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INDIVIDUAL TREE PARAMETERS MODELS FOR MELIA AZEDARACH (CHINABERRY) TREE GROWN IN ERBIL

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ABSTRACT:

The crown width of a tree is very important parameter. It is responsible for tree survival and for producing the food for the whole tree. They produce oxygen, filter out dust and other airborne pollutants from the air, purification of the water, generate shadow and determine the scenic beauty of trees and forests. The tree crowns have a significant effect on the microclimate. But measuring of the crown width is a difficult task that needs much money, time and effort. Thus this study aimed at developing mathematical relationship between the crown width and breast height diameter for Chinaberry trees grown in Sami Abdulrahman Park in Erbil, Iraq. Both crown width and breast height diameters are the most important parameters of a tree. The breast height diameter of a tree can be measured very easily using diameter tape or caliper, unlike the measure of the crown width which is more cumbersome. Therefore, it is accustomed to regress it with breast height diameter in mathematical equations.to be used for predicting the crown width instead of measuring it whenever it is needed. Such regression models were undergone many measures of precision in order to select the most appropriate one that best fits the collected dataset. In this study 50 regression models were developed, of which 25 included the y- intercept and the other 25 regression models were without Y-intercept. The first group of regression models were excluded from the competition list because of the low values of the coefficient of determination. The second group of equations were subjected to many criteria for the purpose of selecting the best one and at last the equation: $Cw = 1.50168\sqrt{D}$ was finally selected for its high prediction ability and simplicity in application. According to this equation the crown width of for Chinaberry trees grown in (Sami Abdulrahman Park in Erbil) increases with 1.50168m for each unit increase in $\sqrt{D}$.

Keywords: crown width, regression analysis, Melia azedarach, crown volume, measures of precision, quantitative variables, and tree attribute relationships.

1. INTRODUCTION

In addition to wood production, the forest trees provide many functions and services to society such as; purification of air and water, increasing the recreation opportunities for the habitats, and storage of carbon. *Melia azedarach* is a small to medium deciduous tree attaining to the height of 5 -15 m and the stem diameter may reach 110cm. It has an attractive ornamental and shade tree with a high lateral branching and drought resistant. It has ferny foliage turning yellow in autumn. For such reasons, it has been introduced to Iraq and is widely used in afforestation of public parks.

Although this type of tree possesses all these distinct characteristics, it lacks many biometric studies necessary to determine the standing volume, the productivity of the species, and determination of growth and yield.

The crown is the most important part of the tree. It is responsible for tree survival and producing the food for the whole tree (Sharma *et al.*, 2016). The tree crowns have a significant effect on the microclimate (Grace *et al.*, 1987) and this effect is more evident in regions with hot, dry summer. The crown width of open grown trees is different in shape and size from that of stand grown trees. The shape and volume of the tree is greater than those of stand grown trees, and they are the results of both genetic and environment interactions (Kozlowski *et al*, 2012). The crown leaves have the ability of capturing radiant energy and making photosynthesis (Sharma *et al*, 2016). Furthermore, there is a significant relationship between the crown width and volume growth of a tree (Korhonen *et al*, 2006). The crown dimensions of a tree are often used as predictive parameters of growth and yield of individual trees (Soares and Tome, 2001; Hynynen *et al*, 2002). The shape and measures of crown dimensions the vigor and health of a tree. However, measuring the crown dimensions, including crown width is not a simple task: it is costly, time consuming and very difficult especially in dense forests (Sharma *et al*, 2016).

Therefore, such measures are regressed with some easily measured tree attribute in mathematical models to be used for estimation of the crown dimensions (Krajicek *et al.,* 1961; Carron 1968; Sönmez, 2009). (Fu *et al*., 2015) used Nonlinear mixed-effects crown width models for individual trees of Chinese fir. Paine and Hann 1982 found that a quadratic expression of stem diameter is superior to the use of linear power of the stem diameter in establishing of the crown width models. The crown width models can be used for estimation of other crown parameters such as crown volume, which can be used for quantification of crown production efficiency (Larocque and Marshall, 1994). The crown width models can be utilized for estimating the potential growing space of the tree under study (Pretzsch *et al*., 2015; Sharma 2016). The breast height diameter is the most often predict variable used in development of crown width models (Foli et al, 2003; Bechtold,W.A., 2004; Rautianinen and Stenberg, 2005; Rautiainen, M., & Stenberg, P. 2005; Sönmez, 2009). Recently there has been a great focus on the development of crown

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width models (Ottorini et al., 1996; Singer and Lorimer, 1997; Meng *et al*., 2009; Crecente-Campo *et al*., 2010; Fu *et al*., 2013; Crecente-Campo *et al*., 2013; Fu *et al*., 2015; Hao *et al*., 2015)

1.1 Purpose of this study

This study is dual – objective: 1) regressing the crown width of Melia azedarach tree on the breast height diameter and testing the performance ability of these models in order to choose the most appropriate one that fits the collected data set to be used for prediction of the crown width. 2) Using the estimated crown width in calculation of the volume of the crown, as it has the direct relationship with carbon sequestration

1.2 Statement of Problem

There is a great lack of biometrical information about Melia azedarach trees, despite the predominance of this type of trees in public parks, as well as its width dominance in road afforestation.

