STORMWATER MANAGEMENT: THE ROLE OF URBAN TREES

ROLUL ARBORILOR URBANI ÎN GESTIONAREA APEI PLUVIALE

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Abstract. *The influence of urban trees in management of stormwater is to moderate the microclimate, to reduce the "urban heat island" (UHI) through shading and evaporative cooling and also, by reducing glare and insolation. Trees intercept a portion of rainfall that evaporates and never reaches the ground. Surface runoff is avoided when precipitation is held on foliage until it returns into the atmosphere. The capacity of water interception is influenced by biological and structural characteristics of the trees (species-specific factors), and by climatic conditions (site-specific factors). The purpose of this paper is to study the water storage and evaporation capacity of the three important tree species identified in a typical urban of Iași: Acer platanoides L., Aesculus hippocastanum L. and Tilia sp.*
Key words: *surface runoff, rainfall interception, stormwater management*

Rezumat. *Arborii din peisajul urban contribuie la gestionarea apelor pluviale prin aportul lor în ceea ce privește ameliorarea microclimatică, diminuarea efectelor datorate fenomenului denumit "insulă de căldură" prin umbrire și evaporare și, de asemenea, prin reducerea iluminării excesive și a insolației. Arborii interceptează în coronament o parte din volumul de precipitații și îl redă atmosferei prin evaporare. Componentele structurale ale arborilor rețin apa care astfel nu ajunge pe suprafața solului, evitându-se scurgerile. Capacitatea de interceptarea a apei din precipitații este influențată de caracteristicile biologice și structurale (factori de specie) și de condițiile climatice (factori de sit). Lucrarea de față analizează capacitatea de stocare și evaporare a apei pluviale prin intermediul a trei dintre cele mai utilizate specii arboricole din mediul urban Iași: Acer platanoides L., Aesculus hippocastanum L. și Tilia sp.*
Cuvinte cheie: *scurgerea de suprafață, interceptarea apei din precipitații, managementul apelor pluviale*

INTRODUCTION

Surface stormwater runoff is a cause for concern in many urban areas. Urbanization alters flow pathways, water storage, rates of evaporation, groundwater recharge, surface runoff, the timing and extent of flooding. Trees reduce stormwater runoff by their canopy cover, which saves city stormwater management costs.

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Stormwater interception by the urban arboreal vegetation is very important. Stormwater is retained by the crown's surface; part of it passes straight through the leaves and branches and reaches the ground (throughfall), another part is temporarily retained by the trunk surface and is drawn towards the ground by gravity (stemflow) or evaporates into the atmosphere, while another part is retained by the crown, absorbed by leaves (Limm et al., 2009) and also evaporates (interception loss) (Xiao and McPherson, 2002). The capacity of stormwater interception depends on both the trees' biological (e.g. species, dimensions, foliage, stems and trunk roughness, leaf area index) and structural features (e.g., gap fraction, foliation period, crown surface and volume, canopy structure, geometric shape) and weather factors (e.g., temperature, relative humidity, net radiation, wind speed, frequency of events, evaporation rates) (Xiao et al., 2000).

The *avoided runoff* term (*AvR*) represents the annual rainfall interception estimated by i-Tree Eco, based on Hirabayashi (2013)'s model.

MATERIAL AND METHOD

This research, approached as case study, was conducted within the urban area of Iași, located in the province of Moldova (North-East of Romania).

The species chosen for the study are the Norway maple (*Acer platanoides* L.), the Horse chestnut (*Aesculus hippocastanum* L.) and the Linden (*Tilia cordata* M. and *Tilia tomentosa* M.).

