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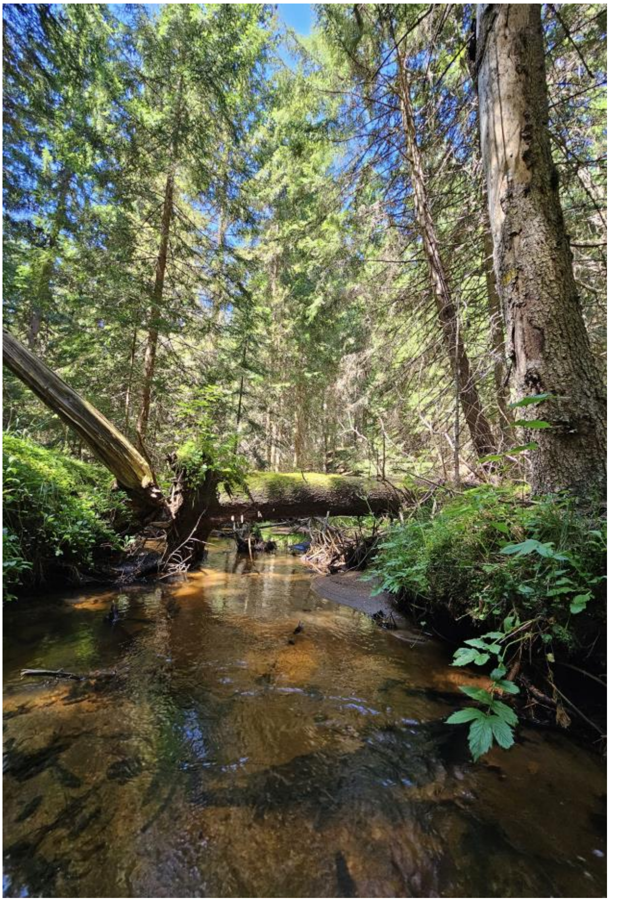

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EFFECTS OF FERTILISATION ON SURVIVAL AND MORPHOLOGICAL GROWTH CHARACTERISTICS OF ONE-YEAR-OLD SEEDLINGS OF *PAULOWNIA ELONGATA*S.Y. HU. AND *PAULOWNIA FORTUNEI* SEEM. HEMSL. IN TWO DIFFERENT SITES IN SERBIA

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Abstract: *This study evaluates the influence of fertilisation during the initial year after planting on the survival and morphometric growth traits of one-year-old Paulownia elongata and Paulownia fortunei seedlings, aimed at assessing their adaptability for potential introduction to various sites in Serbia. Understanding fertilisation impacts on survival and growth parameters is essential for analysing indicators of species adaptability to specific soil types. Experimental plots were established at two distinct sites, Obrenovac and Pambukovica, where seedlings were monitored for key morphometric indicators: height, stem diameter at root collar, and leaf number. The morphometric data were statistically analysed, and findings indicated that fertilisation significantly enhanced all measured growth parameters in the first growing season. This suggests a positive effect of fertilisation on all analysed parameters.*

Keywords: fast-growing species, fertilisation, growth traits, stem diameter at root collar, leaf number, height

UTICAJ PRIHRANJIVANJA NA PREŽIVLJAVANJE I MORFOLOŠKE KARAKTERISTIKE ELEMENATA RASTA JEDNOGODIŠNJIH SADNICA *PAULOWNIA ELONGATA* S. Y. HU. I *PAULOWNIA FORTUNEI* SEEM. HEMSL. NA DVA RAZLIČITA STANIŠTA U SRBIJI

Abstract: *U radu su prikazani rezultati analize uticaja prihranjivanja biljaka u prvoj godini nakon sadnje, na preživljavanje i morfometrijske karakteristike elemenata rasta*

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kao pokazatelje mogućnosti introdukcije i adaptacije paulovnija na različita staništa u Srbiji. Dobijanje rezultata o uticaju prihranjivanja na analizirane parametre je značajno za analizu pokazatelja adaptibilnosti vrsta za gajenje na određenim tipovima zemljišta. Na dva lokaliteta u Obrenovcu i Pambukovici su osnovane ogledne površine sadnjom sadnica vrsta Paulownia elongata S. Y. Hu. i Paulownia fortunei Seem. Hemsl. U okviru oglednih polja vršeno su merenja morfometrijskih karakteristika pokazatelja rasta: visina, prečnik u vratu korena i broj listova. Dobijeni rezultati morfometrijskih merenja statistički su obrađeni i analizirani. Na osnovu rezultata preživljavanja biljaka i merenja morfometrijskih karakteristika pokazatelja rasta u prvoj vegetacionoj sezoni nakon sadnje, utvrđeno je da prihranjivanja ima pozitivan uticaj na sve analizirane parametre.

Keywords: brzorastuće vrste, prihranjivanje, visina, prečnik u vratu korena, broj listova

1. INTRODUCTION

Climate change and consequent ecological shifts have a significant impact on native vegetation. Assessing the potential for introducing various species and their adaptability to new climatic and environmental conditions is critical for identifying effective strategies to mitigate the adverse effects of global warming (Ogden and Innes, 2007; Schroeder, 2007; Aragao et al., 2008; Barlow and Peres, 2008; Betts et al., 2008; Innes et al., 2009; Lavadinović et al., 2010). The growing scarcity of wood resources, coupled with increasing demand, highlights the urgent need for selecting and promoting fast-growing species to enhance wood and biomass production. (Ivetić and Vilotić, 2014; Mishra et al., 2010; Drvodelić, 2015). Due to their rapid growth and high sprouting capacity, species of the genus *Paulownia* Sieb. & Zucc. offer substantial potential for biomass production (Lucas-Borja et al., 2011; Yadav et al., 2013; Mitrović, 2016).

