NON-DESTRUCTIVE LEAF AREA ESTIMATION IN CARNATION PLANTS

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Abstract

Simple, accurate, and nondestructive methods of determining leaf area of plants are important for many experimental comparisons. Determining individual leaf area (LA) of carnation (*Dianthus caryophyllos* L.) can involve measuring leaf length (L) and width (W). Data were collected from experiments of two carnation cultivars grown under greenhouse condition at the end of the experiment. The objective of this field study was to determine the most precise model to predict the area of individual leaves of carnation plants. With these models, estimating carnation leaf area could be done without the use of expensive instruments and destructing the leaves of the plant. It is also possible to carry out the measurements on the same leaves throughout the growing period.

Keywords: leaf area, estimation, models, carnation plant

Karanfil Bitkisinde Yaprak Alanının Bitkiye Zarar Vermeden Tahmin Edilmesi

Özet

Bitkilerin yaprak alanının belirlenmesinde kullanılan basit, doğru ve bitkiye zarar vermeyen yöntemler, birçok deneysel karşılaştırmada önemli yer tutmaktadır. Karanfil bitkisinin (*Dianthus caryophyllos* L.) yaprak alanının (LA) belirlenmesi, yaprak eni ve boyunun ölçülmesine dayanmaktadır. Bu çalışmada kullanılan veriler sera koşullarında yetiştirilen iki farklı karanfil çeşidinden deneme sonunda alınmıştır. Araştırmanın temel amacı karanfil bitkisinin yaprak alanının tahmininde kullanılabilecek en doğru yöntemi belirlemektir. Belirlenen yöntemlerle yaprak alanı, bitkiye zarar vermeden ve pahalı aletler kullanmadan tahmin edilebilecektir. Aynı zamanda yetiştirme sezonu boyunca aynı yaprak üzerinde ölçümlerin alınması da mümkün olabilecektir.

Anahtar Kelimeler: Yaprak alanı, tahmin, model, karanfil

1. Introduction

The plant canopy is a locus of physical and biochemical processes in an ecosystem. The functional and structural attributes of plant canopies are affected by microclimatic conditions, nutrient dynamics, herbivore activities, and many other factors. The amount of foliage contained in plant canopies is one basic ecological characteristic indicating the integrated effects of these factors. In turn, canopy leaf area serves as the dominant control over the primary production (photosynthesis) transpiration energy exchange, and other physiological attributes pertinent to a range of ecosystem processes. Subsequently, canopy leaf area is often treated as a core element of ecological field and modeling studies (Asner et al., 2003).

Leaf area index (LAI) of a crop was defined by Watson (1947) as the one sided area of green leaf tissue per unit area of land occupied by that crop. It determines the size of the plant–atmosphere interface and thus plays a key role in the exchange of energy and mass between the canopy and the atmosphere. The capacity of the crop to intercept photosynthetically active radiation and to synthesize carbohydrates for growth is a nonlinear function of LAI. Accurate estimation of LAI is essential to many crop growth and crop competition studies, simulation models. LAI is also one of the possible components of selection indices in

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crop improvement (Elings, 2000). Because it is a dimensionless parameter, LAI can be measured, analyzed, and modeled across a range of spatial scales, from individual plant canopy or clusters to whole regions or continent (Asner et al., 2003). Any change in canopy leaf area index (by frost, storm, defoliation, drought, management practices) is accompanied by modifications in stand productivity. Process-based ecosystem simulations are then often required to produce quantitative analyses of productivity and LAI is a key input parameter in such models (Breda, 2003).

Measuring of the surface area of a large number of leaves can be both time consuming and labor costing. Many methods have been devised to facilitate the measurement of leaf area. However, these methods, including those of tracing, blueprinting, photographing, or using a conventional planimeter, require the excision of leaves from the plant. It is therefore not possible to make successive measurements of the same leaf. Plant canopy is also damaged, which might cause problems to other measurements or experiments (Lu et al., 2004).

