *P. elongata* and *P. tomentosa*).

Paulownia spp. originate from China, Laos and Vietnam (Hieke 1978; Bergmann et al. 1997) and it was gradually planting as decorative tree – mainly *Paulownia tomentosa* – on all continents, except for Antarctica. From 1980s last century, hybrids suitable for saw-timber production have been cultivated (Maľová et al. 2016; Chinesepaulownia 2016; Paulownia Slovakia 2018). Due to it, many Paulownia plantations were established in world including the Czech Republic (CR), where the first plantation were planted in last ca 10 years (Görner 2017).

Paulownia spp. is relatively demanding on amount of water (Clatterbuck and Hodges 2004; Kays et al. 1997). Zhao-Hua et al. (1986) described it grow in areas with precipitation between 500 and 3,000 mm per year in dependence on species. However, amount of required precipitation or supplied water for individual hybrids is well not available. One from a few hybrids, about which amount of water is known, is Paulownia Clon *in vitro* 112®, which need according to UCLM (2013) recommend 750 mm per year, Jabloński (2018) 800 mm per year or TGG (2011) described that this hybrid need at least 150 mm per month in first years from planting and at least 50 mm per month in other years. Many authors do not

consider decisive of annual precipitation but amount of precipitation, which fall during vegetation season (Zhao-Hua et al. 1986; TGG 2011; Bio tree 2021).

However, needed or required precipitation or supplied water is not known for other hybrids. Therefore, one the most common in the world species *Paulownia tomentosa* and four hybrids - P. bellissia®, P. Clon *in vitro* 112®, P. Shan Tong and P. Hybrid 9502. The aim was to find out how irrigation affects the height and thickness increment, the amount of leaf biomass and leaf area of Paulownia and whether the reaction of the plants to the amount of water differs in the selected species.

Material And Methods

The fenced research area, where we conducted this research (located in Bohdalov; N 49°28'25.0"; E 15°52'40.6"), was established in the autumn of 2018. This research area had mean temperature around 8°C and mean relative air humidity around 73% in vegetation season 2019 (monthly values of relative air humidity and temperature in Table 1). Above this area, we built a shelter with a transparent polyethylene foil cover. This shelter eliminated atmospheric precipitation. The height of the shelter was from ground to up 2.5 m to ensure natural air circulation and from ground to down 70 cm to placed one-hundred-and-fifty 114-litre non-perforated plant pots. We filled the plant pots with the same soil up to approx. 5 cm below the rim. In the spring of 2019, while planting, the soil was sufficiently compact.

Table 1
Mean, minimum and maximum values of relative air humidity and temperature in Bohdalov during April-October 2019. AVG – mean; MAX – maximum; MIN – minimum.

		April		May		June		July		August		September		October	
Relative air humidity	AVG	**63,3**		**75,1**		**68,4**		**67,8**		**72,3**		**78,1**		**85,4**	
	MAX	**92,3**	29th April	**97,5**	20th May	**87,4**	6th June	**90,2**	12th July	**90,2**	3rd August	**96,2**	2nd September	**97,5**	9th October
	MIN	**43,7**	19th April	**55,4**	7th May	**44,6**	27th June	**45,5**	6th July	**57,7**	15th August	**56,7**	22nd September	**72,6**	7th October
Temperature	AVG	**2,4**		**5,2**		**13,6**		**11,6**		**12,2**		**7,7**		**3,6**	
	MAX	**8,3**	26th April	**10,9**	28th May	**18,5**	27th June	**17,4**	30th July	**16,6**	29th August	**14,2**	1st September	**9,3**	9th October
	MIN	**-3,4**	16th April	**-2,6**	7th May	**8,1**	29th June	**5,2**	11th July	**5,9**	15th August	**-0,6**	20th September	**-1,7**	31st October

We used one-year-old container-grown saplings of the one species: *Paulownia tomentosa* (“tomentosa”) as semi-wild type with the worldwide enlargement and four hybrids – Paulownia bellissia® (“bellissia”), P. Clon *in vitro* 112® (“112”), P. Shan Tong (“shan-tong”) and P. Hybrid 9502 (“9502”) as art type cultivated for production of saw-timber. These saplings were cultivated from root cuttings. The cuttings were placed into perforated plant pots in the spring of 2018. We cultivated 110 newly growing plants of each species/hybrid, and, in the spring of 2019 (before budbreak), we measured the heights of the plants, the height of the live part of each stem (i.e. distance from ground to part of stem, which did not freeze), and the thicknesses of the stems 10 cm above ground (Table 2). Based on the results, we eliminated 15 plants of each species with the smallest values and 15 plants of each species with the tallest values. Three times ten randomly selected plants from left of each species were chosen for experiment (Table 2). In the spring of 2019, the chosen plants were transplanted to the plant pots under the shelter and each one received 10 litres of water.

