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SIMPLE MATHEMATICAL MODELS FOR PREDICTING LEAF AREA OF COTTON PLANT

Aboukarima, A. M. ; H. A. Elsoury and M. Minyawi
Agriculture Engineering Research Institute, Agriculture Research Centre, P. O. Box 256, Cairo, Dokki, Giza, Egypt

ABSTRACT

Cotton is considered as one of the most important crops in Egypt. Measuring the leaf area of such plant is one of the most accurate indicators to estimate the quantity of pesticides and productivity. Several research works have shown that deriving mathematical models as a method to estimate the leaf area of various plants is considered more precise, time- saving, cost-reducing and less harmful on the examined plants compared to direct methods of measuring leaf area such as digital planimeter, electronic devices and manual engineering measuring tools. In spite of all this developing mathematical models in the field of determining Egyptian cotton leaves area has not attained the least of research work. Therefore, the aim of the study is deriving a mathematical model suitable for predicting the area of cotton leaves. To achieve this aim, a mathematical model was developed using 240 Egyptian cotton leaves (Giza 86). These leaves were collected at random from different heights and different fields in Kafer El-Dawar centre, El-Behera Governorate, Egypt. Regression analysis has been used in developing 19 mathematical models to choose the best model for predicting leaf area through calculating statistical indicators that included: R^2, root mean square error and mean absolute error. The selected models have been mathematically analyzed to obtain the regression constants of each model. Data analysis has shown that the best model is the one that determined the actual area of the leaf area. The outcome equation is as follows:

$$LA = 2.451 - LW + 1.372\,WL2 + 1.682\,LL1 - 1.345\,L1L2 \qquad R^2 = 0.96$$

Where (LA) is the leaf area (cm^2) and the rest of dimensions are measured in centimeters. The efficiency of this model has been tested by defining R^2 and comparing predicted leaf area results from the model with measured leaf area results. The results have shown that the developed model mentioned above is the most accurate model to be recommended in estimating Egyptian cotton leaves area from leaf width (W), main lobe length (L), right lobe length (L1) and left lobe length (L2). The developed regression model can be considered an alternative method to determine the Egyptian cotton leaves area instead of the direct method represented by for example the leaf area measuring instrument.

INTRODUCTION

Cotton is the most important fibre crop in Egypt and has played a significant role in agriculture sector. Accurate and non-destructive methods to determine individual leaf areas of plants are useful tools in physiological and agronomic research. These methods involve measurements of leaf parameters including leaf length and width, or some combination of these parameters (Olfati et al., 2010). Accurate and rapid measurements of leaves surface area are of special concern to plant scientists as well as to process engineers handling these materials. Sustainability of the leaves affect crop growth and bio-productivity, hence leaf area measurements assume a great significance in plant growth studies. Measurement of leaf area is of value in studies of plant nutrition, plant competition, plant soil-water relations, plant protection measures, crop ecosystems, respiration rate, light reflectance, and heat transfer in heating and cooling processes (Mohsenin, 1986).

Leaf area plays an important role in determining proper application rates of insecticides and fungicides (Suggs et al., 1960). Besides it is of value as an index of plant growth and is related to the accumulation of dry matter, plant metabolism and yield. Crop quality and maturity may also be related to leaf area. Furthermore the knowledge of leaf area dimensions may be useful in estimating the amount of chemicals to be sprayed for disease and pest control (Moustakas and Ntzanis, 1998).The importance of leaf area determination in plant sciences has stimulated the use of a great variety of methods for leaf area measurement. Some of the basic methods are graphical method, length and width correlation, leaf specific weight correlation, and usage of electronic devices (Mohsenin, 1986). Leaf area plays an important role in photosynthesis, light interception, water and nutrient use, crop growth, and yield potential (Aase, 1978; Smart, 1985; Williams, 1987). A simple, rapid, accurate, and non-destructive method for the estimation of leaf area may be useful by determining the relationship between leaf area and plant growth rate (Robbins and Pharr, 1987; Gamiely et al., 1991; Montero et al., 2000).

Measurement of leaf area in crops like cotton with various types of leaf area meters is difficult, labour-intensive and costly because there is much variation in number, size and shape of leaves (Reddy et al., 1989). On the other hand, measuring instruments are very expensive and often not available in developing countries (Daughtry and Hollinger, 1984; De Jesus et al., 2001). So, alternatively, indirect methods for measuring leaf area could be used. They can be classified as non-destructive and destructive methods. In non-destructive methods, leaf area is usually estimated by measuring the number, width or length of plant parts or whole plant, e.g., leaf width, length and number, branch length and number, and plant height. These measurements can be undertaken without cutting the plants. Non-destructive methods eliminate the need for expensive leaf area meters (Sezgin and Celik, 1999) and have been successfully applied for various crops (Lu et al., 2004) such as cotton and castor (Wendt, 1967) and as soybean (Bakhshandeh et al., 2011). In indirect destructive methods, leaf area is usually estimated as a function of dry weight of plant parts or total above ground dry weight (Jonckheere et al., 2004).

Jayeoba et al. (2007) conducted an experiment to develop a mathematical model for predicting leaf area for *Ocimum gratissimum* using linear regression. A total of 300 leaves, representing five various leaf sizes, were randomly selected from the field over a period of three months. The square, sum and product of the L and W were calculated and recorded as the leaf area estimates while the number of squares within which the trace of the leaf fell on the graph paper were counted and also estimated as a leaf area. The best-fit model was selected based on F-test, mean square error and coefficient of determination (R^2). The results of statistical analyses showed that correlation coefficient of all the parameters were highly significant at 1%

level of significance. Linear regression indicated that L, L^2, W, W^2, L+W, L*W and graph paper were 91 %, 92 %, 89 %, 93 %, 95 %, 98 % and 98 % respectively to the actual leaf area. The regression model of LA= 0.5466(L*W) + 0.7501, such that the actual measurements of L and W are simply inserted into the equation and leaf area is computed.