Leaf area can be also measured quickly, accurately, and nondestructively by using a portable scanning planimeter or by a digital camera with image measurement and analysis software. However, the former is suitable small plants with few leaves, while the latter is time consuming and the facilities are generally expensive. Therefore an inexpensive, rapid, reliable and nondestructive method for measuring leaf area is required by those working in the field of ornamental crops. If the mathematical relationships between leaf area and one or more dimensions of the leaf could be established, a method using just linear measurements to estimate leaf area would be more advantageous than many of the methods mentioned above (Lu et al., 2004).

Mathematical relationships between length, width and area of carnation leaves can serve as a basis for direct leaf area estimation. Measuring linear dimension of leaves (length and width) is an established and successful method of nondestructive estimation of leaf area. This method has been used to estimate area of individual leaves or leaf area of individual plants in sunflower (Bange et al., 2000), cucumber and tomato plants (Blanco and Folegatti, 2003), chestnut (Serdar and Demirsoy, 2006), taro (Lu et al., 2004), maize (Elings, 2000) and selected horticultural crops such as avocado, plum, kiwi fruit, aubergine and pepper (Uzun and Celik, 1999).

Although several leaf area estimation models have been developed for some of the crop species such as mentioned above, a leaf area prediction model has not been produced for carnation crop yet. Examining the coefficients in the equations given for different crops in literature shows that the coefficients as well as type of equations are crop specific. Therefore, the aim of this study is to produce a reliable equation that predicts leaf area of carnations using linear measurements.

2. Materials and Methods

Leaf samples used in this study as a material were obtained from an experiment conducted in a plastic greenhouse located at Bati Akdeniz Agricultural Research Institute, which has a latitude of 36º 56’ N and a longitude of 30º53' E. The experiment was carried out from June 2006 to May 2007 using two different varieties of carnation, Judith (standard carnation) and Terry (spray carnation). Two different irrigation intervals (S_1, and S_2) and four-pan coefficient (K_1, K_2, K_3, and K_4) were examined in the study. Irrigation intervals formed the main plots and pan coefficients were designed as sub-plots. Thus, 2x2x4 randomized complete block design were applied and each treatment were replicated four times (Gomez and Gomez, 1984).

Carnation seedlings were planted at depth of 5 cm on 20x20 cm intervals on the ridge of furrows having a width of 80 cm so that every furrow contained 4 rows. Thus, 64 plots, each of them containing 80 carnation plants and having an area of 0.8x4 m^2, were formed. A 0.5 m wide walking space was left between the experimental plots and the ridge of furrows. The plots were maintained with conventional cultural practices including fertilization, insecticide and weed control.

Irrigation intervals were based on the evaporation data (Epan, mm) obtained from the Class A Pan located inside the greenhouse (Doorenbos and Pruitt, 1977). Plants were irrigated when the evaporation reached 10 mm±%10 (S_1) and 20 mm±%10 (S_2). Four different pan coefficients i.e. K_1=0.60 Epan, K_2=0.90 Epan, K_3= 1.20 Epan and K_4= 1.50 Epan were applied.

At the end of the experiment, all of the carnation plants were cut and the length (L), width (W) (Figure 1) and area of the leaves of each individual plant were measured. The leaves belonging to a carnation plant were placed on a white paper and then scanned. Using suitable software (Global Lab Image, Version 2.00), the length, width and area of the leaves were determined in terms of pixel. Pixels were transformed to length, width and area based on a known length and area marked on the paper where leaves were placed.

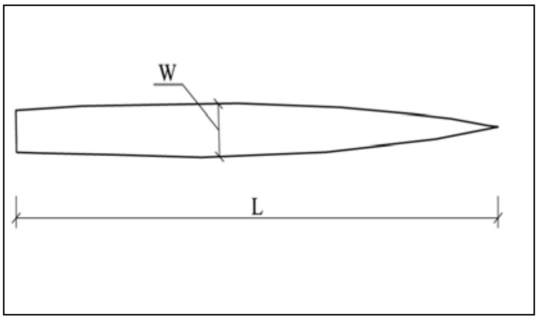

Figure 1 Carnation Leaf Showing the Position of Leaf Length (L) and Width (W)

The measured area of the leaves (LA) was estimated using linear as well as nonlinear equations based on length (L) and width (W) of the leave. The unknown fitting parameters in equations were estimated through an optimization procedure done with MS Excel Solver (Walsh and Diamond, 1995).

