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Estimating Height and Diameter Growth of Some Street Trees in Urban Green Spaces

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Abstract

Estimating urban trees growth, especially tree height is very important in urban landscape management. The aim of the study was to predict of tree height base on tree diameter. To achieve this goal, 921 trees from five species were measured in five areas of Mashhad city in 2014. The evaluated trees were ash tree (*Fraxinus species*), plane tree (*Platanus hybrida*), white mulberry (*Morus alba*), ailanthus tree (*Ailanthus altissima*) and false acacia tree (*Robinia pseudoacacia*). Regression analysis of tree height versus tree diameter revealed several models (linear, logarithmic, exponential and power) that could be used for estimating the tree height of these five species. The logarithmic, power and exponential functions provided a good fit to the data on tree height against tree diameter for ash tree (R^2 = 0.9 and RMSE = 0.74), ailanthus tree (R^2 = 0.92 and RMSE = 0.44) and plane tree (R^2 = 0.72 and RMSE = 0.72), respectively.

Keywords: Growth models, Regression, Tree height, Urban trees.

INTRODUCTION

Estimates of street tree growth are of specific importance to the urban green spaces manager. Available information on dimensional growth of urban trees is usually based on personal observations and often lacks detailed and scientific validation. Trees are symbol of green, healthy cities and have the potential to play a key role in providing high quality urban environments (Draper and Richards, 2009). In addition, they are also used in a landscape architectural context to derive spatial and aesthetic functions (Larsen and Kristoffersen, 2002). In tree planting design, spacing and positioning of trees in relation to structures can be improved with more accurate information on tree growth. As defined by Crowe (2003), one of the garden design principles is scale that refers to how we perceive the size of an element or space relative to ourselves to the dimensions and proportions of the human body often refer to as human scale.

Various theoretical and empirical relationships among tree dimensions have been discovered and their ecological and evolutionary significance has been discussed, among which allometric relationships have been frequently used to infer patterns of tree growth and form (Niklas, 1994). Diameter at breast height (DBH) of a tree can be measured quickly, easily, and accurately, but the measurement of total tree height is relatively complex, time-consuming, and expensive. Furthermore, tree, stand, and site conditions may prevent accurate height measurements (Huang *et al.,* 1994). Therefore, height–diameter relationship models are then used to estimate the heights of trees measured only for diameter. A number of height–diameter equations have been developed using only DBH as the predictor variable for estimating total height. Jayaraman and Zakrzewski (2001) used models to localize height–diameter curves in natural undisturbed sugar maple stands in Southern Ontario. Robinson and Wyckoff (2004) imputed missing tree height measures by using a mixed-effects modeling strategy. Kershaw *et al*. (2008) developed some height-diameter equations based on dominant tree data in south Central Indiana. This models could predicted dominant canopy height and tree heights. In addition to DBH as independent variable, Avsar (2004) used crown diameter, Dauda *et al*. (2004) used competition factor (mean neighboring tree distance, frequency of the neighboring tree and position of the crown), Zhao *et al.* (2006) used stand age, site index and altitude, González *et al*. (2007) used dominant height, dominant under bark diameter at breast height, Newton and Amponsah (2007) used density and developmental effects, Saunders and Wagner (2008) used tree age and genetic material, and Karimian *et al*. (2015) used height, crown height and crown diameter at various ages.

The objective of this study was to find the relationships and develop regression prediction models for tree height and diameter at breast height (DBH) for five tree species that are commonly used and grown in the streets of Mashhad, Iran.

