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Evaluation of new mathematical models for estimation of single olive leaves area

M.A. Mhanna*

General Commission for scientific agricultural research, Latakia research center, Ciano research station, Latakia, Syria

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Abstract. *The study was conducted on „Khoderi“ olive cultivar planted in Jableh Region-Latakia province, Syria in 2017 in order to evaluate some mathematical models adapted for olive single leaf area estimation. Leaf samples were taken from the middle of one-year branches. Actual areas of the leaves were measured using Adobe Photoshop CS5. Leaf dimensions (length and width) were measured accurately. Coefficients of determination were estimated for the relation between leaf dimensions and the actual area. The best coefficient of determination was between the natural logarithm of the product (leaf length × leaf width) and the natural logarithm of leaf area (R^2= 0.962). Linear regression equation of the mentioned relation was fitted and evaluated. The accuracy of the new model ($A=e^{0.9509 \ln LW - 0.2867}$) was compared to other models commonly used for olive single leaf area estimation. The comparison showed no significant differences between leaf area obtained by the new model and the actual leaf area values (p=0.01), whereas significant differences were found for the other models. The new model showed the lowest Root Mean Square Error (RMSE) and high efficiency in estimating olive leaf area of „Khoderi“ cultivar in two different environments; the same results were obtained for olive cultivar „Picholine“ the French. We recommend the new model for olive single leaf area estimation.*

Keywords: olive, Khoderi cultivar, leaf area, adobe photoshop CS5, simple estimation of surface, regression, coefficient of determination

Introduction

Plant leaf area is an important parameter in ecology and physiology (Chen et al., 2011). Leaf area index (LAI) was used for evaluating growth, photosynthesis, precipitation and water relations in plants (Ackerly et al., 2002 and Erdogan, 2012); also plant single leaf area was used in taxonomical and characterization studies (Al-Qaiem, 1999).

Techniques used for single leaf area estimation have developed during the last century. Montgomery (1911) was the first to suggest the formula A= b.L.W to calculate single leaf area, where ‘A’ is the leaf area, ‘L’ is the maximum leaf length, ‘W’ is the maximum width and ‘b’ is constant. Nowadays, programming and information technology have developed, and many programs were adopted to calculate irregular surface area after converting them to digital images; those technologies began to be involved in Biology and Physiology (Omasa and Onoe, 1984; Can et al., 2012). Software companies started developing software intended for digital image processing. Adobe Photoshop© is one of the most widespread software used for image processing which has also been used by many authors for single leaf area estimation (Chen et al., 2011; Can et al., 2012). Apple© company with participation of Adelaide university developed LAICANOPY® an application created to work on iPhone-4S in order to be put on hands of researchers and farmers to be able to direct calculation of leaf area of Grape vine (Fuentes et al., 2012).

Many studies were conducted in order to find the mathematical formulas enabling calculation of plant single leaf area without destructing it or removing it from the mother plant. Most studies used linear regression and the correlation between leaf dimensions (length and width) and leaf area as a tool to create mathematical formulas used to predict single leaf area. Most of the studies focused on field crops and vegetables like *Phaseolus vulgaris* (Bhatt and Chanda, 2003), cucumber (Blanco and Folegatti, 2003), pepper (De Swart et al., 2004) and Faba bean (Eftekhari et al., 2005). Regression analysis was also used to predict leaf area in order to evaluate general and specific combining ability in maize (Aliu et al., 2008). In fruit trees, regression analysis was used to predict single leaf area of Aleppo pistachio (Karimi et al., 2009), sweet cherry (Cittadini and Peri, 2006) and mango (Ghoreishi at al., 2012).

In olive, there were no specific formulas regarding leaf area estimation, so researchers used alternative formulas to estimate olive single leaf area like (Ajayi,1990; Lansari and Bouchra, 1996) formulas. In 2018, Koubouris et al. (2018) were the first to compare some models created for olive single leaf area estimation for some olive cultivars planted in Crete island under irrigated and rain fed conditions, they came to a model which could be used to estimate olive leaf area, but their results indicated that there were variations between olive cultivars hindering the creation of a global formula for estimating the leaf area in olives.

*e-mail: Agrihort@yahoo.com

Regarding the importance of creating a mathematical formula for olive single leaf area estimation, the difficulty in estimating plant leaf area without destructing or removing the leaf from the mother plant and the high cost of digital devices used to calculate leaf area, this study aimed to find a mathematical formula for olive single leaf area estimation depending on leaf dimensions and comparing it with other formulas used to estimate olive single leaf area.