Table 2
Mean values of the total height, the height of the live part of the stem and the thickness (10 cm above-ground) according to species and irrigation group for all plants (n = 110) and same parameters according to species and irrigation group for chosen plants and their statistical significance (n = 10)

		All plants			Chosen plants					
Species	Irrigation group	Total height (± SD) [cm]	Height of live part stem (± SD) [cm]	Thickness (± SD) [mm]	Total height (± SD) [cm]	SS	Height of live part stem (± SD) [cm]	SS	Thickness (± SD) [mm]	SS
Tomentosa	Maximum	60 (± 9.2)	24 (± 4.7)	10.1 (± 3.7)	56 (± 3.3)	ns	25 (± 1.8)	ns	10.2 (± 1.2)	ns
	Medium				55 (± 1.8)	ns	25 (± 2.1)	ns	10.5 (± 1.2)	ns
	Minimum				52 (± 3.5)	ns	23 (± 1.9)	ns	11.0 (± 0.8)	ns
Bellissia	Maximum	56 (± 11.0)	28 (± 5.8)	10.7 (± 1.7)	55 (± 3.6)	ns	25 (± 2.6)	ns	10.1 (± 0.5)	ns
	Medium				54 (± 5.1)	ns	23 (± 2.8)	ns	10.1 (± 0.7)	ns
	Minimum				53 (± 4.2)	ns	23 (± 3.4)	ns	10.5 (± 0.7)	ns
112	Maximum	53 (± 10.3)	25 (± 2.7)	9.5 (± 1.6)	54 (± 3.2)	ns	24 (± 3.2)	ns	10.5 (± 0.5)	ns
	Medium				56 (± 2.2)	ns	25 (± 2.6)	ns	10.7 (± 0.6)	ns
	Minimum				53 (± 4.7)	ns	22 (± 4.9)	ns	10.3 (± 0.4)	ns
Shan-tong	Maximum	56 (± 10.3)	23 (± 3.5)	11.0 (± 2.9)	54 (± 6.0)	ns	24 (± 5.5)	ns	9.9 (± 0.4)	ns
	Medium				56 (± 3.4)	ns	27 (± 3.7)	ns	10.8 (± 0.9)	ns
	Minimum				55 (± 6.4)	ns	25 (± 5.0)	ns	10.3 (± 1.1)	ns
9502	Maximum	50 (± 14.3)	30 (± 6.9)	11.6 (± 3.7)	56 (± 3.7)	ns	26 (± 1.4)	ns	10.0 (± 1.1)	ns
	Medium				56 (± 4.3)	ns	27 (± 4.4)	ns	10.2 (± 1.1)	ns
	Minimum				55 (± 2.7)	ns	24 (± 1.2)	ns	10.6 (± 0.5)	ns

SD – standard deviation

SS – statistical significance

ns – no statistical significance

We divided the plants of each species/hybrid into three irrigation groups, watering them at two-day intervals, where each group received a different amount of water:

- Minimum: 50 l/m^2/month – according to TGG (2011), the recommended amount of water for good growth of Paulownia in other years from planting.
- Medium: 100 l/m^2/month – the middle value between recommended values of TGG (2011).
- Maximum: 150 l/m^2/month – according to TGG (2011), the recommended amount of water for good growth of Paulownia in first years from planting.

In the early evening, the irrigation was carried out with rainwater and we watered the soil. During the growing season, we removed newly created branches and weeds.

At the end of the growing season, we measured the total heights of the plants, the lengths of the current-year shoots, the stem thicknesses of the current-year shoots, 10 cm from where they grew out of the stem from the previous year and the distances of the ends of the leaves furthest from the stem in the directions of all of the four cardinal points. We weighed, scanned, and inserted into marked paper bags all of the leaves from each plant separately and dried them (at 80°C for two days and then at 105°C, until we achieved a constant weight) and weighed the dried leaves. We calculated the projection area of the crown as the area of the circle whose radius was equal to the average distance of the ends of the leaves furthest from the stem in the directions of all of the four cardinal points. We calculated the leaf area index (LAI) as the quotient of the area of the scanned leaves and the projection area.