Akram-Ghaderi and Soltani (2007) developed regression models for estimating leaf area of field-grown cotton (Gossypium hirsutum L.) from measurements of leaf dry weight (LDW), vegetative components (stems and leaves) dry weight (VDW) and plant height (PH). Three cotton cultivars (Deltapine 25, Sahel and Siokra 324) with different leaf morphologies were grown under varying growth conditions created by four different planting dates in a temperate sub-humid environment (Gorgan, Iran). Leaf area, LDW, VDW and PH were measured at one month after emergence, squaring, flowering, bolling, boll opening and second harvest. Measured leaf area ranged from 170 to 8167 cm^2. Different regression models were examined for describing leaf area relationships to LDW, VDW and PH. It was found that the power function gives the best fit in terms of R^2 and root mean square error (RMSE). Cultivar differences were not significant and a general equation was adequate for all the three cultivars. LDW and VDW provided good estimation of leaf area. However, PH was not a good predictor of leaf area. It was concluded that cotton leaf area can be estimated or simulated as a function of LDW or VDW with reasonable accuracy.

Olfati et al. (2010) carried out a research experiment based measurements of leaf parameters including leaf length and width, or some combination of these parameters to determine individual leaf areas on eight cabbage, six broccoli, and three red cabbage genotypes under open field conditions, to see whether an equation could be developed to estimate leaf area of such plants. Regression analysis of leaf area (LA) versus leaf length (L) and leaf width (W) revealed several equations that could be used for estimating the area of individual cabbage and broccoli leaves. A linear equation having leaf width as the independent variable provided the most accurate estimate of red cabbage as well as ordinary cabbage leaf area. The linear equation (LA= a+b W^2) exhibited a high accuracy and precision in estimating red cabbage and non-red cabbage LA. For broccoli a linear equation having LW as the independent variable provided the most accurate estimate of LA, but required twice the time needed for leaf area measurement.

In the field of cotton crop research, a good and independently model of non-destructive leaf area estimation is needed for the physiological and agronomic studies of the cotton plants. Therefore, the objective of this study was to develop a simple mathematical model for predicting leaf area of Egyptian cotton plant.

MATERIALS AND METHODS

1.Cotton leaves samples collection

Cotton leaf samples from cotton plants variety Giza 86 (Long Staple, El-Feky and Hassan, 2011) were randomly collected from four different cotton planting sites (Elnashw (Site 1) – Near Elkarakool (Site4) – Elkhadra (Site 3) – Elkarakool (Site 2)) in Kafer El-Dawar centre, Nile Delta in northern Egypt (latitude 31° 7′ 52″ N, longitude 30° 7′ 48″ E and elevation 6 m), El-Behera Governorate, Egypt, during August 2014. The planting date was nearly the same during April 2014. The neighbour fields were differed and they were rice, maize and cotton fields.

Each cotton field site was divided into 20 equal plots. An individual cotton plant was randomly selected from each plot. Each Cotton plant height was divided into three canopy layers as shown in Figure (1) as reviewed by Alarcona and Sassenrath (2011): from zero (ground level) up to 45 cm, greater than 45 cm to 105 cm, and greater than 105 cm. One randomly leaf was picked from each layer and marked by pen marker. Total 240 leaves were collected. Leaves were kept in plastic pages and reserved in an ice box to keep it fresh.

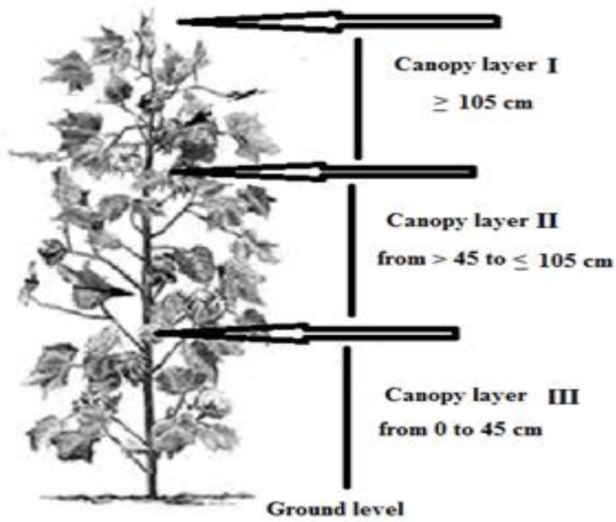

Figure (1). Diagrammatic representation of leaves position on a cotton plant.

2. Leaf parameters measurements

Some leaf dimensions like leaf width (distance between left and right lobes tip, W), leaf length (main-lobe length (Jiang et al., 2000) or distance between main lobe tip and leaf origin, L), right lobe length (distance between right lobe tip and leaf origin (L2) and left lobe length (distance between left lobe tip and leaf origin (L1) as shown in Figure (2) were measured and recorded for use to construct the simplest mathematical model. All these dimensions were measured with a graduated rule. Actual leaves were graphed on papers (Figure 3) and digital planimeter was calibrated and used to measure the actual area (Figure 4). However, planimeter was calibrated by tracing it by the user 5 times (replicates) over each figure of four engineering shapes which of known areas (triangle, square, trapezoid and circle). Area were determined and the average relative error were -0.4 % . The calibration data of the planimeter are illustrated in Table (1).

Table (1). Calibration data of the used planimeter.

Shape	TA	Measured area					AA	SD	RE+
		R1*	R2	R3	R4	R5			
	cm^2	cm^2					cm^2	cm^2	%
Triangle	15	15.1	14.9	15	15.1	15	15.0	0.1	-0.1
Square	25	25.2	25.3	25.2	25.3	24.8	25.2	0.2	-0.6
Trapezoid	50	50.3	50	50.3	50.4	50.2	50.2	0.2	-0.5
Circle	100	100.5	100.2	100.5	100.4	100.2	100.4	0.2	-0.4

TA means actual area, AA means average area, SD means standard deviation
***R means replicate**
+(RE) means relative error, RE= [(Actual area- average area)/ actual area]×100

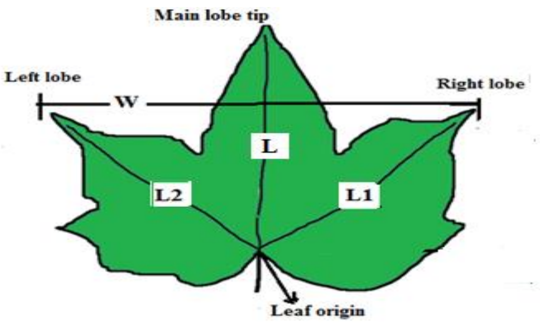

Figure (2). Diagram of cotton leaf, showing positions of leaf width (W), main lobe length (L), right lobe length (L1) and left lobe length (L2).