Material and methods

Leaf samples

Olive cultivar “Khoderi” was used in this study. The trees were more than 50 years old, planted under rainfed conditions in Barka village, Jabelh area (380 m above sea level), province of Latakia, Syria in planting density of 7×7m characterized by calcareous soil. A total of 100 disease-free leaves were sampled from the middle of one year old branches randomly distributed around the tree canopy. Leaf Petioles were removed.

Actual leaf area estimation

Each leaf was numbered and leaf dimensions (length - L and width - W) were measured, then (Can et al., 2012) method with some modification was used to estimate actual leaf area (surface): leaves were scanned using desktop scanner and the scanned images were saved on a computer. For leaf area estimation, images were introduced to Adobe® Photoshop® CS5 with addition of 1 cm^2 paper square used as a standard for converting digital units (pixels) to physical units (cm^2). Images were converted to white and black and the number of pixels in each leaf was measured three times and the means were recorded. The same method was applied to the standard square and the number of pixels was recorded. The actual leaf area (LA) was estimated as follows:

LA= (NoPTL x SSA) / NoPSS, cm^2,

Where NoPTL is Number of pixels of the tested leaf, pixels;

SSA is Standard squere area, cm^2;

NoPSS is Number of pixels in the Standard squere, pixels.

More details about this method could be found on the link: https://www.youtube.com/watch?v=E3O-V6WLw0g.

Coefficients of determination between actual leaf area and leaf dimensions were estimated. A relationship between (L, W and area) with the highest coefficient of determination was selected (Bhatt and Chanda, 2003). Regression analysis was performed for the highest Relationships between (L, W and actual area). The best mathematical model characterizing the relationship between leaf dimension and area was chosen.

Root Mean Square Error (RMSE) was calculated for the new model and the following models used for single olive leaf area estimation:

LA = 0.308 + 0.708LW (Koubouris et al., 2018) (1)

LA = LW^2 (Lansari and Bouchra, 1996) (2)

LA = π/4 L*W (Ajayi, 1990) (3)

Formula number 1 is specific for olive with some concerns about validity for various olive cultivars. Formulas number 2 and 3 were used by Lansari and Bouchra (1996), and Al-Qaiem (1999).

New leaf samples (20 leaves) were taken from olive cultivars “Khoderi” and “Picholine” (the French) grown in olive germoplasm collection of Bouka (40 m above sea level). The trees are planted under rainfed conditions in planting distance of (7×7 m). The leaf area of each leaf was estimated using the new model and the above-mentioned models and the actual area was measured using Adobe® Photoshop® CS5 as mentioned above.

Significant differences between the mentioned models for LA estimation and actual areas were tested using t-student test (p=0.01). SPSS® software Copyright © 2007 Chicago, USA was used for Data analysis.

Results

Coefficients of determination

Table 1 showed that leaf length was responsible for more than 72% of the variation in leaf area, while leaf width was responsible for ~70%. The highest Coefficient of determination (R^2) was between the natural logarithm of the product (leaf length × leaf width) and the natural logarithm of leaf area (R^2= 0.962), while the lowest was between (L/W) and leaf actual area (0.0004).

Table 1. Coefficient of determination (R^2) for some relationships between leaf dimensions and leaf actual area (L: leaf length, W: leaf width)

Parameters	R^2	
	Ln(A)	Actual leaf area (A)
L	0.722	0.731
W	0.703	0.706
L^2	0.692	0.707
W^2	0.690	0.700
L*W	0.944	0.960
L^2*W	0.897	0.922
L*W^2	0.882	0.904
L^2*W^2	0.910	0.942
W/L	0.002	0.002
L/W	0.001	0.0004
Ln(L*W)	0.962	0.960

Based on Table 2 the best model showing the highest R^2 and the lowest RMSE was model 6; while the model used by (Lansari and Bouchra, 1996) produced the highest RMSE. Model 6 was selected and converted as follows: LA= $e^{0.9509*\ln(LW) - 0.2867}$. Note that LA could be calculated in Microsoft Excel by using the function: EXP (number) where the (number) is 0.9509×ln(LW)- 0.2867; or by hand calculator: (shift+ln) the result of {0.9509×ln(LW)- 0.2867}.

