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NON-DESTRUCTIVE LEAF AREA MEASUREMENT USING MATHEMATICAL MODELING FOR PADDY VARIETIES

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Abstract: Leaf area is considered an important parameter in fields such as plant phenotyping and plant breeding. In this study, leaf areas of different rice varieties were measured using a leaf area meter. Subsequently, a mathematical model was developed using leaf dimensions to estimate leaf area. Multiple regression analysis was used in the study to examine how leaf area is related to leaf dimensions. The results showed significant differences in leaf areas among different paddy varieties (Efe, Osmancık-97, Hamzadere, and Paşalı). Additionally, leaf dimensions were found to be a strong predictor for estimating leaf area. The equation of leaf area (LA= a + (b x L) + (c x W) + (d x L^2) + [e x (L x W)] for paddy varieties tested. The R^2 values for paddy varieties between 84% - 99%. The mathematical model is an important tool that can be used in plant phenotyping and plant breeding, and can be further utilized in future research in these fields.

Keywords: Paddy varieties, Leaf area, Modeling

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1. Introduction

Paddy cultivation in the world is carried out using five cultivation systems based on water regime. These systems are grown as 45% irrigated, 30% rain fed, 11% deep-water, 10% upland, and 4% floating paddy, taking into account the cultivation area. In Türkiye, the paddy production system is grown using continuous irrigation, with the field kept underwater. Until20 days before harvesting, the field surface is covered with water. The water level is gradually increased depending on the development of the plants and kept around 15 cm during the maximum growth period (Sezer et al., 2012).

According to data from the Food and Agriculture Organization of the United Nations (FAO), rice is an important food crop that is grown on 164 million hectares of land worldwide, with a production of 760 million tons (FAO, 2020). Rice is such an important product that it is a significant component of food consumption for more than half of the world's population (Lopez et al., 2019). In Türkiye, rice is grown on 125,398 hectares of land, with a production of 980,000 tons and a yield of 782 kg per hectare (TMO, 2023). Rice is an annual crop with different varieties that vary in their sensitivity to day length and temperature. Rice grown between 45° North and 35° South latitude includes many varieties with different adaptation requirements (Fujino et al., 2012). Rice is the only grain that can germinate in water and benefit from dissolved oxygen in water for root growth (Uphoff, 2003).

The nutrients produced by plants are transmitted through the leaves to other parts of the plant that need to be fed and the plant uses this product as energy for growth (Albayrak and Yüksel, 2009). Light is an essential physical environmental factor for plants to grow and develop (Broge and Leblanc, 2001). The most important function of light is photosynthesis for green plants (Odabas et al., 2005). How much light energy can be captured by the leaves depends on the size of the leaf area (Rahman et al., 2012). Increasing leaf area is the main factor in plant growth due to its effect on the amount of photosynthetic radiation intercepted. Leaf area is particularly dependent on the number of leaves and leaf size in the plant (Uzun and Çelik, 1999). It may be possible to infer some aspects of the physiological status of a growing plant directly by analysis of allometric and other growth data (Kandiannan et al., 2002). This method has the advantage of being relatively simple and inexpensive (Causton and Venus, 1981). In this study, mathematical models that can be used to calculate the leaf area of different paddy varieties are proposed. With these models, leaf areas can be measured non-destructively.

2. Materials and Methods

In the research, four paddy varieties (Efe, Osmancık-97, Hamzadere and Paşalı) were used as plant materials. Before sowing, the seeds were completely soaked in water for 24 hours and then pre-germinated on a damp

cloth for 24 hours. After the seeds were pre-germinated, 20 seeds were planted in each pot. As essential fertilization after planting, 500 g of 10-10-10 fertilizer was taken and dissolved in 18.5 liters of water and given to each pot as 100 ml.

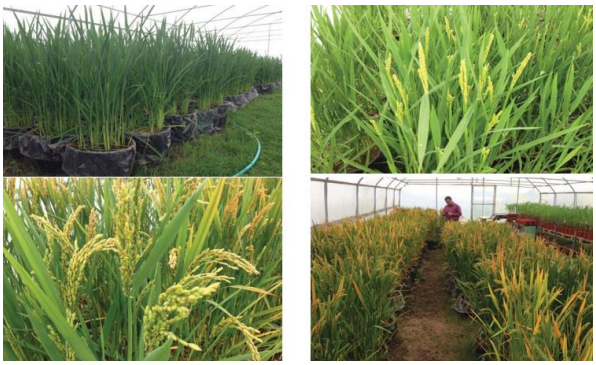

Figure 1. Paddy cultivars.

A mathematical method called curve fitting can be used to determine the functional connection between two or more variables in a dataset. To approximate the underlying mathematical function that produced the data, a series of data points must be fitted to a curve. For estimation, a variety of curve fitting methods can be applied, including the least squares approach, maximum likelihood method, nonlinear least squares method, splines, and genetic algorithms (Odabas et al., 2016). The type of data and the underlying mathematical function that produced it both influence the choice of curve fitting approach. To choose the best-fitting model, it is usual practice to employ a variety of methodologies and compare the outcomes.