The data belonging to the variety of Judith was used to calibrate the equations while those belonging to the variety of Terry were used to validate the equations. The fitting parameters were not adjusted during validation. The best values of the parameters during calibration were found such that the statistics given in Table 1 were satisfied. If all the predicted and observed values were the same, then Maximum Error (ME), Root Mean Squared Error (RMSE), Coefficient of Residual Mass (CRM) would yield zero and, Coefficient of Determination (CD) and Modeling Efficiency (EF) would yield one.

Table 1 Measures for Analysis of Residual Errors (Loague and Green, 1991)

Maximum error,
$\mathrm{ME} = \mathrm{Max}\left\|P_i - O_i\right\|,\ i = 1, \ldots n$
Root mean square error,
$\mathrm{RMSE} = \left[\dfrac{\sum_{i=1}^{n}(P_i - O_i)^2}{n}\right]^{0.5} \cdot \dfrac{100}{O}$
Coefficient of residual mass,
$\mathrm{CRM} = \dfrac{\sum_{i=1}^{n} O_i - \sum_{i=1}^{n} P_i}{\sum_{i=1}^{n} O_i}$
Coefficient of determination,
$\mathrm{CD} = \dfrac{\sum_{i=1}^{n}(O_i - O)^2}{\sum_{i=1}^{n}(P_i - O)^2}$
Modeling efficiency,
$\mathrm{EF} = \dfrac{\sum_{i=1}^{n}(O_i - O)^2 - \sum_{i=1}^{n}(P_i - O_i)^2}{\sum_{i=1}^{n}(O_i - O)^2}$

P_i = predicted values; O_i = observed values; O = mean of the observed data; n = number of samples.

3. Results and Discussion

The results of the models used in calibration and validation process are given in Table 2. During validation process, the coefficients in the equations are not adjusted. Various combinations of measurements (e.g., recording the length and width together or measuring the length and width only) and various models relating linear dimensions to area have been utilized

Table 2 Different Models Proposed to Estimate Individual Leaf Area of Carnation Plant

Model Number	Model
1	$LA = 0.64 - 0.0037L^2 - 0.0012\frac{L^2}{W^2} - 3.482W^2 + 1.174LW$
2	$LA = -0.0022L^2 + 0.0039\frac{L^2}{W^2} - 3.669W^2 + 1.407LW$
3	$LA = 0.52 - 0.0099L^2 - 3.876W^2 + 1.176LW$
4	$LA = 0.0136L^2 - 0.824W^2 + 0.663LW$
5	$LA = 0.0388L^2 + 5.042W^2$
6	$LA = 1.77 + 0.049L^2$
7	$LA = -1.37 + 0.84L$
8	$LA = 0.294L^{1.373}$
9	$LA = 0.91LW$

Model Number	Calibration					Validation				
	RMSE %	EF	CD	ME	CRM	RMSE %	EF	CD	ME	CRM
1	3.37	0.99	1.00	0.66	0.0	6.40	0.94	0.82	0.87	-0.03
2	3.60	0.99	0.99	0.68	0.0	7.35	0.92	0.73	0.95	-0.033
3	3.38	0.99	1.01	0.67	0.0	6.76	0.93	0.79	0.90	-0.03
4	3.96	0.99	0.94	0.68	0.0	5.92	0.95	0.85	0.79	-0.04
5	4.17	0.99	0.96	0.62	0.0	8.43	0.90	0.95	0.81	-0.07
6	10.50	0.92	1.10	1.47	0.0	10.97	0.82	1.08	1.32	0.02
7	8.40	0.95	1.06	1.53	0.0	10.50	0.84	0.72	1.60	-0.03
8	9.20	0.94	1.11	1.51	0.0	10.86	0.83	0.75	1.52	0.02
9	4.60	0.98	0.98	0.84	0.0	8.02	0.91	0.81	0.88	-0.07

(Table 2). The highest RMSE value was obtained from model 6, while the least value was obtained from model 1 both for calibration and validation cases. Usually, the models containing interaction term L*W gave lower values of RMSE and higher values of EF than that of the models including only length (Models 6, 7, 8). Bange et al. (2000) is also reporting that inclusion of interaction term L*W is decreasing RMSE.