MATERIALS AND METHODS

The street trees were measured during the period of tree growth of 2014 in the city of Mashhad. Mashhad is the second most populated city in Iran located in Khorasan Razavi province between 36°17′ N. latitudes and 59°35′ E. longitudes. The measurements were made from five areas of the city (Karmandan, Hefdah-Shahrivar, Tabarsi, Meghdad and Rajaee streets). Five tree species were selected for the study. In total, 921 tree species including 400 ash trees (*Fraxinus species*), 100 plane trees (*Platanus hybrida*), 51 ailanthus trees (*Ailanthus altissima*), 255 white mulberry trees (*Morus alba*) and 115 false acacia trees (Robinia pseudoacacia) were recorded. The selection of the species for the study was mainly based on the importance and frequency of their cultivation in the urban space. The tree height and diameter at breast height were measured with a graduated pole and measuring meter, respectively. Stem DBH (D) (that is, 1.37 m above ground level) was taken by measuring the circumference (C) of the stem. The stem DBH was calculated as follows (Buba, 2013):

$C = D \times \pi,\ D = C/\pi$.

Summary statistics for total height and DBH are presented in Table 1.

The tree height and diameter at breast height were regressed together to compute the growth rate of tree height for each species. In this study, for the individual species, several models including

Table 1. Species diameter-height characteristics

Species	Diameter at breast height (cm)			Total height (m)		
	n	Mean	Stdev	n	Mean	Stdev
Ash tree (*Fraxinus species*)	400	12.58	6.5	400	6.02	2.78
Ailanthus tree (*Ailanthus altissima*)	51	15.53	9.79	51	6.43	3.01
White mulberry (*Morus alba*)	225	17.42	9.33	225	4.3	0.93
False acacia (*Robinia pseudoacacia*)	115	20.36	10.48	115	6.51	3.32
Plane tree (*Platanus hybrid*)	100	21.3	8.87	100	4.93	2.53

linear, exponential, logarithmic, and powers were tested. Therefore, different equations that provided the most appropriate fit to tree height versus diameter at breast height were used to identify appropriate functions for use in models estimating tree height growth rates. Coefficients of determination (R^2), root mean square error (RMSE) and the values of the coefficients (b) and constants (a) were also reported. The estimated tree height was determined by fitting the equation, and the final model was selected based on the combination of the highest coefficient of determination (R^2) and the lowest root mean square error (RMSE). RMSE has been used as a standard statistical metric to measure model performance in many research studies. RMSE is presented as a standard metric for model errors (Chai *et al*., 2013).

RESULTS

The coefficients of determination (R^2), root mean square error (RMSE), fitted coefficient and constant to predict tree height by tree diameter in five tree species are presented in Tables 2-6. Based on selection criteria previously described (higher R^2 and lower RMSE), the best models were selected for estimating tree height of five urban tree species. The DBH was selected as a pre-

Table 2. Estimated regression coefficients (a,b) and root mean square errors (RMSE) for predicting tree height (y) from diameter at breast height (x) in ash tree (*Fraxinus species*)

Models type	Form of model tested	Fitted coefficient and constant		R^2	RMSE
		a	b		
Linear	$y = ax + b$	0.144	4.352	0.82	0.93
Exponential	$y = ae^{bx}$	4.627	0.019	0.8	1.21
Logarithmic	$y = a\ln(x) + b$	3.001	-1.027	0.9	0.74
Power	$y = ax^b$	2.152	0.421	0.92	0.77

Table 3. Estimated regression coefficients (a,b) and root mean square errors (RMSE) for predicting tree height (y) from diameter at breast height (x) ailanthus tree (*Ailanthus altissima*)

Models type	Form of model tested	Fitted coefficient and constant		R^2	RMSE
		a	b		
Linear	$y = ax + b$	0.163	4.052	0.90	0.46
Exponential	$y = ae^{bx}$	4.388	0.024	0.87	0.49
Logarithmic	$y = a\ln(x) + b$	2.325	0.587	0.89	0.47
Power	$y = ax^b$	2.526	0.362	0.92	0.44

Table 4. Estimated regression coefficients (a,b) and root mean square errors (RMSE) for predicting tree height (y) from diameter at breast height (x) in white mulberry (*Morus alba*)