3. Results and Discussion

Leaf area models using leaf length and width have been established in different studies in different plant species. Examples of these plant species are cucumber (*Cucumis sativus* L.), bean (*Phaseolus vulgaris* L.), grape (*Vitis vinifera* L.) and broad bean (*Vicia faba* L.) and in these studies, it has been stated that leaf area and leaf width and length have a very close relationship (Öner et al., 2012). In this study, the length and width of the leaf were considered independent variables in determining the leaf area. Leaf area was used as the dependent variable in the mathematical model. The R^2 value of the model is an important parameter that shows how high accuracy the leaf area can be estimated. Leaf area models of paddy varieties, coefficients of models, R^2, Adj. R^2, and RMSE values are shown in Table 1. RMSE stands for Root Mean Square Error. It is a measure of the difference between a predicted value and an actual value. It is commonly used in regression analysis to evaluate the accuracy of a model's predictions. The lower the RMSE, the better the model is at predicting values.

When these coefficients are substituted in the equation, mathematical models that calculate leaf area for the paddy varieties considered in the study are obtained. Accordingly, the mathematical model for the Efe variety is formed as (equation 1);

$$\text{Leaf Area} = (-14.93) + (2.47 \times L) + (3.78 \times W) - (0.02 \times L^2) - [0.21 \times (L \times W)] \quad (1)$$

Osmancık-97 variety is formed as (equation 2);

$$\text{Leaf Area} = (1.16) + (0.08 \times L) - (1.65 \times W) - (0.01 \times L^2) + [0.83 \times (L \times W)] \quad (2)$$

Hamzadere variety is formed as (equation 3);

$$\text{Leaf Area} = (-8.55) + (1.32 \times L) + (5.81 \times W) - (0.001 \times L^2) - [0.13 \times (L \times W)] \quad (3)$$

Paşalı variety is formed as (equation 4);

$$\text{Leaf Area} = (-2.78) + (1.06 \times L) - (2.54 \times W) - (0.001 \times L^2) + [0.28 \times (L \times W)] \quad (4)$$

Table 1. The equation of leaf area ($LA= a + (b \times L) + (c \times W) + (d \times L^2) + [e \times (L \times W)]$ for paddy cultivars tested

	Coefficiencies							
Paddy Cultivars	a	b	c	d	e	R^2	Adj. R^2	RMSE
Efe	-14.93	2.47	3.78	-0.02	-0.21	0.98	0.96	0.96
Osmancık-97	1.16	0.08	-1.65	-0.01	0.83	0.99	0.99	0.46
Hamzadere	-8.55	1.32	5.81	-0.001	-0.13	0.97	0.97	1.29
Paşalı	-2.78	1.06	-2.54	-0.01	0.28	0.84	0.84	3.03

a, b, c, d, and e are co-efficiencies.
LA= leaf area, L= leaf length, W= leaf width.
R^2 values are significant at $P<0.001$

R^2 values of these models are 0.98, 0.99, 0.97 and 0.84 respectively. The closer the R^2 value is to one, the higher the accuracy of the model. As a result of these models, the effect of leaf width and length on leaf area is graphically shown below for each variety.

Figure 2 shows that the leaf area is affected by the change in leaf width and length in each paddy variety. Especially the increase in leaf length affects the increase in leaf area positively, although slightly more than the increase in leaf width. The leaf area information obtained with these mathematical models is used to measure the capacity of the plant's leaves to photosynthesize. This measurement

allows us to obtain information about plant growth and productivity. In addition, leaf area measurements in plants can also be used to assess the impact of environmental stressors such as plant diseases and pests. These data can help plant breeders to optimize plant growing (Gutierrez-Boem and Thomas, 2001).

Leaf area index (LAI) can be calculated using the leaf area and leaf width and length obtained with the mathematical model. LAI is the ratio of the area covering the leaf of a plant to the surface area of the plant relative to the soil.

The LAI is formulated as (equation 5);

$$LAI = \frac{1}{k}\ x\ ln(N/NO) \quad (5)$$

Where; k is the extinction coefficient of the canopy, N is the total number of leaves per unit ground area, N0 is the leaf number per unit ground area when the canopy is absent or fully transparent. This formula is based on the principle that the amount of light absorbed by a plant canopy is related to the LAI and the extinction coefficient, which represents the reduction in light intensity due to scattering and absorption by leaves in the canopy. By measuring the leaf number and using the extinction coefficient for a given canopy, you can use this formula to calculate the LAI (Myneni et al., 1997).

This ratio can provide information about the plant's photosynthetic capacity and overall growth. LAI can also be used to assess the impact of environmental stressors such as plant diseases and pests.

