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ESTIMATION OF PRUNED BIOMASS THROUGH THE ADAPTATION OF CLASSIC DENDROMETRY ON URBAN FORESTS: CASE STUDY OF *SOPHORA JAPONICA*

OSZACOWANIE ILOŚCI ŚCIĘTEJ BIOMASY W OPARCIU O ADAPTACJĘ METODY KLASYCZNEGO POMIARU DRZEWOSTANU W ZIELENI MIEJSKIEJ NA PRZYKŁADZIE *SOPHORA JAPONICA*

Key words: urban forest, residual biomass, renewable energy, source of alternative energy, bioenergy.

Słowa kluczowe: zieleń miejska, biomasa odpadowa, relacje allometryczne, równania objętości, bioenergia.

Ilość miejskiego drewna pochodzącego z operacji cięć pielęgnacyjnych jest potencjalnie dużym, niewykorzystanym źródłem biomasy, która mogłaby bardziej znacząco przyczynić się do regionalnej i krajowej biogospodarki niż ma to miejsce obecnie. Lepsze wykorzystanie biomasy drzewnej z miejskich terenów zielonych i rekreacyjnych oraz obszarów przemysłowych, stanowiącej biopaliwo do wytwarzania ciepła i energii. Mogłoby to zmniejszyć presję na lasy oraz zmniejszyć koszty składowania odpadów na poziomie lokalnym oraz regionalnym. Określenie ilości miejskiej biomasy drzewnej, stworzenie kompleksowej bazy danych na temat charakterystyki dendrometrycznej, poznanie zależności pomiędzy podstawowymi parametrami drzewa a ilością uzyskanej biomasy uznano za cel tego badania. Wyniki ilościowe drzewnej biomasy odpadowej uzyskanej z rocznych cięć pielęgnacyjnych gatunku Sophora japonica są przedstawione w pracy zgodnie z rodzajem praktyki stosowanych cięć. Drewno stanowiło 59,97% ogólnej masy materiału pochodzącego z cięć pielęgnacyjnych przed procesem suszenia, wilgotność drewna w stanie świeżym wyniosła 44,88%, a średnia ilość suchej biomasy uzyskanej z pojedynczego drzewa wyniosła 18,07 kg. Modele regresji zostały zastosowane do przewidzenia wagi suchej biomasy uzyskanej z pojedyncze-

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go drzewa. Istotne zależności zaobserwowano pomiędzy ilością biomasy oraz średnicą na wysokości pierśnicy w wysokości R^2 = 0,60. Analiza wskazuje, że znaczące ilości biomasy odpadowej pochodzącej z operacji cięć pielęgnacyjnych gatunków ozdobnych mogą być wykorzystywane do osiągnięcia celów ekologicznych i energetycznych. Ponadto, przedstawiona metodologia tworzy narzędzie do lepszego przewidywania zysków, pracy w terenie oraz zarządzania logistycznego na przyszłość.

1. INTRODUCTION

Urban forests and city parks are a potentially abundant source of wood biomass. Due to the lack of information on the availability and characteristics of urban wood residual biomass, proper management of this valuable material is not popular in the renewable energy sector. Currently municipalities pay significant values for maintenance of urban green space and few processes are applied to offset these expenses [McKeever, Skog 2003, Solid Waste… 2002]. Most of urban wood waste biomass is not further processed and lands up in landfills [MacFarlane 2007]. A new and comprehensive approach to waste management in urban forests and city parks could contribute to local and regional economies [MacFarlane 2009]. Moreover, the lack of precise information on the quantity and quality of the raw material as well as basic dendrometric characteristics of species in relation with potential biomass creates a barrier to the rational use of this material.

Sophora japonica L. also known as *Styphnolobium japonicum* and Pagoda Tree is a species in the subfamily *Faboidea* of the pea family *Fabaceae. Sophora japonica* is native to eastern Asia and a popular species in almost all Europe. Reaching up to 25 m in height, cultivated as ornamental or shade tree in streets, city parks and towns often accompanies the *Robinia*, which has a very similar appearance. It is appreciated for flowering in late summer after most flowering trees have finished, its resistance to cold, as well as heat and dryness [López González 2010]. Due to its beautiful deep green colour foliage, that is not attacked by insects and the advantage over *Robinia* to give a denser shade it is widely used in urban zones [De La Torre 2001].

