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ECOLOGICAL MOVEMENT OF NOVI SAD

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MODELLING CROWNS OF HYBRID POPLAR TREES GROWN IN URBAN CONDITION OF NOVI SAD

Abstract

This paper describes the method and present models of hybrid poplar tree crowns grown on open canopy conditions in Novi Sad. Models of crown are based on measurements of elements of tree growth (diameter at breast height, height, height to first live branch) and digitizing the edge of tree crowns from digital photographs. Digitized points of the crown edge were used for modelling its boundary curve line by the 2nd to 8th degree polynomials whose rotation about the axis of the tree the volume and the surface area of the crown were obtained. The obtained elements of tree crowns of different ages allow consideration of their ecological roles in urban conditions, but provide the basis for planning of green areas as well.

Key words: *crown, modelling, polinomial regression, poplar, urban condition.*

INTRODUCTION

Novi Sad is located on the alluvial plain of the Danube, whose zone of influence was expressed in the phase of alluvial soils formation on which is now the city of Novi Sad and the effect of soil water regimes is expressed today. This is the reason that in this area poplar and willow, as a native species, used in the greening of the city. Since the formation of the city in the end of the seventeenth century, the green areas were being formed, which are by the purpose and style vary depending on the period in which they occur. The use of poplar and willow in greening the city center had not a wider character, due to the poplar in the greening of urban settlements and the raising of parks on the outskirts were on periphery of the interests of horticultural experts

because of their modest decorative features, short-liveness, brittleness of wood and an increased incidence of windbreak, and in the present classification of pollen trees and seed allergens (Anastasijević, 2007). Also, the greening of cities were frequent failures due to insufficient knowledge of poplar planting technology.

Intensive urbanization in the wider area of Novi Sad after the World War II meant considerable changes in habitats and soil characteristics: because of the unequal terrain and low elevation, it was necessary to raise the terrain in order to prevent negative impact of the Danube on life of inhabitans, especially groundwater. The raise of the terrain on the "safe" elevation was done with sand from the bed of the Danube, in the thickness of 3-5 m, which is an unfavorable due to the technique of filling sand, where organic matter and clay particles is washed, and especially the inability to keep atmospheric water. In such conditions, planting seedlings of many tree species was doomed to failure. During the sixties of the last century, so-called "deep" planting was introduced in the commercialy important plantations, as new technological method of establishing poplar plantations in which plant it comes in contact with the ground water level (May, 1960). This enabled successful establishment of green areas with poplar trees in urban condition of Novi Sad.

Poplar trees were planted in the alleys (line plantings), alone or in small or large groups in urban foreheads: streets, residential blocks, parks, factory circles, in addition to schools, kindergartens and so on. The basic purpose of poplar plantations was the humanization of urban areas and priority role of greenery was to meet more demands in a short time, above all to achieve its sanitary-hygienic role (the elimination of air pollution, improve the microclimate, noise reduction), and then reached aesthetic and visual effect, which is in accordance with scientifically defined knowledge that trees in urban conditions mitigates microclimate (Akbari et al., 2001), reduce energy use and atmospheric carbon dioxide (McPherson, 1998), improve air, soil, and water quality (Nowak, 2006), mitigate stormwater runoff (Xiao et al., 2000), reduce noise, increase property values, and enhance the social and aesthetic environment of a city (Nowak et al., 2001).

These social, economic and environmental benefits are correlated with the size of trees and their crowns. Tree crowns play an essential role in tree productivity, since crowns are the location of the physiological processes, principally photosynthesis, respiration, and transpiration, leading to growth and development of the tree (Crecente-Campo et al, 2009). Therefore, it is necessary to know the exact dimensions of the crown: length, width, volume, surface area.

Obtaining exact information about the tree crown, especially of its volume is not always possible and is related to extensive and expensive measurements. For this reason modelling of tree crowns is applied today. One of the ways involves the partition of the crown on parts and approximation of regular geometrical figures: paraboloid, cone, cylinder, spheroid, neiloid). The basis for determining the volume of tree crowns is the assumption that the surface projection of the crown is circle, which allows that rotating the crown boundary curve line (crown edge) around the axis of the tree is obtained crown volume (Assmann, 1970).

Direct measurements of crown elements are very difficult and often not precise enough for a successful approximation of its volume. For this reason indirect

measurements of the crown are often performed that include direct measurements of only some elements of the crown (total height, height to the first live branch, etc.)., and other elements of crowns are obtained indirectly, either by takig photographs, using a Spiegel relascope (Waguchi, 2004) or using special devices such as "crown window" (Hussein et al, 2000).