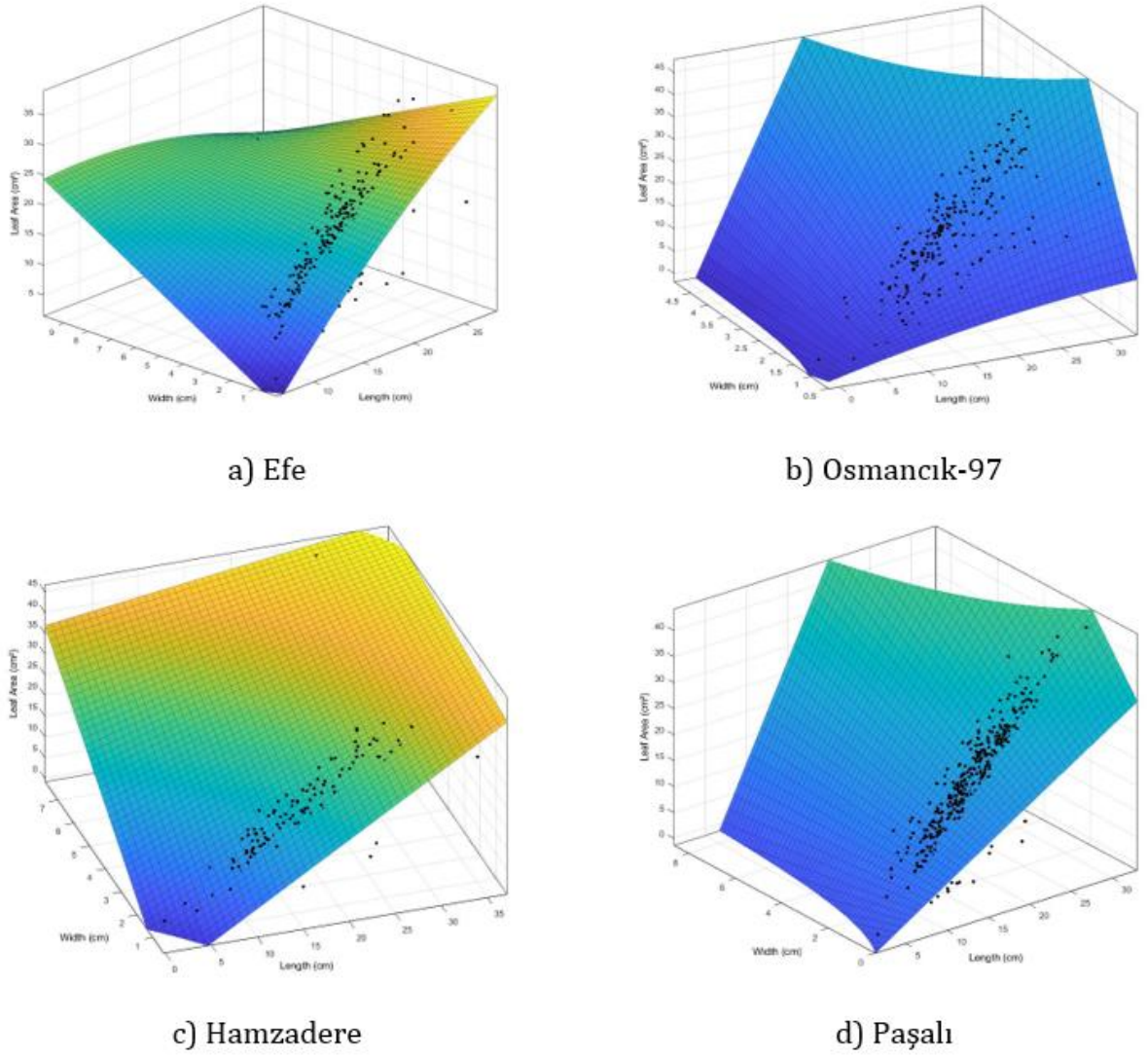

Figure 2. The effect of leaf width and length on leaf area based on mathematical models.

5. Conclusion

Simple, accurate and plant-safe methods for determining the leaf area of plants have an important place in plant physiology studies (Bozkurt and Sayılıkan Mansuroğlu, 2019). Non-destructively Leaf area measurement is important because they provide researchers with the opportunity to work on the same plant and leaf over and over again, thus potentially reducing the high coefficients of variation that can arise in trials. Furthermore, the ability to determine leaf area with simple linear

measurements would eliminate the need for very expensive and complex leaf area measuring devices.

Author Contributions

The percentage of the author(s) contributions is present below. All authors reviewed and approved final version of the manuscript.

	F.Ö.	M.S.O.
C	50	50
D	100	
S		100
DCP	50	50
DAI		100
L	80	20
W	50	50
CR	60	40
SR	60	40
PM	80	20
FA	70	30

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because of there was no study on animals or humans.

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