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ORIGINAL ARTICLE / ORIGINALBEITRAG

A research on Non-Destructive Leaf Area Estimation Modeling for some Apple Cultivars

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Abstract

Accurate and non-destructive methods to determine the plant leaf area are important measurements used in physiological and agronomic studies. This study was aimed to develop the best estimation model in 2017 to determine leaf area in some apple varieties of 'Summerred', 'Mondial Gala', 'Golden Delicious' and 'Braeburn' by using leaf length (L), width (W) and combination of the two parameters. Sixteen different models composed of linear and power were obtained. High coefficient of determination denoted R^2 and low mean square error (MSE) values were used to determine the best models to estimate. Accordingly, combinations of $L \times W$ parameters for 'Summer Red' and 'Mondial Gala' varieties and $L \times W^2$ for 'Golden Delicious' and 'Braeburn' varieties were determined as the efficient parameters in estimation of plant leaf area. The results revealed that the plant leaf area can be estimated in an inexpensive, fast and non-destructive manner by mathematical relationships obtained with high R^2 ('Summer Red': 97.9%; 'Mondial Gala': 99.1%; 'Golden Delicious': 98.6%; 'Braeburn': 95.1%) and low MSE ('Summer Red': 8.48; 'Mondial Gala': 1.594; 'Golden Delicious': 0.005; 'Braeburn': 0.013) values using leaf dimensions of each variety rather than expensive measurement instruments.

Keywords Leaf area index · Apple · Regression · Model · Leaf dimensions

Zerstörungsfreie Ermittlung der Blattfläche bei Apfelsorten

Schlüsselwörter Blattflächenindex · Apfel · Regression · Modell · Blattdimensionen

Introduction

Leaf is the most important photosynthetic organ of plants and affects plant growth and bio-productivity. Leaf area also is a valuable parameter for studies such as plant nutrition, plant protection, plant soil-water relations and ecosystem. Accurate, fast, and non-destructive leaf area measurement is important in plant research on understanding and modeling of ecosystem functions (Li et al. 2007). Plant physiologists and agronomists indicated the importance of this parameter in estimation of plant growth, growth rate, yield potential, radiation utilization efficiency and water and nutrient utilization (Bhatt and Chanda 2003; Williams III and Martinson 2003; Cristofori et al. 2007). The measurement of plant leaf area is a decisive factor in understanding the physiological conditions such as photosynthesis, light interception, water and nutrient uses and yield potential (Clayton et al. 1995; Demirsoy and Lang 2010). However, measuring the leaf area is a time-consuming and costly process, depending on methods used and/or sensitivity demanded (Sala et al. 2015).

The leaf area estimation is an important criterion in many physiological and agronomic studies; thus, easiness and reliability of measurement method are very important criteria. Therefore, leaf area measurements are divided into direct and indirect methods (Çelik et al. 2011). Indirect

Availability of data and material The data was taken by me. It can be shared on demand.

Code availability Not applicable

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leaf area measurement is an inexpensive method in which leaf area is calculated using simple mathematical methods and requires less time than direct measurement methods (Gamiely et al. 1991; Demirsoy and Demirsoy 2003). Villalobos et al. (1995) recommended indirect measurements for the leaf area measurements of perennial plants in contrast to annual plants due to high labor and long time required by direct methods. Similarly, many researchers have also reported that indirect measurement methods have more advantageous than direct methods (Robins and Pharr 1987; Elsner and Jubb 1988; Kersteins and Hawes 1994, Sousa et al. 2005).

The aim of this study was to obtain an estimation model for leaf area and determine the mathematically expression of leaf area calculation by using the leaf width and height measurement values of samples collected from 'Summer Red', 'Mondial Gala', 'Golden Delicious' and 'Braeburn' apple varieties grafted on MM.106 semi-dwarf apple rootstock.

Material and Methods

The study was carried out in 2017 on the leaf samples collected from 'Summer Red', 'Mondial Gala', 'Golden Delicious' and 'Braeburn' apple varieties grafted on MM 106 semi-dwarf apple rootstock in Kirsehir province. The leaf samples were taken from the apple trees during the growth period. The leaves were randomly chosen from the branches located at different heights of the trees. A total of 500 leaf samples, 125 for each apple variety, were taken for the study.