Figure (3). Actual leaves traced on graph papers.

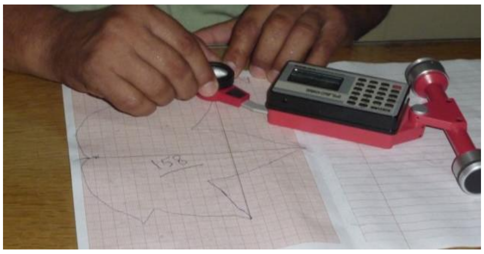

Figure (4). Digital planimeter for measuring the actual area.

3. Leaf area model construction

Different regression models developed by the authors are shown in Table (2) for cotton leaf area predictions. These modes were evaluated for their accuracy in predictions. All equations were composed of various subsets of independent variables, such as distance between left and right lobes tip (W, cm), distance between main lobe tip and leaf origin (L, cm), distance between right lobe tip and leaf origin (L1, cm) and distance between left lobe tip and leaf origin (L2, cm). Nineteen models determined to be the most suitable for predicting leaf area (LA) of cotton were selected. Regression analysis was performed by Excel spread sheet using the mathematical models and the experimental data.

Table (2). Mathematical models used to predict cotton leaf area.

Model form*	Model No.
$LA = a + bWL$	1
$LA = a + bW + cWL$	2
$LA = a + bL + cW + dWL$	3
$LA = a + bL + cW^2 + dWL$	4
$LA = a + bW + cL^2 + dW^2$	5
$LA = a + bL + cL^2 + dW^2$	6
$LA = a + bL + cW + dL1 + eL2$	7
$LA = a + bL + cW + dL1L2$	8
$LA = a + bLW + cL1L2$	9
$LA = a + bL1 + cL2$	10
$LA = a + bL1L2$	11
$LA = a + bL + cW + d(L1 + L2)$	12
$LA = a + bLW + cWL1 + dLL2$	13
$LA = a + bL^2 + cW^2 + dL1L2$	14
$LA = a + bL1^2 + cL2^2$	15
$LA = a + b(L + W) + c(L1 + L2)$	16
$LA = a + bW^2 + cL^2 + dL1^2 + eL2^2$	17
$LA = a + bLW + cWL2 + dLL1$	18
$LA = a + bLW + cWL2 + dLL1 + eL1L2$	19

* **a,b,c,d and e are regression constants.**

4. Model evaluation

There were some criteria to select the best model to predict the cotton leaf area, namely coefficient of determination (R^2), Mean Absolute Error (MAE) which was the mean absolute of the deviations between the measured and predicted values for the models and Root Mean Square Error (RMSE) that was the deviation between the predicted and measured values (Akpina et al., 2003). The model to be selected must show the highest value of R^2, the lowest values RMSE and MAE and ease of use in practice (Thao and Noomhorm, 2011). The mean absolute error (MAE) and root mean square error (RMSE) are calculated as follows:

$$MAE = \frac{\sum_{i=1}^{i=N} \left| LA_{i\,obs} - LA_{i\,pre} \right|}{N} \qquad \text{(1)}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{i=N} \left(LA_{i\,obs} - LA_{i\,pre} \right)^2}{N}} \qquad \text{(2)}$$

Where LA_{iobs} is measured cotton leaf area, LA_{ipre} is predicted cotton leaf area by different models and N is number of observations.

5. Statistical analysis

The field data were statistically analyzed using analysis of variance (ANOVA, Steel and Torrie, 1980). Effect of planting site and leaf position on the cotton stem was studied. All the collected data were subjected to the ANOVA using SAS (1998) statistical computer software. Comparisons among treatment means, when significant, were conducted using least significant difference (LSD) at p = 0.05 level.

RESULTS AND DISCUSSION

1. Descriptive statistical of dimensions of the cotton leaves

The means, standard deviation, skewness, kurtosis, minimum, maximum and coefficient of variation estimates for the appeared dimensions of a cotton leaf in Figure (2) besides measured cotton leaf area for each site and for each leaf position on cotton plant are presented in Table (3). The data from the means reveal the characteristics of the cotton leaf. The standard deviation shows the amount of variation for each dimension among the sites and leaf position on the cotton plant. To identify the most variant dimension among sites and leaf position on the cotton plant, a coefficient of variation was used that was not dependent on the dimensions. Among the studied dimensions, the highest coefficients of variation corresponded to the cotton leaf area. Other coefficients of variation for the studied dimensions were moderate to high and varied from 7.5% to 26.1% (Table 3).The analysis of the descriptive statistics revealed low variability among the studied sites and leaf position on the cotton plant for the studied dimensions.

2. Effect of planting site and leaf position on the main stem of the cotton plant on the selected dimensions of the cotton leaves

Effect of planting site and leaf position on the main stem of the cotton plant on distance between left and right lobes tip (W) is illustrated in Figure (5). It is clear that planting site and leaf position on the main stem of the cotton plant markedly affect the dimension (W) as shown in Figure (5).

