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Assessment of water needs of *Catalpa bignonioides* under subsurface irrigation in row plantings

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Abstract: The research was based on a field experiment on light soil. The sampling used for row plantings was *Catalpa bignonioides*. The reason for this choice was the species recommended for row plantings due to its attractive appearance, long flowering and relatively good resistance to changing climatic conditions. The research aimed to determine water needs: field water consumption of *C. bignonioides* in row plantings on light soil under subsurface drip irrigation conditions. Water needs identified with field water consumption of *C. bignonioides* in row plantings on light soil under optimal soil moisture conditions during the growing season were variable. They depended on the variants of the experiment and the course of precipitation and thermal conditions in all growing seasons. The values of total water consumption of *C. bignonioides* in the growing seasons ranged from 241.3 (2019) to 428.7 mm (2022) for the W1 variant (irrigation performed when soil moisture dropped to –40 kPa). In the W2 variant objects (irrigation performed when soil moisture dropped to –20 kPa), the values of seasonal water consumption were higher and ranged from 266.5 (2019) to 458.8 mm (2022). Daily water consumption increased with the growth of *C. bignonioides*, regardless of the experimental variant. During each year of the experiment, higher values of daily water consumption were characteristic of the W2 variant. Cultivating *C. bignonioides*, growing on light soils, enables implementing subsurface drip irrigation technology, which, while ensuring optimal soil moisture conditions, will allow for the undisturbed growth and development of this species in row plantings.

Keywords: *Catalpa bignonioides*, light soil, row plantings, subsurface drip irrigation, water needs

INTRODUCTION

Urban trees in parks, yards, streets and other areas have been part of urban design and landscape architecture for centuries. They constitute integral elements of public spaces widely recognised as valuable to society. They provide a wide range of ecosystem services, including mitigating the urban heat island effect through shading and evapotranspiration, contributing to urban biodiversity, providing recreational opportunities, improving well-being, and reducing stormwater runoff. Many urban trees experience significant stress from low soil moisture, which depends on the scarcity of water available in the soil and the demand for it by the tree. Drought, water restrictions and climate change affect water availability.

One crucial adaptation to water scarcity is to maximise the efficiency of irrigation water use by minimising the fraction of water lost to soil evaporation, drainage and runoff. Therefore, it is necessary to improve irrigation management to avoid unnecessary water losses and accurately determine water requirements. Of the available irrigation systems for row plantings, drip irrigation is most often used and classified as a water-saving irrigation system. Further, the high efficiency of this structure (up to 95%) and low installation and operating costs positively impact the economic factor of irrigation (Dobrzyńska and Dembek, 2020). Thanks to low water consumption under low pressure and precise administration of water doses directly to the root zone of trees, water resources are used more efficiently (Rolbiecki, 2021).

MATERIALS AND METHODS

DESCRIPTION OF THE FIELD STUDY

The research was conducted as a single-factor study throughout four consecutive years between 2019 and 2022 as strict field experiments. The research included the cultivation of *Catalpa bignonioides* in a row planting. The experimental factor constituting the source of variability was subsurface drip irrigation in three variants: W0 (no subsurface drip irrigation), W1 (irrigation performed when soil moisture dropped to −40 kPa), W2 (irrigation performed when soil moisture dropped to −20 kPa). The experiment was conducted in seven replications. A replicate was a single tree. Five replications were analysed: data on trees at the extreme ends of the variants were omitted due to the edge effect. The distance between trees in a row was 1.5 m. Two-year-old seedlings produced in the Białe Błota forest nursery were used for the row plantings.

Water doses and irrigation dates were determined based on soil suction power monitored by Watermark sensors. Irrigation was performed using a Eurodrip drip line with a dripper capacity of 2 $dm^3 \cdot h^{-1}$. The distance between drippers on the line was 30 cm, and the subsurface was placed at a depth of 15 cm.

The irrigation rates applied were closely related to the occurrence of precipitation. The higher doses were characterised by the W2 water variant and ranged from 96 mm (in the first year of the study) to 219 mm in the last year of the experiment.