The leaf samples were brought to the laboratory in ice bags, and width and lengths of leaves were measured using a ruler from the longest and largest parts (Fig. 1) according to the methods reported in several literature (Blanco and Folegatti 2003, Demirsoy et al. 2004, Cristofori et al. 2008, Sala et al. 2015). Then, the leaf areas of leaves were calculated by 3 repetitive calculations using a Placom Intelligent Planimeter.

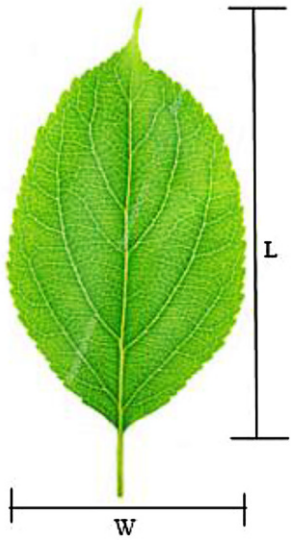

Fig. 1 Illustration of an area covered by a leaf in relation to the area calculated based on leaf dimensions (Length, L and Width, W)

Statistical Evaluation

Sixteen different models were obtained for the leaf area estimation of 4 different apple varieties using the independent variables of leaf width (W) and height (L) values and the combinations of L^2, W^2, $L \times W$, $L^2 \times W$, $L \times W^2$, $L^2 \times W^2$. The relationships between the leaf area and these variables were examined in two different ways as linear [$Y = \beta_{0+}\beta_1(t)$] and power [$Y = \beta_0(X^{\beta_1})$]. High coefficient of determination, denoted R^2 and low mean square error (MSE) values were used as criteria (Tsialtas et al. 2008) in determining the best estimation model among the estimated models. Equational expansions of these statistical criteria were given in Eqs. 1 and 2 (Atıl and Akıllı 2016; Tüzemen and Yıldız 2018).

$$R^2 = \frac{\sum_{i=1}^{n}\left(\widehat{Y}_i - \overline{Y}\right)^2}{\sum_{i=1}^{n}\left(Y_i - \overline{Y}\right)^2} \quad (1)$$

$$\mathrm{MSE} = \frac{\sum_{\mathbf{i=1}}^{\mathbf{n}}(\boldsymbol{Y_i} - \widehat{\mathbf{Y}}_{\boldsymbol{i}})^{\mathbf{2}}}{\mathbf{n}} \quad (2)$$

In equations; Y_i shows the observed value, $\widehat{Y}_i$: is the predicted value (= 1,2,3..., n), $\overline{Y}$: is the mean, n: is the number of observations.

Results

The study was conducted using 'Summer Red', 'Mondial Gala', 'Golden Delicious' and 'Braeburn' apple varieties. Descriptive statistics of the four different apple varieties were given in Table 1. The mean leaf length, leaf width and leaf area values were 8.648 cm, 4.733 cm and 31.766 cm^2 for 'Summer Red', 7.14 cm, 4.560 cm and 23.956 cm^2 for 'Mondial Gala', 8.588 cm, 5.085 cm and 31.947 cm^2 for 'Golden Delicious' and 6.895 cm, 4.208 cm and 21.873 cm^2 for 'Braeburn' variety.

The estimation equations obtained for apple varieties were given in Table 2, 3 and 4 and 5 based on tested model structures. The best estimation model for the 'Summer Red variety was Model 5 obtained by the linear regression. The highest R^2 (97.9%) and lowest MSE (8.48) values compared to the other models tested were obtained for Model 5 with the $L \times W$ independent variable. In addition, the best estimation equation for 'Summer Red' was $Y = 0.737x - 1.371$ (Table 2). The relationship between measured and the predicted values were shown in Fig. 2. The predicted values

Table 1 Descriptive statistics for leaf length, width and area

Apple Variety	Leaf length (cm)				Leaf width (cm)				Leaf area (cm^2)				
	Mean	SE	Max	Min	Mean	SE	Max	Min	Mean	SE	Max	Min	*N*
'Summer Red'	8.648	0.243	17.2	3.50	4.733	0.148	8.10	1.40	31.766	1.793	105.5	3.75	125
'Mondial Gala'	7.14	0.166	12	3.2	4.560	0.117	8.5	2.4	23.956	1.189	72	5.25	125
'Golden D.'	8.588	0.210	13	3.6	5.085	0.124	8	2.2	31.947	1.438	71	6.25	125
'Braeburn'	6.895	0.130	10.6	3.1	4.208	0.100	8.7	1.8	21.873	0.897	56	3.79	125