Statistical analysis of the data for selection of plants and results of this project was performed using TIBCO Statistica™ with a reliability interval of 95%. Normality of the data distribution was examined before the main analysis. The main effects were analysed using ANOVA, after which Fisher's LSD test was applied, in order to identify differences among the main effects and interactions.

Results

Accurate statistically significant values and percentage differences among the species/hybrids and the irrigation groups are shown in Annexes 1-4.

The total height and the length of the current-year shoot

Shan-tong and 112 grew the tallest with medium watering (Fig. 1A,B), 9502 and tomentosa were the tallest when we used maximum watering and bellissia had no statistically significant differences in both parameters among the amounts of the supplied water. Comparing the species and hybrids with one another, 112 grew the tallest when we applied minimum watering (Fig. 1A,B), shan-tong grew tallest under medium watering and tomentosa grew tallest with maximum watering.

The thickness of the current-year shoot

Shan-tong had the thickest current-year shoot with medium watering, tomentosa had the thinnest with minimum watering, bellissia had the thinnest with maximum watering and 112 and 9502 did not show any differences (Fig. 1C). A mutual comparison of the species and hybrids showed that, under medium treatment, shan-tong had the thickest current-year shoot and tomentosa and shan-tong were thicker than bellissia, 112 and 9502 with the maximum amount of the water (Fig. 1C).

Leaf biomass

The plants of all species (except bellissia) had the greatest amount of leaf biomass with medium watering (Fig. 2A). Comparing the species and hybrids with one another, with minimum watering, 9502 had the greatest amount of leaf biomass (Fig. 2A), when we applied medium watering, tomentosa and shan-tong had the greatest amount of leaf biomass and with maximum watering, tomentosa had the greatest amount of leaf biomass.

Leaf area

The differences in the leaf area are very similar to those of the leaf biomass, but with greater dispersion. Almost all species/hybrids with medium watering had the largest leaf areas, however, there were statistically significant differences only in the cases of tomentosa and 9502 (Fig. 2B). A mutual comparison of the species and hybrids showed that under all three types of watering, 9502 had the smallest leaf area (Fig. 2B).

Projected area

The plants of all species/hybrids had the largest projected area with medium watering, except for bellissia, where there were no statistically significant differences among projected areas of the plants grown under all three types of watering (Fig. 2C). Comparing the species and hybrids with one another, when we applied minimum watering, bellissia had the largest projected area (Fig. 2C), with medium watering, tomentosa had the largest projected area and under maximum watering, tomentosa and bellissia gave the largest projected area.

Leaf area index

Although there were obvious differences in the LAI (caused by the type of watering on the individual species), they were not statistically significant. A mutual comparison of the species and hybrids showed that when we supplied the minimum or medium amount of the water, it was shan-tong that had the highest value of LAI (Fig. 2D) and with maximum watering, it was bellissia.

Discussion

The information and knowledge about the individual species of Paulownia spp., especially the artificially created hybrids, that should be available is very limited (Kumar et al. 1999; Guo-qiang et al. 2001). The growth parameters, the climatic and soil conditions and silvicultural measures for

the individual hybrids are not generally available, which is confirmed by Sedlar et al. (2020). Internet shops often sell several hybrids together, without specifying which kinds they are (e.g. chinapaulownia.com or detail.en.china.cn) or they merely specify what purpose these plants serve best (e.g. saw-timber, biomass), what maximal thickness or volume they reach after how many years and what temperature range they can survive. Unfortunately, there is no specification regarding the optimal amount of water these plants should receive and the length of the vegetation period, or any technical reports containing the place of origin, the climatic and pedological conditions and the necessary silvicultural measures. Most authors of scientific articles only describe the hybrid in question, merely as a cross between two named species (e.g. "Structural characterization of the acetylated heteroxylan from the natural hybrid *Paulownia elongata/Paulownia fortunei*"(Goncalves et al. 2008), "EDTA and citrate impact on heavy metals phytoremediation using paulownia hybrids" (Miladinova-Georgieva et al. 2018) or "Metagenomic Analysis of Bacterial and Fungal Community Composition Associated with *Paulownia elongata* x *Paulownia fortunei*" (Wozniak et al. 2019). This could lead to people mistaking one hybrid for another, e.g. the cross between *Paulownia elongata* and *P. fortunei* can be called "P. Clon in vitro 112®" (Moreno et al. 2017) or "P. Cotevisa 2®" (ipaulownia 2018) or even "P. Bellissia®" (Bio Tree 2021), where each name is a registered trademark. All this (above) is why we were unable to find the optimal amount of water to provide the individual species with and, successively, to be able to perform a comparison with our result.