2. MATERIALS AND METHODS

2.1 Study Area and data collection

A sample of 100 trees without external defects was purposely selected from Sami Abdulrahman park in Erbil, Kurdistan region, Iraq.

Figure 1: Map of the study area.
(Source: Google map. 2022. Sami Abdulrahman Park. 1:200. Google Maps (online) Available through: Google maps https://www.google.com/maps/@36.1916448,43.9832965,15.25z (Accessed 20 June 2022)

The following measurements were taken on the selected trees:
1. Diameter at Breast Height (D.B.H.) or simply written as D
a) The diameters of the selected trees were measured over bark at breast height (1.3m above ground level). Such diameter is considered as a standard diameter for a tree (Because the irregularity of the cross-sectional area of most trees, two measurements perpendicular to each other at the breast height for each tree in the sample were taken (using caliper) and recorded (Van Laar A. and Akca A. 2007).
b) The geometric mean of the two measurements were calculated using the following formula (Kershaw et al 2016).

Geometric mean of diameter = $\sqrt{D1 * D2}$ -----------------(1)
Where
D1 and D2 are the two diameter measurements taken at breast height.

2. The total height to the nearest 1dm using Haga Altimeter. (Which is a device based on similar triangles and is used for measuring of height of objects.)

3. Crown diameter or crown width
a) Since the crown of most trees are irregular in shape, more than one measurement has to be taken for such parameter (Salih 2020). The horizontal distance on the ground between the trunk center of the tree to the edge of the projected line from the crown canopy was measured and multiplied with 2 to get the value of the crown diameter (Cw_1).
b) The same process was repeated on the perpendicular direction to get the second value of the crown diameter (Cw_2)
c) The geometric mean of these two values were taken for each tree to represent its crown width or crown diameter as follow:

Geometric Mean (GM): $\sqrt{Cw_1 * Cw_2}$ ------------- (2)

Where, Cw_1 and Cw_2 are the two crown width measurements.
All these measurements are summarized in Table 1.
Where
D.B.H. is the diameter at breast height, Ht is the total height of the tree and Cw is the width of tree crown

2.2 Descriptive Statistics used in this study

The purpose of making such statistics is to give a summarized picture of the collected data. There are different ways to do it, but most of the researchers use the following statistics:

1) The standard deviation (s)
It is the square root of the variance and is calculated according to the following formulas:

Standard deviation (s) = $\sqrt{\frac{\sum x^2 - \frac{(\sum x)^2}{n}}{n-1}}$ -----------------------(3)

2) Coefficient of variation (cv %)
It is the ratio of standard deviation to the mean of the measured parameter, and therefore is calculated as follow:
CV% = $\frac{s}{\bar{x}}$ *100 ----------------------------------(4)

Where, x is the value of the measured parameter, n is the number of observations,

and $\bar{x}$ is the arithmetic mean of the parameter.

Table 1 shows summary of the descriptive statistics for the collected dataset.

	D.B.H	Ht	Cw
Count	100	100	100
Average	19.14	9.72	6.5035
Standard deviation	6.23	2.33	1.61
Coeff. of variation	32.55%	23.98%	24.72%
Minimum	7.5	5.3	3.2
Maximum	40.5	15.45	11.2
Range	33.0	10.15	8.0

2.3 Generation of regression models

The Statographic software 5.1 package was used to estimate the parameters of 50 regression models using the crown width as response variable and breast height diameter as predictive variable. These regression equations belonged to two main groups. The first group consisted of 25 regression models without Y- intercept. Y- intercept is defined as the value of y when x is equal to zero). The second group consisted also of 25 equations, The performance of models that contained y –

intercept based on $R^2$was very low, unlike the models that do not include y- intercept, which had very high values of R^2. Therefore, the first group of equation was omitted from screening process and only the regression equations of the second group was used for selecting of the most appropriate regression model.

2.4 Evaluation of the developed models

The developed equations of the second group were subjected to statistical analysis in order to arrive at the most appropriate equation to be used for predicting the response variable. The type of the regression models determines which criteria can be; therefore, the criteria used for testing the prediction efficiency of the models with homogenous form of response variable is not necessary to be the same used for models with heterogeneous form of the response variable (Neter., et al 1996) .).