2. MATERIAL AND METHODS

2.1. Field study

The study area is located in Mislata, a city of the east of Spain in the province of Valencia. The procedure of trial consisted on a random selection of a municipal street of dense car and pedestrian traffic and 30 individuals of *Sophora japonica* pruned under uniform topping type of pruning practice. Previously to carry out pruning operations, the identification of the selected individuals was performed. Following data were determined:

1. Tree data: diameter at breast height (at 1.3 m height), crown diameter, distance from soil to the crown, total tree height.
2. Tree management information: date and type of last pruning operations.

A total of 30 individuals of *Sophora japonica* with diameter at breast height between 13.8–23.0 cm, crown diameter between 5.7–9.75 m, distance from soil to the crown between 2.8–4.7 m and total tree height between 7.4–12.4 m were examined. All sampled trees were pruned each year under uniform topping type of pruning practice. This type of pruning consists of removing the major part of the canopy from the tree and leaving mostly branch stubs [Michau 1987].

To measure trunk diameters a traditional aluminium calliper was used, for crown diameter a tape measure, and for the height a Vertex IV hypsometer. Once pruning operations ended, the residual biomass was formed in bundles and weighted by means of a dynamometer. Weight measurements were carried out in field conditions. Samples of wood were put into small plastic containers in order to determine moisture content in laboratory conditions and obtain dry matter results. Evolution of the drying process was carried out in two types of conditions: open-air drying with average temperature 21.32ºC and relative humidity 42.41%, stove drying with temperature 105˚C. In both cases, a daily record of results was made until the stabilization of weight. Several branches of each sample-tree were defoliated to determine the percentage of foliage and wood mass. Sampled branches were collected for further dendrometric calculations.

2.2. Dendrometric analysis of the branches

The dendrometric analysis is focused on developing methods to calculate the actual volume of any structure of the tree. From this result, the biomass can be estimated by multiplying the density by the volume. For this, morphic coefficient f (also called form factor) was studied. Morphic coefficient f is defined as the ratio between the actual volume of a branch and a geometric model volume calculated from base diameter and length (Equation 1). The model that provided the form factor closer to 1 defined better the shape of the branch, and hence, it was selected for actual volume estimations.

$$f = \frac{\text{Actual volume of the analyzed structure}}{\text{Model volume}} \tag{1}$$

Therefore, form factor allows determining the volume of any structure by measuring the basal diameter and length. The form factor should be a parameter characteristic of the species and diameter class. However, for each test performed it was detected a statistical variability. Because of this, the mean and dispersion for each case were determined.

Actual volume determination was carried out on sampled branches of *Sophora japonica* that were collected after pruning operations in the selected sampled trees. These data were considered to obtain basic data for the development of relationships between the dimensions of branches and their volume. To calculate the actual volume of a branch, this was divided into several equal sections with the length of 10 cm, such as the Fig. 1 indicates [Lopez Serrano 2003, Velazquez et al. 2010, West 2009]. The volume was calculated by the following equations (Tab. 1).

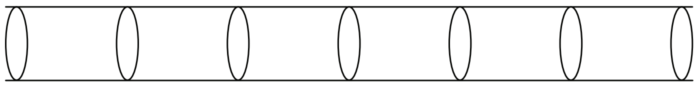

Fig. 1. Measurements of diameters in each interval
Rys. 1. Pomiary średnicy każdego odcinka

Table 1. Sectional volume formulae
Tabela 1. Równania objetości

Volume formulae	Volume model
$V_i = \frac{1}{3} \cdot \pi \cdot h \cdot \left(R^2 + r^2 + R \cdot r\right)$	Volume of a truncated cone
$V_i = \pi \cdot h \cdot R_a^2$ where $R_a = (R + r)/2$	Smalian's formula
$V_i = \pi \cdot \left(\frac{d}{2}\right)^2 \cdot h$	Volume of a cylinder

Where R is the major radius, r is the miner radius, h is the length of interval, d is the diameter.

The total actual volume of the branch was obtained from the sum of volumes of all sections (Equation 2).

$$V_{real} = \sum_{1}^{i} V_i \tag{2}$$

To calculate the model volume of the branch the volume of the following solids of revolution was analyzed: cone, cylinder, paraboloid and neoloid (Tab. 2) [Husch et al. 2003].