Plant growth rates are influenced by the quality of planting material (DuPlissis et al., 2000), climatic conditions (Woods, 2008; Radošević and Vilotić, 2010), soil type (Melhuish et al., 1990; Madejón et al., 2014; Popović et al., 2015; Tu et al., 2017; Wozniak et al., 2022), fertilisation (Mitrović et al., 2012; García-Morote et al., 2014), and plant care practices (Rad and Mirkala, 2015; Moreno et al., 2017). Nutrient-poor soils are frequently chosen for afforestation projects, but their productivity can be enhanced by applying various fertilisers (Óskarsson et al., 2006; Tucović and Simić, 2002; Güsewell et al., 2003; Hawkins et al., 2005). Fertiliser type, application rate, and timing are determined based on soil conditions, biological characteristics, and developmental stages of the plants. To ensure the formation of biologically healthy material that is resilient to adverse environmental conditions, it is essential to provide plants with a well-balanced nutrient supply, ensuring the availability of necessary plant assimilates (Jacobs et al., 2005; Mitrović et al., 2012).

2. MATERIALS AND METHODS

Experimental plots were established across sites with varying orographic features, climatic conditions, and soil physical-chemical properties. Soil samples were analysed at an accredited soil and plant material laboratory at the Institute of

Forestry, Belgrade. The plots were created by planting paulownia trees grown from seeds of well-adapted genotypes of two paulownia species (*Paulownia elongata* S.Y. Hu. and *Paulownia fortunei* Seem. Hemsl.), sourced from plantations in Bela Crkva.

Seedlings of each species were planted in 12 rows, with each row consisting of 25 plants. Planting holes measured 30x30 cm, and seedlings were spaced at 4x4 m intervals within each row.

Table 1. *Overview of Experimental Plots at Obrenovac and Pambukovica Sites*

Site	Obrenovac (I)						Pambukovica (II)					
Treatment/ Number of Seedlings	te1/ n=25	te2/ n=25	te3/ n=25	tf1/ n=25	Tf2/ n=25	Tf3/ n=25	te1/ n=25	te2/ n=25	te3/ n=25	tf1/ n=25	Tf2/ n=25	Tf3/ n=25

te1 – *P. elongata* seedlings from the first treatment (fertilised with a higher amount of fertiliser); te2 – *P. elongata* seedlings from the second treatment (fertilised with a lower amount of fertiliser); te3 – *P. elongata* seedlings not fertilised (control); tf1 – *P. fortunei* seedlings from the first treatment (fertilised with a higher amount of fertiliser); tf2 – *P. fortunei* seedlings from the second treatment (fertilised with a lower amount of fertiliser); tf3 – *P. fortunei* seedlings not fertilised (control);

At the time of planting, each experimental plot was divided into six treatments (four rows of 25 plants per treatment, as shown in Table 1), which varied in the amount of fertiliser applied, with one control treatment receiving no fertilisation. Fertilisation was carried out using a slow-release chicken manure fertiliser, branded as Fertor (http://www.mrf-garden.com). The fertiliser composition consisted of 100% chicken manure, supplemented with organic plant-derived material to enhance its nutritional value. Fertiliser was applied at two rates: 240 grams per plant (treatment t1) and 120 grams per plant (treatment t2). No fertilisation was applied to the control plots (treatment t3).

During the first growing season following planting, the establishment and survival rates of the seedlings were assessed. Morphometric characteristics of the seedlings, including plant height, stem diameter at root collar, and leaf number, were measured monthly. The first measurements were taken in May and the last in October, resulting in six measurements in total. Plant height was recorded with an accuracy of 0.5 cm, while root collar diameter was measured to an accuracy of 0.01 mm. On each experimental plot, 25 plants per treatment were measured monthly throughout the growing season (six measurements).

The data were statistically analysed. The experimental design corresponds to a three-way and two-way analysis of variance (ANOVA III):

- factor A (site) with 2 levels: Site I (Obrenovac) and Site II (Pambukovica)
- factor B (species) with 2 levels: Species 1 (*P. elongata*) and Species 2 (*P. fortunei*)
- factor C (treatment) with 3 levels: Treatment 1, Treatment 2, and Treatment 3.

ANOVA III assesses the effect of each factor individually, as well as their interactions. The total sample size for ANOVA III was n = 900 (6 months × 2 species × 3 treatments × 25 plants = 900). The following traits were measured within this sample: plant height, stem diameter at root collar, number and length of nodes, and number of leaves.

3. RESULTS

The climate at the Obrenovac site is classified as temperate continental, characterised by mild winters and warm summers. The precipitation regime falls between a modified Mediterranean and a true continental climate, with a stronger expression of the latter. Temperature and precipitation are well-aligned throughout the year, with the warmest months also receiving the most rainfall, which coincides with the growing season. The climate at the Pambukovica site is also temperate continental, marked by moderately warm, dry summers and somewhat cooler winters.

The surface soil layer at the Obrenovac site is classified as sandy loam, while the deeper layer is classified as loam (Table 2). Despite the difference in textural classes, both layers exhibit similar physical properties, with minimal variation in texture throughout the soil profile. The textural fractions in both layers are close to the boundary values between sandy loam and loam. The soil demonstrates good water permeability and is well-aerated throughout the entire solum depth, with a relatively high clay content providing a significant water-holding capacity.

Table 2. *Physical Soil Properties*

Site	Physical Soil Properties	Coarse sand	Fine sand	Silt	Clay	Total sand	Total clay	Texture class
		%						
Obrenovac	0-20	0.60	44.50	29.00	25.90	45.10	54.90	Loam
	20-40	0.40	42.20	25.70	31.70	42.60	57.40	Sandy Clay Loam
Pambukovica	0-20	4.50	48.62	20.58	26.30	53.12	46.88	Sandy Loam
	20-40	4.20	46.60	22.30	26.90	50.80	49.20	Loam

At the Pambukovica site, the surface layer is classified as loam and exhibits good permeability for both water and air. With increasing depth, the texture shifts due to rising clay and fine sand content, resulting in a sandy clay loam class. This deeper layer has somewhat reduced water and air permeability.