SOIL CHARACTERISTICS OF THE EXPERIMENTAL FIELD

Based on the percentage of granulometric fractions, the tested soil was classified into the sand granulometric group and the loamy texture (Tab. 1). The soil collected from the experimental field in the surface and subsurface layers was characterised by a very low content of phosphorus and potassium forms available to plants. The magnesium content in both layers indicated an average class of magnesium available to plants. The soil reaction in the 0–30 cm layer was neutral and slightly acidic in the 30–60 cm layer. The pH measurement in a 1 M KCl solution showed an unnecessary need for liming. The soil was relatively rich in organic carbon because the average content was recorded at 24.10 $g \cdot kg^{-1}$.

METEOROLOGICAL CONDITIONS

Precipitation and thermal conditions during the study period were characterised by significant variability. The highest average temperature in the growing season occurred in 2019 – 15.9°C (+1.1°C compared to the average of the multi-year period 1991–2020). The lowest average temperature in the growing season, equal to the average temperature of the multi-year period 1991–2020 (14.8°C), was recorded in 2020 and 2021. In the 4-year study period, in the first two months of the growing season (except for April 2019), lower temperatures were recorded concerning the multi-year average. Average monthly temperatures in the studied growing season were higher than the multi-year values from June to September while lower in April and May. The highest temperature differences compared to the multi-year period were recorded in June (+3.2°C) and July (+3.3°C) (Tab. 2).

The years 2019–2022 were characterised by lower precipitation against the multi-year average values, except for 2020. The average precipitation in 2019–2022 for the growing season was 307.8 mm and was 16.6 mm lower than the multi-year average. The lowest precipitation was recorded in 2021, at 260.7 mm during the growing season. It constituted 80.3% of the multi-year precipitation. The highest precipitation was observed in 2020; it

Table 1. Content of granulometric fractions (%) according to PTG 2008 (PTG, 2009)

Species	Depth (cm)	Percentage of granulometric fractions			Texture	Agronomic category
		0.05–2.0 mm	0.002–0.05 mm	<0.002 mm		
Catalpa bignonioides	0–30	74.6	23.7	1.5	loamy sand	light soil
	30–60	84.8	13.7	1.4	loamy sand	very light soil
Average		79.7	18.7	1.5	–	

Source: own study.

Table 2. Air temperatures (°C) in the 2019–2022 growing seasons juxtaposed with the multi-year average in the Bydgoszcz area[1)]

Period/year	Ten-day period	Month						Average
		IV	V	VI	VII	VIII	IX	IV–IX
1991–2020	I–III	8.3	13.2	16.7	18.9	18.2	13.3	14.8
2019	I	7.6	8.8	21.4	16.0	18.7	15.8	–
	II	6.5	12.3	22.8	18.0	19.0	12.0	
	III	13.7	15.0	21.6	21.6	21.2	12.7	
	I–III	9.3	12.1	21.9	18.6	19.7	13.5	15.9
2020	I	7.3	11.2	14.9	17.9	20.1	14.3	–
	II	7.0	9.6	19.5	17.8	20.0	14.7	
	III	10.4	12.0	19.4	18.3	17.7	17.4	
	I–III	8.2	10.9	17.9	18.0	19.2	14.4	14.8

cont. Tab. 2

Period/year	Ten-day period	Month						Average
		IV	V	VI	VII	VIII	IX	IV–IX
2021	I	3.7	8.8	17.8	19.8	17.9	14.3	–
	II	7.3	15.1	20.4	21.2	18.3	14.4	
	III	6.0	11.8	21.2	20.7	15.0	12.2	
	I–III	5.7	11.9	19.8	20.6	17.0	13.6	14.8
2022	I	4.3	12.1	16.4	18.5	20.6	13.7	–
	II	7.1	14.7	17.9	18.5	23.2	12.1	
	III	9.4	12.9	21.6	20.3	20.0	9.6	
	I–III	6.9	13.2	18.6	19.2	21.2	11.8	15.2
2019–2022	average	7.5	12.0	19.6	19.1	19.3	13.3	15.1
Difference between 2019–2022 and 1991–2020		–0.8	–1.2	+2.9	+0.2	+1.1	0	+0.3

[1)] Measuring station located in Mochełek.
Source: own study.

amounted to 435.5 mm, which constituted 134.2% compared to the multi-year average precipitation. The highest monthly precipitation was recorded in June 2020, at 153.9 mm, representing 35.3% of the precipitation from the entire growing season of the year 2020 (Tab. 3).