The measurements were conducted in four existing sites: Podu de Piatră, Cantemir, Tătăraşi and Copou (neighborhoods in Iaşi). The selected trees were planted on a surfaces with no soil restrictions in the housing districts as green areas associated to three and four-story buildings. The analysed trees were different in age and size. The trees was in good health, and without visible evidence of major injury, void with disease or insect attack and free from natural injuries or human actions (severe cutting, tearing off bark or branches, vandalism, wind, storm, freezing rain). Also, the trees have aesthetic valences (healthy plant, balanced developed), and their aspect represents an important factor in the ecological benefits for the environment and human life. The researches were made during 2012-2013. On the month of July, after the period of active growing of the tree, by the performed measurements, was aimed at obtaining the bio-dimensional parameters, according with i-Tree Eco User's Manual v.5.0, Phase 1: Gathering General Data (http://www.itreetools.org/resources/manuals/Eco_Manual_v5.pdf). The weather data were obtained from NOAA Satellite and Information Service, NNDC Climatic Data Online available for IASI, RO, Station ID: GHCND:ROE00108896, Latitude 47,166º, Longitude 27,633º, Elevation 102m. Reference weather data and formatting documents was available at www.itreetools.org under Resources. The standard .txt file, received from NNDC Climatic Data Online by mail, contains the hourly weather data for period 01.08.2012-31.07.2013. The four projects (inventory data from Podu de Piatră, Cantemir, Tătăraşi and Copou) developed by i-Tree software are complex, but in this paper was used only: stem diameter at breast height (*DBH*), measured at 1.4 m from the ground and ”avoided runoff” (*AvR*), data obtained from i-Tree Eco reports, according with http://www.itreetools.org/resources/manuals/Eco_Manual_v5.pdf.

In order to obtain the *AvR versus DBH* regression models was used the Ordinary Least Squares (OLS) technique (Hutcheson, 2011), with a single explanatory variable. Advanced statistical software uses predefined regression functions of the nonlinear quadratic terms were logarithmically transformed into linear form, as equation 1:

$$\log_{10}(y_i) = a + b_1 \times \log_{10}(x_i) + b_2 \times \log_{10}(x_i^2) \quad (1), \text{ where:}$$

y_i is the observed response for the ith observation; x_i is the observed predictor of the ith observation; and a, b_1, b_2 are the parameters to be estimated.

Minitab® 17.1.0 statistical software was used for the graphic representation, coefficients extraction and statistical analysis. All equations were statistically ($p < 0.001$) significant at an alpha level of 0.05 (Analysis of Variance from Minitab). The two-tailed p value was less than 0.001 and by conventional criteria, this difference is considered to be extremely statistically significant.

RESULTS AND DISCUSSIONS

Conventionally, in landscape design, the graphic representation (plans, sections, details, perspectives, etc.) complies with the dimensional scale. When designing the landscape, the first consideration is to make the plan for the full-grown size (Nolting and Boyer, 2010; Hansen, 2012). The term *mature size* directly relates to the quantitative parameters (e.g., *DBH*, height, crown diameter, crown volume) that trees will have after years of development. Thus, for the statistical processing and interpretation of data it was used as an analysis interval/reference base, the *mature size* between 20 and 30 years for all three species. The parameters *DBH* and *AvR* are shown on table 1.

Table 1

Number of trees, *DBH* and *AvR* range for *mature size* period

Species	Sample size ($n_{mature\ size}/n$)	*DBH* range (cm) (mature size)	*AvR* range(m3/yr) (mature size)
Acer platanoides	22/57	27.0 - 48.0	0.524 - 0.725
Aesculus hippocastanum	11/61	15.5 - 24.5	0.198 - 0.348
Tilia sp.	13/70	21.0 - 32.0	0.288 - 0.503

On the other hand, there is no certain information regarding the age of the measured trees. In this case, the information from other papers was useful on estimation the age values having *DBH* as a reference base. For this estimation were used the scientific sources recommended in table 2. These referring to the age since the planting date and not to the real age (3 - 5 years old when planted).

Table 2.