At the Obrenovac site, the soil solution reaction is moderate. Total adsorption capacity is very high, largely due to the significant clay content in the texture. The sum of adsorbed base cations is also substantial. Based on the degree of base cation saturation, the soil is classified as eutric. Both analysed layers show low humus content; however, despite the low humus, the total nitrogen content is high, with a narrow carbon-to-nitrogen (C/N) ratio that supports effective organic matter mineralisation. Plant-available phosphorus is sufficiently present throughout the soil profile, while potassium availability is moderate (Table 3).

The Pambukovica profile exhibits a strongly acidic soil solution throughout the depth. Total adsorption capacity is high, and despite the low pH of the soil solution, the high sum of adsorbed base cations results in a base saturation level exceeding 60%, categorising this soil as eutric. The total nitrogen content is low, with a narrow C/N ratio. In both analysed soil layers, the amount of plant-available phosphorus across all four profiles is below the detection limit for the Al-method, indicating that this soil is extremely deficient in readily available forms of phosphorus for plants. The levels of plant-accessible potassium are within the range of low availability throughout the entire soil profile (Table 3).

Table 3. *Chemical Soil Properties*

Profile Number	Depth of Profile (cm)	pH		Adsorption Complex					Total		C/N	Plant available	
		H2O	KCl	T	S	T-S	V	Y1	humus	N		P_2O_5	K_2O
				ekv.m.mol/100g			%	cm^3	%	%		mg/100g	
Obrenovac (I)	0-20	5.91	4.74	32.50	24.94	7.56	76.74	11.63	2.55	0.19	7.59	23.55	19.39
	20-40	5.87	4.77	32.90	25.27	7.63	76.80	11.74	2.03	0.12	10.13	21.63	17.45
Pambukovica (II)	0-20	5.35	3.84	32.13	19.56	12.57	60.87	19.34	1.47	0.15	5.87	<LD	8.76
	20-40	5.41	3.94	32.66	21.51	11.15	65.86	17.15	0.98	0.13	4.41	<LD	7.94

To analyse plant survival at specific sites, the number of living seedlings was counted at three intervals: one month after planting, during the summer, and at the end of the first growing season.

Table 4. *Seedling Survival Rate from Planting to the End of the Growing Season*

Site	Species	Treatment	June	Aug.	Oct.
			%		
Obrenovac (I)	*Paulownia elongata*	te1	100	98	95
		te2	100	96	92
		te3	100	93	90
	Paulownia fortunei	tf1	100	94	87
		tf2	100	89	80
		tf3	100	84	76
Pambukovica (II)	*Paulownia elongata*	te1	100	96	92
		te2	100	93	87
		te3	100	90	82
	Paulownia fortunei	tf1	100	90	86
		tf2	100	87	78
		tf3	100	84	74

Paulownia elongata seedlings: te1 – fertilised with a higher amount of fertiliser; te2 – fertilised with a lower amount of fertiliser; te3 – not fertilised (control); *Paulownia fortunei* seedlings: tf1 – fertilised with a higher amount of fertiliser; tf2 – fertilised with a lower amount of fertiliser; tf3 – not fertilised (control).

At the end of the growing season, the survival rate of *Paulownia elongata* seedlings at the site in Obrenovac ranged from 90-95%, depending on the treatment. The highest percentage of surviving seedlings was in the treatment with a higher amount of fertiliser, while the lowest was in the control treatment. The same survival trend was observed for *Paulownia fortunei* seedlings, which ranged from 84-94%. A similar trend was noted at the site in Pambukovica, but with lower survival rates. At the end of the first growing season, the survival rate of *Paulownia elongata* seedlings was recorded at 82-92%, while for *Paulownia fortunei* it was 74-86%, depending on the treatment.

Regarding the height of seedlings at the sites in Obrenovac and Pambukovica during the first year (Table 5), there were differences in the mean values of groups (measurements) depending on the factors of site, species, and treatment. Seedlings at the Obrenovac site showed significantly higher mean height values in all six measurements compared to seedlings at the Pambukovica site. At the beginning of the growing season, the lowest mean height of seedlings at the

Obrenovac site was 13.28 cm, while at the Pambukovica site it was 9.06 cm. At the end of the growing season, the mean height of seedlings at the Obrenovac site was 32.95 cm, while at the Pambukovica site it was 25.32 cm. *Paulownia fortunei* seedlings showed higher mean height values compared to *Paulownia elongata* seedlings throughout the growing season. The difference between the species was significant during all six measurements. At the end of the first growing season, *Paulownia fortunei* seedlings had higher mean heights (31.18 cm) than *Paulownia elongata* seedlings (27.10 cm).

There was a statistically significant difference in the mean height values of seedlings between treatments (fertilisation and control) throughout the growing season. In the first measurement, there was no significant difference between seedlings in the treatment with a lower amount of fertiliser and the control treatment, and in the fourth measurement, there was no significant difference among seedlings from the fertilised treatments. Seedlings in the treatment with a higher amount of fertiliser showed greater mean height values throughout the growing season compared to seedlings from the second treatment and the control. At the end of the first season, the highest mean height was recorded for seedlings in the treatment with the higher amount of fertiliser (34.74 cm), followed by seedlings in the treatment with a lower amount of fertiliser (30.02 cm), while the smallest height was recorded in the control treatment (22.64 cm). Regarding the characteristic of mean height of seedlings, the interaction between the factors of species (*P. elongata* and *P. fortunei*) and treatment (fertilisation and control) was significant only in the last (sixth) measurement at the end of the first growing season. The interaction between the species factor (*P. elongata* and *P. fortunei*) and the site factor was significant only in the fifth measurement. The mutual interaction between the site factor (Obrenovac and Pambukovica) and the treatment factor (fertilisation and control) was statistically significant throughout the entire growing season.