Table 2. Equations to compute volume of solids of revolution
Tabela 2. Równania wykorzystane do obliczenia objętości brył obrotowych

Model type	Volume model
Cylinder	$v = \frac{\pi d^2}{4} \cdot h$
Paraboloid	$v = \frac{1}{2} \cdot \frac{\pi d^2}{4} \cdot h$
Cone	$v = \frac{1}{3} \cdot \frac{\pi d^2}{4} \cdot h$
Neoloid	$v = \frac{1}{4} \cdot \frac{\pi d^2}{4} \cdot h$

Where v is the volume model, d is the base diameter of a branch, h is the height of the branch, which has been measured for each individual of the sample.

2.3. Residual biomass prediction models

Apparent volume of a tree crown was related with the biomass obtained from pruning operations. The apparent volume of a tree crown was determined using simple measurements taken at field: crown diameter, total tree height and height from soil to the crown. From these data, three solids of revolution (cone, paraboloid and semisphere) were applied for volume calculation. It is assumed that growth models of tree crowns resemble the form of semispheric, parabolic and conical growth (Tab. 3) [Dieguez et al. 2003].

Table 3. Growth models
Tabela 3. Modele wzrostu

Growth models	Volume model
Cone	$vc = \frac{\pi \cdot CD^2 \cdot hc}{12}$
Parabolid	$vc = \frac{\pi \cdot CD^2 \cdot hc}{8}$
Semisphere	$vc = \frac{\pi \cdot CD^3}{12}$

Where vc is the crown volume, CD is the crown diameter, hc is the crown height.

Regression models were also calculated to predict the amount of residual biomass from pruning operations of *Sophora japonica* from simple measures such as diameter at breast height, crown diameter and total tree height.

3. RESULTS AND SUMARRY

The results of quantification of the residual wood biomass obtained from pruning operations of *Sophora japonica* are presented. The results are shown according to the topping type of pruning practice applied. The procedure of pruning was held every year. The frequency and type of pruning operations have a key influence on the quantity of the material produced [Drénou 2006]. Compared sample trees are characterised with mean diameter at breast height 17.80 cm, mean crown diameter 6.95 m, mean height from soil to the crown 3.53 m and mean total height 10.22 m. In this work could be noted that wood formed 59.97% of total weight of all pruned material before drying. The rest 40.02% of weight was formed by leaves. Wood moisture content was 44.88% in wet basis. The mean and dispersion obtained comparing all sample trees analyzed according to the quantity of residual biomass obtained were 18.07 kg of dry wood biomass per tree and standard deviation 4.25 kg. Fig. 2 shows the variation of moisture content during the evaluation of the drying process carried out in both open-air drying and convection drying conditions. It is observed that the minimum moisture content in open-air was obtained after 26 days and in stove drying conditions after 24 hours. Dry matter results allow calculating the amount of dry wood biomass obtained from pruning operations.

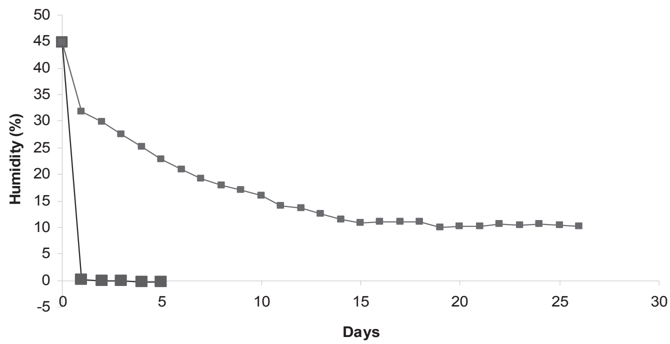

Fig. 2. Drying curves

Rys. 2. Krzywa wysychania

3.1. Branch form factor

Table 4 shows the results of mean and standard deviation values of the branch form factors obtained for different models. From these values, the actual volume of each branch can be obtained from simple measures such as base diameter and length. The model that produced a form factor closer to 1 was the cylinder. This model represented the best fit to characterize the actual volume.

Table 4. Mean values and standard deviation of form factor of sample branches of *Sophora japonica*

Tabela 4. Wartości średnie i odchylenie standardowe czynnika kształtu próbek gałęzi *Sophora japonica*

Model volume	Real volume					
	Smalian		Trunced cone		Cylinder	
	ƒ	σ *ƒ*	*ƒ*	σ *ƒ*	*ƒ*	σ *ƒ*
Cylinder	0,57058382	0,09620885	0,57001005	0,09612454	0,61456002	0,10167947
Paraboloid	1,14116765	0,19241771	1,1400201	0,19224909	1,22912004	0,20335894
Cone	1,71175147	0,28862656	1,71003014	0,28837363	1,84368006	0,3050384
Neoloid	2,2823353	0,38483541	2,28004019	0,38449817	2,45824009	0,40671787

Where *ƒ* is the mean form factor, σ is the standard deviation.