Using digital photographs enable accurately enough determination of the elements of crown such as the total volume (gross volume) that refers to the total volume of branch leaf, stem and the air between them. With digital photographs it is possible to successfully obtained and a three-dimensional picture of a tree with the elements of interest, such as leaves, branches and trunk (Phattaralerphong and Sinoquet, 2005).

The aim of this study was, based on direct measurements of tree height and using digital photographs, to define crown shape models of open grown hybrid poplar trees in urban conditions of Novi Sad. Based on the crown profile models the width, the volume and the surface area of tree crowns of different ages are obtained, which enables us to consider their ecological role in the urban environment, but provides the elements and represents the basis for planning of green areas.

MATEIJAL I METOD RADA

Researches were done on hybrid poplar trees of different ages in the urban conditions of Novi Sad. The trees were chosen so that they grown in open space, with no interaction between neighboring trees or building structure. A total of 30 trees were measured.

Each tree was measured diameter at breast height ($d_{1,3}$) from two perpendicular measurements with an accuracy of 1 mm, total height (h_t) and height of the beginning of the first live branches in the crown (h_d) with altimeter Vertex III type with an accuracy of 0.1 m. In order to determine the age of trees drilling the tree at breast height by Presler's borer to the center of the tree was done, and the number of rings were determined.

Every tree was photographed in two mutually perpendicular directions with digital camera Olympus E-PL1 with a resolution of 12 megapixels and measured the distance to the tree. Photographs were used to carry out digitalization of the edge of tree crowns with at least 15 points on each side of the crown profile. Digitalization are formed pairs of points, $M_i(x,y)$, in the local coordinate system (top of the tree is the origin, and x axis is the tree spindle) who served in the next step of modelling curve border line of the edge of tree crowns by polynomial of the 2nd to 8th degree by the formula 1:

$$y = a_0 + a_1x + a_2x^2 + a_3x^3 + a_4x^4 + a_5x^5 + a_6x^6 + a_7x^7 + a_8x^8 \qquad (1)$$

where: y - radius of curve border line of the crown profile, x - distance from the top of the trees along the spindle (axis) of the tree.

The choice of the polynomial degree was based on the coefficient of determination (R^2) and form of the beginning (top tree) and the end of curves (the height of the first live branch in the crown), which has to gravitate to the top or to the first live branch in the crown.

Length of the crown was obtained as the difference between the total tree height and height to the first live branches in the crown ($l_k=h_t-h_d$). The maximum width of the crown (b) is obtained as the maximum of the polynomial ($b/2$) in the interval of the length of the crown (l_k), and the crown projection area (c_p) with the formula for the area of the circle to the maximum width of the crown (b). The crown surface area is obtained by integration of the curve border line of the edge of the crown around the axis of the tree within the boundaries of the peak ($x_1=0$) to of the first live branches in the crown ($x_2=l_k$) by the formula (2), while volume of the crown are obtained by the formula (3) (Stewart , 2012):

$$S = 2\pi \int_0^{x_2} y \sqrt{1+\left(\frac{dy}{dx}\right)^2}\, dx \qquad (2)$$

$$V = \pi \int_0^{x_2} y^2 dx \qquad (3)$$

These elements, as well as the measured elements of growth of trees ($d_{1,3}$, h_t, h_d), were used to obtain other derived elements of the crown: the crown projection area (p_c), the form factor of the crown (f_c), the crown percent (l_k/h_t), the degree of spread of the crown (b/h_t), the crown fullness ratio (b/l_k) (Assmann, 1970).

Data processing was performed by Excel and STATISTICA ver. 8.0 (StatSoft).

RESULTS

In defining the models of curve border line of the crown of hybrid poplar trees in urban conditions of Novi Sad polynomials of degree II-VI have been used successfully (Table 1). The majority, 14 trees or 47%, is successfully modeled by a polynomial of degree IV, and in 9 of trees or 30% was used by polynomial degree VI. In the analyzed sample trees polynomials VII and VIII degrees have not proved good enough for their poor service to gravitate to top of the tree and to the first live branch in the crown.

Table 1. Number of trees with a selected degree polynomial models of curve border line of the crown profile

Degree of polynomial:	*a(2)*	*a(3)*	*a(4)*	*a(5)*	*a(6)*	*a(7)*	*a(8)*
n	2	4	14	1	9	-	-

Sample trees included trees 10-47 years old, average 31 years, with breast height diameters of 17.5 to 94.0 cm, an average of 65.2 cm and a height of 10.5 to 36.0 m, an average of 25.2 m (Table 2). Crown length ranged from 8.2 to 32.1 m, with an average 20.2 m and crown width of 3.5 to 22.7 m, an average 14.5 m. The crown surface area, obtained by rotation of the crown curve border line by the formula 2, ranged from 77-1760 m^2, an average 806 m^2 and volume of crown ranged from 56-7250 m^3, an average 2180 m^3 (Table 2 and 3).

