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Non-destructive leaf area estimation in pomegranate cv. Bhagwa

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ABSTRACT

Non-destructive and mathematical approach for modeling can be very convenient and useful for plant growth estimation. In this research, a model for predicting the leaf area was developed for pomegranate cv. Bhagwa by measuring the lamina width, length and leaf area. Multiple regression analysis for the pomegranate leaf area was performed. The proposed leaf area (LA) prediction model is: LA = -0.0477 + 0.0282*L + 0.0842*W + 0.965*L*W; R^2 = 0.999, LA is leaf area, W is leaf width and L is leaf length. The model was validated by measuring leaf samples of pomegranate trees. The aim of this research was to develop a simple, accurate and non-destructive predictive model for leaf area (LA) estimation of pomegranate trees. The developed model can estimate pomegranate leaf area without the use of expensive instruments and destructing the leaves with 94% accuracy.

Key words: Pomegranate, leaf area, stepwise regression analysis, model, validation.

INTRODUCTION

Pomegranate (*Punica granatum* L.) is one of the oldest known edible fruits and is capable of growing in different agro-climatic conditions ranging from the tropical to sub-tropical (Levin, 5; Jalikop, 4). It is highly suitable for growing under arid and semi-arid regions due to its versatile adaptability, hardy nature, low cost maintenance and high returns. In recent past its wide significance in health, nutrition and livelihood security has been recognized which resulted in heavy demand for fruit consumption not only in India but throughout the globe. India is the largest producer of pomegranate in the world with production around 0.8 MT and area 0.13 MH (Anon, 1). In India, pomegranate is commercially cultivated in Maharashtra, Karnataka and Andhra Pradesh and the most important cultivar in this pomegranate belt is 'Bhagwa' which covers around 80 per cent area under pomegranate in Maharashtra. Leaf area of a plant is a subject of interest for various physiological studies like photosynthesis, transpiration, water use efficiency, etc. In addition, leaf number and leaf area of tree are important in terms of cultural practices such as training, pruning, estimation of leaf area index, crop coefficient, irrigation and fertigation. Non-destructive prediction models of the leaf area are useful tools for researchers in horticultural experiments. Such models enable researchers to measure leaf area without destructing/detaching the leaves during the growth period and may reduce variability in the experiment (Nesmith, 8). The leaf area can be determined by using instruments or prediction models. A non-destructive prediction model of the leaf area saves time when compared with geometric assessments and this does not require the use of costly instruments (Robbins and Pharr, 10). Though, several leaf area prediction models have been developed for plant species such as grape, avocado, banana, citrus, almond, pecan and olive in previous studies (Potdar and Pawar, 9) but the leaf area estimation model for pomegranate is not available till date. Therefore, an attempt has been made in this study to develop a simple, precise, non-destructive and fast predictive model for leaf area estimation of pomegranate cv. Bhagwa based on length and width of leaf lamina.

MATERIALS AND METHODS

The experiment was conducted at commercial orchard in August, 2008 - July, 2009 for the estimation of leaf area of pomegranate trees, planted at 4.5 m × 3 m in light texture soil. Twenty commercial pomegranate orchards of 1- to 5-year-old were selected and five plants from each orchard were randomly taken as representative samples. The study area located at Sangola taluka of Solapur district (North latitude 17° 10' to 18° 32', East longitude by 74° 42' to 76° 15' and 483.5 m amsl).

Samples were made by harvesting three leaves from selected trees on a weekly basis. Peripheral leaves from the middle portion of the shoots that developed during the same growing season were harvested. Leaves were taken from shoots in the middle of the tree canopy located at the four cardinal points. Three leaves (i.e. small, medium and large) were harvested as samples from each tree. Because of the morphological differences in terminal leaves, they were excluded from this study. Leaves were kept

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refrigerated in plastic bags until the determinations were made. For each sample, the width (W) was measured at the middle/widest part of the leaf lamina and the length (L) was measured from lamina tip to the point of petiole intersection along the midrib (Fig. 1). A total of 7800 leaves were measured, out of 7800 samples, 7700 samples were used for model development and 100 samples for validation. A digital leaf area meter (LI-3000 LiCor) was used to measure the actual leaf area. All values were recorded to the nearest 0.1 cm.

Multiple regression analysis of the leaf samples was performed. For this reason, analysis was conducted with various subsets of the independent variables, namely, leaf length/width (L/W) and leaf width*length (W*L) to develop the best model for predicting the leaf area (LA). The multiple regression analysis was carried out until the least sum of squares obtained. Pomegranate leaves were taken during growing period for validating the developed leaf area prediction model. Leaf width, length and actual leaf area of these leaf samples were measured as mentioned during the sampling process. For validation of procedure, leaf area values obtained by using the model were plotted against actual leaf areas measured using the leaf area meter. The Excel 7.0 Package program was used for this analysis. The leaf data of pomegranate was used to validate the equations. The fitting parameters were not adjusted during validation. The best values of the parameters during validation were found such that the statistics given in Table 1 were satisfied. If all the predicted and observed values were the same, then the 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.