Models type	Form of model tested	Fitted coefficient and constant		R^2	RMSE
		a	b		
Linear	$y = ax + b$	0.007	4.184	0.39	0.13
Exponential	$y = ae^{bx}$	4.189	0.001	0.38	0.16
Logarithmic	$y = a\ln(x) + b$	0.097	4.075	0.17	0.21
Power	$y = ax^b$	4.091	0.021	0.16	0.16

Table 5. Estimated regression coefficients (a,b) and root mean square errors (RMSE) for predicting tree height (y) from diameter at breast height (x) in false acacia (*Robinia pseudoacacia*)

Models type	Form of model tested	Fitted coefficient and constant		R^2	RMSE
		a	b		
Linear	y = ax + b	0.096	3.978	0.41	1.66
Exponential	$y = ae^{bx}$	4.746	0.015	0.39	1.70
Logarithmic	y = aln(x) + b	1.966	0.514	0.48	1.56
Power	$y = ax^b$	2.198	0.336	0.51	1.60

Table 6. Estimated regression coefficients (a,b) and root mean square errors (RMSE) for predicting tree height (y) from diameter at breast height (x) in plane tree (*Platanus hybrid*)

Models type	Form of model tested	Fitted coefficient and constant		R^2	RMSE
		a	b		
Linear	y = ax + b	0.089	3.286	0.70	0.72
Exponential	$y = ae^{bx}$	3.532	0.017	0.72	0.72
Logarithmic	y = aln(x) + b	1.463	1.006	0.58	0.85
Power	$y = ax^b$	2.319	0.271	0.60	0.82

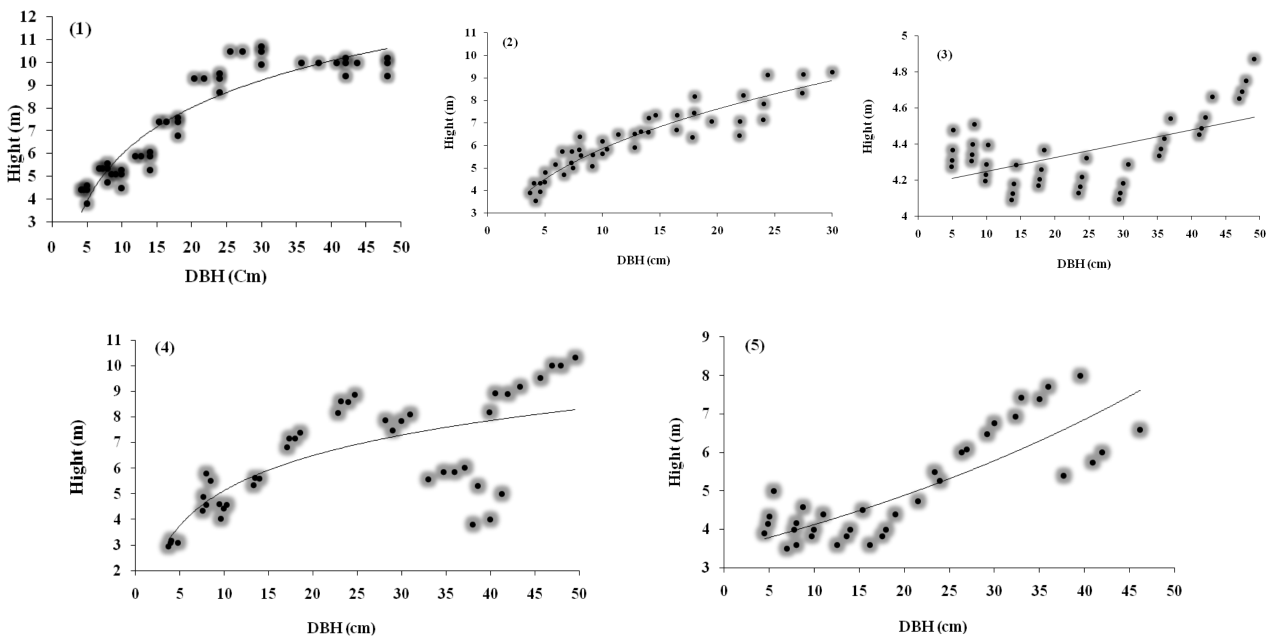

Fig. 1. Tree height (m) regressed on tree diameter at breast height (cm) by a various equations indicating confidence intervals at a level of 95% to the estimated mean for), ash tree (*Fraxinus species*) (1), ailanthus tree (*Ailanthus altissima*) (2), white mulberry (*Morus alba*) (3), false acacia (*Robinia pseudoacasia*) (4) and plane tree (*Plantanus hybrid*) (5)