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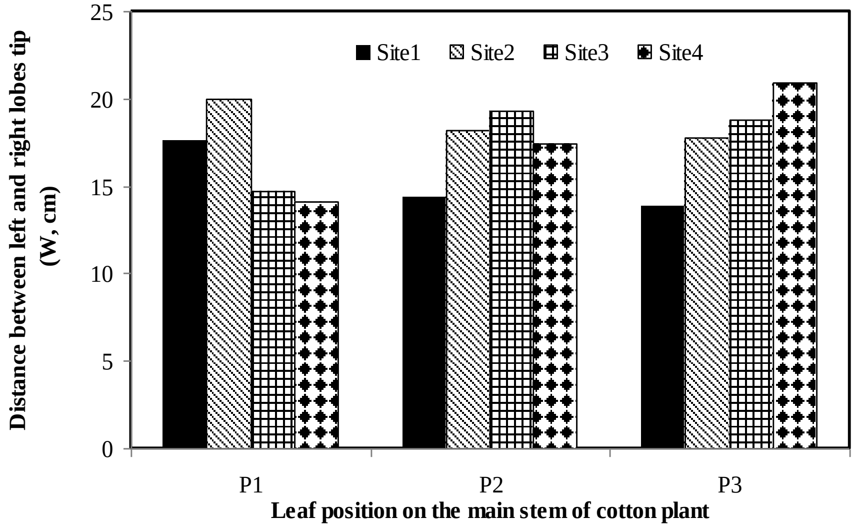

Figure (5). Changes in distance between left and right lobes tip (W) with leaf position on the main stem of cotton plant for different planting sites.

Planting site and leaf position on the main stem of the cotton plant and interaction showed significant effect on (W) (Table 4). Mean distance between left and right lobes tip differs with planting site; it was lowest with the planting site1 (15.27 cm) and the highest (W) was 18.66 cm at planting site 2 (Table 5). Meanwhile, mean distance between left and right lobes tip (W) was also differed by leaf position on the main stem of the cotton plant (Table 6); it was lowest at position (P1) with value of 16.59 cm and the highest (W) was 17.86 cm at position (P3).

Table (4). Probabilities of significance for different dimensions of cotton leaf as affected by planting site (PS) and leaf position on the main stem of cotton plant (LP).

Parameters	PS	LP	PS×LP
Distance between left and right lobes tip (W)	**	*	**
Distance between main lobe tip and leaf origin (L)	**	**	**
Distance between right lobe tip and leaf origin (L1)	**	**	**
Distance between left lobe tip and leaf origin (L2)	**	**	**
Measured cotton leaf area (LA)	**	**	**

**** and * are significant at $p<0.01$ and $p<0.05$, respectively.**

Table (5). Mean* W, L, L1, L2 and measured LA as affected by planting site.

Planting site	(W)	(L)	(L1)	(L2)	(LA)
Site1	15.27b	13.27c	10.85c	10.61c	111.94 c
Site2	18.66a	16.36a	13.71a	13.89a	176.05a
Site3	17.61a	15.46b	12.59b	12.52b	153.99b
Site4	17.65a	15.13b	12.75b	12.67b	155.99b
LSD (5%)**	1.22	0.69	0.69	0.69	14.27

*** Means followed by different letters in each column are significantly different at P = 0.05.**
**** LSD = least significance difference.**

Table (6). Mean* W, L, L1, L2 and measured LA as affected by leaf position on the main stem of cotton plant.

Leaf position	(W)	(L)	(L1)	(L2)	(LA)
P1	16.59b	14.52b	11.80b	11.74b	132.32b
P2	17.32ab	14.56b	11.85b	11.95b	139.10b
P3	17.86a	16.08a	13.77a	13.57a	177.06a
LSD (5%)**	1.06	0.60	0.60	0.60	12.36

*** Means followed by different letters in each column are significantly different at P = 0.05.**
**** LSD = least significance difference.**

Effect of planting site and leaf position on the main stem of the cotton plant on distance between main lobe tip and leaf origin (L) is illustrated in Figure (6). It is clear that planting site and leaf position markedly affect the dimension (L). Planting site and leaf position on the main stem of the cotton plant and interaction showed significant effect on (L) (Table 4). Mean distance between main lobe tip and leaf origin differs with planting site; it was lowest with the planting site1 (13.27 cm) and the highest (L) was 16.36 cm at planting site 2 (Table 5). Meanwhile, mean distance between main lobe tip and leaf origin (L) was also differed by leaf position plant (Table 6); it was lowest at position (P1) with value of 14.52 cm and the highest (L) was 16.08 cm at position (P3).

Effect of planting site and leaf position on the main stem of the cotton plant on distance between right lobe tip and leaf origin (L1) is illustrated in Figure (7). It is clear that planting site and leaf position markedly affect the dimension (L1). Planting site and leaf position and interaction showed significant effect on (L1) (Table 4). Mean distance between right lobe tip and leaf origin (L1) differs with planting site; it was lowest with the planting site1 (10.85 cm) and the highest (L1) was 13.71 cm at planting site 2 (Table 5). Meanwhile, mean (L1) was also differed by leaf position on the main stem of the cotton plant (Table 6); it was lowest at position (P1) with value of 11.80 cm and the highest (L1) was 13.77 cm at position (P3).

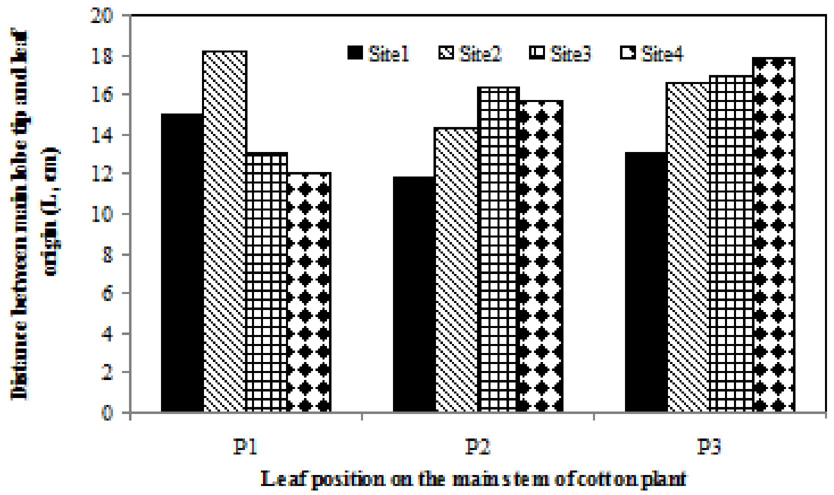

Figure (6). Changes in distance between main lobe tip and leaf origin (L) with leaf position on the main stem of cotton plant for different planting sites.