RESULTS AND DISCUSSION

The results of the models used in validation process are given in Table 2. Several combinations of measurements and models relating linear dimensions to area have been utilized (Table 2). The highest RMSE value was obtained from model 4, while the least value was obtained from model 2 in validation cases. Usually, the models containing interaction term L * W gave lower values of RMSE and higher values of EF (Models 2, 5, 6, 8, 9) than the models including length and width only. Results showed that all the models given in Table 2 are able to estimate individual leaf area. 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, based on width and length can be more precise than estimates based on one dimension only. Bange *et al*. (2), reported that inclusion of interaction term L*W has decreased root mean square error.

Higher values of coefficient for determination were obtained from seven models which showed that the leaf area is highly correlated with length and interaction term L*W. The best leaf area prediction model is LA= -0.0477 + 0.0282L + 0.0842W + 0.965LW, R^2 = 0.999, LA is leaf area, W is leaf width and L is leaf length. Various studies carried out to establish reliable relationships between leaf area and leaf dimensions of different plant species such as cherry (Demirsoy and Demirsoy, 3), coconut (Mathes *et al*., 7), pecan (Whithworth *et al*., 11) and banana (Potdar and Pawar, 9), showed that there were close relationships between leaf width, leaf length and leaf area. The same authors found that there were close relationship between leaf area, leaf length and leaf width for these plants (R^2 = 0.985 for kiwifruit, R^2 = 0.95 to 0.99 for cherry, R^2 =

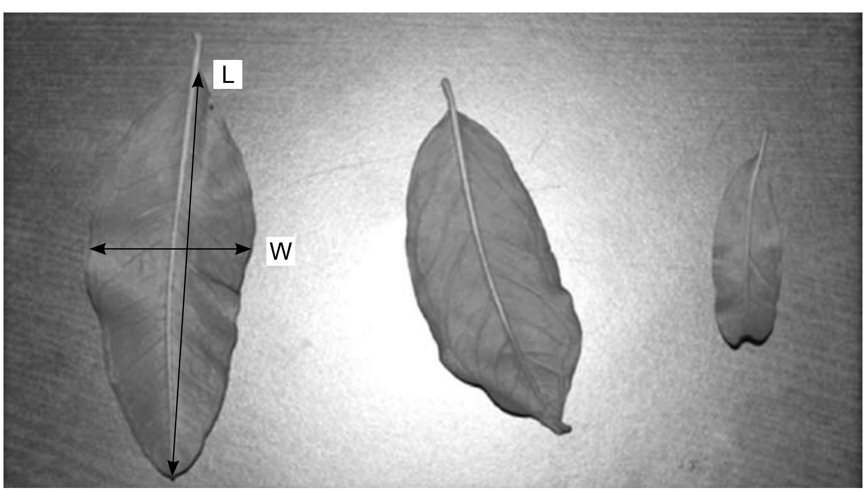

Fig.1. Large, medium and small leaves of pomegranate showing length (L) and width (W).

Table 1. Measures of analysis of residuals error (Loague and Green, 6).

Measures of analysis of residuals errors
Maximum Error, ME = $\|Pi - Oi\|$, i = 1.......................n
Root mean square error, RMSE = $\left[\frac{\sum_{i=1}^{n} (P_i - O_i)^2}{n} \right]^{0.5} \times \frac{100}{O}$
Coefficients of residuals mass, CRM = $\frac{\sum_{i=1}^{n} O_i - \sum_{i=1}^{n} P_i}{\sum_{i=1}^{n} O_i}$
Coefficients of determinations, CD = $\frac{\sum_{i=1}^{n} (O_i - O)^2}{\sum_{i=1}^{n} (P_i - P)^2}$
Modeling Efficiency, EF = $\frac{\sum_{i=1}^{n} (O_i - O)^2 - \sum_{i=1}^{n} (P_i = O_i)^2}{\sum_{i=1}^{n} (O_i - O)^2}$

(Note: P_i = Predicted values, O_i = Observed values, O = Mean of the observed data, n = Number of samples).

Table 2. Different models proposed to estimate individual leaf area of pomegranate tree.

Model No.	Model	R^2
1	LA = -0.2614 +1.78L	0.745
2	LA = -0.0477 + 0.0282L+0.0842W+0.965LW	0.999
3	LA = 2.686 +0.226L^2	0.731
4	LA = 0.3292 +0.224L^2+0.7594W^2	0.922
5	LA = 0.086 + 0.9828LW	0.995
6	LA = 0.0736 – 0.00147L^2 + 0.004W^2 + 0.9865LW	0.992
7	LA = 2.162 + 2.56 L – 1.46 L/W + 1.418W	0.979
8	LA = 0.0528 – 0.00426L^2/W^2 + 0.00351W^2 + 0.994LW	0.995
9	LA = 0.1013 – 0.0103L/W + 0.9841LW	0.992

Model No.	Validation				
	ME	RMSE	CRM	CD	EF
1	-18.6	3.96	0.039	1.08	0.99
2	-3.3	0.69	0.006	1.01	1.00
3	-17.0	3.62	0.036	1.07	0.99
4	20.4	4.33	-0.04	0.91	0.99
5	-4.5	0.94	0.009	1.01	0.99
6	-3.7	0.79	0.007	1.01	0.99
7	7.5	1.59	-0.01	0.96	0.99
8	-3.6	0.75	0.007	1.01	0.99
9	-4.2	0.88	0.008	1.01	0.99

0.95 to 0.98 for coconut, R^2 = 0.98 to 0.99 for grapes, R^2 = 0.93 for pecan, R^2 = 0.98 for banana).