We found no significant differences in the total heights and lengths of the current-year shoots among the species that received the minimum amount of water. These results correspond with the results of Ayan et al. (2006), who investigated the influence of the amount of water on the growth of several species and did not reveal any differences among them, either. On the other hand, we found differences in the heights and lengths of the current-year shoots of the species when we used a greater amount of water. When given medium watering, Paulownia Shan Tong were the tallest and, when given the maximum amount of water, *Paulownia tomentosa* were the tallest of all species. These results are similar to those of Ptach et al. (2018), who described that when they applied a greater the amount of water, the plants grew taller. Also, the growth trend of Paulownia Hybrid 9502 shows the same results, as is stated by Ptach et al. (2018). We achieved the tallest plants with maximum watering, however, the total heights and lengths of the current-year shoots of these plants were ca. 1/3 shorter than those of *Paulownia tomentosa*. The growth trends of Paulownia Clon in vitro 112® and P. Bellissia® were similar to those of P. Shan Tong, however, the total heights and lengths of the current-year shoots of these plants were ca. 1/3 shorter than those of P. Shan Tong. The different reaction of *Paulownia tomentosa* and P. Hybrid 9502 to P. Shan Tong, P. Clon in vitro 112® and P. Bellissia® may have been due to the different amount of water necessary for optimal growth and their sensitivity to waterlogging. *Paulownia tomentosa* naturally occurs in places with precipitation from 500 to 1,500 mm (Zhao-Hua et al. 1986). This species may grow according to the rule: the more water, the greater the growth. Paulownia Hybrid 9502 may have a similar rule. On the other hand, Paulownia Clon in vitro 112® needs 750 mm (UCLM 2013) or 800 mm annual precipitation (Jabloński 2016). When the plants of this species occur in conditions with such precipitation, they should grow best. This amount of water corresponds to our medium watering. Paulownia Shan Tong and P. Bellissia® may need a similar amount of the water. Moreover, some of these five species may be affected by waterlogging. Jazireyi (2003) classified Paulownia as a plant demanding moisture, but our results show that not all species of Paulownia respond equally to soil moisture. Paulownia Shan Tong might be more intolerant to soil waterlogging, which occurred due to the large amount of water supplied in the case of maximum watering. This could correspond to the study conducted by Barickman et al. (2019), who state that excessive water slows down the growth. The same trend (as was in the case of Paulownia Shan Tong) was observed with Paulownia Clon in vitro 112® and P. Bellissia®.

The thickness of each newly-formed terminal shoot was measured 10 cm from the stem. Unlike the observations of Ayan et al. (2006), we did not find any differences among the species – only in the case of minimum watering, because when we applied medium and maximum watering, we found differences which do not correspond to the results of Ayan et al. (2006). The response of the shoot thickness to the medium and higher amount of water supplied varies, depending on the species. The plants of *Paulownia tomentosa* and P. Shan Tong were thicker than others in these irrigation groups. We expected the plants of individual species to react similarly to the amount of irrigation and, with an increase in the amount of water, their thicknesses to increase. The same is described by Ptach et al. (2018) who used Paulownia Shan Tong, where they applied two types of watering. It was confirmed only in the thicknesses of the shoots of *Paulownia tomentosa*. This may be due to the fact that *Paulownia tomentosa* naturally occur in places with precipitation from 500 to 1,500 mm (Zhao-Hua et al. 1986). The thickness (as well as the height) of this species can increase according to the statement: the more water, the greater the growth. This species manifests the same trend in the stem thickness and the height. Paulownia Shan Tong is a hybrid of *P. tomentosa* and *P. fortunei*, which naturally occur in places with precipitation of 500-1,500 mm and 1,200-2,500 mm, respectively (Zhao-Hua et al. 1986), therefore we expected the growth trend to be similar to that of *P. tomentosa*. However, the plants of Paulownia Shan Tong had the thickest shoots when we applied medium watering, which can partially correspond with the results of Ptach et al. (2018). This trend was the same as the trend of the height. Therefore, we assumed that Paulownia Shan Tong is intolerant to intense waterlogging, which occurred due to the great amount of water supplied, thus reducing the height and thickness increment. On the other hand, Paulownia Clon in vitro 112®, P. Hybrid 9502 and P. Bellissia® had similar thicknesses when we applied all three types of watering. This trend is similar to that in the study by Rad and Mirkala (2015), where they did not find any differences between the thicknesses of the plants grown with a different amount of water.