2.4.1 Criteria for testing the performance ability of equations with homogeneous form of dependent variable

The following criteria used for models with the same form of dependent variable:

1- Coefficient of Determination R^2, or Fit Index

It is the ratio of the total sum of squares of variation in the dependent variable ($\sum(y_i - \bar{y})^2$that can be explained by the independent variable/ variables. Its value ranges between (0 and 1). The precision of an equation increases as the R^2 increases. As the number of independent variables increase the value of R^2 increases but in such cases the equation may include some variables which are not significantly contribute to the model, which contradicts the principle of parsimony that encourages using of having as few parameters in a model as possible. There is another type of R^2 called adjusted coefficient of determination (R'^2).Unlike the first one, it takes in account the number of independent variables in testing the efficiency of regression equations in prediction of dependent variable. Therefore, the first one (R^2) applied in testing the precision of equations having the same number of independent variables, while $R^{2\prime}$ can be used even if the equations under test have different number of independent variables. They can be used for testing the prediction ability of equations having the same form of the dependent variable (Furnival, 1961; Neter *et al*, 1996; Studenmund, 2005; Salih *et al*, 2020). These criteria have been used by many authors among them (Amin, *et al,* 2016; younis 2019. The following formulas are used for calculation of these criteria:

$$R^2, (\,Fit\ Index) = (\,1 - \frac{RSS}{TSS})\text{------------------------- } (5)$$

$$R^{2\prime} = (1 - \frac{\frac{RSS}{n-p-1}}{\frac{TSS}{n-1}}) \text{ ------------------------------------- } (6)$$

Where, RSS is residual sum of squares, which is $(\sum(y_i - \hat{y})^2)$, y and $\hat{y}$ are the actual and estimated y value, (which is calculated by substitution of the values of independent variable/variables in the regression equation) respectively, (Studenmund, AH., 2005), TSS is the total sum of squares, $(\sum(y - \bar{y})^2$, n is the number of observation, p is number independent variable in the regression equation. The difference between R^2 and R'^2 is the first one doesn't take in account the number of independent variables in calculation unlike the R'^2 which takes in account the number of independent variables in the equations to be tested for their prediction performance. Therefore R'^2 can be used for testing the precision of regression models even if they have different numbers of independent variables.

2- Durbin Watson Statistics (DWS)

Basically, this measure is used to detect the presence of the autocorrelation between the residuals from the least squares regressions. It can be calculated as follow:

$$DWS = \frac{\sum(e_i - e_{i-1})^2}{\sum e^2{}_i} \text{---} (7)$$

Where DWS is calculated value of DW and $e_i\ and\ e_{i-1}$ is the difference between the residuals of the i^{th} observation and the previous one

The value of this statistics ranges from 0 to 4. The approximate value of this statistics is equal 2(1 – r). If there is no autocorrelation; r = 0, then the expression leads to 2. If r = 1, then it leads to zero (2(1-1) = 0), positive autocorrelation. When r = -1, then the DWS will be equal to 4, (2 (1-(-1)). According to this criterion the best equation is the one having the value close to 2. In general, the accepted value of DWS for an equation when it lies between 1.5 – 2.5. However, it should not be less than 1, otherwise there will be clear autocorrelation.

2.3.2 Evaluation of regression models with heterogeneous form of dependent variables

The following statistics can be used for testing the performance of regression models in prediction even if they have different forms of dependent variable.

1- Conduction of Ohtomo's unbiased test

According to Furnival 1961; Amaro 1998; Studenmund, (2005) it is not possible to compare the precision of equations in estimation of the dependent variable, unless their dependent variable appeared in the same form. Ohtomo in (1956) proposed a method to overcome such problem. He proposed regressing the predicted values of the dependent variable with the actual (observed) values in a simple linear regression; $\hat{y} = k + my$. Here, three parameters can be used for testing the performance of models in prediction. As it can be seen, the best equation is having the predicted $\hat{y}$ – values close to the actual y – values. This happens when the values of k and m are close to 0 and 1 respectively. However, the value of R^2 is also very important criterion to be taken in consideration. Instead of taking these three statistics separately, Salih (2021) proposed a new index, which is a modification to Ohtomo's unbiased test as follow:

$$\textbf{Proposed Index} = |\boldsymbol{k - 0}| + |\boldsymbol{1 - m}| + |\boldsymbol{1 - R^2}| \text{ ----- } (8)$$

As it can be seen that the first term calculates the deviation of k value from zero, while the second and third terms calculate the deviation of both m and R^2 from one. Based on this criterion, the most accurate equation is the one having lowest value.

2- Mean absolute error (MAE)

This measure can be used for testing the performance ability of equations in estimation of the dependent variable, even if their response variable appears in different forms, but they should have the same number of independent variables.

$$\textbf{MAE} = \frac{\sum|y_i - \hat{y}_i|}{\boldsymbol{n}} \text{ ---} (9)$$

Based on this criterion, the best regression model is that having the lowest value of MAE.

3- Bias%

It is a percentage ratio of the residual sum of squares $(\sum(y_i - \hat{y})^2$ to the sum of actual values of the dependent variables. $(\sum y_i)$ So, this statistic is calculated as follows:

$$\text{Bias\%} = \frac{\sum(y_i - \hat{y}_i)^2}{\sum y_i} * 100 \text{ ----------------------------------- } (10)$$

This criterion is directly proportional with residual sum of squares (RSS), and inversely proportional with summation of y- values. The lower the value of this statistics, the more precise is the model in prediction.