Since the analyzed sample of trees included a wide range of ages, this has caused and a huge range and variations of elements of growth of trees and their crown. The coefficient of variation was the lowest for height of trees and is 21.1%. Length and width of the crown, as well as breast height diameters, ranged from 25-29%, age ranged 39%, the crown surface area 40%, while the highest varies the crown volume from over 60% (Table 2).

Table 2. Elements of growth of hybrid poplar trees and their crown.

	Age [year]	$d_{1.3}$ [cm]	h_t [m]	l_k [m]	*b* [m]	p_c [m^2]
average	31	65.2	25.2	20.2	14.50	178.2
c_v [%]	38.8	29.3	21.1	25.1	28.6	48.5
min	10	17.5	10.5	8.2	3.44	9.3
max	47	94.0	36.0	32.1	22.74	406.2

Crown projection area (p_c), as derived element from the crown width (*b*), varies in the range of 9-406 m^2, with an average area of 178 m^2. Form factor of the crown (f_c), as the ratio of the crown volume and the cylinder of the same width and length as the crown, ranged from 0.39 to 0.74, an average 0.59, with a much lower coefficient of variation than the crown projection area (Tables 2 and 3).

Table 3. Derived elements of crowns of hybrid poplar trees.

	S [m^2]	V_c [m^3]	f_c [$m^3 \cdot m^{-3}$]	l_k/h_t [$m \cdot m^{-1}$]	b/h_t [$m \cdot m^{-1}$]	b/l_k [$m \cdot m^{-1}$]
average	806	2180	0.594	0.803	0.574	0.725
c_v [%]	40.4	60.7	16.3	11.7	23.3	26.3
min	77	56	0.387	0.597	0.327	0.419
max	1763	7256	0.739	0.949	0.880	1.167

Mean values of tree growth elements and their crown, grouped into age categories of 10 years width, are shown in Tables 4 and 5.

Results of ANOVA tests showed significant differences between trees of different age categories in all studied elements of growth of trees and their crowns (Tables 4 and 5). The greatest differences were detected in diameter at breast height, height and the crowns width. Based on the results of the $LSD_{0.05}$ test trees of different age categories are grouped in significantly different groups. In all elements of growth of trees and their crowns the youngest and the oldest trees differ significantly. Elements of growth of trees medium age categories are significantly lagging behind the oldest categories in breast height diameter, height and crown width, but not far behind in terms of volume and crown surface area of the trees.

The crown projection area (p_c), as derived elements of the crown, differs significantly depending on the age of the trees (Table 5). Older trees have a larger crown projection area, but, as with other elements of the crown (*b, S, V*), medium-sized tree age category (age 21-30 years) does not significantly lag behind the older trees.

Table 4. Mean values of the elements of growth of trees and their crown grouped by age categories and results of ANOVA and $LSD_{0.05}$ test.

Age category	*Age* [year]	$d_{1.3}$ [cm]	h_t [m]	l_k [m]	*b* [m]	p_c [m^2]
1-10 year	10	20.8 d	11.4 c	9.1 b	4.00 d	12.8 c
11-20 year	15	47.4 c	23.2 b	18.3 a	12.21 c	121.2 b
21-30 year	26	63.0 b	25.9 b	21.0 a	14.26 bc	168.9 ab
31-40 year	34	80.0 a	23.6 b	21.1 a	16.07 ab	204.2 a
41-50 year	45	77.1 a	29.1 a	22.2 a	17.25 a	236.1 a
F	-	16.27	13.15	4.3964	11.52	5.5891
p	-	$0.1 \cdot 10^{-5}$	$0.7 \cdot 10^{-5}$	$7.91 \cdot 10^{-3}$	$1.9 \cdot 10^{-5}$	$2.35 \cdot 10^{-3}$

Table 5. Mean values of derived elements of crowns grouped by age categories and results of ANOVA and $LSD_{0.05}$ test.

Age category	*S* [m^2]	V_c [m^3]	f_c [$m^3 \cdot m^{-3}$]	l_k/h_t [$m \cdot m^{-1}$]	b/h_t [$m \cdot m^{-1}$]	b/l_k [$m \cdot m^{-1}$]
1-10 year	99 c	86 c	0.725 a	0.793 ab	0.349 c	0.440 b
11-20 year	594 b	1337 b	0.618 ab	0.788 ab	0.536 b	0.685 ab
21-30 year	811 ab	2253 ab	0.596 ab	0.807 ab	0.547 b	0.682 ab
31-40 year	960 a	2715 a	0.645 a	0.894 a	0.688 a	0.769 a
41-50 year	965 a	2642 a	0.523 b	0.755 b	0.606 ab	0.829 a
F	6.1413	6.3537	3.307	2.038	3.5675	2.4315
p	$1.38 \cdot 10^{-3}$	$1.14 \cdot 10^{-3}$	$2.63 \cdot 10^{-2}$	$1.2 \cdot 10^{-1}$	$1.96 \cdot 10^{-2}$	$7.4 \cdot 10^{-2}$

Form factor of the crown was the highest in the youngest and the smallest in the oldest trees. However, in other age groups of trees no clear regularities in the influence of age on the form factor of the tree crown of hybrid poplar trees (Table 5).

