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ABOVEGROUND DENDROMASS ESTIMATION OF JUVENILE *PAULOWNIA* SP.

PROCJENA NADZEMNE DENDROMASE KOD JUVENILNIH *PAULOWNIA* SP.

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Abstract

Species of the genus *Paulownia* have been introduced to Bulgaria since the beginning of the XX-th century and their multipurpose uses - as ornamental trees, for wood and biomass production - have been tested ever since. We present a study, which examines the early growth of four *Paulownia* clones at southern locations in Bulgaria and derives biometric models for dendromass estimation of juvenile *Paulownia* trees.
The data originated from two experimental plantations established on nursery land using one-year-old in vitro propagated plant material. Forty six, 1 to 3 year-old saplings from two clones of *P. tomentosa* and two *P. elongata × P. fortunei* hybrids were sampled. Their stem biomass was modeled as a function of the breast height tree diameter and total tree height or the stem diameter alone and a set of goodness-of-fit criteria was applied to select the most adequate among the 29 tested formulations. The regression models were fitted in log-transformed form to the logarithm of the stem biomass and MM correction factor for bias was applied to the back-transformed prediction data. Two allometric relationships were derived, which adequately assess stem dendromass of young *Paulownia* sp. from easily measurable tree characteristics. Both models are applicable for stem biomass estimation of juvenile *Paulownia* trees of diameter up to 5 cm and total height up to 3.5 m.

Key words: allometry, biometric models, *Paulownia elongata×P. fortunei*, *Paulownia tomentosa*, stem biomass

1. INTRODUCTION / UVOD

Species of the genus *Paulownia* are known as “multipurpose trees” and the management system is determined by the objective of the plantation establishment: agro-forestry system, short rotation forestry for biomass production, rehabilitation of different terrains (Zhao-Hua et al., 1986; Maier & Vetter, 2004; Gyuleva et al., 2012a).

In Bulgaria, *Paulownia tomentosa* (Steud.) was introduced at the beginning of the XXth century. The species has been successfully cultivated in the warmer parts of Bulgaria, providing viable seeds with high germination rate, as observed in the late 50s (Stefanov & Ganchev, 1958). In the early 70s Dimitrov (1973) reported the first results of application of *Paulownia tomentosa* (Steud.) as ornamental tree in the landscapes of the country. At present, old *Paulownia* trees can be seen in the urban areas and parks of the bigger towns of Bulgaria - Sofia, Plovdiv, Burgas, Ruse, Yambol. *Paulownia tomentosa* has been cultivated for wood production for almost three decades at the Station for Fast Growing Trees Species in Svishtov (Kalmukov, 1995, 2009).

Ten hybrid *Paulownia* clones have been tested on three different sites in Bulgaria (Gyuleva et al., 2012a, 2012b) in 2010–2012. A clone of *Paulownia tomentosa* (Steud.) and a promising clone of *Paulownia elongata x fortunei* “07_3” of the highest survival rate and growth capacity have been examined for short rotation biomass production on agricultural land in Zlatna Panega, north-western Bulgaria (Gyuleva et al., 2012b; Gyuleva et al., 2013; Gyuleva, 2014) since 2010. The survival rate of the tested *Paulownia* clones three years later is more than 85% (Gyuleva, preliminary results).

Tree biomass production is a key quantitative characteristic of the forests and among the most important parameters of the short rotation plantations established at specific soil-climatic conditions. Several indirect methods for biomass estimation have been developed, such as the allometric equations. Biomass equations relate tree biomass (kg) or stand biomass (t/ha), as well as their components, with easily measurable tree and stand variables, e.g., stem diameter, total tree height, wood density. Our study examines the early growth of four *Paulownia* clones and is the first attempt to derive biometric models for dendromass estimation of juvenile *Paulownia* trees in Bulgaria.

2. MATERIAL AND METHODS / MATERIJAL I METODE

2.1 Data collection / Prikupljanje podataka

Data originated from two experimental plantations established on nursery land using one-year-old in vitro propagated (Gyuleva, 2010) plant material (Figure 1). The first plantation is situated in south-eastern Bulgaria and was created in 2010 on Fluvisols in randomized complete block design with three replications, using square 4x4 m spacing (Figure 2) (Gyuleva et al., 2012a, 2012b). The entire plantation was coppiced in March 2012 and trees from 3 of the 10 represented in the experiment *Paulownia* clones (2 trees per clone) were sampled in 2013 for determination of the fresh weight (Table 1). The second experimental plantation was established in the autumn of 2013 in south-western Bulgaria on Fluvisols applying Nelder wheel design (Nelder, 1962; Namkoong, 1965) with 2 *Paulownia* clones and 12 nearly-square spacings ranging from 0.6 to 9.4 m^2 (Figure 3). The trees of 4 spokes were sampled in the winter of 2014–2015 (Table 1). Combined N:P:K (20:20:20) fertilizer (31.25 kg/dka) was applied during each growing season. Up to 12 irrigations per year, using 8 l of water per plant were done and the number of irrigations took account of the amount of precipitations in each region (Figure 4).