Model 8 and 9 are also shown in Figure 2 and 3, respectively, together with the coefficient of determination on the figures. Higher values of coefficient of determination were obtained from both of the models which shows that the leaf area is highly correlated with length and interaction term L*W. It is clearly seen in Figure 2 that square of leaf length is a straight line on a logarithmic paper. The intercept value of 0.2937 is the value when square of length is equal to one (Figure 2). The leaf area can be computed simply by multiplying interaction term L*W by 0.91, i.e. LA = 0.91* (L*W) (Figure 3). For this type of model, Blanco and Folegatti, (2003) is reporting the value of 0.85 in cucumber, while Elings, (2000) is suggesting the value of 0.75 for maize.

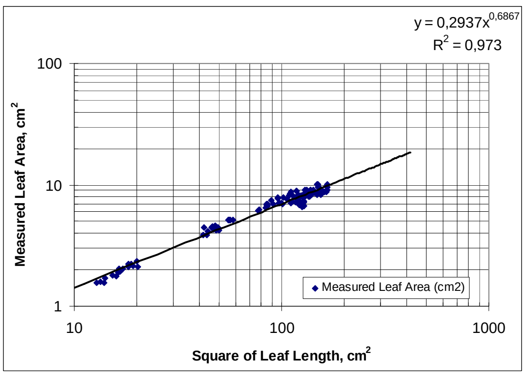

Figure 2 Measured Area of a Leaf as a Function of Square of Leaf Length.

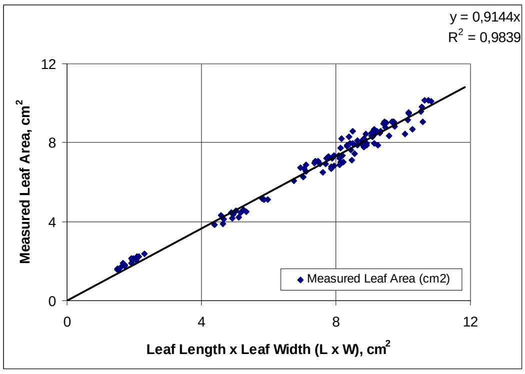

Figure 3 Measured Area of a Leaf as a Function of L*W

Measured and estimated individual leaf areas are plotted in Figures 4 through 7 for calibration case in order to show visually the correlation between them. In Figure 4, estimated and measured values are plotted using model 8, whereas in Figure 5, equation given in Model 9 is used to plot measured and estimated leaf areas. The RMSE of model 8 (Figure 4) is two fold of the RMSE of model 9 (Figure 5). Higher RMSE causes discrepancies from one to one line as seen in Figure 4.

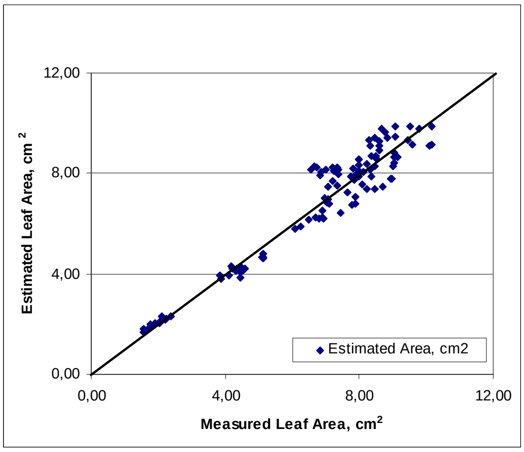

Figure 4 Estimated and Measured Leaf Area Using Model No 8.