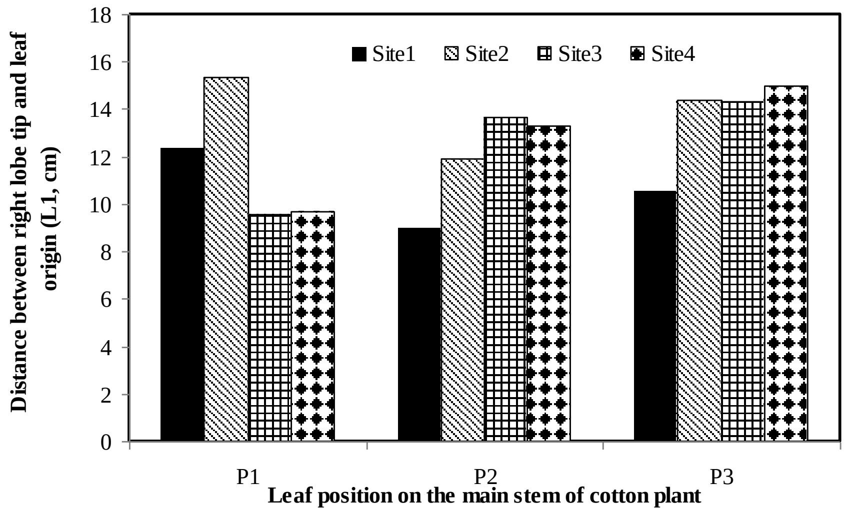

Figure (7). Changes in distance between right lobe tip and leaf origin (L1) with leaf position on the main stem of cotton plant for different planting sites.

Effect of planting site and leaf position on the main stem of the cotton plant on distance between left lobe tip and leaf origin (L2) is illustrated in Figure (8). It is clear that planting site and leaf position markedly affect the dimension (L2). Planting site and leaf position on the main stem of the cotton plant and interaction showed significant effect on (L2) (Table 4). Mean distance between left lobe tip and leaf origin (L2) differs with planting site; it was lowest with the planting site1 (10.61 cm) and the highest (L2) was 13.89 cm at planting site 2 (Table 5). Meanwhile, mean distance between left lobe tip and leaf origin (L2) was also differed by leaf position on the main stem of the cotton plant (Table 6); it was lowest at position (P1) with value of 11.74 cm and the highest (L2) was 13.89 cm at position (P3).

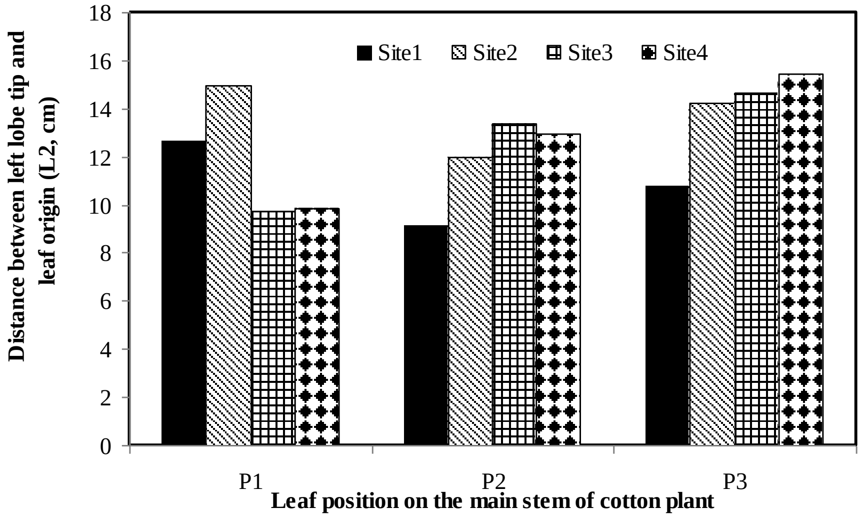

Figure (8). Changes in distance between left lobe tip and leaf origin (L2) with leaf position on the main stem of cotton plant for different planting sites.

Effect of planting site and leaf position on the main stem of the cotton plant on measured cotton leaf area (LA) is illustrated in Figure (9). It is clear that planting site and leaf position markedly affect measured cotton leaf area (LA). Planting site and leaf position on the main stem of the cotton plant and interaction showed significant effect on measured cotton leaf area (LA) (Table 4). Mean measured cotton leaf area (LA) differs with planting site; it was lowest with the planting site1 (111.94 cm^2) and the highest measured cotton leaf area (LA) was 176.05 cm^2 at planting site 2 (Table 5). Meanwhile, mean measured cotton leaf area (LA) was also differed by leaf position on the main stem of the cotton plant (Table 6); it was lowest at position (P1) with value of 132.32 cm^2 and the highest measured cotton leaf area (LA) was 177.06 cm^2 at position (P3).

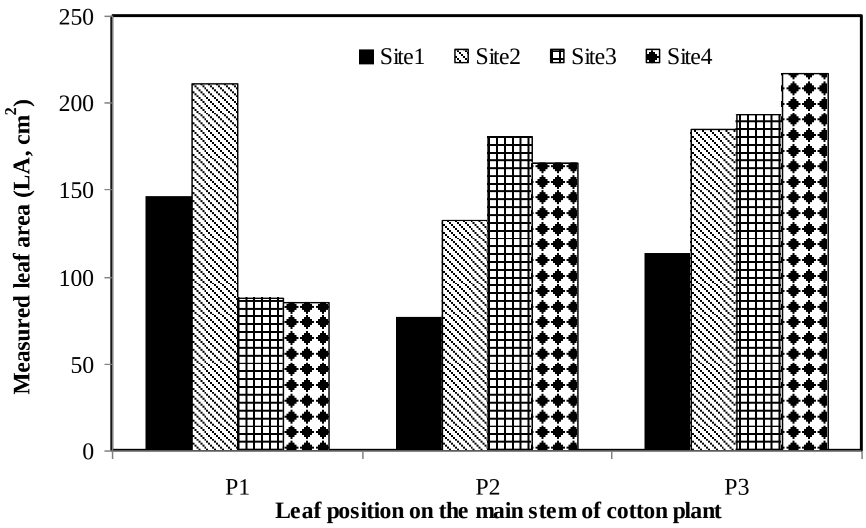

Figure (9). Changes in measured cotton leaf area (LA) with leaf position on the main stem of cotton plant for different planting sites.