dictor variable because it is easier to measure than tree height.

The highest R^2 for ash tree (*Fraxinus species*), ailanthus tree (*Ailanthus altissima*) and false acacia (*Robinia pseudoacacia*) was found in power model to be 0.92, 0.92 and 0.51, respectively. Unlike the ailanthus tree, in ash tree (*Fraxinus species*) and also false acacia (*Robinia pseudoacacia*), the best model (logarithmic model) was selected first on the basis of lower RMSE (0.74 and 1.56 respectively) and then, on the basis of higher R^2 (Tables 2, 3 and 5, Fig. 1).

RMSE is a good measure of how accurately the model predicts the response, and is the most important criterion for fit if the main purpose of the model is prediction (Grace-Martin, 2012). In white mulberry (*Morus alba*) and plane tree (Platanus hybrid), the highest R^2's were related to linear and exponential model, $R^2 = 0.39$ and $R^2 = 0.72$, respectively (Tables 4 and 6, Fig. 2).

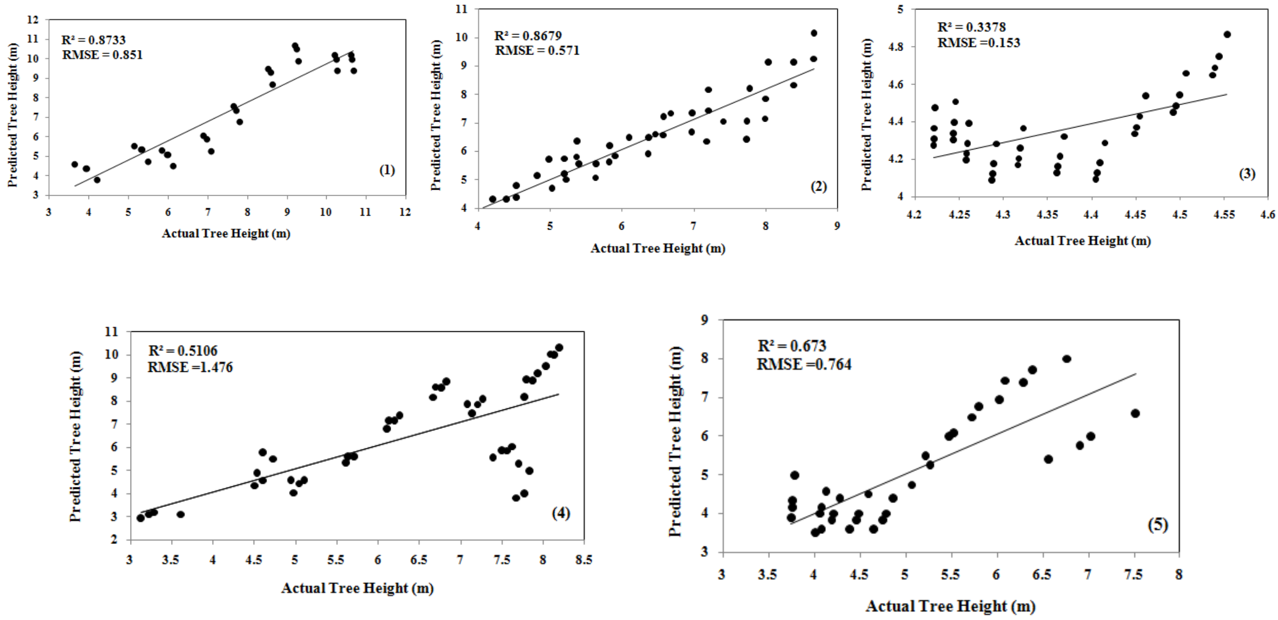

Fig. 2. Comparison of actual and predicted tree height in ash tree (*Fraxinus species*) (1), ailanthus tree (*Ailanthus altissima*) (2), white mulberry (*Morus alba*) (3), false acacia (*Robinia pseudoacacia*) (4) and plane tree (*Plantanus hybrid*) (5), (n=40)

Model validation

To validate the models for prediction of tree height based on diameter, about 40 trees of five species were selected from different experiments during 2014. The tree height and diameter at breast height were measured as described. Tree height was, then, estimated using the best model from the calibration experiment and, the estimated tree heights were compared to tree heights measured in the urban streets. Regression analyses were conducted and comparisons were made between measured versus calculated (predicted) tree height. In ash tree (*Fraxinus species*) and ailanthus tree (*Ailanthus altissima*), correlations between calculated and measured tree height were $R^2 = 0.87$ for both of them with RMSE = 0.85 and RMSE = 0.57, respectively. In plane tree (*Plantanus hybrid*), false acacia (*Robinia pseudoacacia*) and white mulberry (*Morus alba*), this correlations were estimated as $R^2 = 0.67$, 0.51 and 0.34 and RMSE = 0.76, 1.47 and 0.15, respectively.

DISCUSSION

Accurate tree height-diameter equations are a valuable tool for a planting designer in urban areas. An important design is to distinguish areas on a plan using canopy height because plant height establishes much of the spatial framework and controls vision, movement, and physical experience (Robinson, 2004). While tree DBH is easy to measure accurately, the measurement of tree height is time consuming and prone to error (Colbert *et al.*, 2002; Trincado and Leal, 2006). Therefore, height–diameter relationship model that is only based on diameter can be used to estimate the heights of trees. Tree height has been estimated using different methods and models (Stoffberg, 2006; Ritchie and Hamann, 2008; Yang and Bozdogan, 2011).

