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A Nondestructive Method for Estimation of Leaf Area in *Quercus aegilops* L. Tree

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Abstract. Non-destructive techniques for leaf area estimation are much sought after by both forest managers and researchers in the fields of biology and forest ecology. Leaf area (LA) can be determined by developing linear metrics, such as leaf length (L) and width (W). The objective of this study was to create a reliable approach for accurately estimating the leaf area (LA) of *Quercus aegilops* L. by using data of leaf length, width, or other dimensions. Seven non-destructive models were formulated to accurately estimate the leaf area (LA) of the species under investigation, developing the leaf dimensions of length (L) and width (W). The regression models that utilized a single dimension, such as length or breadth, were shown to be less effective in predicting the leaf area of *Q. aegilops* L. compared to models that integrated the product of length and width measurements. Among the seven produced models, the equation $LA = 0.3256L*W^{1.016}$ was chosen as the final equation since it was considered the most suitable among the other equations.

Keywords. Actual leaf area, Leaf length, Leaf width, Predicted Leaf area, *Quercus aegilops* L., Validation.

1. Introduction

The highland regions of Iraq's natural forests consist of a range of mountains that stretch from the northern border with Turkey to the eastern border with Iran [1]. Almost 90% of the forest covers in the Kurdistan area of Iraq is made up of oak woods [1]. The primary oak species, *Quercus aegilops* L., is a member of the fagaceae family, along with other oak species including *Q. libani, Q. infectoria*, and *Q. macranthera.* With the exception of *Q. macranthera,* these species are considered native to the region [2]. The lifespan of *Quercus aegilops* L. can approach 200 years. This species exhibits certain characteristics, such as a crown width that can reach up to 7 meters, a tree height of 20 meters, and a diameter of 100 centimeters [3]. In addition, wood can be used to produce various tools, while leaves can be utilized as fodder for livestock, particularly during winter. Additionally, branches can be used to construct shelters during the summer. Apart from these advantages, this species also offers numerous ecological benefits [4].
Measuring of leaf area is one of the most essential measurement factors in agricultural research mainly in plant physiology experiments [5]. This measurement is an indicative of it is relationship with photosynthesis, light absorption and respiration processes which are a vital for plant development and growth [6]. Chlorophyll contents in green leaves regulation of biological mechanisms on vegetation cover for that reason the measurement of leaf area index (LAI) is a fundamental structure for the

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attributes of forests ecosystems as a consequence an estimation of LAI is precisely needed for studying tree eco-physiology and interaction of environmental impact [7 and 8]. In addition, this measurement is widely applied to describe both the plant photosynthesis and respiration levels [9].
Measuring a substantial amount of leaf surface area can be hard, expensive, and time-consuming. Several methodologies have been devised to assist in the quantification of leaf area (LA) [10]. However, these approaches, along with those that involve the use of a traditional planimeter and tracing, require the removal of leaves from the plants. Therefore, it is not possible to make subsequent measurements of the same leaf, as this could potentially damage the plant canopy and make difficulties for other researchers [10]. In addition, obtaining measurements of leaf area for an entire plant using direct methods requires a significant amount of effort and is time-consuming. Consequently, numerous investigations in direct approaches have developed various equations to estimate leaf area. [11] was originally established that leaf area (LA) may be determined by developing linear metrics such as leaf length (L) and width (W). The leaf area can be estimated by employing a linear equation LA = b L W, where b represents a coefficient that is specific to each cultivated species, as observed by Pinto et al. in 2004.
According to [12], simplifying the mathematical correlations between leaf area and other leaf dimensions, such as length and width, may build an approach that exclusively relies on these models more practical and advantageous compared to other methods. Various methods and models have been developed to estimate leaf area in different types of forest trees. These models have used measurements of length and width to establish the relationship between leaf area and these dimensions. For example, models have been build for *Juglans nigra* L. [13], *Pistia stratiotes* L. [14], [15] developed a model for different pear cultivars, *platanus orientalis* L. [16] and some cultivars of Apple [17 and 18]. However, there is currently a lack of information regarding leaf area estimation for oak species in the Kurdistan region, specifically *Q. aegilops* L. Consequently, there is a need for nondestructive techniques to estimate leaf area, not only from forest managers but also from biologists and ecologists. The objective of this study was to build a reliable model for estimating the leaf area (LA) of *Q. aegilops* L. by using measurements of leaf length, width, or other dimensions.