Each sampled tree was cut to the ground and the stem length and breast-height tree diameter were measured with 1.0 cm and 0.1 cm precision, respectively. The stem and the branches were separated and weighted in situ with 0.005 kg precision. One stem sample and one sample of branches were taken from each tree. Fresh weight of the samples was measured in the field; they were packed in paper bags and transported to the laboratory. The samples were oven-dried at 105 °C to constant weight, which was measured with 0.001 kg precision. Proportion of dry mass relative to the fresh sample weight was used to estimate the total amount of dry mass of the respective tree compartment.

Figure 1. *Paulownia* propagules / **Slika 1**. *Paulownia* propagule (© V. Gyuleva)

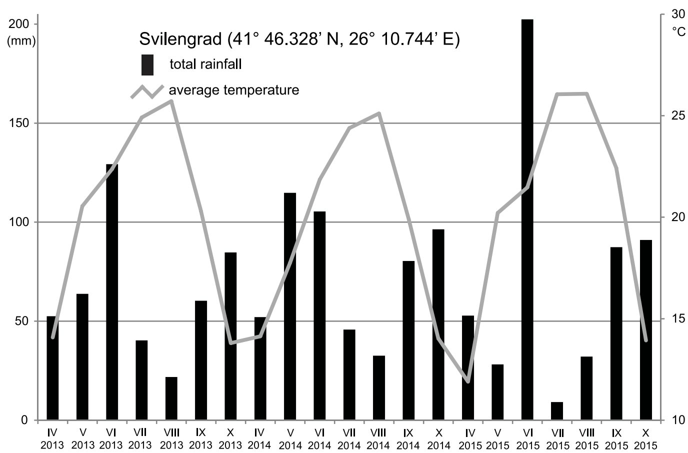
Figure 2. Experimental plantation with 10 *Paulownia* clones in Svilengrad, south-eastern Bulgaria (41° 46.328´ N, 26° 10.744´ E) / **Slika 2**. Eksperimentalni zasad sa 10 *Paulownia* klonova u Svilengradu, jugoistočna Bugarska (© V. Gyuleva)

Table 1. Description of the experimental data used to derive the stem biomass models of *Paulownia* sp. / **Tabela 1**. Eksperimentalni podaci korišteni pri izradi modela biomase stabla kod *Paulownia* sp.

Lot	*Paulownia* clone	Growth space (m²)	Plant age (years)[a]	Sampled trees	*dbh* (cm)[b]	*h* (m)[b]	w_s (kg)[b]	w_b (kg)[b]
Plot 1	*P. elongata x fortunei* "07_3"	16	3+1	2	2.8 (1.9-3.6)	2.1 (1.8-2.4)	0.419 (0.262-0.576)	0.067 (0.021-0.112)
Plot 2	*P. elongata x fortunei* "07_21"	16	3+1	2	2.5 (1.3-3.7)	2.1 (1.4-2.8)	0.405 (0.172-0.639)	0.047 (0.023-0.071)
Plot 3	*P. tomentosa* 2	16	3+1	2	3.2 (2.6-3.7)	2.3 (2.0-2.7)	0.761 (0.358-1.163)	0.048 (0.033-0.062)
Spoke 1	*P. tomentosa*	0.6-9.4	1+1	11	3.1 (1.7-4.7)	2.6 (1.6-3.4)	0.847 (0.117-1.771)	0.158 (0.101-0.198)
Spoke 2	*P. tomentosa*	0.6-9.4	1+1	9	2.1 (1.0-2.9)	1.9 (1.4-2.4)	0.329 (0.162-0.621)	0.069 (0.064-0.074)
Spoke 3	*P. tomentosa*	0.6-9.4	1+1	9	3.1 (1.6-4.3)	2.4 (1.5-3.3)	0.752 (0.220-1.371)	0.149 (0.098-0.214)
Spoke 4	*P. tomentosa*	0.6-9.4	1+1	11	2.2. (1.3-3.3)	1.9 (1.5-2.6)	0.355 (0.168-0.642)	0.029 (0.005-0.054)

Note. *dbh* - breast height diameter of the tree (cm); *h* - total tree height (m); w_s - dry biomass of stem (kg); w_b - dry biomass of branches (kg). [a] Plant age = Root age + Stem age; [b] Average variable values with minimum and maximum values shown in brackets