Measured and estimated leaf area using model 1, which has the least RMSE and the highest modeling efficiency (EF), 3.37% and 0.99, respectively (Table 2), is plotted in Figure 6 while the results obtained using model 6, which has the highest RMSE and least EF, 10.5% and 0.915, respectively (Table 2), are plotted in Figure 7. Higher divergences from one to one line, compared to Figure 6, were observed in Figure 7 as a result of higher RMSE and lower EF.

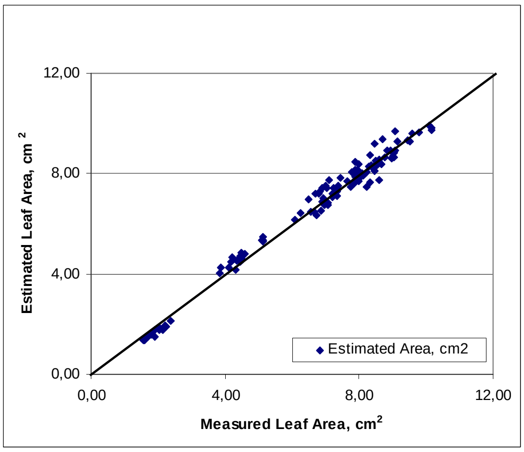

Figure 5 Estimated and Measured Leaf Area Using Model No 9.

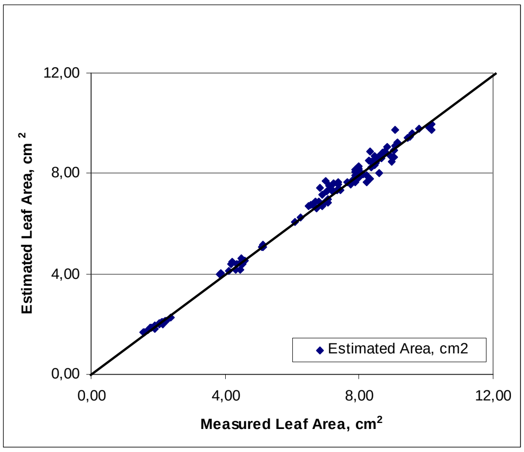

Figure 6 Estimated and Measured Leaf Area Using Model No 1 (lowest RMSE).

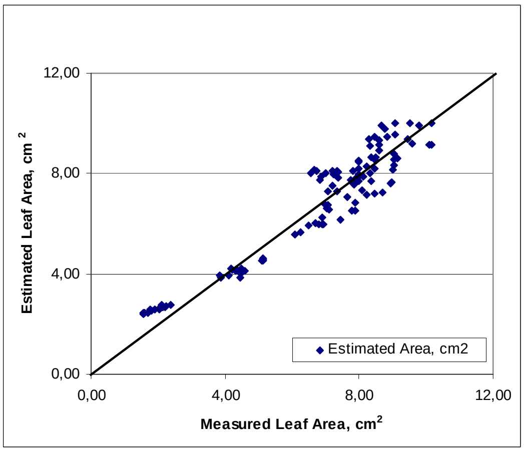

Figure 7 Estimated and Measured Leaf Area Using Model No 6 (highest RMSE).

The models given in Table 2 are validated against data set obtained from the variety of Terry. The fitted parameters in the equations are not changed in the validation process. In this process, basically, an answer is tried to find to the question of "If only the length and width of the leave are known, how you would estimate the area of an individual leaf?" In this case the RMSE is increased almost two fold for lower values of RMSE and EF decreased slightly. In the validation, the highest RMSE value was obtained from model 6 which had the highest RMSE also in the calibration process. Note that this equation was based only length of the leave. Not only in this equation, but also in models 7 and 8, which were based only one parameter; the error was at close proximity of 10 percent, which is, from an engineering point of view, in acceptable limits.

Measured and estimated individual leaf areas are plotted in Figures 8 through 11 for validation case in order to show visually the correlation between them. The results obtained from model 8, where only length of the leaf is depended variable, are plotted in Figure 8, whereas in Figure 9, the equation given in Model 9 is used to plot measured and estimated leaf areas. Apparently, leaf areas obtained using equation 9 slightly over estimated the measured leaf areas (Figure 9).