Table 2. Coefficient of determination (R^2) and RMSE for the models tested for estimating single leaf area of olive cultivar "Khoderi" planted in Barka with measurements from leaf length (L), leaf width (W) and product of length × width (LW) and some models used by many authors for leaf area estimation in olive

Model number	Model	R^2	RMSE
1	LA= 1.235*L-1.996	0.731	0.330
2	LA= 4.908*W -1.567	0.706	0.345
3	LA = 0.641*LW + 0.284	0.960	0.128
4	Ln(LA)= 0.143LW + 0.557	0.944	0.155
5	LA= 4.239*ln(L*W) – 3.436	0.960	0.127
6	Ln(LA)= 0.9509*ln(LW)-0.2867)	0.962	0.127
7	Koubouris et al. (2018)	0.9598	0.492
8	Lansari and Bouchra (1996)	0.9041	4.132
9	Ajayi (1990)	0.9598	0.706

Accuracy and relative efficiency of the studied models

As mentioned in M&M, a sample of 20 leaves from olive cultivars "Khoderi" and French "Picholine" was taken from Bouka olive germoplasm collection, the validity and significance of the tested models in estimating leaf area are presented in Tables 3 and 4.

Table 3 shows that the new model gave the lowest RMSE, while model (8) gave the highest. The relative efficiency of the new model was more than twice the relative efficiency of model (7) and more than 2.5 times model (9). Significant differences between actual and estimated olive leaf area measured using models 7, 8 and 9 were found, while no significant differences were found in case of model (6). The same results were obtained for cultivar "Picholine" (Table 4).

Table 3. Root Mean Square Error (RMSE), relative efficiency, and significance of tested models used for olive cultivar "Khoderi" leaf area estimation comparing to actual leaf area measured using Adobe® Photoshop® CS5

Model number	RMSE	Relative efficiency[(1)]	Significance (p= 0.01)[(2)]
6	0.400047	1	ns
7	0.858831	2.147	*
8	4.566548	11.415	*
9	1.114543	2.786	*

(1) Relative efficiency= RMSE of the tested model/ RMSE of the new model (model 6);
(2) *Significant at (p=0.01) using Student t test. ns, non-significant at (p=0.01) using Student t test.

Table 4. Root Mean Square Error (RMSE), relative efficiency, and significance of tested models used for olive cultivar "Picholine" leaf area estimation comparing to actual leaf area measured using Adobe® Photoshop® CS5

Model	RMSE	Relative efficiency[(1)]	Significance (p= 0.01)[(2)]
6	0.615	1	ns
7	1.058	1.72	*
8	6.486	10.55	*
9	1.388	2.26	*

(1) Relative efficiency= RMSE of the tested model/ RMSE of model (6);
(2) *significant at (P=0.01) using Student t test. ns, non-significant at (p=0.01) using Student t test.

Discussion

The study was conducted to evaluate some models used for single leaf area estimation of olive depending on leaf dimensions, also aimed to create a new model adopted for autochthonous olive cultivar "Khoderi" and non-destructive and easy to handle as possible. Sampled data and regression analysis resulted in a new model which was tested, evaluated and compared with other models used by many authors for single leaf area estimation in olive. The highest coefficient of determination was always obtained when both leaf length and width were involved, which was in accordance with (Koubouris et al., 2018). Using normal logarithm in estimating leaf area increased R^2 and reduced root mean square error, the new model (**$A=e^{0.9509\ln(LW) - 0.2867}$**) had the lowest RMSE without any significant difference from the actual leaf area measured using Adobe Photoshop. Those results were true in the case of "Khoderi" - an autochthonous olive cultivar in Syria as well as "Picholine" - a French olive cultivar. This might give the new model a wide potential for estimating olive leaf area from different origins. Some tested models like model number (8) mustn't be used for leaf area estimation because it gives values significantly higher than the actual ones, with very high RMSE. The new model suggested was more efficient than the tested models even model (7) which was adopted for olive. This is true because (Koubouris et al., 2018) reported that universal leaf area estimation model had moderate accuracy because of cultivar differences rather than environmental effects which was trivial. Any way, scientific caliculator, MS Excel or any other statistical or mathematical softwares could be used easily to calculate single leaf surfaces of olive with only two simple measurements (length and width of the leaves) using the new model.

Conclusion

The created and tested new model ($A=e^{0.9509\ln(LW) - 0.2867}$) could be used for a single leaf area estimation of olive cultivars "Khoderi" and "Picholine" without any doubts about its accuracy. Application of the new model on other olive cultivars could be useful but needs to be evaluated.

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