Figure 3. Experimental plantation with two *Paulownia* clones in a Nelder wheel in Strumyani, south-western Bulgaria (41° 38.015´ N, 23° 11.605´ E); a. at the time of establishment in October 2013; b. in October 2015 / **Slika 3**. Eksperimantalni zasad tipa *Nelder wheel* sa dva *Paulownia* klona u Strumjaniju, jugozapadna Bugarska; a. u vrijeme podizanja zasada u oktobru 2013; b. u oktobru 2015 (© V. Gyuleva)



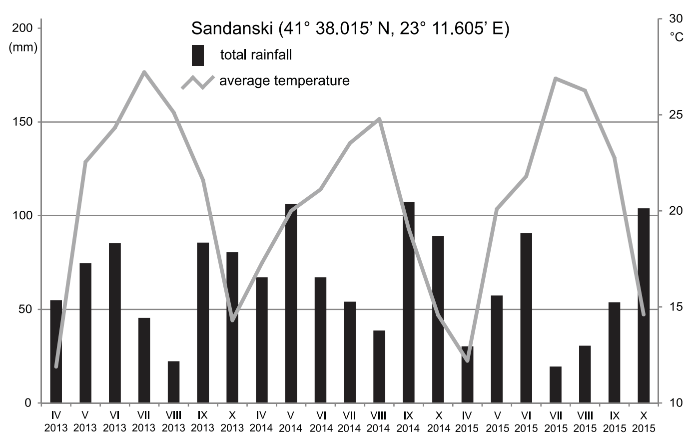


Figure 4. Climatic conditions at the test sites in 2013–2015 / **Slika 4**. Klimatski parametri na eksperimentalnim plohama od 2013. do 2015. godine

2.2 Model development / Razvoj modela

The models for total aboveground biomass, or total dendromass, are usually derived in two stages (Canga et al., 2013; Menéndez-Miguélez et al., 2013). In the first stage, models for each particular biomass fraction are developed and in the next stage, they are combined in a system of equations that are fitted simultaneously taking into account the system additivity, which requires that the estimate of the total biomass equals the sum of the estimates of the individual compartments (Parresol, 1999; Burkhart & Tomé, 2012). Screening of the available woody biomass data from *Paulownia* sp. showed that only 35% of the juvenile trees possessed branches and the average proportion of the dendromass allocated in the branches was around 3% (Figure 5). The preliminary analyses showed rather poor fit of the allometric biomass models when tested with the branch biomass data of the just 18 trees with branches. Considering these preliminary results and the insignificant contribution of the branches to the total woody biomass of the juvenile *Paulownia* trees, we decided to perform a one-step derivation and to limit the dendromass model to the biomass model of the stems alone.

Biomass models for aboveground compartments of individual trees commonly utilize two principle tree dimensions as predictor variables: diameter at breast height (*dbh*, cm), which is used alone or together with the total tree height (*h*, m) (Clutter et al., 1983; Burkhart & Tomé, 2012). We performed graphical examination of the data, by plotting the stem dry mass against each of these two predictors (Figure 6), to explore the nature of the mean relation and the variance distribution (Picard et al., 2012). The charts showed a nonlinear mean relationship and multiplicative, heteroscedastic, lognormal error distribution for each of the independent variables (Figure 6). Therefore, the regression models, which were tested, were fitted in log-transformed form to the logarithm of the stem biomass, as suggested by Xiao et al. (2011) and Sileshi (2014).

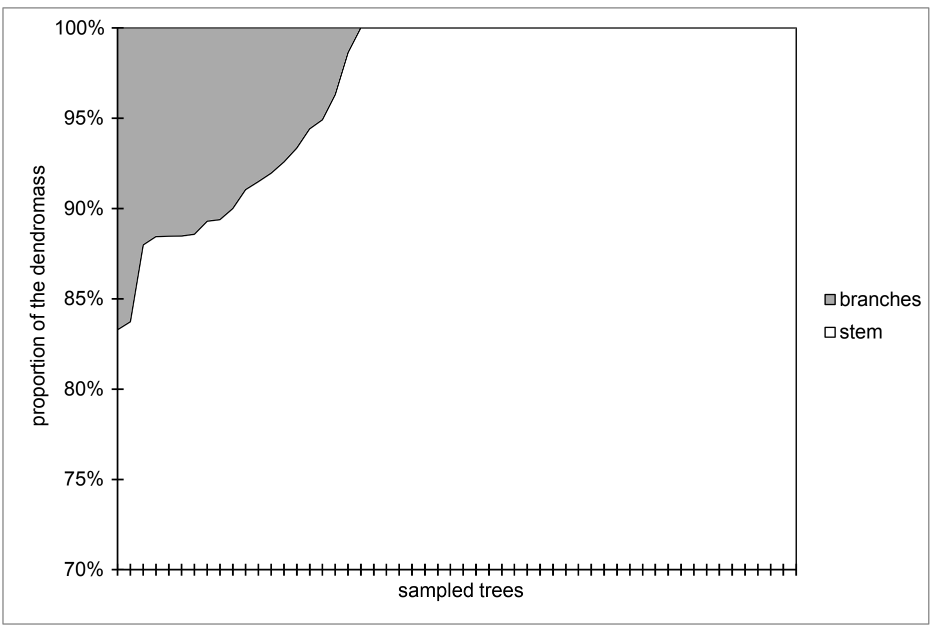


Figure 5. Distribution of the aboveground woody compartments of the juvenile *Paulownia* sp. / **Slika 5**. Distribucija nadzemnnih dijelova juvenilnih *Paulownia* sp.