SE Std. Error

Table 2 Leaf area estimation equations for 'Summer Red' apple variety

Model no	*Equations of model tested*	*Fitted coefficients and constants*		*F Value*	*P value*	R^2	*MSE*
	Equation	$a \pm SE$	$b \pm SE$				
1	$LA = aL + b$	7.056 ± 0.190	–29.26 ± 1.727	1370.752	0.000	0.917	33.39
2	$LA = aW + b$	11.211 ± 0.42	–21.304 ± 2.08	729.04	0.000	0.856	58.54
3	$LA = aL^2 + b$	0.384 ± 0.01	0.205 ± 0.939	1550.16	0.000	0.926	29.81
4	$LA = aW^2 + b$	1.202 ± 0.038	1.557 ± 1.120	1011.74	0.000	0.892	43.95
5	$LA = a(LW) + b$	0.737 ± 0.010	–1.371 ± 0.509	5753.62	0.000	0.979	8.48
6	$LA = a(L^2W) + b$	0.049 ± 0.001	9.347 ± 0.626	47293.98	0.000	0.948	21.01
7	$LA = a(LW^2) + b$	0.091 ± 0.002	8.541 ± 0.560	2937.88	0.000	0.960	16.29
8	$LA = a(L^2W^2) + b$	0.006 ± 0.000	14.648 ± 0.745	45171.89	0.000	0.906	38.26
9	$LA = aL^b$	2.103 ± 0.048	0.301 ± 0.030	1919.95	0.000	0.939	0.033
10	$LA = aW^b$	1.760 ± 0.053	1.84 ± 0.149	1119.58	0.000	0.901	0.053
11	$LA = a(L^2)^b$	1.052 ± 0.024	0.301 ± 0.031	1919.95	0.000	0.939	0.033
12	$LA = a(W^2)^b$	0.880 ± 0.026	1.848 ± 0.149	1119.58	0.000	0.901	0.054
13	$LA = a(LW)^b$	1.004 ± 0.018	0.687 ± 0.045	3127.48	0.000	0.962	0.020
14	$LA = a(L^2W)^b$	0.687 ± 0.012	0.503 ± 0.034	3517.42	0.000	0.966	0.018
15	$LA = a(LW^2)^b$	0.645 ± 0.014	0.955 ± 0.067	2271.86	0.000	0.949	0.028
16	$LA = a(L^2W^2)^b$	0.502 ± 0.009	0.687 ± 0.045	3127.48	0.000	0.962	0.020

Table 3 Leaf area estimation equations for 'Mondial Gala' apple variety

Model no	*Equations of model tested*	*Fitted coefficients and constants*		*F value*	*P value*	R^2	*MSE*
	Equation	$a \pm SE$	$b \pm SE$				
1	$LA = aL + b$	6.828 ± 0.192	–24.798 ± 1.414	1269.03	0.000	0.912	15.752
2	$LA = aW + b$	9.796 ± 0.234	–20.722 ± 1.110	1754.33	0.000	0.934	11.680
3	$LA = aL^2 + b$	0.462 ± 0.011	–1.172 ± 0.659	1832.82	0.000	0.937	11.211
4	$LA = aW^2 + b$	1.019 ± 0.020	1.029 ± 0.519	2573.61	0.000	0.954	8.131
5	$LA = a(LW) + b$	0.720 ± 0.006	–1.099 ± 0.243	13625.91	0.000	0.991	1.594
6	$LA = a(L^2W) + b$	0.060 ± 0.001	7.097 ± 0.340	3918.87	0.000	0.970	5.425
7	$LA = a(LW^2) + b$	0.090 ± 0.001	7.652 ± 0.328	4052.69	0.000	0.971	5.251
8	$LA = a(L^2W^2) + b$	0.008 ± 0.000	11.877 ± 0.454	1497.437	0.000	0.924	13.532
9	$LA = aL^b$	2.046 ± 0.049	0.395 ± 0.037	1771.84	0.000	0.935	0.022
10	$LA = aW^b$	1.914 ± 0.035	1.218 ± 0.063	3068.72	0.000	0.961	0.013
11	$LA = a(L^2)^b$	1.023 ± 0.024	0.395 ± 0.037	1771.84	0.000	0.935	0.022
12	$LA = a(W^2)^b$	0.957 ± 0.017	1.218 ± 0.063	3068.72	0.000	0.961	0.013
13	$LA = a(LW)^b$	1.031 ± 0.010	0.613 ± 0.021	10998.59	0.000	0.989	0.004
14	$LA = a(L^2W)^b$	0.692 ± 0.009	0.510 ± 0.024	6251.201	0.000	0.981	0.006
15	$LA = a(LW^2)^b$	0.676 ± 0.007	0.757 ± 0.025	9987.806	0.000	0.988	0.004
16	$LA = a(L^2W^2)^b$	0.515 ± 0.005	0.612 ± 0.021	10998.59	0.000	0.989	0.004