4- Akaike Information Criterion (AIC)

It is a measure of the relative quality of a statistical model for a given dataset. It deals with the trade - off between goodness of fit of a model and its complexity. It offers a relative estimate of the information lost when a given model is used to represent the process that generate the data. The general form of this criteria is:

AIC= $n * \ln n(\frac{RSS}{n}) + 2k$ if $\frac{n}{k} > 40$. -------------------(11)

If $\frac{n}{k} < 40$. then an adjustment factor must be added and it will take the following form:

AIC= $n * \ln n(\frac{RSS}{n}) + 2k + \frac{2k(k+1)}{(n-k-1)}$ -------------------(12)

Where RSS = residual sum of squares, and k = number of independent variable plus 2, (K= p+2), k= 1+2= 3 for all tested equations The precision of an equation increases as the value of AIC decreases.

2.4 Validation test of the selected equation

The validity of a regression model refers to analyzing the goodness of the equation when will be applied to an independent data, (the data which was not used in construction model), (Rykiel 1996; Amin 2016; Salih *et al*., 2020). This can be done in two different ways:

1) collection of two data sets, one of the for development of regression models and the other set for validation of the selected equation. 2) collection of one set of data and then portioning it into two parts (about 80 to 90%) for estimating the parameters of the regression models and the rest (10 to 20%). Amaro 1998 used the test proposed by Ohtomo 1956 for validation height increment models. Husch 2003 used the coefficient of variation and aggregate differences for such purposes. Parresol 1999; Tedeschi 2006 and vanderchaaf 2008) used the bias% as validation criterion.

3. RESULTS AND DISCUSSION

3.1 Generation of regression models

As mentioned earlier that using the Statographic 5.1 software package. 50 regression models were developed between crown width (Cw) as dependent variable in five different transform form and the breast height diameter (D) with its different transformed forms. The developed regression equations belonged to two groups. The first group included y- intercept, while the other group did not include it. The R^2 of the first group ranged from 23.5% to 34.2%, which is very low as compared with models without y- intercept. Their R^2 ranged from 53.9 to 98.8%. Therefore, the first group of models was excluded and the focus was on the approved group, which included. 25 equations as it is clear in Table 2.

Table 2. The developed regression equations without y-intercept (Y-intercept is the value of y when x =0).

	Regression equation	R^2%		DW
	Group 1 equation with original form of (Cw)			
G11	$Cw = 0.3219 * D$	93.44		1.57
G12	$Cw = 1.50168 * sqrt(D)$	96.21		1.45
G13	$Cw = 2.25097 * ln(D)$	96.14		1.35
G14	$Cw = 95.206/D$	76.52		1.18
G15	$Cw = 0.01227 * D^2$	87.62		1.28
	Group 2 Equations with sqrt of (Cw)			
G21	$\sqrt{Cw} = 0.12247 * D$	93.31		1.49
G22	$\sqrt{Cw} = 0.5777 * sqrt(D)$	98.19		1.65
G23	$\sqrt{Cw} = 0.8689 * \ln(D)$	98.81		1.62
G24	$\sqrt{Cw} = 37.9373/D$	83.80		1.24
G25	$\sqrt{Cw} = 0.00457 * D^2$	75.28		1.17
	Group 3 Equations with logarithmic form of (Cw)			
G31	$\ln(Cw) = 0.08927 * D$	93.35		1.52
G32	$\ln(Cw) = 0.4207 * sqrt(D)$	98.05		1.69
G33	$\ln(Cw)$=0.6326*ln (D)	98.61		1.65
G34	$\ln(Cw) = 27.51/D$	82.97		1.24
G35	$\ln(Cw) = 0.00334*D^2$	75.52		1.19
	Group 4 Equations with reciprocal form of (Cw)			
G41	$1/Cw = 0.0074 * D$	76.24		1.23
G42	$1/Cw = 0.03617 * sqrt(D)$	86.08		1.31
G43	$1/Cw = 0.0549 * \ln(D)$	88.51		1.33
G44	$1/Cw = 2.6611/D$	92.23		1.76
G45	$1/Cw = 0.0002674 * D^2$	53.86		1.01
	Group 5 Equations with square form of (Cw)			
G51	$(Cw)^2 = 2.3170 * D$	87.46		1.33
G52	$(Cw)^2$=10.584*sqrt(D)	86.32		1.20
G53	$(Cw)^2$=15.7564*ln (D)	85.08		1.18
G54	$(Cw)^2$=627.566/D	60.05		1.12
G55	$(Cw)^2 = 0.09208 * D^2$	79.89		1.40

Where G is the group of equation, G11=the first equation of the first group, and G23 is the third equation of the second group.

Based on the transformed form of the dependent variable the developed equations belong to five (groups).The first group having Cw as the dependent variable, $\sqrt{Cw}$, $\ln(Cw)$, $1/_{Cw}$ and $(Cw)^2$ are the form of dependent variables of the second, third, fourth and fifth group respectively.