Age had no significant effect on the percent of the crown (l_k/h_t), but had a significant effect on the degree of spread (b/h_t) and crown fullness ratio of the crown

(b/l_k). With increasing age significantly increases the degree of spread and crown fullness ratio of the crown (Table 5).

DISCUSSION AND CONCLUSIONS

The results showed that for modelling elements of tree crowns grown on open canopy conditions can be used the combined method direct measurement of trees height and digitizing the edge of crown profile with digital photographs. The models of the edge of the crown profiles were obtained by polynomials of second to sixth degree. In doing so polynomials of fourth and sixth degree show as the most suitable to obtain the crown profile model of most of the analyzed hybrid poplar trees in urban conditions of Novi Sad.

Elements of the growth of tree crowns of hybrid poplar in conditions of Novi Sad significantly differ from the same elements in productive poplar plantations, primarily due to the significant influence of space to grow on of the tree crown. Exploring the elements of tree crowns of poplar clone I-214 in productive plantations aged 7 Marković (1980) found a strong dependence of the elements of the tree crowns on both, the density of planting or space to grow, and on the characteristics of soil. The obtained elements of growth of tree crowns of hybrid poplar youngest age category (under 10) in conditions of Novi Sad are within the limits to that obtained by Marković (1980) by applying an approximation of the crown shape with regular geometrical figures (paraboloid, cylinder and cone). Applying the approximation of the crown profile of pedunculate oak and common hornbeam in the stands of hygrophilic forest in Slavonia Dubravac et al (2009) found that the volume of the oldest oak and hornbeam trees not exceed 2000 m^3, with an average value in the sixth age categories (101-120 years) of 1100 m^3 with oak and 385 m^3, with hornbeam. Our results show that the hybrid poplar trees grown in open canopy conditions in the urban environment of Novi Sad aged over 20 years had the crown volume that is twice the volume of the pedunculate oak trees in natural stands.

As tree growth and its size increasing. Our results showed that the trees of 21-30 years old are significantly lagging behind the oldest categories of trees (41-50 years) by size of diameter at breast height, height and width of the tree crowns, but do not lag significantly in terms of the volume and the crown surface area of trees. Lagging behind in terms of diameter at breast height was expected considering that trees are in open canopy conditions, and where the growth in diameter caused by providing mechanical stability of trees. Small differences in the crown volume are in agreement with the biological regularities of growth of poplar trees, primarily emphasized in earlier research relating to the duration of the production cycle in poplar plantations in length from 20 to 25, and not more than 30 years when trees in productive plantations achieved the highest production of wood volume (Marković and Pudar, 1990; Andrašev, 2008).

Having in mind diverse and multiple benefits of trees in urban conditions, which can be grouped into three main categories: social, economic and ecological, it is necessary to know the elements of the growth of trees and their crowns because it allows experts and researchers to define a model of cost-benefit, analyzes the different management scenarios, and define the best management practices in order to ensure sustainable urban forestry (McPherson et al, 2000).

The obtained elements of tree crowns of hybrid poplar trees grown in urban conditions of Novi Sad are the basic elements in the spatial planning of green areas.

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MODELOVANJE KROŠANJA STABALA HIBRIDNE TOPOLE ODRASLIH U URBANIM USLOVIMA NOVOG SADA

Apstrakt

U radu se opisuje metod i iznose modeli krošnji stabala hibridnih topola raslih u uslovima otvorenog sklopa u Novom Sadu. Modeli krošnji su dobijeni na osnovu merenja elemenata rasta stabala (prsni prečnik, visina, visina do prve žive grane) i digitalizacije oboda krošnji stabala sa digitalnih fotografija. Digitalizovane tačke oboda krošnji su poslužile za modelovanje njene izvodnice polinomima II-VIII stepena čijom rotacijom oko ose stabla se dobija zapremina i površina omotača krošnje. Dobijeni elementi krošnji stabala različite starosti omogućavaju sagledavanje njihove ekološke uloge u urbanim uslovima, ali predstavljaju i osnovu za planiranje zelenih površina.

Ključne reči: *krošnja, modelovanje, polinomna regersija, topola, urbani uslovi*