***DBH* range estimation for *mature size* period**

	Acer platanoides	*Aesculus hippo.*	*Tilia* sp.
Age range (yrs) (since planting) *mature size*	*DBH* range estimation (cm) for *mature size* period		
	(fast growth rates)	(slow-moderate growth rates)	(moderate-fast growth rates)
20 - 30	27 - 48	15.5 - 24.5	21 – 32
Sources	Frelich L.E., 1992; Semenzato *et al.*, 2011; Troxel *et al.*, 2013	Lukaszkiewicz and Kosmala, 2008; White J., 1998	Frelich L.E., 1992; Lukaszkiewicz and Kosmala, 2008; Troxel *et al.*, 2013

Generating *Avoided Runoff versus DBH* models, where *DBH* values are the easily measured predictor variable, is necessary to calculate the volume of stormwater that is intercepted and retained by the analysed tree species and, respectively for their classification by efficiency.

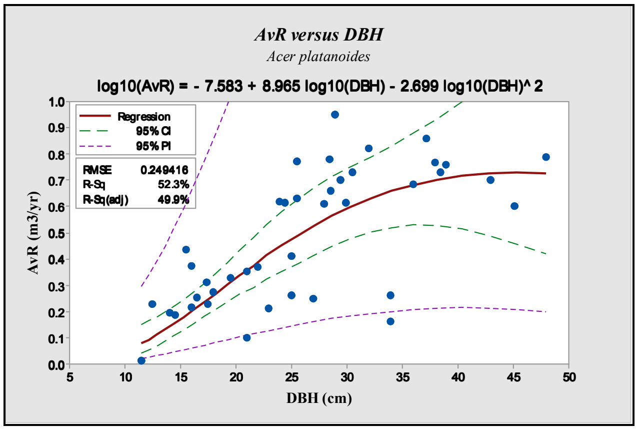

Fig. 1 - Regression model *AvR versus DBH* for *Acer platanoides*

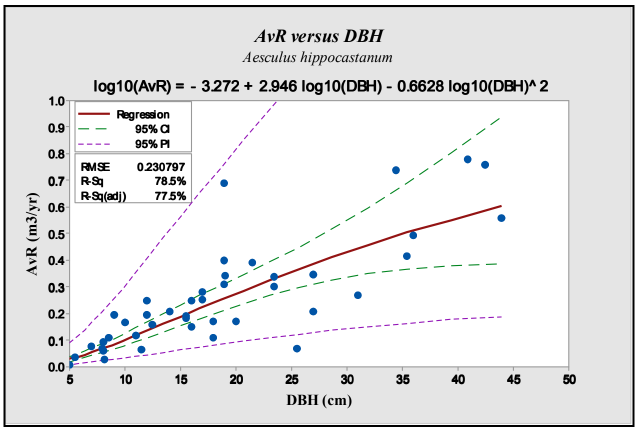

Fig. 2 - Regression model *AvR versus DBH* for *Aesculus hippocastanum*

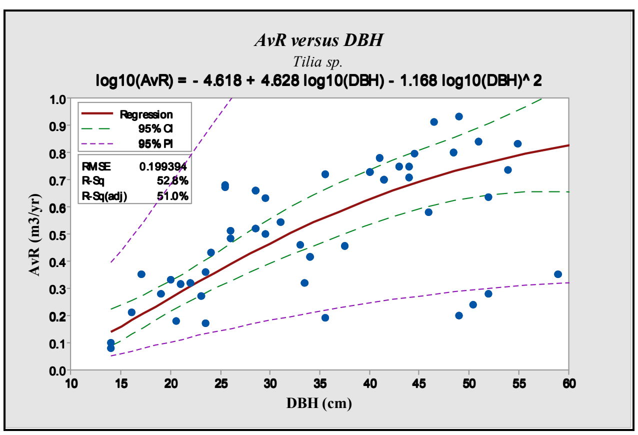

Fig. 3 - Regression model *AvR versus DBH* for *Tilia* sp.