The equations developed in the current study cover a broad range of height and DBH of urban trees and they appear to adequately predict height-diameter relationships in these five tree species.

The result of the present study showed that the height of three species of these five trees are well correlated to the product of DBH with high R^2 values that are in agreement with those reported by Huang *et al*. (2000) for white spruce, Colbert *et al*. (2002) for some hardwood species, Sharma and Zhang (2004) for *Pinus banksiana* and *Picea mariana,* Trincado, Leal (2006) for radiata pine, and Lootens *et al*. (2007) for 12 upland species.

Also, model validation showed that in ash tree (*Fraxinus species*) and ailanthus tree (*Ailanthus altissima*), the tree height estimated by the model strongly agreed with the measured value that is evident from higher value of R^2 and lower RMSE. Although R^2 and RMSE were not very high and low in other tree species, respectively, it can be stated that the tree height estimated by the models were fairly acceptable in plane tree (*Plantanus hybrid*) and false acacia (*Robinia pseudoacasia*).

Although three different equations (logarithmic, power, linear and exponential) were considered to provide the most appropriate fit to DBH versus tree height data for the three species of trees, , they can be also recommended for all tree species except white mulberry (*Morus alba*) because of slight differences between R^2 and RMSE of mentioned models as compared to other models. The results of the study indicated a nearly good relationship between DBH and tree height in three urban tree species including ash tree (*Fraxinus species*), plane tree (*Platanus hybrida*) and ailanthus tree (*Ailanthus altissima*), so that we can use this method when we are in short of time for many measurements, especially tree height.

The development of equations to predict tree height from stem DBH of a tree species will enable urban landscape experts, researchers and urban managers to model costs and benefits, analyze alternative management scenarios, and determine the best management practices for sustainable green space (Paula *et al.*, 2001).

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