3.2. Regression models for the prediction of residual biomass

Regression models were calculated to predict the amount of residual biomass from annual crown raising pruning operations of *Sophora japonica* from simple measures such as diameter at breast height, crown diameter and total tree height. The best result is presented below.

1) Relationship between biomass and diameter at breast height:

$$B(kg) = -0.1029 \cdot dbh^2 + 5.122 \cdot dbh - 39.912\,;\ \ \mathrm{R}^2 = 0.6028$$

Where *B* is the biomass obtained from pruning operations, *dbh* is the diameter at breast height (cm). A relationship between quantity of biomass and diameter at breast height is observed in the quadratic model. This variable provided the best fit, with a value of $R^2 = 0.60$, what indicates a good explanatory power for predicting biomass;

2) Biomass calculation from crown diameter and height, and diameter at breast height.
In addition, regression models for predicting residual biomass were tested from combinations of the parameters such us diameter at breast height, crown diameter, total tree height and distance from soil to the crown. The best result is shown in the following

equation. Although was obtained a higher R^2 value (R = 0.65), the combination of these parameters did not improve significantly the prediction model obtained from only the diameter at breast height:

$$B(kg) = 6.76079 - 0.796866 \cdot hc \cdot H + 31.5802 \cdot hc \cdot dbh + 0.112431 \cdot H^2 + 0.0338995 \cdot hc \cdot H \cdot DC.$$

Where *B* is the biomass obtained from pruning (kg), *H* is the tree height (m), *hc* is distance from soil to the crown (m), *CD* is crown diameter, *dbh* is the diameter at breast height (cm).

On the other hand, prediction models calculated from the apparent volume of the crown were also analyzed. As observed in Fig. 4, there is a low linear relationship between the conical volume model and the amount of dry biomass obtained from pruning (R^2=0.378). The same result is obtained with parabolic volume model. A minor difference is observed in the semispheric volume model. These results demonstrate a low interdependence between mentioned parameters.

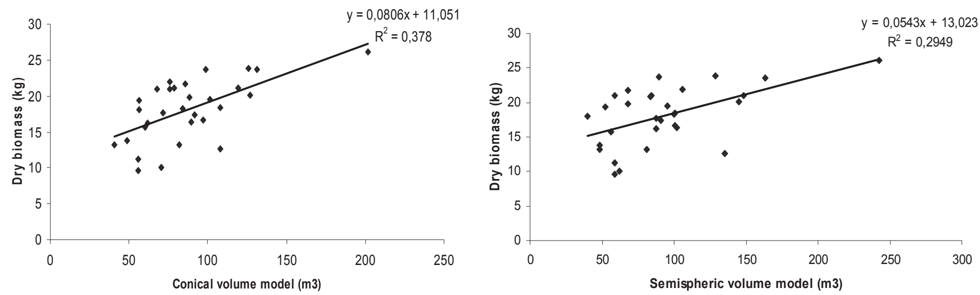

Fig. 4. Regression model presenting dry biomass versus conical and semispheric volume model
Rys. 4. Model regresji suchej biomasy w zależności od wykorzystanego modelu stożkowej i półkolistej objętości

4. CONCLUSIONS

The analysis indicates that a significant amount of residual biomass originates from pruning operations of *Sophora japonica,* and this can be used to achieve ecological and energy targets.

The total benefit of recovering utilizable biomass from urban wood waste is the cost avoided plus the market value for the biomass. Knowledge and ability to foresee the availability of raw material gives the possibility to implement long-term investments and to introduce urban wood residual biomass as a reliable and noteworthy source of renewable energy or alternative raw material.

From an environmental point of view, the increased recycling of recovered urban wood residual biomass can be seen as a positive evolution because it leads to incensement of the total volume of CO_2 stored as wood-based products, enlarging the life-cycle of the fixed carbon in the new recycled products.

Due to the continuing expand of urban land, the increasing expansion of urban forests is predictable. Taking into account reasons of safety, aesthetics and increasing environmental awareness the case of this study is found logical and justified.

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