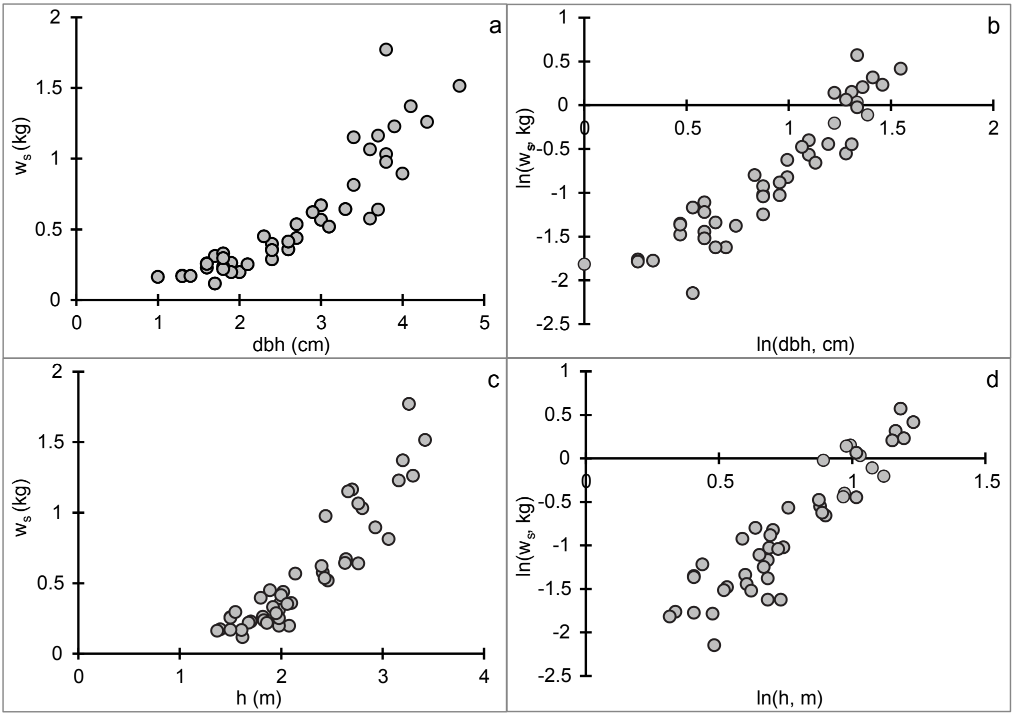


Figure 6. Graphical examination of dry stem mass w_s (kg) data plotted against a) b) breast height diameter of the tree *dbh* (cm), c) d) total tree height *h* (m) / **Slika 6**. Podaci o suvoj masi stabla w_s (kg) u odnosu na a) b) prsni prečnik stabla *dbh* (cm), c) d) ukupna visina stabla *h* (m)

We examined 22 principal two-predictor model formulations, selected in the study by Stankova et al. (2015) for modelling aboveground biomass of black poplar hybrids. The regression equations were fitted by Ordinary Least-Squares Method (OLS), and the model adequacy was assessed by a set of nine criteria (Table 2), e.g., tests for normality, homoscedasticity, unbiasedness (Gadow & Hui, 1999; Paressol, 1999; Picard et al., 2012; Sileshi, 2014). The selected adequate models were then compared using eight test statistics (Table 3), derived from Gadow & Hui (1999), Paressol (1999), Picard et al. (2012) and Sileshi (2014).

To convert the predicted values to arithmetic, untransformed units, additional correction for bias is required, because the antilogarithm of lny is not an unbiased estimate of the arithmetic mean of y (Burkhart & Tomé, 2012). Various bias-correcting factors have been tested in terms of their ability to estimate biomass and predict biomass for new trees (Clifford et al., 2013). Since evaluation of the dendromass production of juvenile *Paulownia* trees grown in short rotation crops was the primary goal of this model derivation, we implemented the MM estimator for bias correction:

$$C_{MM}(x_0) = \exp\left(\frac{ms^2}{2(m+2+3nv(x_0))+3s^2}\right) \quad (1),$$

where C_{MM} is the correction factor, n is the total number of observations, m is the number degrees of freedom, s^2 is the mean squared error of the fitted regression, $v(x_0)=\mathbf{X_0}^{\mathbf{T}}[\mathbf{XX}^{\mathbf{T}}]^{-1}\mathbf{X_0}$, **X** are the predictor values of the parametrization data and $\mathbf{X_0}$ are the predictor values of the new trees, which biomass need to be estimated ($\mathbf{X=X_0}$ for the purpose of our derivation). The MM correction factor was designed to