2. Materials and Methods

2.1. Study Description

A specific region inside Erbil Governorate was selected for practical purposes. This location is habitat to oak species that belong to the fagaceae family and the *Quercus* L. genus. One of the species found there is *Quercus aegilops* L. The current study has chosen the Hijran locale as the research site. The place is situated at an elevation of 890 meters above sea level (A.S.L.), with latitude ranging from 36°24” to 36°22” North and an east longitude ranging from 44°19” to 44°16”. Hijran is located approximately 40 kilometers northeast of the city of Erbil. It has a total area of around 5120 hectares, with 3500 hectares consisting of natural forest.

2.2. Data Collection

A complete set of fully developed leaf samples was used for the building of the model. A collection of oak tree leaves was sampled in July 2022. A total of 171 leaves were collected as samples during the summer growing season of 2022. The leaves were chosen randomly from different heights of 10 trees at a specific location. For the purpose of obtaining the samples, a branch was chosen from each of the four primary directions (North, South, East, and West) for each tree.

2.3. Estimating Leaf Area

The study selected trees that were nearly identical in age, solar exposure, and had regular height and development model. The leaves were transported to the laboratory where the individual leaf area (LA) was quantified using Image software, while the leaf length (LL) and leaf width (LW) were measured using a ruler (Table, 1). The leaf area of *Q. aegilops* L. tree leaves ranged from 8.6 to 52.9 cm^2, with

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lengths ranging from 7.3 to 16.2 cm and widths ranging from 3.6 to 8.5 cm (Table, 1). The LA was measured in square centimeters, whereas both L and W were measured in centimeters. The length of the leaf (LL) was measured from the tip of the leaf to the point where the lamina intersects. The width of the leaf (W) was measured in a straight line from the widest lobes of the lamina to the midrib, as described by [16] (Figure 1).

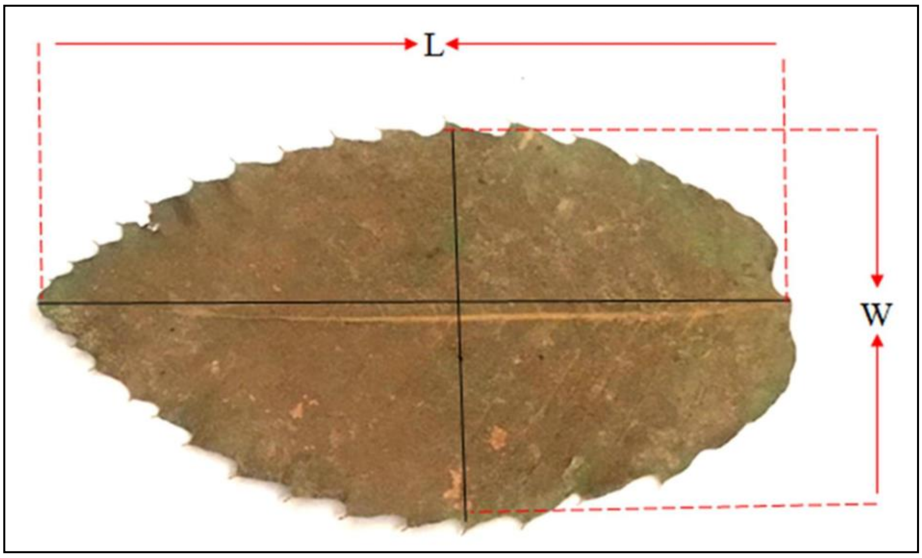

Figure 1. Position of leaf length (L) and leaf width (W) of *Quercus aegilops* L.