3.2 Testing of performance ability of developed models in prediction

According to Studenmund (2005), the performance of regression equation can't be done directly unless their dependent variable has the same transform, therefore the developed regression models were divided into two main groups:

3.2.1 Regression equations with homogenous y-form: As mentioned earlier that the developed regression equations belonged to five homogenous subgroups. Each of them consisted of 5 models. As it was previously mentioned, it is not permissible to use R^2 in comparing the accuracy of competing equations unless the dependent variable appears in the same transformed form (Furnival, 1961; Studenmund 2005; Amin, 2016; Salih, 2019). Since all the equations belonging to each subgroup share the same form of dependent variable, they were tested to find the best one based on the value of R^2 and Durbin Watson. As a result, the following regression models were selected because of having the highest value of R^2 , and accepted values of D-W as it is clear in Table 3.

Table 3. the selected equations from the first stage of comparisons, along with testing criteria.

Sub- group and eq no.	Regression Model	R^2	D-W
Sub group 1	$Cw = 1.50168\sqrt{D}$	0.96	1.45
Sub group 3	$\sqrt{Cw} = 0.5777\sqrt{D}$	0.98	1.65
Sub group 2	$\ln(Cw) = 0.42068\sqrt{D}$	0.98	1.69
Sub group 4	$Cw^{-1} = 2.6611^{D^{-1}}$	0.92	1.65
Sub group 5	$Cw^2 = 2.3170D$	0.87	1.33

The R^2 value for an equation ranges from (0 to 1), and the precision of an equation increases as the value of R^2 increases. On other hand, the value of D-W ranges from (0 to 4) and the most precise equation is that having the value of D-W close to 2. Accordingly, the equation

$\ln(Cw) = 0.42068\sqrt{D}$, seems to be superior to the rest of regression, but this conclusion can't be drawn because their dependent variables appeared in different form (Furnival, 1961; Studenmund 2005; Amin, 2016; Salih, 2019; Younis 2019). These models are considered as heterogeneous models and were subjected to other measures of criteria.

3.2.2 Testing of performance ability of heterogeneous models: The dependent variable in regression models listed in Table 2 appeared in different forms. Therefore, they cannot be examined for their precision using the previous criteria, such as R^2 and DW. Many researchers have proposed other measures of precisions, among them are Ohtomo's unbiased test, Furnival Index, Bias%, MAE and Akaike Information Criterion

1. Ohtomo's unbiased test

In this study, the regression models listed in Table 3 were subjected to the proposed modified test of Ohtomo that was proposed by Salih 2021 Table 4

Table 4 Shows the proposed index of Ohtomo's unbiased test for selected equation

Sub Gr and eq.	Equation	$\lvert k-0\rvert + \lvert 1-m\rvert + \lvert 1-R^2\rvert$
G1(1)	$\widehat{Cw} = 1.43 + 0.72Cw$	2.37
G1(2)	$\widehat{Cw} = 3.98 + 0.38Cw$	5.26
G3(4)	$\widehat{Cw} = 1.49 + 0.75Cw$	2.40
G4(3)	$\widehat{Cw} = 1.67 + 0.85Cw$	2.48
G5(3)	$\widehat{Cw} = 4.04 + 0.39Cw$	5.31

Based on this criterion, the best regression equation is the one having the lowest value of this proposed index. Accordingly, it can be concluded that the equations G1 (2), and G5 (3) should be excluded from competition list of equations because of having high values of the proposed index, but they were remained for further examination with other criteria to make a confident decision.

2. Bias%

The formula for calculating the bias is already given under topic of materials and methods. According to this criterion, the best equation is having the lowest value of the criterion. The result of this criterion conducted on the competed equations is given in Table 5.

3. Mean absolute error (MAE)

The formula for calculating this criterion is already given in materials and methods and its calculated values for the candidates under examination is given in Table 5. There is a negative relationship between the precision of an equation and the value of **(MAE)**

4. Akaike Information Criterion

The formulas of calculating for this criterion is already given in materials and methods. The calculated values of such criteria for the competed regression models are given in Table 5. Considering the AIC criteria, the following formula was used:

$AIC = n * \ln(\frac{RSS}{n}) + 2k + \frac{2k(k+1)}{(n-k-1)}$ as $\frac{n}{k}$

for our data was less than 40. The values of this measure for the five candidates is given in Table 5

Table 5 shows the statistics for measuring of bias, MAE and AIC statistics for the competed models

	Equation	$\sum(y_{ij}-\hat{y})^2$	$\sum y_{ij}$	Bias%	MAE	AIC
G1	$Cw = 1.50168\sqrt{D}$	170.1	650.4	26.16	1.05	59.3
G3	$\sqrt{Cw} = 0.5777\sqrt{D}$	299.7	650.4	46.09	1.43	116.0
G2	Ln (Cw) = $0.42068\sqrt{D}$	281.9	650.4	43.34	1.37	109.9
G4	$Cw^{-1} = 2.6611^{D^{-1}}$	411.7	650.4	63.30	1.63	147.8
G5	$Cw^2 = 2.3170D$	270.4	650.4	41.58	1.06	105.6