Table 2. Criteria used to establish model adequacy / **Tabela 2**. Kriterijumi korišteni za određivanje adekvatnosti modela

Criterion	Statistical test [a]	Reference value
Normality of errors	Anderson-Darling test	P > 0.05
Homoscedasticity of errors	Breusch-Pagan test	P > 0.05
Mean error*	t-test for mean absolute error different from zero	P > 0.05
Model bias*	simultaneous F-test for slope equal to 1 and zero intercept of the linear regression relating observed and predicted values	P > 0.05
Collinearity	Condition Number	max 30
Outliers	Studentised residuals ϵ [-2; 2]	max 10% > |2|
Leverage points	Reference Leverage value: 2(k+1)/n, k - number of predictors, n - sample size	max 10% > Leverage
Influential points	Reference Cook's D value: 4/n, n - sample size	max 10% > D
Stability of parameter estimate	Parameter Relative Standard Error (%): PRSE=100xSE/|parameter|, SE - standard error of the parameter	< 30%

Note. [a] Selection based on Gadow and Hui 1999; Paressol 1999; Picard et al. 2012; Sileshi 2014
* Criterion applied at both log-transformed and back-transformed (original) scale.

Table 3. Criteria used to compare the selected adequate models / **Tabela 3**. Kriterijumi korišteni pri poređenju odabranih modela

Scale of application	Criterion [a]	Reference value
Log-transformed	Adjusted R^2 (R^2_{adj})	maximum
	Root Mean Squared Error (RMSE)	minimum
	Akaike Information Criterion (AIC)	minimum
	Variance Ratio (VR)	maximum
Log-transformed and back-transformed	Model efficiency (ME)	minimum
	Mean absolute error (MAE)	minimum
Back-transformed	Mean absolute relative error (MARE)	minimum
	10^{th}, 50^{th}, 75^{th} and 90^{th} percentile of the absolute values of the relative errors (Perc10, Perc50, Perc75 and Perc90)	minimum

Note. [a] Selection based on Gadow and Hui 1999; Paressol 1999; Picard et al. 2012; Sileshi 2014

Abbreviations: $R^2_{\text{adj}} = 1 - \frac{(n-1)\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{(n-k)\sum_{i=1}^{n}(y_i - \bar{y})^2}$; $\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{n}}$; AIC=-2LL + 2k , where -2LL = -2 x logarithm of likelihood function; $\text{VR} = \frac{\sum(\hat{y}_i - \bar{\hat{y}})^2}{\sum(y_i - \bar{y})^2}$; $\text{ME} = \frac{\sum(y_i - \hat{y}_i)^2}{\sum(y_i - \bar{y})^2}$; $\text{MAE} = \frac{1}{n}\sum y_i - \hat{y}_i$; $\text{MARE\%} = \frac{1}{n}\sum\frac{|y_i - \hat{y}_i|}{y_i}100$, where $y_i, \hat{y}_i, \bar{y}, \bar{\hat{y}}$ represent observed, predicted, mean observed and mean predicted biomass values, respectively, n is the total sample size, and k is the number of model parameters.

minimize the asymptotic mean squared error (Shen & Zhu, 2008) and was recommended by Clifford et al. (2013) for predicting biomass of new trees. Its estimated values, which differ among the individual trees, are multiplied by the antilogarithm of the predicted values of the log-transformed biomass to produce unbiased estimates.

3. RESULTS / REZULTATI

The aboveground dendromass of the investigated juvenile *Paulownia* trees ranged from 0.03 to 1.94 kg (0.53 kg on the average). Under the examined planting densities, the average amount of the total dendromass varied from 0.3 to 4.5 t/ha.

Seven of the 22 examined models of two independent (predictor) variables were tested also with the variable *dbh* alone, and all 29 fitted regression equations were rigorously examined using the set of adequacy criteria (Table 2) applied to the log-transformed model forms and to the back-transformed prediction data. Four model formulations were flawless (Table 4) and their goodness-of-fit was further compared (Table 5). The combined variable model form (M1) was merely superior to the other equations, obtaining the optimal estimates of nearly all test statistics and the exponential function of *dbh* (M4) was the second best model. Model M1, which uses the two principal tree dimensions is more easily applicable for determination of aboveground biomass in single trees or harvested saplings. Model M4, which is based on the breast-height tree diameter alone, can be used to assess rapidly and accurately the biomass of standing stock. Both models are applicable for stem biomass estimation of juvenile *Paulownia* trees of diameter up to 5 cm and total height up to 3.5 m (Figures 6, 7).