Plotting process was carried out between actual leaf area values measured by using LiCor-3000C portable leaf area meter and predicted leaf areas of the samples calculated by the model developed in this study to determine the degree of accuracy of the model (Fig. 2). It was found that the relationship (R^2 values) between actual and predicted leaf areas varied from 0.288 to 0.999 (from the lowest to the highest value). As it can be seen from the Fig. 2, most reliable model for prediction of leaf area of the pomegranate cv. Bhagwa was model-2 (R^2 = 0.999). The best results, in terms of statistics given in Table 2, were obtained from model - 2 because it has included length (L), width (W) and interaction term (L*W).

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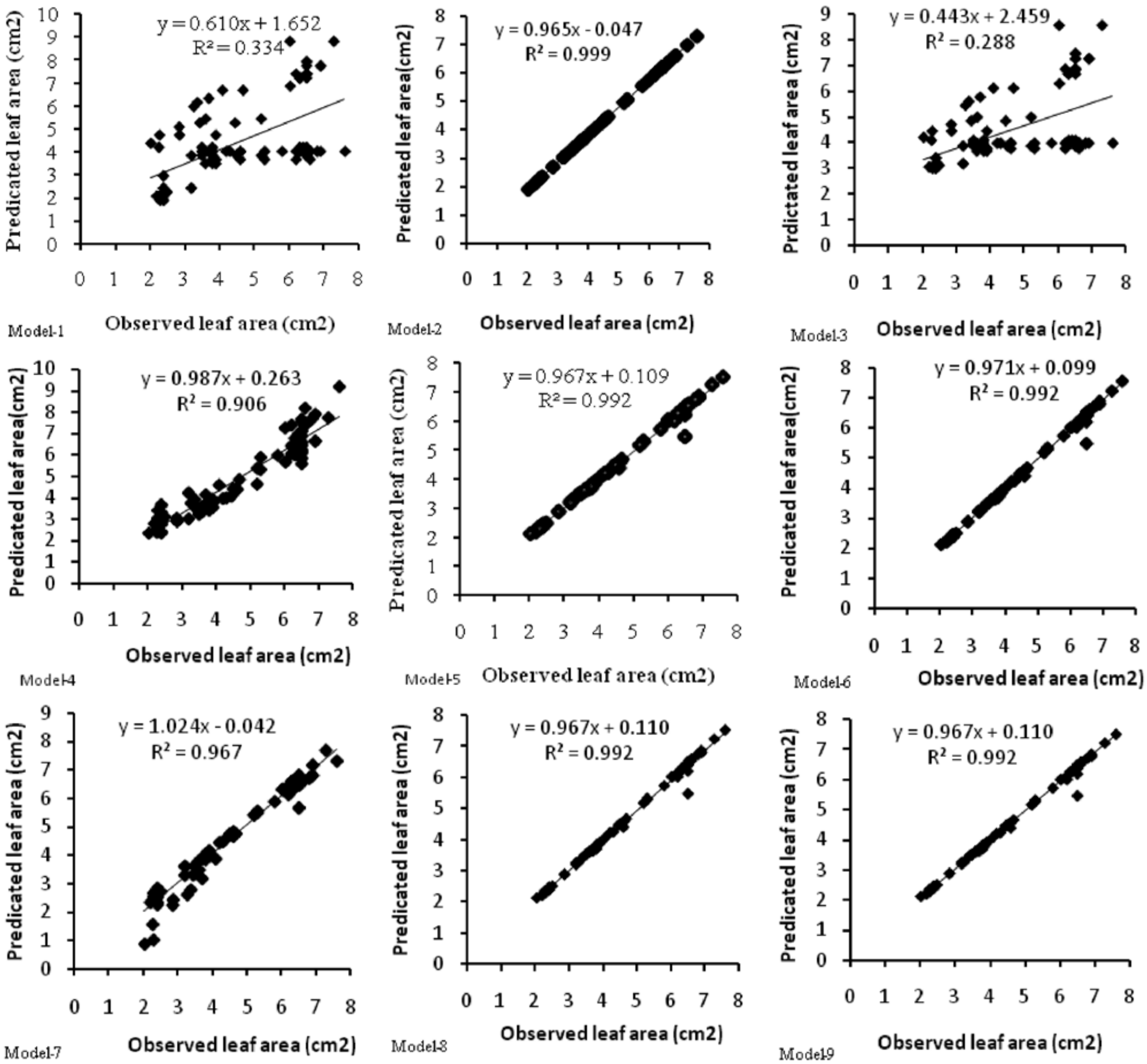

Fig. 2. Observed and predicated leaf area of pomegranate using mode l to 9.

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