Journal of Environmental Biology **September 2009,** 30(5) 785-790 (2009)
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Non-destructive leaf area measurement in maize (*Zea mays* L.)

Ismail Sezer[1], Fatih Oner*[1] and Zeki Mut[2]

Department of Agronomy, Faculty of Agriculture, [2]The High School of Profession of Bafra,
Ondokuz Mayis University - 55139, Samsun, Turkey

(Received: March 15, 2008; Revised received: September 10, 2008; Accepted: Octover 11, 2008)

Abstract: *In this research, leaf area prediction model was developed for some leaf-used maize (Zea mays L.) cultivars namely Coluna, Luce, Maveric, Ranchero, TTM-813, Zamora and RX-788 grown in Black Sea region of Turkey. Lamina width, length and leaf area were measured without destroying the leaf to develop the models. The actual leaf areas of the plants were measured by PLACOM Digital Planimeter, and multiple regression analysis with Excel 2003 computer package program was performed for the plants separately. The produced leaf area prediction models in the present study were formulized as LA= a - (b x W^2) + [c x (W x L)] where LA is leaf area, W is leaf width, L is leaf length and a, b, c are coefficiencies. R^2 values for maize cultivars tested varied with species from 0.95 in Luce to 0.98 in Maveric. All R^2 values and standard errors were found to be significant at the $p<0.001$ level.*

Key words: *Corn, Zea mays, Leaf area, Modeling*
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Introduction

In many parts of the world, maize is the most important food source and one of the most efficient field crops for producing a superior amount of dry matter per unit area. Maize is produced primarily for animal feed and industrial uses such as starch, flour, ethanol, cooking oil, frying and crisps. In addition, sweet maize is produced for human consumption as either a fresh or processed more or less wrinkled at maturity. Sweet maize, before it is ripe and dry, has a sweeter taste than do other types because the endosperm contains sugar as well as starch. Sweet maize is favorable for fresh consumption because of its delicious taste, delicate crust and soft and sugary texture compared to other maize varieties (Oktem *et al.,* 2004).

Plant growth is dynamic, and a vegetative plant produces a succession of new leaves with the elapse of the time to contribute to total plant dry weight. Therefore, leaf area measurements for physiological studies is one of the most essential processes, such as one of the physiological determinants of plant growth is the efficiency of the leaves with which the intercepted light energy is used in the production of new dry matter (Evans, 1972; Uzun, 1996; Odabas *et al.,* 2008).

Moreover, leaf area is an indicator of photosynthetic capacity and growth rate of a plant and its measurement is of value in studies of plant competition for light and nutrients, plant-soil-water relations and in crop like tobacco, where leaf area is the major commercial product, leaf area is good indicator of yield potential (Mohsenin, 1980). On the other hand, leaf area measurements at the same time may be one of the most tedious works. It is accordingly not surprising that many attempts have been made to produce some quick, simple and reliable means of determining leaf area during destructive or non-destructive plant harvests (Evans, 1972; Charles-Edwards *et al.*, 1986).

The most important photosynthetic organ of the plant is leaves (Wareing and Philips, 1970). Leaf area (LA) is an indicator of crop growth and productivity, and many methods are available with which to estimate it. Recently, new instruments, such as hand scanners and laser optic apparatuses were developed for leaf area measurements. However these are very expensive and complex devices for basic and simple studies. A non-destructive prediction of the leaf area saves time compared with geometric measurements, and no expensive instruments are needed (Robbins and Pharr, 1987). Leaf area has been measured in experiments concerning some physiological phenomenon such as light, photosynthesis, respiration, plant water consumption and transpiration (Horsley and Gottschalk, 1993; Gottschalk, 1994; Kersteins and Hawes, 1994; Picchioni and Weinbaum, 1995; Uzun, 1996; Centritto *et al.,* 2000; Odabas and Mut, 2007).

Models for the non-destructive prediction of the leaf area are useful tools for researchers in agricultural experiments. For instance, such models enable researchers to measure leaf area on the same plants during the plant growth period and that may reduce variability in the experiments (Gamiely *et al*., 1991; NeSmith, 1992).