Table 4. Models for stem biomass of *Paulownia* sp. / **Tabela 4**. Modeli za biomasu stabla kod *Paulownia* sp.

Model	Parameter	b_0	b_1	b_2
M1	Estimate	0.119	0.021	
$\ln w_s=\ln(b_0+b_1 hdbh^2)$	SE	0.014	0.001	
$w_s=b_0+b_1 hdbh^2$	PRSE %	11.6	6.4	
M2	Estimate	-2.942	0.963	0.564
$\ln w_s=b_0+b_1\ln(dbh)+b_2 h$	SE	0.182	0.240	0.161
$w_s=\exp(b_0+b_2 h)dbh^{b_1}$	PRSE %	6.2	25.0	28.6
M3	Estimate	-2.614	3.199	1.043
$\ln w_s=b_0+b_1\ln(h)+b_2\ln(dbh/h^2)$	SE	0.131	0.225	0.292
$w_s=\exp(b_0)\ h^{b_1}(dbh/h^2)^{b_2}$	PRSE %	5.0	7.0	28.0
M4	Estimate	-2.685	0.706	
$\ln w_s=b_0+b_1 dbh$	SE	-0.102	0.036	
$w_s=\exp(b_0+b_1 dbh)$	PRSE %	3.8	5.1	

Abbreviations: SE - standard error, PRSE % - Parameter Relative Standard Error (%).

Table 5. Goodness-of-fit tests for stem biomass models / **Tabela 5**. Goodness-of-fit testovi za modele biomase stabla

Model*	R^2	RMSE	AIC	VR	ME1	*ME2***	MAE1	*MAE2*	*MARE*	*Perc10*	*Perc50*	*Perc75*	*Perc90*
M1	0.905	0.221	-136.985	0.897	0.093	0.133	0.169	0.097	0.174	0.042	0.135	0.234	0.365
M2	0.889	0.239	-128.963	0.894	0.106	0.121	0.183	0.098	0.189	0.011	0.145	0.245	0.331
M3	0.875	0.252	-123.794	0.881	0.119	0.137	0.194	0.101	0.201	0.034	0.159	0.264	0.379
M4	0.893	0.234	-131.856	0.896	0.104	0.178	0.176	0.106	0.181	0.023	0.148	0.245	0.423

Abbreviations: R^2 - Adjusted R^2; RMSE - Root Mean Squared Error; AIC - Akaike Information Criterion; VR - Variance Ratio; ME1, ME2 - Model efficiency; MAE1, MAE2 - Mean absolute error; MARE - Mean absolute relative error; Perc10, Perc50, Perc75 and Perc90 - 10th, 50th, 75th and 90th percentile, respectively, of the absolute values of the relative errors.

* The parameters of the MM correction factor of Eq. 1 are as follows: n=46 for all models; m=44 for M1 and M4, m=43 for M2 and M3; s^2: M1 – 0.049, M2 – 0.057, M3 – 0.064 , M4 – 0.055; **X**: M1 – [1 dbh^2h], M2 – [1 ln(dbh) h], M3 – [1 ln(h) ln(dbh/h^2)], M4 – [1 dbh].