Table 5. *Basic parameters of descriptive statistics and three-way ANOVA for six periodic measurements of seedling height (cm) during the first growing season, at the site in Obrenovac (I) and in Pambukovica (II)*

Factor	Level	Measurement I	Measurement II	Measurement III	Measurement IV	Measurement V	Measurement VI
Site (A)	Site I	[A] 13.28 (3.60)[b]	18.18 (6.67)[b]	23.51 (9.26)[b]	27.42 (10.96)[b]	31.76 (12.96)[b]	32.95 (13.14)[b]
	Site II	9.06 (2.59)[a]	12.48 (3.96)[a]	16.56 (4.89)[a]	19.85 (6.14)[a]	23.00 (6.89)[a]	25.32 (14.95)[a]
		[B] $F_{1.290}$ =155.11*	$F_{1.290}$ =113.94*	$F_{1.290}$ = 106.44 *	$F_{1.290}$ =93.65*	$F_{1.290}$ =107.59*	$F_{1.290}$ = 31.34*
Species (B)	*P. elongata*	10.70 (3.78)[b]	14.54 (6.09)[a]	18.99 (7.75)[a]	22.52 (8.96)[a]	26.09 (10.08)[a]	27.10 (9.87)[a]
	P. fortunei	11.63 (3.72)[a]	16.12 (6.17)[b]	21.08 (8.46)[b]	24.75 (10.20)[b]	28.67 (12.21)[b]	31.18 (17.88)[b]
		$F_{1.290}$ =7.55*	$F_{1.290}$ =8.75*	$F_{1.290}$ =9.63*	$F_{1.290}$ =8.19*	$F_{1.290}$ = 9.32*	$F_{1.290}$ = 8.97*
Treatment (C)	Treatment 1	11.85 (4.57)[b]	17.39 (7.84)[c]	22.65 (10.12)[c]	26.84 (11.41)[b]	31.61 (13.37)[c]	34.74 (20.48)[c]
	Treatment 2	11.02 (3.84)[a]	15.31 (6.01)[b]	20.85 (8.10)[b]	25.03 (9.64)[b]	29.06 (10.66)[b]	30.02 (10.41)[b]
	Treatment 3	10.63 (2.56)[a]	13.28 (3.00)[a]	16.59 (3.72)[a]	19.03 (4.91)[a]	21.46 (5.80)[a]	22.64 (6.11)[a]
		$F_{2.290}$ =4.56*	$F_{2.290}$ =19.71*	$F_{2.290}$ =28.47*	$F_{2.290}$ =36.43*	$F_{2.290}$ = 52.10*	$F_{2.290}$ = 26.70*
***Interactions* (AXB)**		ns	ns	ns	ns	$F_{1.290}$ = 4.98*	ns
***Interactions* (AXC)**		$F_{2.290}$= 15.7*	$F_{2.290}$= 39.0*	$F_{2.290}$ =61.1*	$F_{2.290}$ =67.8*	$F_{2.290}$ = 92.05*	$F_{2.290}$ = 32.07*
***Interactions* (BXC)**		ns	ns	ns	ns	$F_{2.290}$ = 3.85*	$F_{2.290}$ = 3.56 *

Table 6. *Basic parameters of descriptive statistics and three-way ANOVA for six periodic measurements of root collar diameter (mm) of seedlings during the first growing season, at the site in Obrenovac (I) and in Pambukovica (II)*

Factor	Level	Measurement I	Measurement II	Measurement III	Measurement IV	Measurement V	Measurement I
Site (A)	Site I	4.33 (1.14)[b]	4.81 (1.27)[b]	5.21 (1.27)[b]	5.80 (1.47)	6.26 (1.60)	6.67 (1.71)
	Site II	3.60 (0.87)[a]	4.03 (1.01)[a]	4.78 (1.48)[a]	5.57 (1.37)	6.25 (1.49)	7.03 (4.33)
		$F_{1.290}$=39.26*	$F_{1.290}$=36.34*	$F_{1.290}$=10.67*	ns	ns	ns
Species (B)	*P. elongata*	4.06 (1.09)	4.59 (1.26)[b]	5.14 (1.30)[b]	6.01 (1.50)[b]	6.39 (1.61)	7.08 (4.37)
	P. fortunei	3.87 (1.05)	4.24 (1.13)[a]	4.84 (1.13)[a]	5.34 (1.40)[a]	6.12 (1.47)	6.61 (1.59)
		ns	$F_{1.290}$=7.10*	$F_{1.290}$=5.24*	$F_{1.290}$= 3.95*	ns	ns
Treatment (C)	Treatment 1	4.03 (1.17)	4.63 (1.41)[b]	5.18 (1.38)	6.01 (1.50)[b]	6.63 (1.58)[b]	7.08 (1.63)
	Treatment 2	3.94 (1.07)	4.44 (1.63)[ab]	4.95 (1.14)	5.71 (1.29)[b]	6.37 (1.34)[b]	6.88 (1.39)
	Treatment 3	3.92 (0.98)	4.18 (0.99)[a]	4.86 (1.14)	5.34 (1.40)[a]	5.77 (1.59)[a]	6.59 (5.29)
		ns	$F_{2.290}$=4.02*	ns	$F_{2.290}$= 6.85*	$F_{2.290}$= 10.37*	ns
***Interactions* (AXB)**		ns	ns	ns	ns	ns	ns
***Interactions* (AXC)**		ns	ns	$F_{2.290}$= 16.31*	$F_{2.290}$= 26.22*	$F_{2.290}$= 33.79*	$F_{2.290}$= 15.58*
***Interactions* (BXC)**		ns	ns	ns	ns	ns	$F_{2.290}$= 3.36*

Three-way Analysis of Variance (ANOVA III). Factor A (Site) with 2 levels: Site 1 (Obrenovac) and Site 2 (Pambukovica); Factor B (Species) with 2 levels: Species 1 (*P. elongata*) and Species 2 (*P. fortunei*); Factor C (Treatment) with 3 levels: Treatment 1 (high fertiliser amount), Treatment 2 (low fertiliser amount), and Treatment 3 (control), along with their interactions. The total sample size (number of sample elements) is **n = 300** (2 sites × 2 species × 3 treatments × 25 = 300). [A] = mean value (standard deviation); [B] = F-test statistic with degrees of freedom; ns = no significant difference between population means ($P > 0.05$); * = statistically significant difference ($P \leq 0.05$).