The leaf area and the leaf biomass showed similar trends. According to Ptach et al. (2019), the more watering there was, the greater the leaf area and the amount of biomass. Our results, similarly, show that the amount of the leaf biomass and leaf area were usually the smallest with the

minimum amount of water. A study conducted on *Pinus ponderosa* Douglas ex C.Lawson (Maherali and DeLucia, 2001) describes similar results. These studies, however, examined the effect of only two types of watering on the leaf biomass.

Our results indicate that the greatest amount of leaf biomass and leaf area were gained with medium watering. On the one hand, little water could bring about a drop in the level of cytokinin and auxin and, subsequently, lead to limited growth (Seeley 1990), on the other hand, a large amount of water could cause waterlogging, which also reduces growth (Barickman et al., 2019). Our results show that *Paulownia tomentosa* and P. Shan Tong gave the most leaf biomass and leaf area with medium watering, whereas the plants of Paulownia Hybrid 9502 had the smallest amount of biomass and leaf area in all types of watering.

We did not find differences in the LAI within each species after the three different types of watering, which does not correspond to the results of, for example, Devakumar et al. (1999), who investigated the effect of water supply on *Hevea brasiliensis* (Willd. ex A. Juss.) Müll. Arg. They found that the differences in the LAI between the non-irrigated and the irrigated plants were almost 50%. We found differences in the LAI only among certain species receiving the same amount of water. With the minimum water, we found a difference between Paulownia Shan Tong and P. Hybrid 9502 (i.e. between the highest and lowest LAI, respectively). In this case, the difference in LAI was evident due to their amount of the leaf biomass and leaf area, because the plants of Paulownia Hybrid 9502 had a fraction of the leaf biomass of P. Shan Tong, but the projection areas of their crowns were similar. There was a difference between Paulownia bellissia® and P. Clon in vitro 112®, which had the same maximum watering, i.e. between the highest and lowest value of LAI. A comparison of the individual parameters indicated that the projection area of the crown of Paulownia Clon in vitro 112® was almost 50% smaller than that of P. bellissia®; Paulownia Clon in vitro 112® was taller and also its leaf area was smaller. This means that Paulownia Clon in vitro 112® was taller (with fewer leaves that were closer to the stem) than P. bellissia®, whose leaves were more spread out. In the case of P. bellissia®, there may have been changes in the distribution of the biomass (Lei 2006), where it is the roots and leaves that grow first and then all the other parts (Zhang et al. 2004; Duan et al. 2005). With the medium amount of the water, Paulownia Shan Tong had the highest LAI value. There were differences in the LAI between Paulownia Shan Tong and P. Clon in vitro 112®, P. Hybrid 9502 and P. bellissia®, due to the greater amount of leaf biomass and larger leaf area in Paulownia Shan Tong plants, compared to those of the above-mentioned species (whereas the projected area of the crowns was similar). In contrast, the difference between Paulownia Shan Tong and *P. tomentosa* was probably in the distribution of their crowns because the amount of the leaf biomass and size of leaf area of these species were similar, but the projected area of the crown of *Paulownia tomentosa* was nearly 100% larger, compared to that of P. Shan Tong.

Conclusion

There is no value for optimal irrigation or precipitation for any hybrid of Paulownia (except for Paulownia Clon *in vitro* 112®). We assumed that the same rule applies to all species of Paulownia: the more water supplied, the more intense the growth. However, our results concluded that Paulownia species have a different response to the amount of water supplied.