If we assume that leaf blades have an invariant, genetically controlled shape and symmetry regardless of age and position on the plant, then variation of LA would be a result of proportional enlargement or reduction of this fixed shape. Leaf blade area has been found to be related to linear dimensions such as the length and

* **Corresponding author:** fatiho@omu.edu.tr

Table - 1: The coefficients, their standard errors and r² values of the new produced equations predicting the leaf area LA= a - (b x W^2) + [c x (W x L)] based on leaf length and leaf width for some maize species

Maize varieties and sandard errors (SE)	Coefficients (for leaf area)			
	a	b	c	R^2
Coluna	7.95±13.45*	-1.13±0.36***	0.95±0.05***	0.96***
Luce	79.23±16.54***	-1.53±0.29***	0.89±0.04***	0.95**
Maveric	13.31±7.59*	-2.45±0.32***	1.17±0.04***	0.98***
Ranchero	1.24±12.03*	-0.48±0.34*	0.85±0.04***	0.96***
RX-788	23.44±9.96*	-0.008±0.004*	0.70±0.04***	0.97***
TTM-813	1.77±10.70*	-1.60±0.51***	1.04±0.05***	0.96***
Zamora	7.13±10.11*	-1.19±0.25***	0.93±0.03***	0.97***

R^2 : Regression coefficiency, SE: Standard error, a, b and c are coefficiencies of produced equations, *, **, ***: Significant at the level of p < 0.05, 0.01 and 0.001 respectively

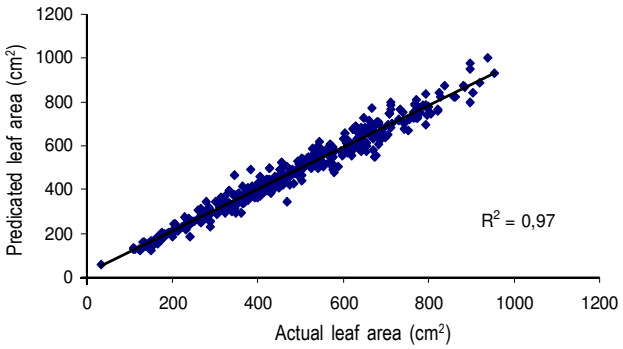

Fig. 1: The overall relationship between actual leaf area (cm^2) and predicted leaf area (cm^2) for the cultivars

width of the leaf. A non-destructive method in the measurement the LA of corn would be a useful tool for studying its growth and development. It is easier to measure leaf length than leaf width, and more observations can be made per unit time if only length is measured rather than both leaf length and width.

The objectives of this study were to investigate the allometric relationship between measurement of leaf length (L) with leaf width (W) and the actual leaf area (ALA) measured with a planimeter and to use the developed model to predict LA. The aim produced reliable equations for maize that predict leaf area with linear measurements.

Materials and Methods

Seven maize cultivars (Coluna, Luce, Maveric, Ranchero, TTM-813, Zamora and RX-788) were used. Leaf samples for each cultivar were selected randomly six times during the growing period in 2004. A total of 2100 leaves were measured (300 leaf samples for each cultivar). Each leaf was copied, and then a Placom Digital Planimeter (Sokkisha Planimeter Inc., Model KP-90) was used to measure the actual leaf area. The leaf width (W) and length (L) of the leaf samples were measured from tip to tip at the widest part of the lamina and leaf length (cm) was measured from end to end. All values were recorded to the nearest 0.1 cm (Uzun and Celik, 1999).

Multiple regression analysis of the data was performed for each cultivar separately. For this reason, analysis was conducted with various subsets of the independent variables, namely, leaf width square (W^2) and leaf width x leaf length (W x L) to develop the best model for predicting the leaf area (LA) by using the Excel 2003 package program. The multiple regression analysis was carried out until the least sum of square was obtained.

In addition, leaf samples were used for model development. We were taken from different maize cultivars during the growing period for validation of leaf area prediction model in 2005. Varying between 42 and 67 new leaf samples for each cultivar were used (42, 48, 55, 56, 59, 64 and 67 for Coluna, Luce, Maveric, Ranchero, TTM-813, Zamora and RX-788, respectively).