Descriptive statistics for the mean stem diameter at the root collar of seedlings at the Obrenovac and Pambukovica sites are presented in Table 6, based on six measurements taken throughout the first growing season.

At the Obrenovac site, the mean stem diameters at root collar were significantly larger in the first, second, and third measurements compared to those at the Pambukovica site. No statistically significant differences were observed in the remaining measurements. At the end of the first growing season, the mean stem diameters at root collar were greater for seedlings at the Pambukovica site (7.03 mm) compared to those at Obrenovac (6.67 mm).

Seedlings of *Paulownia elongata* exhibited larger mean stem diameters at root collar compared to *Paulownia fortunei* seedlings in the second, third, and fourth measurements, with these differences being statistically significant. For the remaining measurements, no significant differences were observed. By the end of the first growing season, *P. elongata* seedlings had a greater mean stem diameter (7.08 mm) than *P. fortunei* seedlings (6.61 mm).

A statistically significant difference in the mean stem diameter at root collar was observed between treatments in the second, fourth, and fifth measurements. For the remaining measurements, while no significant differences were found, the highest mean stem diameters were consistently observed in seedlings from the treatment with the higher fertiliser application. In the second measurement, no statistically significant difference in mean stem diameter was detected between the lower fertiliser treatment and the control. However, the treatment with the higher fertiliser dose resulted in a statistically significant increase in stem diameter compared to the control. In the fourth and fifth measurements, no significant differences were found between fertilised treatments, though both differed significantly from the control treatment. Seedlings from the treatment with a higher fertiliser dose had consistently larger mean stem diameters at root collar compared to those in the other treatments and the control across all six measurements.

The interaction between the site factor (Obrenovac and Pambukovica) and the species factor (*P. elongata* and *P. fortunei*) was not statistically significant in any of the six measurements. However, the interaction between the species factor (*P. elongata* and *P. fortunei*) and the treatment factor (fertilisation and control) was significantly different in the fifth and sixth measurements, with no significant differences in the remaining measurements. The interaction between the site factor (Obrenovac and Pambukovica) and the treatment factor (fertilisation and control) was statistically significant in the third, fourth, fifth, and sixth measurements.

The average number of leaves of seedlings at the Obrenovac and Pambukovica sites throughout the growing season is shown in Table 7, based on all six measurements. The effect of the interaction between site, treatment, and species factors on leaf number is presented in Table 8, covering all six measurements throughout the growing season.

Table 7. *Average Number of Leaves of Seedlings at Obrenovac and Pambukovica Sites During the First Growing Season*

Site	Species	Treatment	Measurement					
			I	II	III	IV	V	VI
Obrenovac (I)	*P.elongata*	te1	4.88	7.04	10.72	11.12	10.32	8.00
		te2	4.80	6.88	10.80	12.32	13.52	7.76
		te3	4.80	6.72	8.72	10.32	11.44	6.32
		aver.	**4.83**	**6.88**	**10.08**	**11.25**	**11.76**	**7.36**
	P.fortunei	tf1	4.72	6.80	10.96	12.48	14.88	8.64
		tf2	4.96	7.44	10.64	12.08	14.32	8.88
		tf3	5.36	7.44	10.64	12.80	14.32	8.32
		aver.	**5.01**	**7.23**	**10.75**	**12.45**	**14.51**	**8.61**
Pambukovica (II)	*P.elongata*	te1	5.36	6.40	8.16	9.44	9.44	6.08
		te2	4.56	6.16	8.48	10.72	12.32	6.88
		te3	4.96	6.40	8.80	10.32	11.04	6.00
		aver.	**4.96**	**6.32**	**8.48**	**10.16**	**10.93**	**6.32**
	P.fortunei	tf1	5.68	8.48	11.04	11.76	13.52	7.28
		tf2	6.08	7.76	10.08	12.32	13.36	7.04
		tf3	5.36	7.44	10.64	12.80	14.32	8.32
		aver.	**5.71**	**7.89**	**10.59**	**12.29**	**13.73**	**7.55**

(I) – Obrenovac site; (II) – Pambukovica site; te1 – *P. elongata* seedlings under Treatment 1 (fertilised with a higher amount of fertiliser); te2 – *P. elongata* seedlings under Treatment 2 (fertilised with a lower amount of fertiliser); te3 – *P. elongata* seedlings with no fertilisation (control); tf1 – *P. fortunei* seedlings under Treatment 1 (fertilised with a higher amount of fertiliser); tf2 – *P. fortunei* seedlings under Treatment 2 (fertilised with a lower amount of fertiliser); tf3 – *P. fortunei* seedlings with no fertilisation (control).

Table 8. *Effects of Interactions Between Site, Species, and Treatment on Leaf Count of Seedlings at the Obrenovac (I) and Pambukovica (II) Sites During the First Growing Season*

	Measurement I	**Measurement II**	**Measurement III**	**Measurement IV**	**Measurement V**	**Measurement VI**
	count of leaves	**count of leaves**	**count of leaves**	**count of leaves**	**count of leaves**	**count of leaves**
***interactions* (AXB)** $^{B}F_{1,290}$=	ns	4,17*	5,74*	ns	ns	ns
***interactions* (AXC)** $F_{2,290}$=	ns	ns	8,39*	14,18*	16,55*	19,22*
***interactions* (BXC)** $F_{2,290}$=	6,60*	8,21*	5,47*	ns	6,39*	9,94*

Derived from a three-way analysis of variance (ANOVA III). AXB = interactions between the factors of site and species, AXC = interactions between the factors of site and treatment, and BXC = interactions between the factors of species and treatment. Total sample size (number of elements in the sample), n = 300 (2 sites × 2 species × 3 treatments × 25 = 300). ns = nonsignificant difference between population means (P > 0.05); ^{B} = *F*-test statistic with degrees of freedom; *= a statistically significant difference (P ≤ 0.05).