** The titles of the test statistics estimated at back-transformed (original) scale are indicated in Italics.

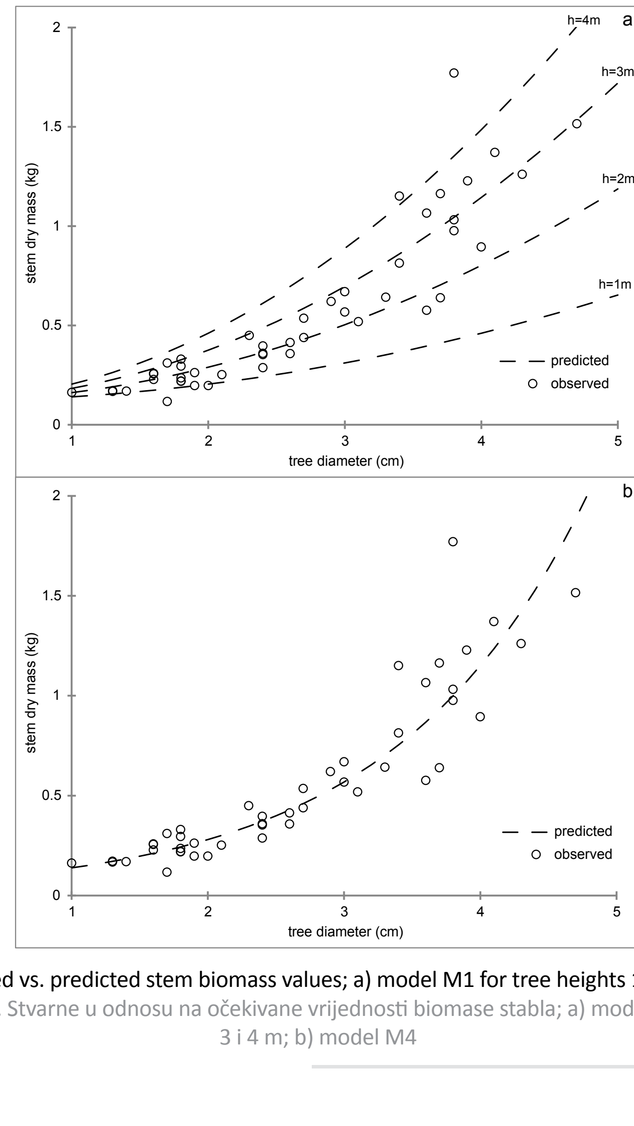


Figure 7. Observed vs. predicted stem biomass values; a) model M1 for tree heights 1, 2, 3 and 4 m; b) model M4 / **Slika 7**. Stvarne u odnosu na očekivane vrijednosti biomase stabla; a) model M1 za visine 1, 2, 3 i 4 m; b) model M4

4. DISCUSSION / DISKUSIJA

Both clones *Paulownia tomentosa* and *Paulownia elongata* x *fortunei* "07_3" tolerate the temperatures during the growing season in Bulgaria and the optimal temperatures for their growth (above 26 °C) are during July and August. The towns of Sandanski and Svilengrad are situated in the southern part of Bulgaria. Both locations are characterized by well-expressed variation of the temperatures at the beginning of the growing season and occurrence of frost is more likely in April and October (e.g., in October 2014). Experiments conducted in China showed, that *Paulownia* species tolerate different temperature regimes: *Paulownia tomentosa* suffers the minimum from frost, followed by *Paulownia elongata* and *Paulownia catalpifolia*. Depending on the origin of the reproductive material *Paulownia fortunei* endures winter temperatures as low as -10 °C (Zhao-Hua et al., 1986). A 40-days-long frost period at the beginning of 2012 caused severe damages on the *Paulownia* stems in the test trial in Svilengrad, which was the reason for their coppicing in March 2012. The average total amount of rainfall during the growing season, was registered 494.42 mm in Svilengrad and 454.73 mm in Sandanski and the most suitable conditions for the development of the tested clones of *Paulownia* were present between May and September (Figure 4). Durán Zuazo et al. (2013) observed that the woody biomass production of two clones *Paulownia elongata* x *fortunei* was negatively affected by the potential evapotranspiration and according to Lyons (1993), *Paulownia* trees thrive best in high-rainfall areas with more than 800 mm, if there is good soil drainage, with temperatures ranging from 24 to 30 °C. Consequently, some ecological constraints to the expression of the biomass potential of the *Paulownia* clones in our experimental plantations were present. The long-term average biomass yield of *Paulownia tomentosa* at density 10 000 plants/ha in the region of Mülheim (Germany), without additional irrigation and rotation cycle 5 years was 10.3 t/ha (Maier & Vetter, 2004), i.e., around 1 kg average dendromass per tree. Our data suggest that, if care is taken to assure satisfactory survival rate (e.g., regular watering), such biomass yield is possible under the investigated site conditions (Table 1). However, Olave et al. (2015), who tested 9 *Paulownia* genotypes in the cool temperate climate of Northern Ireland, concluded that just 4.2 t dry matter per hectare per year should be considered a low performance in biomass production.

Significant difference has been observed between survival rate and growth performance of the different clones of *Paulownia tomentosa* x *fortunei* "Shantong" (Barton et al., 2007). Comparative studies reveal that stem volume of *Paulownia fortunei* is usually 18–36% higher than that of *Paulownia elongata* of the same breast height diameter (Zhao-Hua et al., 1986; Gyuleva, 2008). Our data showed that size and dendromass of *Paulownia tomentosa* doubled those of the two *Paulownia elongata* x *fortunei* hybrids, grown at the same site conditions (Table 1).

The combined variable equation (M1) was derived as the most adequate to describe the stem biomass of the investigated juvenile *Paulownia* sp. This model form is regarded as "combining" the two predictors – *dbh* and *h* into the single predictor dbh^2h (Burkhart & Tomé, 2012) and can be considered a generalization of the constant form factor equation, more appropriate to describe young (i.e., of smaller size) plant material. Indeed, the intercept of the combined variable equation obtains small positive value (*see* Table 4), which substitutes for the biomass value of the trees, which height is less than 1.3 m, i.e., where $dbh^2h = 0$.