FIELD WATER CONSUMPTION

Field water consumption is one of the basic measures of water needs, assuming that water reserves in the soil are maintained within the range of water easily accessible to plants. In such

Table 3. Atmospheric rainfall in the 2019–2022 growing seasons juxtaposed with the multi-year average in the Bydgoszcz area[1)] (°C)

Period/year	Ten–day period	Month						Average
		IV	V	VI	VII	VIII	IX	IV–IX
1991–2020	I–III	25.8	55.1	56.6	77.4	60.3	49.2	324.4
2019	I	0	9.3	0	14.7	27.3	57.2	–
	II	0	56.4	16.2	2.0	4.2	9.9	
	III	1.5	23.5	1.5	5.7	6.2	31.4	
	Σ I–III	1.5	89.2	17.7	22.4	37.7	98.5	267.0
2020	I	0	16.4	63.0	32.5	32.7	32	–
	II	0	11.0	33.5	47.1	3.2	0	
	III	0.7	7.2	57.4	5.5	54.1	39.2	
	Σ I–III	0.7	34.6	153.9	85.1	90.0	71.2	435.5
2021	I	7.6	30.2	5.2	23.3	13.9	0	–
	II	16.9	21.7	8.8	17.4	8.2	30.5	
	III	5.9	17.6	19.8	0	28.5	5.2	
	Σ I–III	30.4	69.5	33.8	40.7	50.6	35.7	260.7
2022	I	11.5	3.6	11.4	34.1	6.0	26.0	–
	II	10.9	7.5	22.7	5.4	49.0	11.4	
	III	0	16.5	8.1	7.8	14.0	21.8	
	Σ I–III	22.4	27.6	42.2	47.3	69.0	59.2	267.7
2019–2022	average	13.8	55.2	61.9	48.9	61.8	66.2	307.7
Difference between 2019–2022 and 1991–2020		–12.0	+0.1	+5.3	–28.5	–1.5	+17.0	–16.7

[1)] Measuring station located in Mochełek.
Source: own study.

a case, field water consumption can be classified as potential evapotranspiration measured for a specific plant species. Such a state must last throughout the period for which field water consumption is calculated. In the field experiment with *C. bignonioides*, optimal moisture conditions were obtained on all objects irrigated with the drip system. Field water consumption was calculated for the irrigated variants of the experiment. Field water consumption was calculated from the Equation (1) (Drozd and Nowak, 2006):

$$S = M_I + R - M_F \tag{1}$$

where: S = field water consumption (mm), M_I = initial moisture (mm), M_F = final moisture (mm); R = water revenue (effective rainfall + irrigation; mm).

Initial moisture (M_I) and final moisture (M_F) were determined based on soil suction pressure readings from Watermark soil sensors (kPa) for the controlled moisture layer (0–60 cm), which contains over 80% of the plant root system (Drost, 1996). Moisture content (in $cm^3 \cdot cm^{-3}$) was determined from soil retention curves in the range of readily available water. The soil retention curve for the controlled moisture layer was plotted based on the soil granulometric composition using the indirect Varallyay method (Varallyay and Mironienko, 1979).

Based on the pF curves for the experimental soil, soil moisture content was determined in volume per cent and water content for the controlled moisture layer was calculated (Drozd and Nowak, 2006).

$$Q = Ma \cdot H/10 \tag{2}$$

where: Q = water reserve (mm), Ma = moisture (vol%), H = soil layer thickness (cm), 10 = water conversion factor from $Mg \cdot ha^{-1}$ to mm H_2O.

The result of the above formula was used to calculate the field water consumption for the growing season from a layer with controlled moisture (up to 60 cm in depth), which allowed determining the water demand during the growing season of *C. bignonioides*. Water consumption was balanced in pentad periods, and then, the decade, monthly, and seasonal consumption was calculated for irrigated facilities. The average daily water consumption in the months of the growing season was also calculated.