The *Paulownia fortunei* seedlings consistently exhibited a higher average leaf count than *Paulownia elongata* seedlings across all six measurements. The first measurement of *Paulownia elongata* seedlings, and the first and second measurements of *Paulownia fortunei* exhibited a higher average leaf count at the site in Pambukovica, However, in subsequent measurements, seedlings at the Obrenovac site displayed a greater average leaf count. *Paulownia elongata* seedlings achieved the highest average leaf count in fertilised treatments. Specifically, in the first, second, and sixth measurements, the highest average leaf count in Obrenovac was recorded for seedlings treated with a higher fertiliser dose, whereas in the third, fourth, and fifth measurements, seedlings fertilised with a lower amount showed the highest leaf counts.

For *Paulownia fortunei* seedlings at this site, the control treatment resulted in the highest average leaf count during the first and fourth measurements, the lower fertilisation treatment yielded the highest counts in the second and sixth measurements, and the higher fertilisation treatment showed the highest counts in the third and fifth measurements. At this site, both species reached peak average leaf counts during the fifth measurement, with *Paulownia elongata* averaging 11.76 leaves and P*aulownia fortunei* 14.51 leaves.

At the Pambukovica site, *Paulownia elongata* seedlings in the first and second measurements had the highest average leaf count in the higher fertilisation treatment. The third measurement showed the highest count in the control treatment, while subsequent measurements indicated the highest counts for seedlings treated with lower fertilisation levels. *Paulownia fortunei* seedlings in Pambukovica showed the highest average leaf count in the first measurement under the lower fertilisation treatment, in the second and third measurements under the higher fertilisation treatment, and in the fourth, fifth, and sixth measurements in the control treatment. In Pambukovica, peak average leaf counts for both species were observed during the fifth measurement, with *Paulownia elongata* averaging 10.93 leaves and *Paulownia fortunei* 13.73 leaves (Table 8).

For leaf count, the interaction between site and species (AxB) was statistically significant in only two measurements, while the interaction between site and treatment (AxC) was significant in four measurements. The interaction between species and treatment (BxC) was statistically significant in five out of six measurements (Table 8).

4. DISCUSSION

Plants possess the remarkable ability to modulate their growth, development, and physiological processes in response to environmental conditions, enabling them to mitigate stress impacts and sustain development (Murchie and Horton, 1997; Walters et al., 2003). The results obtained from our field trials demonstrate significant differences in phenotypic stability between two paulownia species, *Paulownia elongata* S. Y. Hu and *Paulownia fortunei* Seem. Hemsl., in relation to different sites and treatments.

Analysis of morphological characteristics indicates that nutrient supplementation substantially promotes seedling development (Madejón et al., 2016). Studies by Campoe et al. (2013) and García-Morote et al. (2014) also show that fertilisation significantly enhances growth in paulownia plantations, though growth rate largely depends on water availability and soil fertility (Carpenter and Smith, 1979; Beckjord, 1984; Donald, 1990; Rad et al., 2015). Seedling parameter values for *Paulownia elongata* and *Paulownia fortunei* in Obrenovac (Site I) and Pambukovica (Site II) fell below those reported in previous studies on these species

(Johnson et al., 2003; Šoškić et al., 2003; Woods, 2008; Vilotić et al., 2011; Tisserat et al., 2013; Olave et al., 2015).

Marović et al. (1989) report a notably higher survival rate among fertilised seedlings, which is consistent with our findings at both Obrenovac and Pambukovica sites, where survival rates were highest among seedlings receiving higher fertilisation. According to Zhu et al. (1986), *Paulownia elongata* demonstrates better tolerance to lower temperatures than *Paulownia fortunei*, which likely contributes to its higher survival rate across the study sites. Consistent findings by Olave et al. (2015) in Northern Ireland reveal survival rates of 70.8% and 32% for two paulownia genotypes (Spanish and Moroccan, respectively) under cold conditions by the end of the third year.

The heavy soil texture in the experimental plots also affected the root system development of paulownia seedlings during the first year after planting. According to studies by Hu (1959), Dhiman (1997), Longbrake et al. (2001), and Johnson et al. (2003), this period marks a phase of intensive root system development for paulownia. Limited nutrient availability and specific soil properties affected the aboveground growth of the seedlings, which exhibited low mean height values throughout the study period. At the end of the first growing season, the men height of the seedlings differed significantly between species, reaching 27.10 cm for *Paulownia elongata* and 31.18 cm for *Paulownia fortunei* (Table 5). Monitoring growth parameters of these species under controlled nursery conditions, Ayan et al. (2006) reported mean heights of 69.06 cm for *Paulownia elongata* and 48.09 cm for *Paulownia fortunei* by the end of the first growing season. Comparative studies by Zhu et al. (1986) and Woods (2008) revealed that *Paulownia fortunei* tolerates heavier soils with higher clay content and lower pH values better than *Paulownia elongata*, although both species thrive best in well-drained soils with pH values between 5.5 and 7.5 (Kays et al., 1998; Mitchem et al., 2002; Barkley, 2007). The results from this study support these findings, indicating that seedlings at the Pambukovica site, where the soil had a heavier mechanical composition with over 55% clay content and lower pH (5.35–5.66), showed poorer growth compared to seedlings at the Obrenovac site, which had an average clay content of 53% and a soil pH of 5.87–6.13.

Extensive research has demonstrated that fertilisation positively impacts the development of a well-structured root system with a higher number of lateral roots and a stem with a greater number of leaves, thereby enhancing overall seedling vigour and promoting more uniform plant growth (Mead and Gadgil, 1978; Marović et al., 1989; Marković and Marković, 1989; Veselinović, 1989; Cromer and Jarvis, 1990; Šijačić-Nikolić et al., 2006; Brown, 2007; Brown et al., 2011; Ćirković-Mitrović, 2015; Mitrović et al., 2022). Results from the Obrenovac and Pambukovica sites showed that height differences between seedlings treated with varying amounts of fertiliser and those in unfertilised control plots were statistically significant. The impact of fertilisation varied and showed a greater effect at the Obrenovac site, where seedlings of both species achieved better results. At the end of the first growing season, seedlings in the high-fertiliser treatment reached an average height of 34.74 cm, compared to 22.64 cm in the control treatment.