An exponential function of the breast height tree diameter (M4) was also shown to describe adequately the dendromass of the young *Paulownia* trees of this investigation. Joshi et al. (2015) employed a simple linear relationship of the breast height tree diameter and successfully modeled all below and aboveground biomass compartments of 15–20 year old *Paulownia tomentosa* in Nepal. Other studies, known to model the stem biomass of *Paulownia elongata* × *P. fortunei* hybrids (Martínez García et al., 2010; García-Morote et al., 2014), use the general allometric equation (Huxley, 1972), by relating the dry biomass weight to a power function of tree diameter at a certain height above ground. García-Morote et al. (2014) examined an expanded model, which included dummy variables to encounter for possible variability due to designed irrigation and fertilization treatments. However, the authors found that the dummy variables were non-significant and a strong direct allometric relationship between stem biomass and basal tree diameter was derived regardless of treatment, because diameter is the reflection of vigor and productivity of trees (García-Morote et al., 2014).

Following the recommendation by Clifford et al. (2013), we applied the MM correction factor by Shen & Zhu (2008) to amend the bias of the back-transformed predicted stem biomass. Although it is supposed to remove the bulk of the gross bias and must have superior performance in terms of the mean squared prediction error (Clifford et al., 2013), its estimation requires information of the parametrization data and operations with matrices (Equation 1). Therefore, a sufficiently reliable and less sophisticated alternative to the MM coefficient could be the ratio correction factor (Snowdon, 1991; Clifford et al., 2013), which is the quotient between the antilogarithms of the mean experimental and the mean predicted values of the dependent variable. We estimated values of the ratio correction factor of 1.025 and 1.024 for models M1 and M4, respectively.

5. CONCLUSIONS / ZAKLJUČCI

Four *Paulownia* clones (two *P. tomentosa* clones and two *P. elongata* × *P. fortunei* hybrids) were examined at two southern locations in Bulgaria and showed good survival rate, although their early-stage biomass growth underperformed. Two allometric relationships were derived, which adequately assess stem dendromass of young *Paulownia sp*. by employing as predictor variables the breast height stem diameter alone (model M4) or stem diameter and total tree height (model M1). Model M1 is more easily applicable for determination of aboveground biomass in single trees or harvested saplings, while model M4 can be used to assess rapidly and accurately the biomass of standing stock. Both models are applicable for stem biomass estimation of juvenile *Paulownia* trees of diameter up to 5 cm and total height up to 3.5 m.

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Sažetak

Vrste roda *Paulownia* introdukovane su u Bugarsku od početka XX vijeka, a njihova višestruka upotreba - kao ukrasno drveće, za proizvodnju drveta i biomase - odavno se ispituje (Dimitrov, 1973; Kalmukov, 1995, 2009; Gyuleva et al., 2012a, 2012b; Gyuleva et al., 2013; Gyuleva, 2014). U ovom radu je predstavljeno israživanje, koje ispituje rani rast četiri *Paulownia* klona na lokalitetima južne Bugarske i izvodi biometričke modele za procjenu dendromase juvenilnih *Paulownia* stabala.

Podaci potiču iz dva eksperimentalna zasada (Slike 3 i 4), osnovana u rasadniku korištenjem jednogodišnjeg in vitro propagiranog biljnog materijala (Slika 1). Uzorkovano je 46 jednogodišnjih do trogodišnjih sadnica, porijeklom od dva klona vrste *P. tomentosa* i dva hibrida *P. elongata × P. fortunei* (Tabela 1). Modelirana je biomasa njihovog stabla kao funkcija prsnog prečnika i ukupne visine stabla, ili samog prečnika, pri čemu je primjenjen skup goodness-

of-fit kriterijuma (Tabele 2 i 3) radi izbora najdekvatnije između 29 testiranih formulacija. Regresioni modeli su uklopljeni u log-transformisne oblike logaritma biomase stabla, pri čemu je, na povratno-transformisanim predikcionim podacima korišten MM korektivni faktor za odstupanje (Shen & Zhu, 2008; Clifford et al., 2013).

Iako su na testnim plohama bila prisutna određena ekološka ograničenja za određivanje potencijala biomase *Paulownia* klonova (Slika 4), ispitivani klonovi su pokazali dobar stepen preživljavanja, mada je rani porast biomase podbacio. Izvedene su dvije alometričke veze koje lako ocjenjuju dendromasu stabla mladih *Paulownia* sp. na osnovu lako mjerljivih karakteristika stabla (Tabele 4 i 5). Model M1, koji koristi dvije osnovne dimenzije stabla je primjenjiviji za određivanje nadzemne biomase pojedinačnih stabala ili posječenih sadnica. Model M4, koji se bazira samo na prsnom prečniku, može se koristiti za brzu i tačnu procjenu biomase zasada. Oba modela su primjenjiva za procjenu biomase stabla juvenilnih *Paulownia* stabala prečnika do 5 cm i ukupne visine do 3,5 m (Slike 6 i 7).

Ključne riječi: alometrija, biomasa stabla, biometrički modeli, *Paulownia elongata×P. fortunei, Paulownia tomentosa*