Table 1. Mean maximum, minimum, standard deviation and coefficient of variation and range values for the in dependable variables and leaf area of *Quercus aegilops* L.

Models	No.	Standard deviation	Mean	CV	Max	Min	Range
Leaf length (LL)	171	1.588	10.91	14.552	16.2	7.3	8.9
Leaf width(LW)	171	1.074	5.61	19.140	8.5	3.6	4.9
L^2	171	35.60	121.62	29.276	262.44	53.29	209.15
W^2	171	12.63	32.67	38.67927	72.25	12.96	59.29
L+W	171	2.43	16.52	14.72522	24.7	11.3	13.4
L*W	171	19.38	62.40	31.058	137.7	28.5	109.2
$(L+W)^2$	171	82.81	279.1053	29.67295	610.09	127.69	482.4
OLA	171	7.11	21.2	32.611	52.9	8.6	44.3

2.4. Development Modeling

The study used 171 leaf measurements to determine the correlation between leaf area (LA) and the length (L) and width (W) parameters. The objective was to identify suitable mathematical functions that may be used in models to estimate the total leaf area of *Q. aegilops* L. trees, as shown in Table 1. The dependent variable in this study was the leaf area, whereas the independent factors included L, L^2, W, W^2, the product of L*W, the sum of L+W, $(L+W)^2$, and $(LxW)^2$, based on the data obtained from the samples.

2.5. Evaluating the Practicality of the Developed Models

An analysis was conducted to compare different models in calculating the statistical measures of Determination Coefficient (R^2), Mean Square Error (MSE), Root Mean Square Error (RMSE), Coefficient of variation (CV) and The coefficient of residual mass (CRM) This analysis aimed to evaluate the predictive performance of the descriptive variables in estimating the response variable, as described by [5].

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3. Results

The leaf area of *Q. aegilops* L. tree leaves varied between 8.6 and 52.9 cm^2, with lengths ranging from 7.3 to 16.2 cm and widths ranging from 8.5 to 3.6 cm (Table 1). A comparative analysis was conducted on various quantitative models to obtain the statistical measures of Determination Coefficient (R^2), Root Mean Square Error (RMSE), coefficient of variation (CV), The coefficient of residual mass (CRM) and Mean Square Error (MSE) for a specific equation (equation 1). The leaf area was estimated by applying mathematical calculations. The predicted and observed leaf areas were compared using statistical tests to determine the significance of the regression equation and the degree of goodness of fit (R^2) between the estimated and measured values. The optimal leaf area estimation model was chosen by considering the combination of the highest R^2 value and the lowest root mean square error (RMSE).

$$\mathrm{MSE} = \frac{\sum(\mathrm{Yi}-\hat{\mathrm{Y}}\mathrm{i})^2}{n} \qquad (1)$$

The linear regression analysis (equations no. 6 in Table 2) showed that the combination of the highest R^2 value (>0.90) and the most significant p residuals was observed in the case of the analyzed tree species, with W*L as an independent variable (Table 2). Regression analysis revealed a strong correlation between leaf area (LA) and the product of LW, the sum of L+W, $(L+W)^2$, and $(LxW)^2$ as the independent variables based on the data obtained from collected samples (Table 2). However, the suitability of these models differed depending on the aforementioned selection criteria. All estimated equations, except for model 6, had a coefficient of determination (R^2) less than 0.90 (Table 2). The current investigation demonstrated that models 1, 2, 3, and 4 (Table 2), which only included a single measurement of L, W, L^2, and W^2, were not suitable for accurately estimating the LA of studied species. This conclusion was based on their low coefficient of determination (R^2), elevated Residual values, mean squared error (MSE), and greater root mean squared error (RMSE) values. Furthermore, by utilizing independent variables such as L, W, L^2, and W^2, it was possible to enhance the accuracy of single LA estimation (Table 2). For the purpose of precisely predicting the single LA of the tested species, the independent variable employed was the product of L×W, referred to as model 6. It was preferred the trend line power model ($LA = 0.3256(LxW)^{1.016}$) due to its high accuracy. It has the highest R^2 value (> 0.91) and the smallest MSE, which confirms the validity of the fitted regression model. The MSE is also useful as an indicator of the predictive potential of this model, as stated by [19] To accurately estimate the leaf area (LA) of *Q. aegilops* L. trees, it was necessary to take into account both the length (L) and width (W) measurements.