RESULTS AND DISCUSSION

SOIL WATER POTENTIAL

Soil water potential during the experiment period showed variability and depended strictly on the conditions of rainfall management and subsurface irrigation doses (Fig. 1). By analysing the moisture conditions of the experiment for layers 0–30 cm, the validity and correct course of irrigation can be confirmed. Irrigation variants W1 and W2 did not exceed the limit values of water potential: W1 to –40 kPa and W2 to –20 kPa. For the control conditions W0, the water potential in the soil was strictly dependent on rainfall conditions and was characterised by

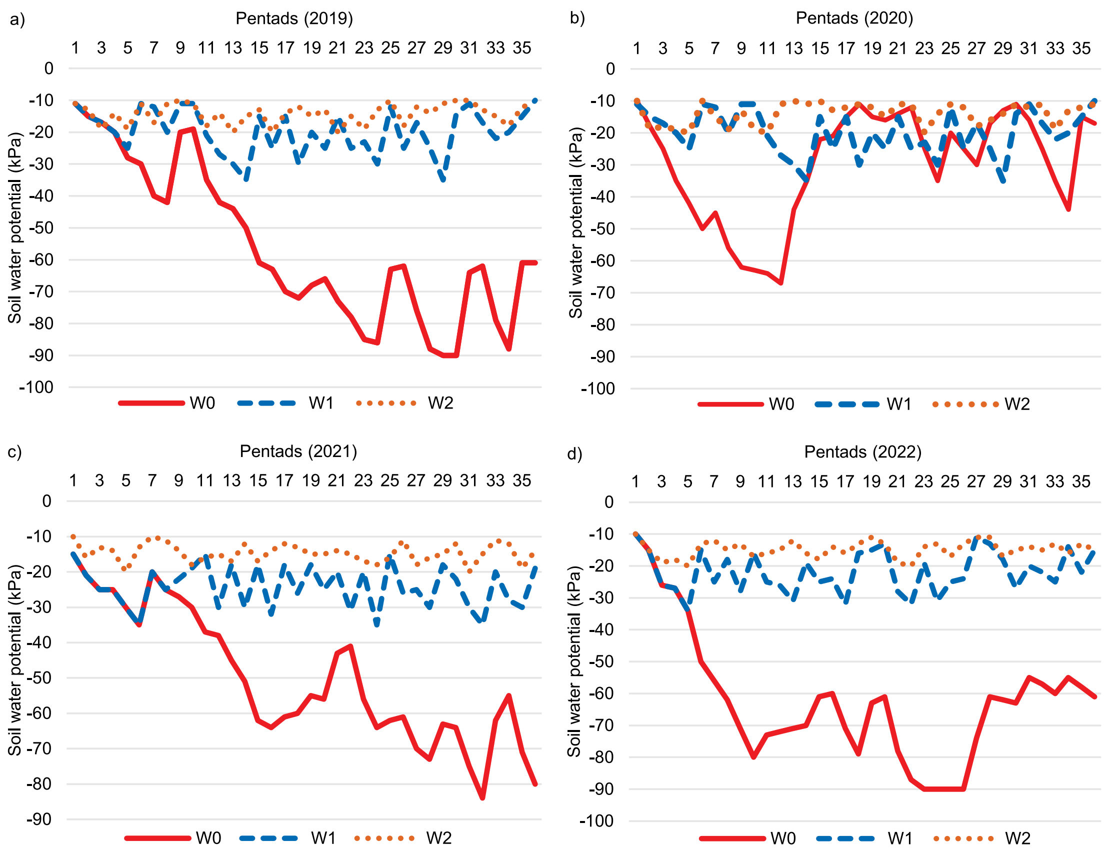

Fig. 1. Soil water potential for the variants of the experiment for a soil thickness level of 0–30 cm in the year: a) 2019, b) 2020, c) 2021, d) 2022; source: own study

high variability. In the control variant, a decrease in water potential was noted during the growing season to the level of −90 kPa, which significantly exceeded the critical values, except for 2020, where the decrease in potential occurred only in the initial period of the growing season and in its later part remained at a level of water easily accessible to plants. The highest water deficit was observed in 2021, and the lowest in 2020.