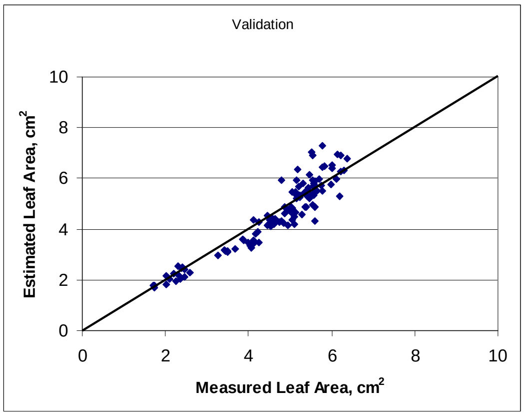

Figure 8 Estimated and Measured Leaf Area Using Model No 8.

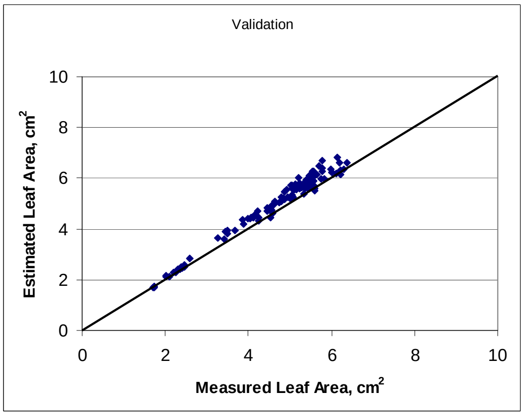

Figure 9 Estimated and Measured Leaf Area Using Model No 9.

Results obtained from models having the least (model 1) and highest (model 6) RMSE values are shown visually in Figures 10 and 11, respectively. As the RMSE is increasing the discrepancy is also increasing (Figure 11). The best results, in terms of statistics given in Table 1 as well as visually, were obtained from model 1 because it included length (L), width (W) and interaction term (L*W).

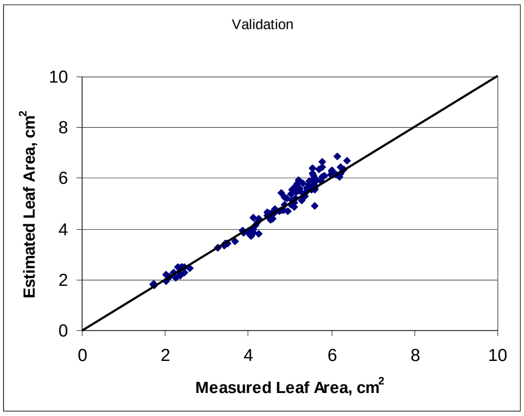

Figure 10 Estimated and Measured Leaf Area Using Model No 1.

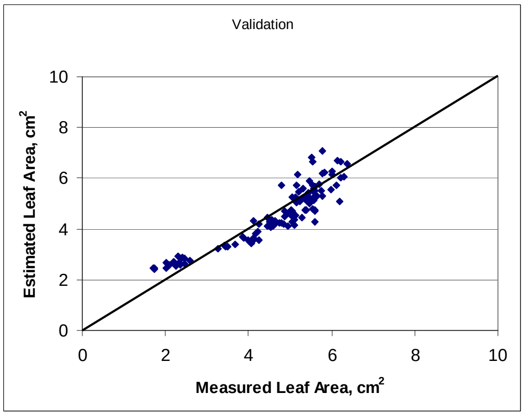

Figure 11 Estimated and Measured Leaf Area Using Model No 6.

4. Conclusions

Results showed that all the models given in Table 2 are able to predict individual leaf area. The highest error was around 10 percent, which is an acceptable limit from an engineering point of view. The method that could be chosen by an individual researcher depends on the time available to take measurements and the level of precision desired. While measurements of both width and length can be more precise than estimates based on one dimension, this method requires twice the number of measurements.

Using the models obtained in this study, individual leaf area as well as LAI of carnation plants can be computed without using expensive instruments. This method would not destruct the leaves and the plant when the number of plants in the experimental plots is limited. Also, the method would make it possible to carry out the measurements on the same leaves throughout the growing season.

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