Thus, using the prediction models given by the logarithmic equation (1) were obtained the estimated parameters (a, b_1, b_2), Adjusted R-squared R^2 (Adj.) and Root Mean Square Error (RMSE) for *Acer platanoides* (fig. 1), *Aesculus hippocastanum* (fig. 2.) and *Tilia* sp. (fig. 3.), in the relation *AvR versus DBH.*

Actual measurements (points), predicted responses (solid line), 95% confidence interval (CI), 95% prediction intervals (PI), R^2(Adj), RMSE and regression equations for the models are represented in fig. 1. (*AvR versus DBH* for *Acer platanoides*), fig. 2. (*AvR versus DBH* for *Aesculus hippocastanum*) and fig. 3. (*AvR versus DBH* for *Tilia* sp.).

After analysing the equation models for predicting *AvR*, the *Acer platanoides* (R^2(Adj)=0.49) and *Tilia* sp. (R^2(Adj)=0.51) show a moderate correlation between the regression curve and the values obtained from measurements, while *Aesculus hippo.* (R^2(Adj)=0.77) show a strong correlation.

For the comparative analysis of the three species regarding their efficiency in retaining rainwater in their foliage and avoiding surface leakage, there were overlapped the three regression functions, using the *mature size* period as an analysis standard (fig. 4.).

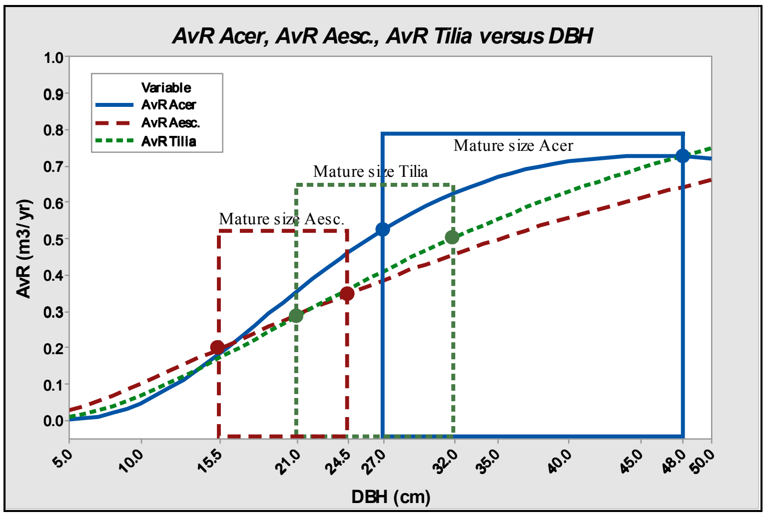

Fig. 4 - Regression models layers comparison *AvR versus DBH*

Summary statistics, including mean, minimum, maximum, standard deviation, and standard error of each of the individual tree data sets are shown in table 3.

Table 3

A summary statistics of AvR reported on *mature size* period

Species	*AvR (m^3/yr)*				
	min.	max.	mean	Stdev	SE
Acer platanoides	0.524	0.725	0.668	0.064	0.0137
Aesculus hippocastanum	0.197	0.348	0.274	0.053	0.0159
Tilia sp.	0.288	0.503	0.396	0.068	0.0190

CONCLUSIONS

1. The results obtained within this experiment by using three species with different individual characteristics (*Acer platanoides*, *Aesculus hippocastanum* and *Tilia* sp.), show a different response on the reduction of the level of *avoided runoff* by bio-retention.

2. The tree species have different contributions on stormwater retention in their foliage:

- *Acer platanoides* has the highest contribution (0.668±0.014 m^3/yr);
- *Aesculus hippocastanum* (0.274±0.016 m^3/yr) is the least efficient; the retained volume represents 41% of the volume retained by *Acer platanoides*;
- *Tilia* sp. (0.396±0.019 m^3/yr) has an intermediate yield, approx. 60% of the *Acer platanoides* and 45% higher than the *Aesculus hippocastanum*.

3. The results provide explicit information about the contribution of each species in the stormwater management, with a practical use in the landscape design of urban green spaces.

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