Based on the above mentioned criteria in Table 5 the first equation

$Cw = 1.50168\sqrt{D}$ was selected as the most appropriate model that fits our data, because of having the lowest values of Bias%, MAE and AIC, as well as the lowest value of the Index proposed by (Salih 2021)

3.2 Test of independence of residuals

As it is known statistically, the selected model should have the same precision level for the whole range of data. This condition can be fulfilled if the residuals ($Y_i - \hat{Y}_i$) are normally and independently distributed with the mean of zero and a standard deviation of σ , when the residuals are plotted against the independent variable/variables, Figure 2. The Y_i is the actual value of the dependent variable which is the crown width in this study for i^{th} observation and the $\hat{Y}_i$ is the estimated value of the dependent variable for the i^{th} observation.

This statement can be expressed as follow:

Residuals or Error $(\boldsymbol{\varepsilon}) \sim \mathbf{NID}(\mathbf{0}, \boldsymbol{\sigma})$. This can be read as, the error is Normally and Independently Distributed with a mean of zero and a standard deviation of σ.

This means that there should be no clear trend for the plotted points, otherwise there will be autocorrelation between independent variables. The figure shows that there is no special trend for the plotted points, this means that the selected equation has a consistent accuracy for the whole range of data and the sum of the positive deviations is equal to the sum of negative deviations.

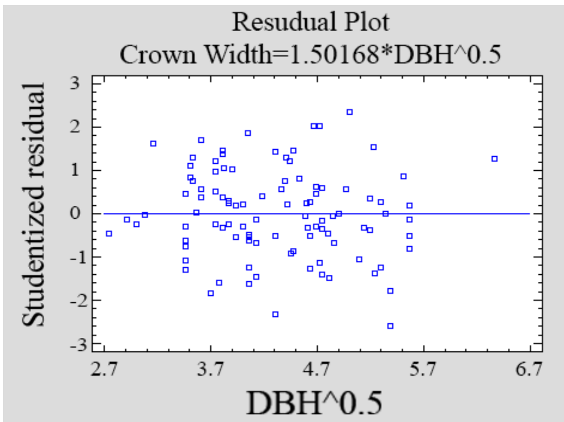

Fig.1. Plotting of the residuals against the square root of the breast height diameter of trees. Each of the blue points represents two coordinates, the X- coordinate (which is $\sqrt{DBH}$) and the Y- coordinate (which is the difference

between the actual Cw-values and their corresponding estimated values $(Cw_i - \widehat{Cw_i})$

3.3 Validation of the selected equation

Validation was conducted on 20 individual trees selected from the same park. The tools used here were consisted of MAE, Bias and AIC. The values of the MAE, Bias and AIC for the validation data were 1.26, 34.97 and 24.54 respectively. Such results are not so far from the results of the selected equation. Such results agreed with what was found by other researchers, among them (Amin, 2019) who found that the R^2 for original equation was 0.8085 and decreased to 0.7019 for validation data when studying the relationship between the height and diameter at breast height of *Quercus infectoria* in Chamanke locality, Kurdistan region.

3.4 Crown volume estimation

As it is earlier mentioned, this study has a dual purpose, the first one is the development of the best regression model for crown width estimation of *Melia azedarach* and the second one is the calculation of the crown volume because it has a direct relationship with carbon sequestration. The crown of broad leave trees is assumed to be very close to spherical form. Therefore, the following formula was used for volume calculation:

$$Crown\ volume = 1.3333 * \pi * r^3 \text{ ----------------------(13)}$$
$$= 1.3333 * \pi * (\frac{CD}{2})^3$$
$$= 1.3333 * \pi * \frac{(CD)^3}{8}$$
$$= 0.52332 * (CD)^3$$

Where r is crown radius and CD is crown diameter.

The crown diameter is the same as crown width, therefore the last equation can be written as:

Crown volume = 0.52332* $(Cw)^3$ ------------------------(14)

Here the selected model for crown width estimation can be substituted in the above equation to get the last equation that can be used for determination of the crown volume of a tree of this species and grown in the same location.

The selected crown width model was;

Cw =1.5168 $\sqrt{D}$ ---(15)

Where D is the breast height diameter.