Leaf length, width and actual leaf area of these leaf samples were measured as mentioned in the model production. Leaf length was measured to the nearest millimeter from the leaf tip to the point at which the lamina is attached to the petiole. Leaf width was measured from edge to edge at the widest part of the leaf lamina. The actual leaf area of individual leaves measured using Placom digital planimeter (Sokkisha Planimeter Inc., Model KP-90). The Excel 2003 package program was used for this procedure.

Results and Discussion

For the studied maize cultivars, regression analysis showed that the most of the variation in leaf area values was explained by leaf length and leaf width. The overall variation explained by the parameters was 97% for all the cultivars (Fig. 1). The proposed leaf area (LA) prediction models are LA= a - (b x W^2) + [c x (WxL)], here, LA is leaf area (W is leaf width, L is leaf length). Prediction models are shown in Table 1.

Plotting processes were carried out between actual leaf area values measured by using Placom Digital Planimeter and predicted leaf areas of the tried cultivars calculated by the developed model in this research to determine the degree of accuracy of the model (Fig. 2). It was found that the relationship between actual and predicted leaf areas varied between 98.0% in “Maveric” to 95.0% in “Luce”

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Table - 2: The predicted leaf area of corn cultivars according to the produced equaitions and the actual leaf area of the corresponding compounds by Planimeter (cm^2)

*Samples	Coluna		Luce		Maveric		Ranchero		TTM-813		Zamora		RX-788	
	Actual	Predicted	Actual	Predicted	Actual	Predicted	Actual	Predicted	Actual	Predicted	Actual	Predicted	Actual	Predicted
1	567.8	588.9	897.8	930.4	682.6	673.2	529.8	532.3	372.5	436.4	247.6	243.0	229.0	237.8
2	609.2	629.5	615.0	572.2	320.0	327.7	405.8	394.8	364.4	438.9	534.3	553.4	679.3	690.8
3	311.5	326.9	590.1	515.6	320.9	314.1	390.0	373.2	467.6	513.3	279.8	260.6	622.2	661.6
4	288.3	286.5	734.0	761.7	214.0	210.1	596.0	559.9	430.9	455.7	567.2	572.7	438.7	446.1
5	692.6	693.7	489.9	510.6	743.4	737.2	521.1	510.5	320.5	399.8	544.2	579.4	476.8	472.7
6	792.3	714.6	836.4	845.8	189.6	190.9	499.0	462.3	202.8	236.9	440.0	451.0	631.1	668.5
7	269.8	253.4	884.3	848.5	537.6	531.2	288.7	275.1	449.3	530.1	469.1	490.8	333.4	333.5
8	756.7	742.1	302.0	361.9	652.6	635.1	656.2	654.0	282.5	373.5	603.2	642.1	660.7	706.4
9	621.3	567.2	397.5	417.8	610.4	633.9	643.6	650.4	229.0	318.6	206.4	235.2	532.0	520.6
10	699.2	658.3	770.2	769.3	361.0	367.7	376.7	375.3	684.0	786.2	397.0	371.4	648.9	707.6
11	265.0	275.0	713.0	749.6	753.3	722.6	663.4	667.1	571.2	631.7	571.0	593.5	406.1	425.3
12	825.3	868.0	820.7	754.8	537.7	534.8	675.7	640.1	345.1	405.6	498.0	481.9	429.7	486.9
13	158.6	149.6	469.0	382.5	544.4	574.4	793.3	775.4	336.6	423.5	357.0	373.4	645.7	653.3
14	407.7	404.0	668.0	754.5	562.4	591.3	233.2	231.9	416.2	498.1	552.5	545.7	158.6	171.6
15	453.3	470.4	533.9	550.7	310.7	312.4	240.7	229.9	331.5	390.8	356.2	367.3	202.4	215.8
16	784.6	798.9	452.8	461.1	444.8	446.6	708.8	737.5	143.4	200.1	316.0	350.6	390.4	393.6
17	882.3	904.4	541.3	574.8	430.4	448.2	347.7	362.7	35.3	66.3	405.6	403.6	454.0	480.2
18	605.5	589.7	896.5	784.5	476.6	459.5	653.7	653.3	181.7	262.2	575.6	575.5	455.6	507.3
19	744.1	700.5	629.8	661.0	330.7	347.4	225.6	217.1	764.7	897.5	373.0	373.8	403.1	400.2
20	542.5	505.3	504.2	489.3	150.9	151.3	515.7	526.2	134.5	180.4	168.0	147.5	599.3	561.8
21	768.5	757.5	643.3	688.5	611.7	615.5	577.2	552.2	291.9	386.9	665.8	632.0	568.0	581.1
22	345.8	321.9	407.6	470.2	110.2	114.1	318.8	321.8	352.8	473.1	378.2	400.6	461.6	461.6
23	675.6	722.7	350.8	329.9	251.6	256.1	574.6	540.6	201.9	250.0	421.4	433.1	319.6	371.5
24	651.8	701.7	396.3	438.5	113.7	107.7	414.5	422.0	407.8	471.5	165.6	174.4	290.7	265.0
25	859.3	847.4	602.8	637.3	483.0	494.5	729.6	698.0	438.5	526.6	550.0	562.0	277.2	288.0