The same moisture formation trends in the subsurface layer (30–60 cm) were observed in each water variant as in the surface layer. Similar trends, course and values of the soil suction force in the conditions of vegetative irrigation in perennial crops were observed, among others, by Pacholak (1986) in an orchard, Żakowicz (2010) in reclamation plantings, Rolbiecki (2013) in asparagus cultivation, and Sositko (2019) in row plantings of linden and birch for phyto-improvement purposes.

FIELD WATER CONSUMPTION

Daily water consumption depended mainly on the water variants used in the experiment and the year of cultivation (Tab. 4). Water consumption in the months of the growing season was similar for the irrigated variants of the experiment (differences did not exceed 0.6 mm). The highest values of field water consumption were recorded in 2021 and 2022 in July. The average daily water consumption in these months was in the range of 3.4–3.5 mm. The highest differences between the experiment variants were recorded in 2020 in June and August. The average difference was at the level of 0.3 mm.

In the 2019 and 2020 growing seasons, a tendency towards increasing water consumption was observed in May and August; in the following years of the study, i.e. 2021 and 2022 – in May and July. Daily water consumption decreased in September 2019 and 2020 and August 2021 and 2022. Daily water consumption increased with the growth of *C. bignonioides* in the following years, regardless of the experimental variant. In each year of the experiment, trees growing on W2 variants were characterised by higher values of daily water consumption. There is no information on the water needs of *C. bignonioides* in the domestic literature.

International literature on the subject is scarce and refers mainly to the growth parameters of this species. Therefore, in reviewing the results, the data obtained and calculated in the self-directed experiment were juxtaposed with the species of deciduous plants with similar growth parameters. Sositko (2019), in research conducted in phyto-improvement plantings, estimated the highest values of daily water consumption for small-leaved lime in July (nearly 3 mm), while for birch in the same month it was close to 3.5 mm. Żakowicz (2010), on the other hand, states that evapotranspiration in July can be even over 6 mm per day and in August over 5 mm, depending on the daily temperature. Bac and Ostrowski (1969) give similar values of daily water consumption. According to them, daily water consumption by silver birch can be even 6.6 mm per day, but it should be noted that this applies to trees over 5 m high. Based on their research, Bastiaanssen *et al.* (2001) report that the daily evapotranspiration of deciduous trees, regardless of species, ranges from 2 to 3 mm. Testi *et al.* (2003) report that in the case of 3-year-old olive trees, the daily evaporation was 3 mm.

Table 5 presents the total water consumption by *C. bignonioides* for the irrigation variants of the experiment (monthly and annually).

Table 4. Daily water consumption of *Catalpa bignonioides* during the growing season (IV–IX) in the study years 2019–2022

Year	Water variant	Month					
		IV	V	VI	VII	VIII	IX
2019	W1	0.4	0.9	1.6	1.7	1.8	1.5
	W2	0.6	1.0	1.8	1.8	1.9	1.6
2020	W1	0.5	1.5	2.1	2.8	2.8	1.1
	W2	0.8	1.6	2.5	3.0	3.0	1.6
2021	W1	0.8	1.7	2.6	3.2	3.2	1.6
	W2	0.9	1.9	2.8	3.4	3.2	1.7
2022	W1	1.0	2.1	2.8	3.3	3.2	1.7
	W2	1.1	2.3	3.0	3.5	3.4	1.8

Explanations: W1 = irrigation performed when soil moisture decreases to −40 kPa, W2 = irrigation performed when soil moisture decreases to −20 kPa.
Source: own study.

Table 5. Total water consumption of *Catalpa bignonioides* during the growing season (IV–IX) in the 2019–2022 study years in a controllable moisture layer

Year	Water variant	Month						Total water consumption
		IV	V	VI	VII	VIII	IX	
2019	W1	10.8	28.9	49.4	52.7	55.4	44.1	241.3
	W2	18.6	31.6	53.3	56.6	58.7	47.7	266.5
2020	W1	14.5	46.7	63.8	86.9	87.1	45.2	344.2
	W2	23.5	50.8	74.0	92.9	94.5	48.6	384.3

cont. Tab. 5

Year	Water variant	Month						Total water consumption
		IV	V	VI	VII	VIII	IX	
2021	W1	24.2	51.8	78.9	99.6	98.7	48.7	401.9
	W2	27.4	57.4	85.2	104.8	100.3	51.2	426.3
2022	W1	30.5	63.7	83.6	100.8	99.4	50.7	428.7
	W2	32.3	70.6	90.9	106.9	104.6	53.4	458.8

Explanations: W1 and W2 as in Tab. 4.
Source: own study.