Table 4 Leaf area estimation equations for the 'Golden Delicious' apple variety

Model no	*Equation of model tested*	*Fitted coefficient and constant*		*F value*	*P value*	R^2	*MSE*
	Equation	*a ± SE*	*b ± SE*				
1	$LA = aL + b$	6.451 ± 0.204	–23.456 ± 1.812	1004.64	0.000	0.891	28.435
2	$LA = aW + b$	–11.108 ± 0.273	24.545 ± 1.437	1661.451	0.000	0.931	17.969
3	$LA = aL^2 + b$	0.396 ± 0.011	0.557 ± 0.990	1242.972	0.000	0.910	23.474
4	$LA = aW^2 + b$	1.124 ± 0.025	0.706 ± 0.780	2001.18	0.000	0.942	15.095
5	$LA = a(LW) + b$	0.700 ± 0.010	–0.705 ± 0.543	4465.97	0.000	0.973	6.987
6	$LA = a(L^2W) + b$	0.053 ± 0.001	8.157 ± 0.569	2507.49	0.000	0.953	12.189
7	$LA = a(LW^2) + b$	0.088 ± 0.002	8.453 ± 0.532	2820.03	0.000	0.958	10.895
8	$LA = a(L^2W^2) + b$	0.007 ± 0.000	13.002 ± 0.618	1563.66	0.000	0.927	19.010
9	$LA = aL^b$	1.872 ± 0.052	0.527 ± 0.059	1273.622	0.000	0.912	0.033
10	$LA = aW^b$	1.958 ± 0.04	1.225 ± 0.078	2445.156	0.000	0.952	0.018
11	$LA = a(L^2)^b$	0.936 ± 0.026	0.528 ± 0.059	1273.62	0.000	0.912	0.033
12	$LA = a(W^2)^b$	0.979 ± 0.020	1.225 ± 0.078	2445.15	0.000	0.952	0.018
13	$LA = a(LW)^b$	1.011 ± 0.011	0.652 ± 0.028	7828.56	0.000	0.985	0.006
14	$LA = a(L^2W)^b$	0.665 ± 0.010	0.577 ± 0.035	4117.81	0.000	0.971	0.011
15	$LA = a(LW^2)^b$	0.675 ± 0.007	0.773 ± 0.03	8552.64	0.000	0.986	0.005
16	$LA = a(L^2W^2)^b$	0.506 ± 0.006	0.652 ± 0.028	7828.56	0.000	0.985	0.006