* Samples for actual and predicted leaf areas are randomly chosen during the experiment

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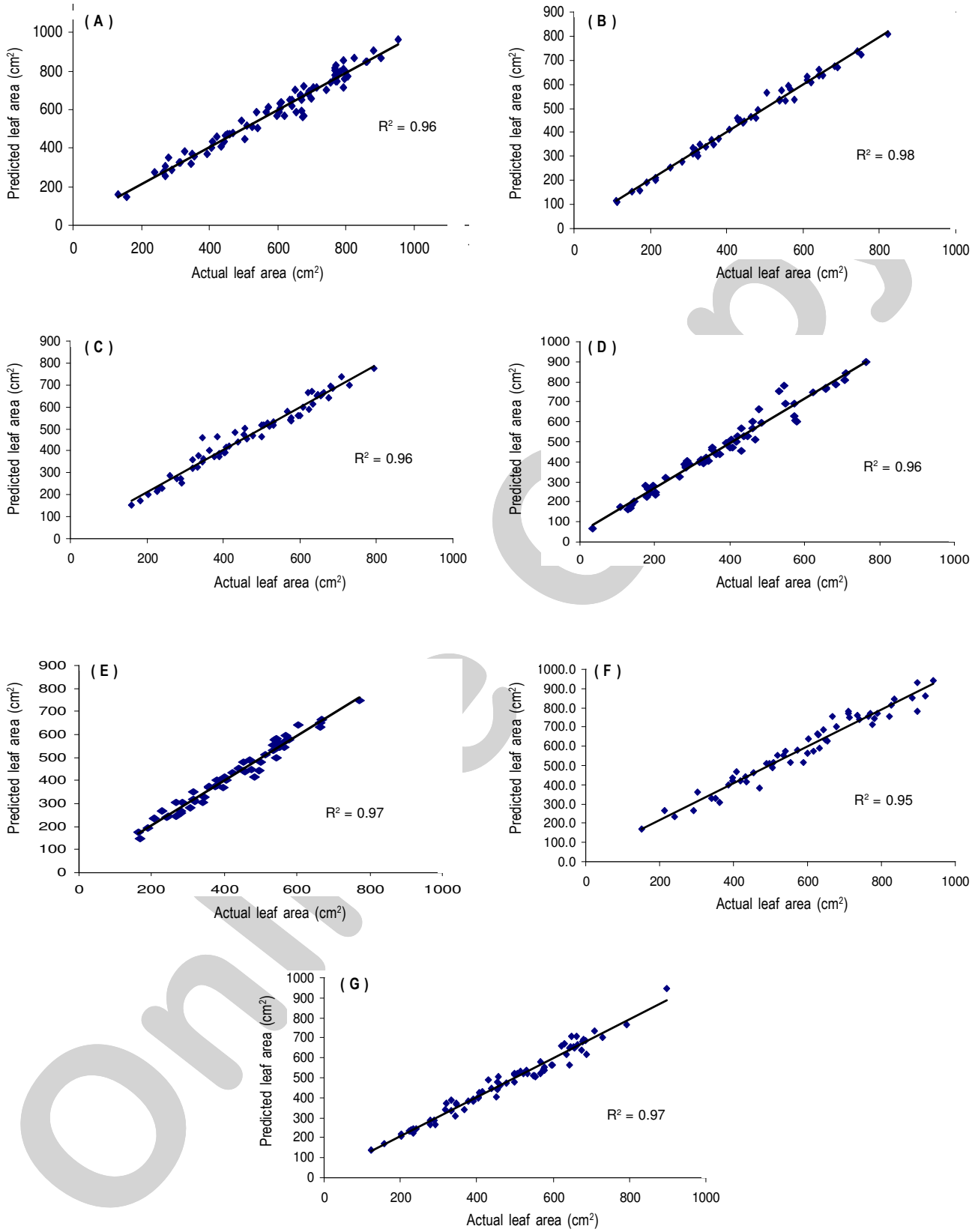