For the irrigation variant W1, total water consumption was 241.3 mm (2019), 344.2 mm (2020), 401.9 mm (2021) and 428.7 mm (2022). This variant's highest annual increase in total water consumption was in 2020 compared to the 2019 season and amounted to +42.6%. In the 2021 and 2022 seasons, the average increase in total water consumption was 11.7%. For irrigation variant W2, total water consumption was 266.5 mm (2019), 384.3 mm (2020), 426.3 mm (2021) and 458.8 mm (2022). The highest annual increase in total water consumption for this variant was in 2020 compared to the 2019 season and amounted to +44.4%. In the 2021 and 2022 seasons, the average increase in total water consumption was +9.2%. Comparing water consumption for both irrigation variants in the four-year study period, we can see similar trends in the obtained water consumption values. Minor differences between variants W1 and W2 were recorded in September of each year of the study and did not exceed 4 mm.

Taking into account the total water consumption for irrigation variants W1 and W2 (Tab. 5), it can be stated that the highest monthly water consumption values were recorded for the first two years of the study (2019 and 2020) in August, while for the years 2021 and 2022 – in July. The most negligible differences in monthly terms between the variants occurred at the beginning of each growing season.

The average seasonal total values of field water consumption calculated in the self-directed experiment under conditions of optimum moisture were at a level similar to those presented by Lechnio (2005), who estimates the water requirements for broadleaf trees in very light soil conditions (loose sand) from 377 to 483 mm in the growing season, depending on precipitation and thermal conditions. Slightly lower evapotranspiration values (355 mm) are given by Hall and Roberts (1990) for beech. Żakowicz (2010) gives higher values than those obtained in the self-directed experiment for broadleaf trees in reclamation plantings. The results of his research indicate that water requirements in the growing season amount to approx. 500 mm in the second stage after reclamation (i.e. after the third year of growth). Much higher water requirements for broadleaf trees (ash-leafed maple) are given by Rolbiecki *et al.* (2019) for central Poland in April–October. Potential evapotranspiration values for trees over three years of growth are estimated at over 600 mm. The differences can be explained, among others, by the fact that in the studies by Rolbiecki *et al.* (2019), the water needs of the ash-leafed maple included, apart from the summer half-year (April–September), also the month of October. In addition, they were determined using the indicator evapotranspiration according to the Blaney–Criddle climate model. These studies also included other regions of Poland and a more extended period (1981–2010). Sositko (2019), in experiments on determining the water needs of small-leaved lime and silver birch in row plantings on very light soils, obtained very similar values to those gained in the self-directed experiment; he determined the value of field water consumption in the fourth year of cultivation at 396 mm and 451 mm, for lime and birch, respectively.

CONCLUSIONS

In optimal soil moisture conditions, water identified as field water consumption (*S*) of *Catalpa bignonioides* in row plantings on light soils was variable in the studied vegetation period. It depended on the experimental variants: W1 (irrigation performed when soil moisture dropped to −40 kPa), W2 (irrigation performed when soil moisture dropped to −20 kPa) and the course of rainfall conditions.

It was found that in the conditions of subsurface drip irrigation, the total water consumption in the studied vegetation seasons for the W1 variant ranged from 241.3 mm to 428.7 mm. On the W2 variant objects, the values of seasonal water consumption were higher and ranged from 266.5 mm to 458.8 mm.

Daily water consumption increased with the growth of *C. bignonioides*, regardless of the experimental variant. In each year of the experiment, higher values of daily water consumption were characteristic of *C. bignonioides* growing on W2 variants.

Applying a subsurface drip irrigation system improved the success of *C. bignonioides* in row plantings, providing them with optimal water conditions for undisturbed growth and development.

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CONFLICT OF INTERESTS

The author declares no conflict of interests.

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