3. The models proposed to estimate individual leaf area of cotton plant

The study is proposing a simple model to prediction leaf area of cotton crop cultivated in Egypt by measuring of length, width and other dimensions of leaves. Relationship among measured cotton leaf area and the dimensions (W, L, L1 and L2) were drawn and presented in Figure (10). The best fit was selected between different pairs of characters and it was differed from polynomial to power function with coefficient of termination (R^2) rang of 0.7759 to 0.9025 as illustrated in Figure (10).

Simple correlation coefficients that were computed between different pairs of characters for all data (240 points) are presented in Table (7). There were positive significant linear relationships between the studied dimensions. For example, the distance between left and right lobes tip (W) positively and strongly correlated with measured cotton leaf area (LA) (r = 0.864). The distance between main lobe tip and leaf origin (L), distance between right lobe tip and leaf origin (L1) and distance between left lobe tip and leaf origin (L2) were positively and strongly correlated with the measured cotton leaf area (LA) as shown in Table (7). In the study of Jiang et al. (2000), positive correlations were observed between L and L1 and L2 and leaf length and width are also positively correlated. These results showed that cotton leaf area has a high positive correlation with its selected dimensions in this study. The results of correlation studies can be used as an indirect estimating for leaf area.

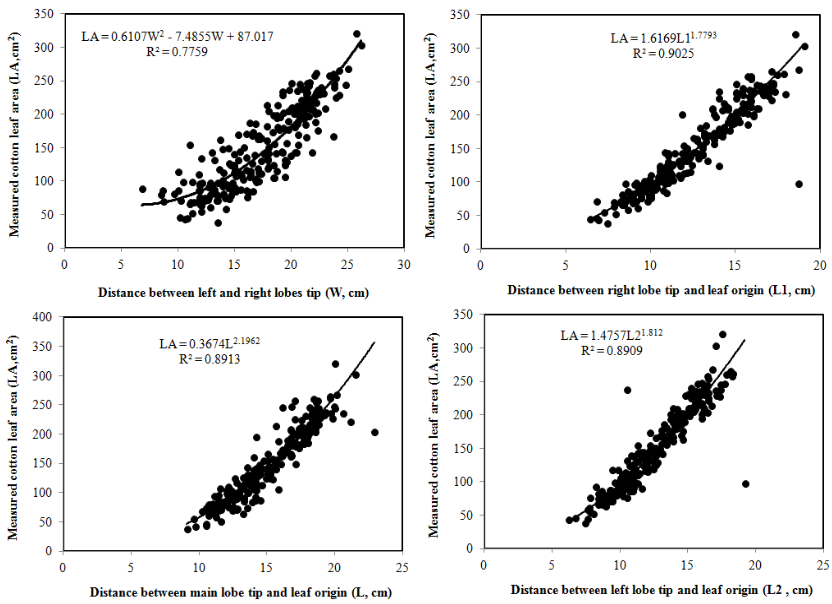

Figure (10). Relationship among measured cotton leaf area (LA) and the dimensions (W, L, L1 and L2).

The degree of fitness of 19 models was compared on the basis of R^2, RMSE and MRE. The results from Table (8) show that R^2 rang (0.894 to 0.964), RMSE rang (11.731 to 20.04) as well as MRE rang (8.727 to 15.813) were found for all models. This indicated that all models could be used for predict cotton leaf area. However, the best model was observed in Model No.19. According to these results, distance between left and right lobes tip (W), distance between main lobe tip and leaf origin (L), distance between right lobe tip and leaf origin (L1) and distance between left lobe tip and leaf origin (L2) contribute to accurately determine cotton leaf. To validate the developed model for the estimation of leaf area, actual and predicted data were compared. Figure (11) shows the comparison between the actual (experimental) and predicted leaf area for model No.19. Some variability around the regression line may be due to planting site and different canopy layer on the cotton plant.

Table (7). Correlation matrix among the studied characteristics of Egyptian cotton leaves.

	W	L	L1	L2	LA
W	1				
L	0.827	1			
L1	0.824	0.903	1		
L2	0.814	0.906	0.926	1	
LA	0.864	0.941	0.942	0.935	1

Table (8). Statistical results of modeling criteria (R^2, RMSE and MAE), and regression constants to predict cotton leaf area.

Model No.	Regression constants					R^2	RMSE	MAE
	(a)	(b)	(c)	(d)	(e)			
1	0.171	0.555				0.89	20.04	15.81
2	59.250	-7.977	0.847			0.92	17.85	13.11
3	-5.671	4.927	-4.675	0.601		0.92	17.65	12.92
4	-82.680	10.135	0.015	0.279		0.92	17.91	13.27
5	35.392	-5.270	0.471	0.301		0.91	18.02	13.11
6	-92.918	11.460	0.110	0.140		0.92	17.96	13.31
7	-143.921	7.330	2.322	6.739	4.754	0.95	14.47	10.32
8	-83.248	8.002	2.575	0.418		0.95	14.42	10.04
9	0.806	0.279	0.453			0.94	14.70	10.26
10	-113.653	11.621	9.525			0.92	17.96	10.59
11	14.974	0.828				0.90	19.29	10.49
12	-144.121	7.292	2.350	5.756		0.95	14.51	10.28
13	0.505	-0.070	0.341	0.469		0.95	13.46	9.52
14	-2.986	0.244	0.093	0.406		0.95	14.24	9.93
15	14.683	0.458	0.370			0.91	19.02	10.47
16	-134.404	3.595	6.738			0.94	15.12	10.52
17	-2.840	0.092	0.241	0.241	0.171	0.95	14.13	9.89
18	-0.150	-0.049	0.285	0.510	0.000	0.95	13.27	9.48
19	2.451	-1.000	1.372	1.682	-1.345	0.96	11.73	8.73