Table 5 Leaf area estimation equations for the 'Braeburn' apple variety

Model no	*Equation of model tested*	*Fitted coefficient and constant*		*F value*	*P value*	R^2	*MSE*
	Equation	*a ± SE*	*b ± SE*				
1	$LA = aL + b$	5.533 ± 0.370	–16.281 ± 2.608	223.57	0.000	0.645	35.99
2	$LA = aW + b$	8.460 ± 0.260	–13.726 ± 1.130	1062.30	0.000	0.896	10.52
3	$LA = aL^2 + b$	0.408 ± 0.027	1.608 ± 1.1433	231.62	0.000	0.653	35.17
4	$LA = aW^2 + b$	0.896 ± 0.033	4.881 ± 0.714	733.87	0.000	0.856	14.55
5	$LA = a(LW) + b$	0.698 ± 0.025	0.720 ± 0.841	753.45	0.000	0.860	14.233
6	$LA = a(L^2W) + b$	0.061 ± 0.003	8.018 ± 0.811	407.94	0.000	0.768	23.495
7	$LA = a(LW^2) + b$	0.085 ± 0.004	9.782 ± 0.695	465.633	0.000	0.791	21.192
8	$LA = a(L^2W^2) + b$	0.008 ± 0.000	13.366 ± 0.724	268.494	0.000	0.686	31.863
9	$LA = aL^b$	1.978 ± 0.092	0.448 ± 0.079	467.422	0.000	0.792	0.056
10	$LA = aW^b$	1.756 ± 0.047	1.666 ± 0.112	1397.82	0.000	0.919	0.021
11	$LA = a(L^2)^b$	0.989 ± 0.046	0.448 ± 0.079	467.42	0.000	0.792	0.056
12	$LA = a(W^2)^b$	0.878 ± 0.023	1.666 ± 0.112	1397.82	0.000	0.919	0.022
13	$LA = a(LW)^b$	1.022 ± 0.023	0.665 ± 0.050	2051.90	0.000	0.943	0.015
14	$LA = a(L^2W)^b$	0.691 ± 0.019	0.530 ± 0.053	1326.90	0.000	0.915	0.023
15	$LA = a(LW^2)^b$	0.657 ± 0.013	0.884 ± 0.057	2377.07	0.000	0.951	0.013
16	$LA = a(L^2W^2)^b$	0.511 ± 0.011	0.665 ± 0.050	2051.90	0.000	0.943	0.015

were quite close to the actual values in comparison to the linear equation of Model 5 (Fig. 2).

The best estimation model for the 'Mondial Gala' variety was determined as Model 5 obtained by the linear regression (Table 3). The Model 5 with L × W independent variable had the highest R^2 (99.1%) and the lowest MSE (1.594) values compared to the other models tested. The best estimation equation for the 'Mondial Gala' variety was $y = 0.720x - 1.099$. The measurement and estimation values were shown in Fig. 3. The R^2 value was very close to 1.0 (Fig. 3).

The best estimation model for the 'Golden Delicious' variety was Model 15 which is a power model. The highest R^2 (98.6%) and lowest MSE (0.005) values compared to the other models tested were obtained for Model-15 with the $L \times W^2$ independent variable. In addition, the best estimation equation for 'Golden Delicious' was $y = 0.675 \times^{0.773}$ (Table 4; Fig. 4).

Similar to the Golden Delicious variety, the best estimation model for the 'Braeburn' variety was Model 15 which was obtained according to the power model. The highest R^2 (95.1%) and the lowest MSE (0.013) values compared to the other models tested were obtained for Model 15 with the

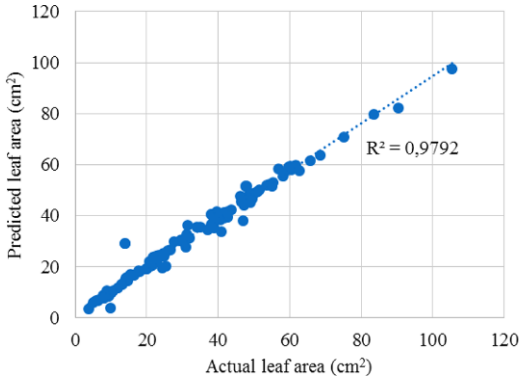

Fig. 2 The relationship between actual and predicted values for the 'Summer Red' apple variety

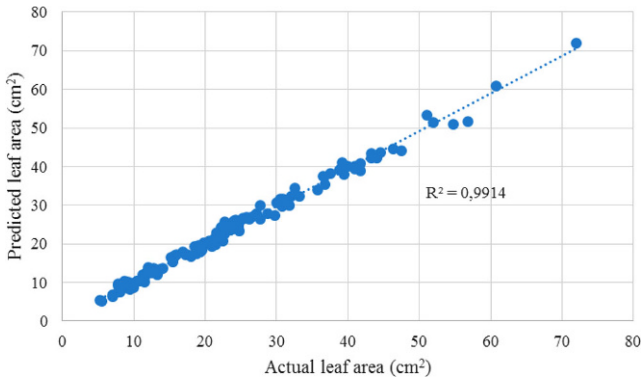

Fig. 3 The relationship between actual and predicted values for the 'Mondial Gala' apple variety