Johnson et al. (2003) reported similar findings regarding mean height on acidic and heavy soils, with seedlings reaching a mean height of 27.60 cm by the end of the first growing season. Although *Paulownia fortunei* shows greater tolerance to heavier soils compared to *Paulownia elongata*, both species achieve optimal height and diameter growth on loose, well-drained, and moist soils (Zhu et al., 1986; Woods, 2008). Results from the Obrenovac and Pambukovica sites, where *Paulownia fortunei* seedlings displayed greater mean heights than those of *Paulownia elongata* in the first year, confirm that *P. fortunei* is more resilient on heavy soils. The interaction between site and species factors was significant only in the fifth measurement, whereas the interaction between treatment and species was significant in the last two measurements. Throughout the first growing season, the interaction between site and treatment factors significantly affected mean seedling height across all measurements, with superior results observed at the Obrenovac site (Table 5).

Stem diameter at root collar, a key indicator of plant quality at the juvenile stage (Stilinović, 1987), further suggests that in such soil conditions, neither paulownia species exhibits the growth rates that characterise them as woody species with the highest annual increases (Šijačić-Nikolić et al., 2009).

According to Radošević and Vilotić (2010), the culmination of diameter growth is periodic, with the first peak occurring as early as the second or third year of tree age. This finding aligns with studies by Hu (1959), Dhiman (1997), Longbrake et al. (2001), and Johnson et al. (2003), who observed that the aboveground portion of paulownia seedlings grows more slowly during the first year, as physiological processes are directed primarily towards the intensive development of the root system.

A statistically significant difference in the mean root collar diameters between species (Table 6) was observed only in the second half of the first growing season, while no significant differences were found in the other measurements. At the end of the growing season, *Paulownia elongata* seedlings exhibited larger mean root collar diameters (7.08 mm), with higher values recorded at the Pambukovica site. The mean root collar diameters reported by Ayan et al. (2006) at the end of the first growing season were greater than those observed in the trials at Obrenovac and Pambukovica, with *Paulownia elongata* averaging 9.04 mm and *Paulownia fortunei* averaging 8.71 mm. These results were obtained under controlled nursery conditions, where plants grew in enriched forest soil and received more intensive care, contributing to larger root collar diameters.

During both growing seasons, seedlings at the Obrenovac site had larger mean root collar diameters in the first five measurements, except for the final measurement. This difference is likely due to climatic factors; although temperatures were slightly higher at the Obrenovac site at the end of the growing season, rainfall was significantly lower starting in August, with a continuing downward trend into September. As a result, seedlings at the Pambukovica site continued to increase in diameter at root collar throughout the growing season. According to Zhu et al. (1986), diameter growth cessation coincides with leaf drop, while height growth typically ceases earlier.

As with height, the interaction between site and treatment had a significant effect on root collar diameter in both growing seasons, particularly in the final two measurements (Table 6). The soil at Obrenovac contains a lower clay percentage and has a lighter mechanical composition compared to the soil at Pambukovica. The pH of the soil solution at Obrenovac ranges from 5.87 to 6.13, which is more favourable for paulownia growth than the pH range of 5.33 to 5.66 at Pambukovica. According to Kays et al. (1998) and Barkley (2007), most paulownia species thrive in soils with a pH range of 5.5 to 7.5. Consequently, the high clay content (>55%) at the Pambukovica site limits nutrient availability, which has likely impacted seedling growth.

Paulownia fortunei demonstrates greater tolerance to lower soil pH values compared to *Paulownia elongata* (Zhu et al., 1986), a finding confirmed in this study, where seedlings of *P. fortunei* achieved higher mean heights. In contrast, *P. elongata* seedlings exhibited larger mean root collar diameters, as *P. fortunei*—with its faster growth rate (Barton, 2007) – directed more energy into height growth. Statistically significant differences in mean root collar diameters were observed between seedlings in different treatments, with those receiving higher fertiliser applications exhibiting greater growth. The interaction between species and treatment was statistically significant only in the final measurement of the first growing season, where seedlings of both species showed larger root collar diameters in the high-fertiliser treatment compared to those in the lower-fertiliser and control treatments.

The findings of this study confirm the results of previous research investigating the impact of fertilisation on plant growth (Jey, 1998; Šijačić-Nikolić et al., 2011). García-Morote et al. (2014) concluded that the application of water and fertilisers significantly enhances plant growth in plantations, although the rate of growth primarily depends on the availability of water and soil fertility. Similar conclusions were reached by Carpenter and Smith (1979), Beckjord (1984), and Donald (1990). Besides these two crucial factors, several studies (Zhu et al., 1986; Kays et al., 1998; Barkley, 2007; Woods, 2008; Innes, 2009) have highlighted that the mechanical composition of the soil is a limiting factor for the growth and development of paulownia species, as was observed at the trial sites in Obrenovac and Pambukovica.

Fast-growing species are characterised by large and numerous leaves (Ceulemans et al., 1990; Gardner et al., 1995). The average number of leaves observed during the study was higher for seedlings at the Obrenovac site (Tables 7 and 8) for both paulownia species, except in the first measurement of the first growing season, which was not statistically significant. This could likely be attributed to the uneven quality of the initial planting material. Seedling growth and quality improve when cultivated in soils with higher calcium content (Tucović and Simić, 2002; Nešković et al., 2003), higher pH values (Stanković, 2006; Krstić et al., 2011; Škvorc et al., 2014), and greater concentrations of carbon (Fender et al., 2011) and nitrogen (Vukadinović and Vukadinović, 2011), as well as a lower C/N ratio (Bown et al., 2011). Pedological analysis of the soils at the study sites (Tables 2 and 3) indicates that the Obrenovac site had significantly higher levels of calcium, nitrogen, and humus compared to the Pambukovica site. Additionally, the pH values and C/N ratios were more favourable at Obrenovac. Considering the lighter soil texture, which is a key factor in seedling development (Beckjord, 1984; Stringer, 1986; Graves, 1989; Graves and Stringer, 1989; Donald, 1990; Torbert and Johnson, 1990; Johnson et al., 1992; Kays et al., 1998), the results from the Obrenovac site, where seedlings produced a greater number of leaves compared to those at

Pambukovica, align with previous research. In contrast, the heavy mechanical composition and highly acidic soil at Pambukovica limit nutrient availability, which adversely affects plant growth (Tucović and Simić, 2002; Stanković, 2006; Krstić et al., 2011). The average number of leaves at the Obrenovac site did not show a clear pattern relative to the treatments (Tables 7 and 8).