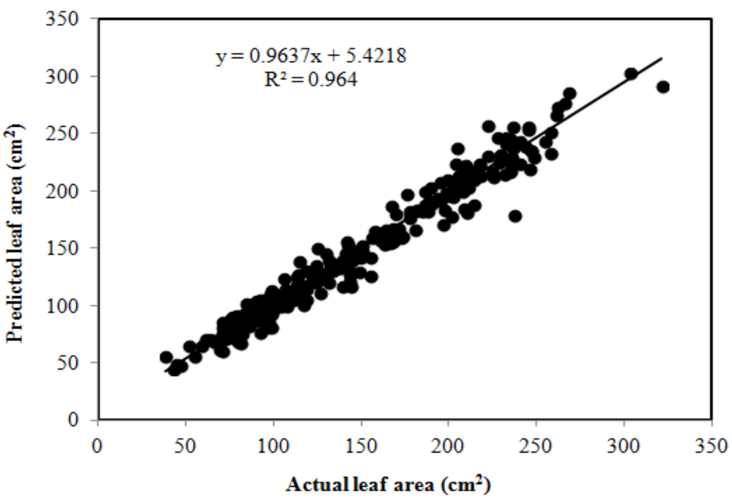

Figure (11). Comparison between the actual and predicted leaf area form model No.19.

In accordance with the present study, many studies carried out to establish reliable relationships between leaf area and leaf dimensions of different plant species such as cotton, caster, sorghum (Wendt, 1967), watermelon (Rajendran and Thamburaj, 1987), tomato (Dumas, 1990), bean

(Rai et al., 1990), grape (Elsner and Jubb, 1988; Pedro et al., 1989), pearly millet (Payne et al., 1991), orange (Ramkhelawan and Brathwaite, 1992), avocado, kiwifruit, cucumber, raspberry and grape (Uzun and Celik, 1998), cherry (Demirsoy and Demirsoy,2003a and 2003b), peach (Demirsoy et al., 2004) and strawberry (Demirsoy et al., 2005) show that there were close relationship between leaf dimensions and leaf area. Results from the present study were in accordance with some of the previous studies on establishing reliable equations for predicting leaf area through measuring leaf dimensions.

CONCLUSION

In this study, a multiple regression model was obtained to estimate the leaf area of cotton crop that could be used in the crop studies. The results indicated that the leaf area of cotton crop with acceptable accuracy (R^2 = 0.96, RMSE = 11.73 cm^2 and MAE = 8.73 cm^2) can be achieved by measuring distance between left and right lobes tip, distance between main lobe tip and leaf origin, distance between right lobe tip and leaf origin and distance between left lobe tip and leaf origin without using expensive equipments. The developed model can be convenient and quick alternative, especially at places where there is no access to modern equipment or other devices for measuring the leaf area.

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نماذج رياضية مبسطة للتنبؤ بمساحة الورقة لنبات القطن

عبد الواحد محمد أبوكريمة، حسين أحمد الصوري و ممدوح منياوي
معهد بحوث الهندسة الزراعية، مركز البحوث الزراعية، مصر

يعتبر نبات القطن أحد أهم المحاصيل الاقتصادية فى مصر، كما أن قياس مساحة أوراق هذا النبات يعتبر من أهم المؤشرات الدقيقة لتقدير كلا من كميات المبيدات وإنتاجية المحصول، وقد أشارت أبحاث عديدة إلى أن اشتقاق نماذج رياضية لتقدير مساحة أوراق العديد من النباتات تعتبر أداة أكثر دقة وموفرة للوقت والتكاليف، وأنها أقل ضررا للنباتات المختبرة، وذلك مقارنة بالطرق المباشرة للقياس التى تتمثل فى استخدام الجهاز الرقمى (البلانيميتر) والأجهزة الالكترونية أو استخدام أدوات القياس الهندسية اليدوية). إلا أن تطوير نماذج رياضية فى مجال تقدير مساحة أوراق نبات القطن المصرى لم تنل ولو قدرًا ضئيلا من البحث .لذلك كان الهدف من هذه الدراسة هو اشتقاق نموذج رياضى ملائم للتنبؤ بمساحة أوراق نبات القطن المصري. ولتحقيق هذا الهدف تم تطوير نموذج رياضى على عدد من النباتات 240 ورقة من القطن المصرى صنف جيزة 86 ، هذه الأوراق تم جمعها عشوائيًا من ثلاث ارتفاعات مختلفة ومن مواقع زراعة مختلفة فى مركز كفر الدوار، محافظة البحيرة ، جمهورية مصر العربية. وقد استخدم تحليل الانحدار فى تطوير النماذج الرياضية لـ 19 نموذج تم وضعهم من قبل الباحثين لتحديد النموذج الأفضل لحساب مساحة الورقة، عن طريق تحديد مؤشرات إحصائية شملت معامل التحديد (R^2)، والجذر التربيعي لمتوسط مربع الخطأ ومتوسط الخطأ المطلق. وقد تم التوصل إلى أفضل نموذج رياضى من تلك النماذج عن طريق التحليل الرياضى لها، وأظهر تحليل البيانات إلى أن أفضل نموذج يعبر عن المساحة الفعلية للورقة هو النموذج الرياضى الملائم الذى أشارت إليه نتائج هذه الدراسة، وكانت صورة المعادلة الناتجة هي:

$$LA = 2.451 - LW + 1.372\,WL2 + 1.682\,LL1 - 1.345\,L1L2 \qquad R^2 = 0.96$$

حيث (LA) هي مساحة الورقة (سم2) وباقي الأبعاد مقاسة بالـــ (سم). وقد تم اختبار مدى صحة هذا النموذج المقترح بحساب معامل التحديد (R^2)، إضافة إلى مقارنة نتائج قياسات فعلية لمساحة الورقة مع نتائج لمساحة الورقة ناتجة من النموذج. وأشارت النتائج أن النموذج المطور والمذكور أعلاه هو أدق النماذح التى يمكن التوصية بها لتقدير مساحة ورق نبات القطن المصري من عرض الورقة، وطول الفص الرئيسي، وطول الفص الأيمن وطول الفص الأيسر بدرجة مقبولة من الدقة. ويمكن لنموذج الانحدار المطور أن يكون طريقة بديلة جيدة لتقدير مساحة ورقة نبات القطن المصري بدلاً من الطريقة المباشرة مثل جهاز قياس مساحة الورقة.