Table 2. Power regression models were used for predicting leaf area of *Quercus aegilops* L. from leaf length (l), leaf width (w).

Model No.	Independent variable	Models	R^2	CRM	MSE	RMSE
1	L	$LA = 0.227x^{1.8967}$	0.725	37.28694	5.24	2.29
2	W	$LA = 1.5291x^{1.5261}$	0.794	37.2869	3.38	1.83
3	L^2	$LA = 0.227x^{0.9484}$	0.725	37.28694	5.26	2.29
4	W^2	$LA = 1.5291x^{0.7631}$	0.794	37.2869	3.35	1.83
5	L+W	$LA = 0.0597x^{2.0932}$	0.898	37.28684	1.37	1.17
6	LxW	$LA = 0.3256x^{1.016}$	0.917	37.28684	0.86	0.92
7	$(L+W)^2$	$LA = 0.0597x^{1.0466}$	0.898	37.28685	1.37	1.17

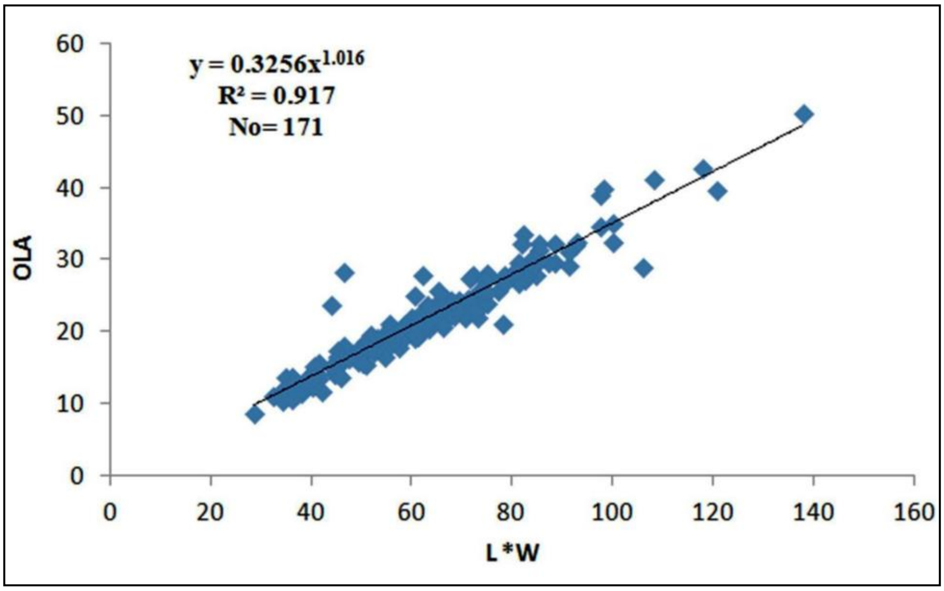

Figure 2. Regression equation for estimating the leaf area from the product of leaf length and width (L *W).

3.1. Validation of the Proposed Equation

Proceeding to use the chosen equation for prediction, it is necessary to subject it to a validation test. In order to achieve this objective, a fresh set of leaves consisting of 32 samples was collected. Their dimensions, including length, width, and leaf area, were documented. The initial measurements of leaf metric, specifically leaf length (Min=9, Max=13.4, Mean=11.15, and range=9.7) and leaf width (Min=5.2, Max=7.7, Mean=6.6, and range=6.6), were recorded (Table 3). Subsequently, these values were inserted into the chosen equation, resulting in the acquirement of the projected values for the leaf area of each individual leaf. The projected values of LA were subjected to regression analysis using a simple linear equation as follows: The equation is $\hat{Y} = 6.916 + 0.879*LA$, where B0 is 6.916 and B1 is 0.879. If the sum of B0 and B1 is approximately zero and one respectively, and if the R^2 value is within an acceptable range, it suggests that the selected model is dependable and may be developed for predicting other data, and vice versa.