So, the crown volume equation will take the following form:

Crown volume = 0.52332* $(1.5168\sqrt{D})^3$
= 1.82621* $D^{1.5}$ --------------------------(16)

Suppose that the diameter of a tree is 10 cm then the expected crown volume of such tree will be

The estimated crown volume will be
1.82621* $D^{1.5} = 57.75\ m^3$

The estimated crown volume for a tree having breast height diameter of 20 cm will be calculated as:

The crown volume =1.82621* $D^{1.5}$
= 163.34 m^3

This means that the total volume of the crown of a tree with a diameter at breast of 10 cm is expected to be 57.75m^3 ,which represents of three parts, namely the leaves, the branches and the air space. When the breast height diameter becomes twice, the volume becomes 163.34m^3, which is equivalent to an increase of 282.8% (which can be calculated as ($\frac{163.34}{57.75}$ x 100%)

CONCLUSION

The result of this study showed the $\sqrt{D}$ was the most significant transformed form of independent variable that had the highest explained variability of the dependent variable. According to the result of this study, there was a curvilinear relationship between the crown width and the breast height diameter of a tree. This result was in harmony with what was found by (Salih et al 2020), who found that there is a simple regression model between the crown width and the breast height diameter for Pinus brutia grown in Swaratoka location, Duhok, Kurdistan region

Another conclusion was drawn that when the diameter of a tree is increased x times, then the crown volume will increase as $x^{1.5}$ times. For example, if the diameter of a tree is increased from 10 cm to 20 cm, (which means that x=2 and therefore the volume increase will be ($2^{1.5}$) = 2.828 or 282.8%. The volume increase will be expected to reach 5.196 or 519.6% ($3^{1.5}$) if the diameter increases from 10 cm to 30 cm

The methodology used in this study can be used for all quantitative studies that deal with modeling of relationship between variables.

REFERENCES

Amaro, A., Reed, D., Tomé, M. and Themido, I., 1998. Modeling dominant height growth: Eucalyptus plantations in Portugal. *Forest Science*, *44*(1), pp.37-46.

Amin, H. M. (2016). *Quantification of dimensional properties of Quercus infectoria oliv. Grown naturally in Chamanke area, Duhok Governorate* [Master]. Duhok University.

Bechtold, W. A. (2004). Largest-Crown-Width Prediction Models for 53 Species in the Western United States. *Western Journal of Applied Forestry*, *19*(4), 245–251. https://doi.org/10.1093/wjaf/19.4.245

Crecente-Campo, F., Alvarez-Gonzalez, J. G., Castedo-Dorado, F., Gomez-Garcia, E., & Dieguez-Aranda, U. (2013). Development of crown profile models for Pinus pinaster Ait. and Pinus sylvestris L. in northwestern Spain. *Forestry*, *86*(4), 481–491. https://doi.org/10.1093/forestry/cpt019

Crecente-Campo, F., Tomé, M., Soares, P., & Diéguez-Aranda, U. (2010). A generalized nonlinear mixed-effects height–diameter model for Eucalyptus globulus L. in northwestern Spain. *Forest Ecology and Management*, *259*(5), 943–952. https://doi.org/10.1016/j.foreco.2009.11.036

Foli, E. G., Alder, D., Miller, H. G., & Swaine, M. D. (2003). Modelling growing space requirements for some tropical forest tree species. *Forest Ecology and Management*, *173*(1–3), 79–88. https://doi.org/10.1016/S0378-1127(01)00815-5

Fu, L., Sun, H., Sharma, R. P., Lei, Y., Zhang, H., & Tang, S. (2013). Nonlinear mixed-effects crown width models for individual trees of Chinese fir (Cunninghamia lanceolata) in south-central China. *Forest Ecology and Management*, *302*, 210–220. https://doi.org/10.1016/j.foreco.2013.03.036

Fu, L., Zhang, H., Lu, J., Zang, H., Lou, M., & Wang, G. (2015). Multilevel Nonlinear Mixed-Effect Crown Ratio Models for Individual Trees of Mongolian Oak (Quercus mongolica) in Northeast China. *PLOS ONE*, *10*(8), e0133294. https://doi.org/10.1371/journal.pone.0133294

Furnival, G. M. (1961). An Index for Comparing Equations Used In Constructing Volume Tables. *Forest Science*, *7*(4), 337–341.

Grace, J. C., Jarvis, P. G., & Norman, J. M. (1987). Modelling the interception of solar radiant energy in intensively managed stands. *New Zealand Journal of Forestry Science*, *17*, 193–209. https://www.scionresearch.com/__data/assets/pdf_file/0009/30600/NZJFS172-31987GRACE193_209.pdf

Hao, X., Yujun, S., Xinjie, W., Jin, W., & Yao, F. (2015). Linear Mixed-Effects Models to Describe Individual Tree Crown

Width for China-Fir in Fujian Province, Southeast China. *PLOS ONE*, *10*(4), e0122257. https://doi.org/10.1371/journal.pone.0122257

Husch, B., Beers, T.W. and Kershaw Jr, J.A., 2002. *Forest mensuration*. John Wiley & Sons.

Hynynen, J., Ojansuu, R., Hökkä, H., Siipilehto, J., Salminen, H., & Haapala, P. (2002). Models for predicting stand development in MELA System. *Metsäntutkimuslaitoksen Tiedonantoja*, *835*, 116. http://urn.fi/URN:ISBN:951-40-1815-X

Kershaw Jr, J.A., Ducey, M.J., Beers, T.W. and Husch, B., 2016. *Forest mensuration*. John Wiley & Sons.