Table (3). Descriptive statistics of data of leaf cotton dimensions and area.

Statistics	W (cm)			L (cm)			L1 (cm)			L2 (cm)			Measured area (LA, cm^2)		
	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
	Site 1														
Mean	17.6	14.4	13.9	14.9	11.8	13.1	12.3	9.0	10.6	12.7	9.1	10.8	145.8	77.2	112.8
Standard Deviation	3.5	2.6	3.5	1.8	1.5	1.9	2.5	1.4	1.8	2.5	1.5	1.6	45.7	23.7	31.7
Kurtosis	-1.1	-0.6	0.3	-1.2	-0.8	-0.5	0.7	-0.9	3.2	0.9	-0.5	0.2	-1.5	-1.0	1.6
Skewness	-0.3	0.1	-0.04	0.2	-0.1	0.6	0.8	-0.3	1.5	0.7	-0.2	0.5	0.2	-0.1	1.2
Minimum	11.0	10.1	6.8	12.2	9.1	10.2	9.2	6.4	8.3	8.2	6.2	8.4	86.1	38.7	68.8
Maximum	22.1	19.4	21.3	18.0	14.1	17.2	18.7	11.2	16.0	19.2	11.8	14.5	210.0	116.5	199.4
CV (%)	19.8	17.9	24.9	12.1	12.7	14.7	20.0	15.9	17.1	20.0	16.6	14.7	31.4	30.7	28.1
	Site 2														
Mean	20.0	18.2	17.8	18.1	14.4	16.6	15.4	11.9	14.4	14.9	12.0	14.2	210.7	132.5	184.9
Standard Deviation	3.0	2.4	4.0	1.8	1.1	2.5	1.7	1.0	2.4	1.6	0.9	2.5	40.3	17.7	53.5
Kurtosis	0.1	0.4	-0.8	1.5	-0.1	0.3	0.1	-0.8	-0.7	-1.1	-0.6	-1.0	1.6	-0.3	-1.0
Skewness	-0.2	0.3	-0.5	0.5	-0.1	-0.7	0.3	0.2	-0.6	0.0	0.2	-0.7	1.0	-0.1	-0.6
Minimum	13.9	13.9	10.0	14.4	12.1	11.1	12.1	10.4	9.7	12.2	10.6	10.1	148.9	100.7	93.0
Maximum	25.7	23.7	23.7	22.9	16.7	21.1	18.7	13.7	17.4	17.5	13.9	17.8	321.4	167.4	261.0
CV (%)	15.0	13.1	22.3	10.1	7.7	15.0	10.8	8.4	16.5	10.4	7.5	17.3	19.1	13.4	28.9

Table (3) continue.

Statistics	W (cm)			L (cm)			L1 (cm)			L2 (cm)			Measured area (LA, cm^2)		
	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
	Site 3														
Mean	14.7	19.3	18.8	13.1	16.4	16.9	9.6	13.7	14.3	9.7	13.4	14.7	87.8	180.8	193.3
Standard Deviation	2.6	3.4	4.9	1.4	2.2	2.5	1.3	1.9	2.6	1.2	1.8	2.7	19.6	45.9	58.1
Kurtosis	-1.2	-0.6	-0.5	-0.4	0.3	1.3	-0.1	1.8	0.5	0.3	0.4	-0.2	-0.4	1.2	-0.5
Skewness	0.2	0.2	-0.8	-0.03	0.4	-1.2	0.6	0.8	-0.9	0.5	-0.1	-0.6	0.3	0.9	-0.6
Minimum	11.1	13.2	8.7	10.5	12.7	10.5	7.8	10.8	7.8	7.8	9.4	8.5	52.1	115.6	69.7
Maximum	19.4	26.2	24.8	15.8	21.5	20.0	12.4	19.0	17.8	12.6	17.0	18.3	125.1	303.3	265.8
CV (%)	17.9	17.9	25.9	10.8	13.2	14.6	13.1	14.1	18.4	12.5	13.3	18.4	22.3	25.4	30.1
	Site 4														
Mean	14.1	17.4	20.9	12.0	15.7	17.8	9.7	13.3	15.0	9.9	12.9	15.4	84.9	165.9	217.2
Standard Deviation	2.4	4.5	2.1	1.1	2.8	1.7	1.3	2.7	1.5	1.3	2.8	1.6	18.3	57.1	30.8
Kurtosis	0.4	-1.2	1.4	-1.1	-1.8	2.0	0.5	-1.0	-0.3	-0.9	-1.6	3.1	1.0	-1.6	1.7
Skewness	0.7	-0.5	-1.0	0.3	-0.1	-1.1	-0.1	-0.3	-0.6	0.3	0.0	-1.6	1.1	-0.2	-1.2
Minimum	10.2	8.6	15.3	10.5	11.9	13.5	6.8	8.5	11.8	7.7	8.6	10.5	61.3	86.0	131.4
Maximum	19.4	22.8	23.9	13.9	19.9	20.6	12.3	17.9	17.1	12.1	17.7	17.3	132.3	247.1	258.3
CV (%)	16.9	26.1	10.0	8.9	18.2	9.3	13.1	20.0	9.7	12.9	21.8	10.6	21.6	34.4	14.2