Table 3. Statistic summary of both observed and selected predicted equation.

	Mean	Maximum	Minimum	Range	SD	CV
OLA	29.6	41.8	22.3	52.95	4.35	16.25
L	11.15	9	13.4	9.7	1.21	10.87
W	6.60	7.7	5.2	6.6	0.62	9.52
LxW	73.93	96.25	52.78	74.51	11.87	16.06
PLA	25.79	33.7	18.3	42.87	4.20	16.31

N=32

When we performed the division of B0 by the mean anticipated leaf area (6.916/26 = 0.26), the resulting value was very near to zero. Similarly, the value of B1 was also close to zero. Despite the R^2 value of 0.667 being lower than the original R^2 value of 0.91 for the chosen equation, it can still be considered acceptable based on the relationship depicted in figure 2 between the observed leaf area and predicted leaf area. This was observed for both the leaf area measured using imageJ software and the leaf area predicted. The observed leaf area had a skewness of 0.247 (standard error = 0.414) and a kurtosis of -0.257 (standard error = 0.809), while the predicted leaf area had a skewness of 0.061 (standard error = 0.414) and a kurtosis of -0.781 (standard error = 0.809) (Figure 3).

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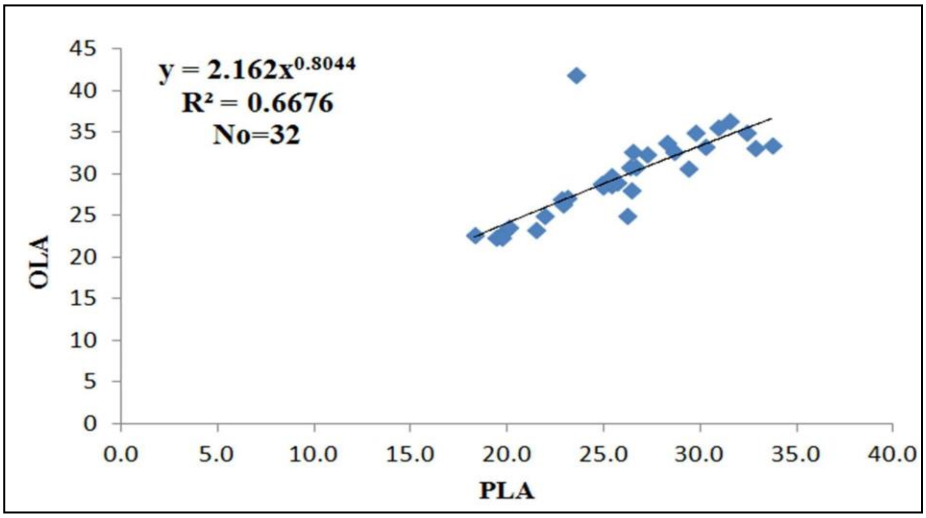

Figure 3. Observed leaf area (OLA) plotted against predicted leaf area (PLA).

4. Discussion

When assessing the suitability of regression equations for each study, two main concerns must be taken into account: precision and simplicity. Equation 6th, for example, contains only one variable (a combined variable) or includes one parameter (b LxW), while 7th equation includes one parameter, suggesting that it may require more than one measurement in application. After careful evaluation, it was found that Equation 6 provided the necessary precision and simplicity and was thus selected, side with with the selective standard recommended by [20]. Many previous studies have suggested non-destructive equations for measuring leaf area in a variety of crops. However, there is not a model in particular developed for studied species such as *Quercus aegilops* L. trees. Therefore, researchers are frequently alternative to excising leaves for measurement purposes, as documented by [21]. Remarkably, non-destructive methods are crucial for obtaining accurate measurements on the same leaf, as different plant samples may give in not in agreement results. In this study, the equation $LA = 0.3256L*W^{1.016}$ proved effective in accurately measuring the leaf area of *Quercus aegilops* L. trees. Both leaf length and width determination were found to be essential for accurately estimating the leaf area of *Quercus aegilops* L. trees. Our findings support with earlier research on other species, such as hazelnut trees, where a high correlation was found between actual and predicted leaf areas using a combination of measured leaf length and width [20]. Several researchers have applied similar methodologies, employing multiplicative equations (length × width) for leaf area estimation [22; 23; 24; 25 and 10].