In terms of growth characteristics in area with mean temperature around 8°C and mean relative air humidity around 73% in vegetation season, it seems that:

Fifty millimetres per month in the vegetation season seems to be insufficient for optimal growth in the first years after planting for all species/hybrids, because under this amount of water, the measured values of these species/hybrids were the smallest from all.

We assume that precipitation around 100 mm per month in the vegetation season is most suitable for best growth of plants of Paulownia Shan Tong, which grew more than 160 cm per year under this amount of water. Moreover, planting this hybrid should not be placed on an area with high groundwater levels or near watercourses, because it seems to lose growth potential when it is waterlogged.

The plants *Paulownia tomentosa* reached annual height increment almost 160 cm with maximum watering, therefore we assume that they need at least 150 mm per month in vegetation season.

The heights of Paulownia Hybrid 9502, P. bellissia® and P. Clon in vitro 112® reached approx. 100 cm, which present lower values of the measured parameters (regardless of the amount of water) than P. Shan Tong and *P. tomentosa*. Therefore, we do not recommend planted them in areas where there is less than 150 mm of precipitation per month in the vegetation season.

When plantations will establish in areas with this precipitation, plants will be need supplementary irrigation until the plants produce a rich and deep root system with which they can draw groundwater from the soil.

Declarations

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Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Author Contributions

Kadlec – main idea, methodology, work coordination, measurement, software, validation, formal analysis, writing – original draft preparation, project administration, funding acquisition

Novosadová – methodology, measurement, writing – original draft preparation, writing – editing,

Pokorný – modification of methodology, writing – review, supervision, funding acquisition

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Figures

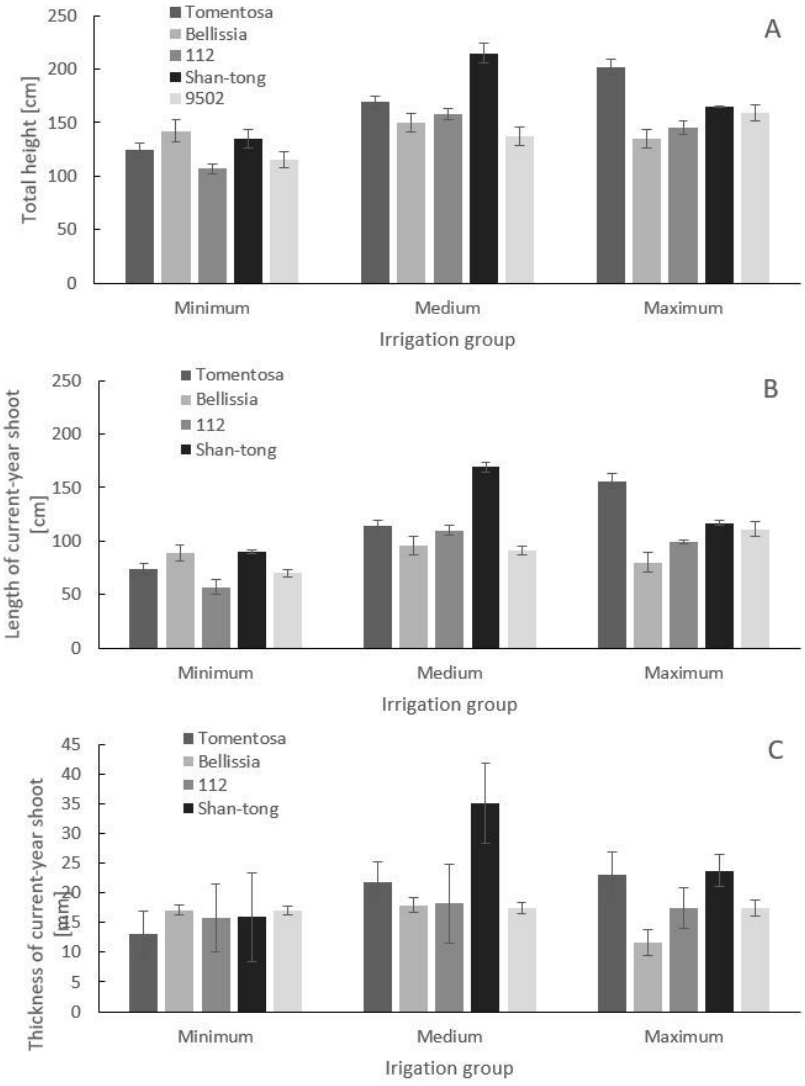


Figure 1

Mean values of the total height (A); the length of the current-year shoot (B) and the thickness of the current-year shoot (C) according to species and irrigation group. Whiskers denote standard deviation.