Fig. 2: The relationships between actual leaf area (cm²) and predicted leaf area (cm²) for the Coluna (2A), Maveric (2B), Ranchero (2C), TTM-813 (2D), Zamora (2E), Luce (2F) and RX-788 (2G)

cv. (from the highest to lowest the value). As it can be seen from Fig. 2, the model predicted leaf area of the tried maize cultivars were most reliable for Coluna (96.0%), Luce (95.0%), Maveric (98.0%), Ranchero (96.0%), TTM-813 (96.0%), Zamora (97.0%) and RX-788 (97.0%).

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 sweet sorghum (Almadores *et al.*, 2007), kiwifruit, aubergine, squash (Elsner and Jubb, 1988; Ramkhelawan and Brathwaite, 1992; Uzun and Celik, 1999), cherry (Demirsoy and Demirsoy, 2003), peach (Demirsoy *et al.*, 2004), tomato (Dumas, 1990), flax (Kurt *et al.,* 2005), summer snowflake (Cirak *et al.,* 2005a), *Calamintha nepeta, Datura stromonium, Melissa officinalis, Mentha piperita, Nerium oleander, Origanum onitesand* and *Urtica dioica* (Cirak *et al.,* 2005b), *Ecballium elaterium* L.*, Papaver somniferum* L.*, Physalis alkekengi* L. and *Verbascum phlomoides* L. (Odabas *et al.,* 2005), *Vicia faba* L. (Odabas *et al.,* 2007a,b) and showed that there were close relationship between leaf width, leaf length 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.

Here, we developed the models for predicting leaf area for the maize (*Zea mays* L.) cultivars namely Coluna, Luce, Maveric, Ranchero, TTM-813, Zamora and RX-788 growing in Black Sea region which are important in Turkey and over the world economically. As the understanding of plant growth and development has been increasing, such mathematical model will be very useful tools for prediction of leaf area for many plants without using of expensive devices. Because maximum leaf width and length are dimensions that can be easily measured in the field, use of these equations would enable researchers to make non-destructive measurements or repeated measurements on the same leaves. Such equations would also allow researchers to estimate leaf area in relation to factors like crop load, drought stress, and insect damage. Therefore, the models produced in the present study can be used safely by maize researchers for the species used in this research. On the other hand, different models can be developed by researches studying on maize different from those used in the present study. The relationship between actual and predicted leaf areas were shown in Table 2. Samples for actual and predicted leaf areas are randomly chosen during the experiment.

In the study, the simple model for predicting leaf area was developed for maize cultivars. There were no significant differences among the cultivars in terms of being a parameter in the model. Therefore, the model can be used for physiological and quantitative studies in maize. However, care and caution must be taken when the models are extrapolated to other maize cultivars.

Acknowledgments

We wish to thank Dr. S. Uzun, Dr. M.S. Odabas, Dr. H. Demirsoy and Emel Oner for their technical assistance.

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