The outcome of this study showed that the product of the measured factors serves as a vital variable for determining leaf growth index by regression models. The variable with the highest descriptive potential was utilized to develop a general equation for estimating leaf area (LA). [26] also found that acceptable predictions of leaf area for *Mangifera indica* L. trees could be achieved by measuring non-destructive parameters such as leaf length and width, relying on regression equations with the highest determination coefficient (R^2). In a study on *Beta vulgaris* L. by [27] a strong correlation was observed between LA and leaf length and width using a simple power model ($y = 0.1933\ x^{\wedge 2.2238}$). Souza and Amaral (2015) gained similar results when estimating leaf area for *Vernonia ferruginea* Less trees, resulting that combined parameters by using the product of length and width dimensions were more effective for predicting LA than models based on single dimensions or their squares, thus provided that more accurate measurements. Correspondingly, A study by [28] varying degrees of precision in leaf area estimation for four agroforestry tree species in Indonesia, depending on the combination of linear leaf dimensions used. On the other hand, [29] observed, in their study on estimating leaf area for *Nerium oleander* L. trees cultivated in the Iraqi Kurdistan Region, that multiple linear regressions followed by a simple linear regression produced the most accurate and precise results, whereas the exponential model revealed the lowest accuracy. Finally, among the seven linear regression models developed, [16] determined that Equation 6, incorporating the product of leaf length and width (L*W), was the most suitable for estimating LA for *Platanus orientalis* L. trees in Erbil city. Utilizing measurements of leaf width, length, and leaf area, a vital model was established, revealing a high coefficient of determination, representing its value in predicting leaf area of different apple cultivars [17and18]. The limitation of this research is there not present any accurate tools in our country if it is available can be very expensive for measuring leaf area of this species. The reason of low value of B1 and R^2 is the outlier observation. If we delete it you may improve both B1 and R^2. It might evaluate the performance of Artificial Neural Network (ANN) models for predicting the leaf area index (LAI) using stand parameters in oak forests in Northern Iraq. ANN modeling could prove to be a practical technique for predicting LAI in these forests, proposing that ANN can be an effective another technique to classical regression equations, mainly when regression equations be unsuccessful to perform adequately [30], however, this model can be used as alternative method to estimate the studied species for ecophysiological studies.

Conclusion

The current study focused on developing power regression models to estimate the leaf area of *Quercus aegilops L.* in field conditions. The model was found to be efficient and time-saving for leaf area prediction, mostly in locations lacking up-to-date equipment for leaf area measurement. The chosen equations proved to be a suitable and quick option for predicting leaf growth indexes of the studied species. Results showed that the leaf area of the studied species could be predicted using the developed power regression model, which included the product of length (L) and width (W) values, demonstrating relatively high precision in predicting leaf area. Even though a few level of deviation is expected owing to certain disadvantages in precision, but increasing the sample size in the study location may help decrease these variations. Furthermore, the developed equations show promise for applicability in different environmental conditions and other oak species. By simply measuring the length of the longest leaf and the width of the widest leaf with no the need for expensive equipment, researchers may precisely obtain the leaf area of *Quercus aegilops* L. trees. In cooperation greenhouse and field conditions, leaf parameters can be simply measured in pot experiments. Using this model can allow researchers to carry out non-destructive measurements on the same leaves, assist physiological and quantitative studies with large quantities of leaf area measurements.

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