The success of afforestation or plantation cultivation is closely linked to plant survival rates (Óskarsson and Brynleyfsdottir, 2009), which are influenced by numerous factors. As noted by Tackett and Graves (1983), survival rates of paulownia vary considerably, ranging from very high to very low, depending on environmental conditions (Beckjord and McIntosh, 1983; Pollio and Davidson, 1992; Mitchem et al., 2002; Johnson et al., 2003; Kadlec et al., 2021). According to Johnson et al. (2003), although plants are highly sensitive during their first years of development, survival rates in the first year can reach up to 99.5% under favourable conditions.

5. CONCLUSIONS

The primary objective of this study was to assess the impact of fertilisation on the survival and morphological growth characteristics of one-year-old P*aulownia elongata* S.Y. Hu. and *Paulownia fortunei* Seem. Hemsl. seedlings across various sites.

Through a comparative analysis of the phenotypic stability of paulownia seedlings in the juvenile phase, it was determined that in sites with heavy soil textures, and insufficient water and nutrient availability, both survival and growth of the plants were significantly reduced. The underdeveloped and stunted root system, which is a primary cause of poor seedling establishment and growth, is further influenced by the mechanical properties and acidic reaction of the soil, decreasing nutrient uptake. At sites with a heavier texture and less favourable conditions for paulownia, seedlings in fertilised treatments exhibited higher survival rates, better growth, and increased biomass production, owing to more favourable nutritional conditions.

The analysis of seedling height, root collar diameter, and leaf number at these sites confirmed that paulownia seedlings grown in loose, permeable, well-aerated soils with optimal water-holding capacity, combined with appropriate fertilisation during the first year, did not express their characteristic fast-growing traits.

Our findings suggest the potential of paulownia for plantation use; however, to conclusively determine its success in energy plantations in our region, further research is needed. This should focus on the species' growth and development at ages beyond two years, considering the influence of climatic factors, different care practices, and preventive measures for protection against diseases and pests.

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EFFECTS OF FERTILISATION ON SURVIVAL AND MORPHOLOGICAL GROWTH CHARACTERISTICS OF ONE-YEAR-OLD SEEDLINGS OF *PAULOWNIA ELONGATA* S.Y. HU. AND *PAULOWNIA FORTUNEI* SEEM. HEMSL. IN TWO DIFFERENT SITES IN SERBIA

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Summary

This study was conducted on two experimental plots where seedlings of *Paulownia elongata* S.Y. Hu. and *Paulownia fortunei* Seem. Hemsl. were planted. The plots were established in areas with different orographic features, climatic conditions, and soil physicochemical properties. The seedlings, derived from well-adapted genotypes of both species, were produced generatively from seeds collected from plantations in Bela Crkva. The research presents the results of examining the impact of fertilisation during the first year after planting on seedling survival and the morphometric characteristics of their growth. The analysis demonstrated that fertilisation significantly influenced both survival rates and all measured parameters. Additionally, the results highlighted the relevance of fertilisation in assessing the adaptability of these species to various soil types.

The survival rates suggest a potential for these species, while the analysis of seedling height, root collar diameter, and leaf size confirms that paulownia did not exhibit its characteristic fast growth in the studied environments. Future research should focus on evaluating the growth and development of these species at two years of age and older to validate their potential for cultivation in energy plantations.

UTICAJ PRIHRANJIVANJA NA PREŽIVLJAVANJE I MORFOLOŠKE KARAKTERISTIKE ELEMENATA RASTA JEDNOGODIŠNJIH SADNICA *PAULOWNIA ELONGATA* S. Y. HU. I *PAULOWNIA FORTUNEI* SEEM. HEMSL. NA DVA RAZLIČITA STANIŠTA U SRBIJI

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Rezime

Istraživanja su vršena na dve ogledne površine sadnjom sadnica vrsta *Paulownia elongata* S. Y. Hu. i *Paulownia fortunei* Seem. Hemsl. Ogledna polja su osnovana na lokalitetima različite orografskih osobina, klimatskih uslova i fizičko-hemijskih osobina zemljišta sadnjom sadnica paulovnija proizvedenih generativnim putem od semena dobro adapriranih genotipova dve vrste paulovnije, iz zasada u Beloj Crkvi. U radu su prikazani

rezultati istraživanja uticaja prihranjivanja biljaka u prvoj godini nakon sadnje, na preživljavanje i morfometrijske karakteristike elemenata rasta. Analiza ovih rezultta je pokazala da je prihranjivanje sadnica imalo signifikantan uticaj na preživljavanje i na sve analizirane parameter. Takođe, utvrđeno je da su dobijeni rezultati uticaja prihranjivanja značajni za analizu pokazatelja adaptibilnosti vrsta za gajenje na određenim tipovima zemljišta.

Dobijeni rezultati preživljavanja ukazuju na potencijal ove vrste. Analiza rezultata visine sadnica, prečnika u vratu korena, veličine listova potvrđuje da paulovnija na istraživanim staništima ne iskazuje svoje osobine kao brzorastuća vrsta. Istraživanja treba nastaviti u pravcu sagledavanja njenog rasta i razvoja u stadijumu dve i više godina starosti kako bi se potvrdila pretpostavka da je potencijal ovih vrsta u gajenju energetskih zasada.

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