Korhonen, L., Korhonen, K., Rautiainen, M., & Stenberg, P. (2006). Estimation of forest canopy cover: a comparison of field measurement techniques. *Silva Fennica*, *40*(4). https://doi.org/10.14214/sf.315

Kozlowski, T. T., Kramer, P. J., Pallardy, S. G., & Roy, J. (2012). *The Physiological Ecology of Woody Plants*. Elsevier Science. https://books.google.iq/books?id=iSTOcsNbVxMC

Krajicek, J. E., Brinkman, K. A., & Gingrich, S. F. (1961). Crown competition—a measure of density . *Forest Science*, *7*(1), 35–42.

Larocque, G. R., & Marshall, P. L. (1994). Crown development in red pine stands. II. Relationships with stem growth. *Canadian Journal of Forest Research*, *24*(4), 775–784. https://doi.org/10.1139/x94-102

Meng, S. X., Huang, S., Yang, Y., Trincado, G., & VanderSchaaf, C. L. (2009). Evaluation of population-averaged and subject-specific approaches for modeling the dominant or codominant height of lodgepole pine trees. *Canadian Journal of Forest Research*, *39*(6), 1148–1158. https://doi.org/10.1139/X09-039

Neter, J., Kutner, M. H., Nachtsheim, C. J., & Wasserman, W. (1996). *Applied linear statistical models*.

Ottorini, J.-M., Goff, N. le, & Cluzeau, C. (1996). Relationships between crown dimensions and stem development in *Fraxinus excelsior*. *Canadian Journal of Forest Research*, *26*(3), 394–401. https://doi.org/10.1139/x26-044

Parresol, B.R., 1999. Assessing tree and stand biomass: a review with examples and critical comparisons. *Forest science*, *45*(4), pp.573-593.

Pretzsch, H., Biber, P., Uhl, E., Dahlhausen, J., Rötzer, T., Caldentey, J., Koike, T., van Con, T., Chavanne, A., Seifert, T., Toit, B. du, Farnden, C., & Pauleit, S. (2015). Crown size and growing space requirement of common tree species in urban centres, parks, and forests. *Urban Forestry & Urban Greening*, *14*(3), 466–479. https://doi.org/10.1016/j.ufug.2015.04.006

Rautiainen, M., & Stenberg, P. (2005). Simplified tree crown model using standard forest mensuration data for Scots pine. *Agricultural and Forest Meteorology*, *128*(1–2), 123–129. https://doi.org/10.1016/j.agrformet.2004.09.002

Rykiel Jr, E.J., 1996. Testing ecological models: the meaning of validation. *Ecological modelling*, *90*(3), pp.229-244.

Salih, T. K. (2020). *Growth functions Modeling of Quercus aegilops L. and Dendroclimatological Analysis of Pinus brutia Ten. In Duhok Governorate* [Dissertation]. University of Duhok.

Salih, T. K., Younis, M. S., & Wali, S. T. (2019). *Dendroclimatological Analysis of Pinus brutia Ten. Grown in Swaratoka, Kurdistan Region—Iraq* (pp. 9–19). https://doi.org/10.1007/978-3-030-18641-8_2

Salih, T. K., Younis, M. S., & Wali, S. T. (2021). Allometric regression equations between diameter growth and age of valonia oak trees grown in Duhok province, Iraq. *INTERNATIONAL HASANKEYF SCIENTIFIC RESEARCH AND INNOVATION CONGRESS*, 557–576.

Schlaegel, B.E., 1981, June. Testing, reporting, and using biomass estimation models. In *Southern Forest Biomass Workshop* (Vol. 1, pp. 95-112). Clemson: Clemson University.

Sharma, R. P., Vacek, Z., & Vacek, S. (2016). Individual tree crown width models for Norway spruce and European beech in Czech Republic. *Forest Ecology and Management*, *366*, 208–220. https://doi.org/10.1016/j.foreco.2016.01.040

Singer, M. T., & Lorimer, C. G. (1997). Crown release as a potential old-growth restoration approach in northern hardwoods. *Canadian Journal of Forest Research*, *27*(8), 1222–1232. https://doi.org/10.1139/x97-071

Sönmez, T. (2009). Diameter at breast height-crown diameter prediction models for Picea orientalis. *AFRICAN JOURNAL OF AGRICULTURAL RESEARCH*, *4*(3), 215–219.

Studenmund, A. H. (2005). *Using Econometrics: A Practical Guide* (5th ed.). Addison Wesley.

VanderSchaaf, C., 2008. Compatible stem taper and total tree volume equations for loblolly pine plantations in southeastern Arkansas. *Journal of the Arkansas Academy of Science*, *62*(1), pp.103-106.

Van Laar, A. and Akça, A., 2007. *Forest mensuration* (Vol. 13). Springer Science & Business Media.

YOUNIS, A.J. and HASSAN, M.K., 2019. Assessing volume of Quercus aegilops L. trees in Duhok Governorate, Kurdistan Region of Iraq. *Journal of Duhok University*, *22*(1), pp.265-276.