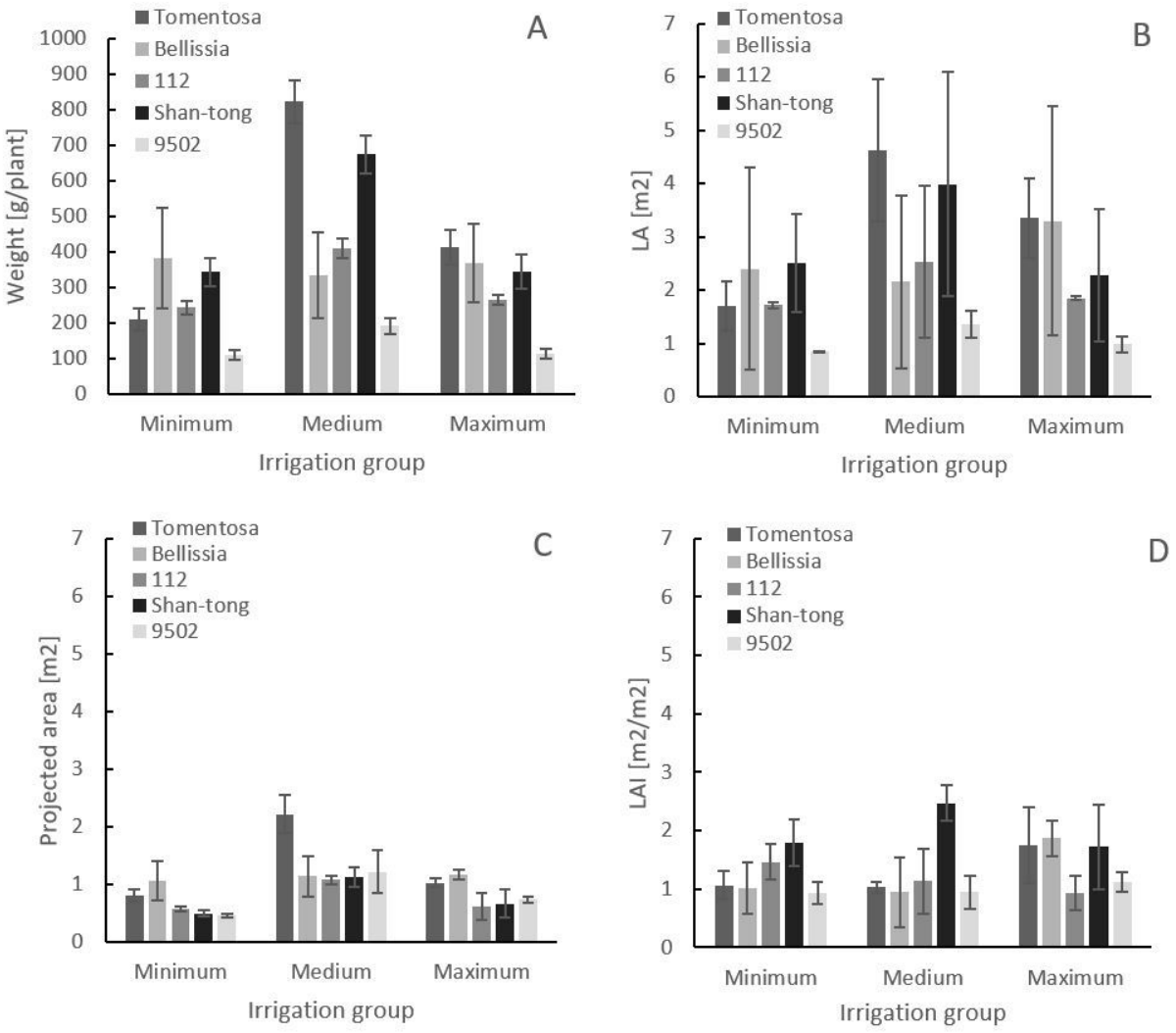


Figure 2

Mean values of the leaf biomass (A); the leaf area (B); the projected area of the crown (C) and the leaf area index (LAI) (D) according to species and irrigation group. Whiskers denote standard deviation.

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