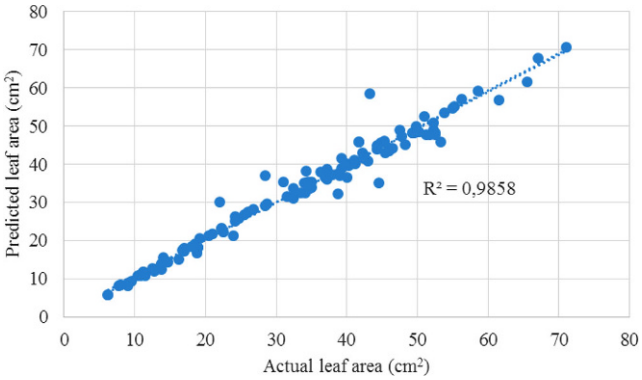

Fig. 4 The relationship between actual and predicted values for the 'Golden Delicious' apple variety

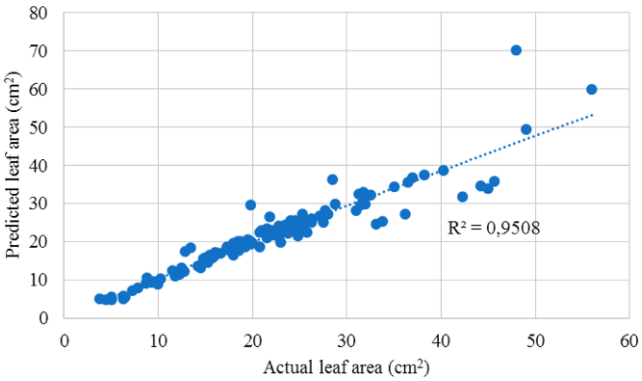

Fig. 5 The relationship between actual and predicted values for the 'Braeburn' apple variety

$L \times W^2$ independent variable. In addition, the best estimation equation for 'Braeburn' was $y = 0.657 \times^{0.884}$ (Table 5; Fig. 5).

Discussion

The best estimation of leaf area for the 'Golden Delicious' and 'Braeburn' apple varieties was obtained by linear, while the best estimation of leaf area for the 'Summer Red' and the 'Mondial Gala' apple varieties were obtained by power equation. Horticulturalists and agronomists need an inexpensive, fast, reliable, and non-destructive method to measure the leaf area (Blanco and Folegatti 2003, Peksen 2007; Olfati et al. 2010, Küçükönder et al. 2016). Therefore, the results indicated that mathematical models arising from the relationships between leaf area and leaf dimensions (length and width) can be used to determine the apple leaf area as a faster and more practical method compared to the other expensive leaf area estimating methods.

Several mathematical models using leaf dimensions have been developed estimating the leaf area indirectly in various crops, such as apple (Palmer 1987; Sala et al. 2015; Clayton et al. 1995), grapes (Montero et al. 2000; Beslic et al. 2010), cherry (Demirsoy and Demirsoy 2003, Demirsoy and Lang 2010), chestnut (Serdar and Demirsoy 2006), coconut (Sousa et al. 2005), hazelnut (Cristofori et al. 2007), peach (Demirsoy et al. 2004), Persimmon (Cristofori et al. 2008), olive (Villalobos et al. 1995) tomatoes (Küçükönder et al. 2016), cucumber (Cho et al. 2007), onion (Gamiely et al. 1991), cabbage and broccoli (Olfati et al. 2010).

The results obtained in this study are consistent with the results of researchers who developed reliable equations to estimate the leaf area with non-destructive models using simple linear leaf dimension measurements. The results revealed that the coefficient of determination between predicted values calculated with the mathematical models and the leaf areas determined by the actual measurement was quite close to 1.0. This high correlation pointed out that the leaf width and length parameters were effective in estimating the apple leaf area, and therefore the leaf area could

be estimated using these parameters. Similar results on leaf area estimation models have been reported by many others (Montero et al. 2000; Blanco and Folegatti 2003; Çelik et al. 2011; Rouphael et al., 2010; Sala et al. 2015). The strong relationships indicated that leaf areas of apple varieties can be measured quickly, accurately, and non-destructively.

Conclusion

This study introduced the mathematical equations created from the leaf length and width measurements for 'Summer Red', 'Mondial Gala', 'Golden Delicious' and 'Braeburn' apple varieties. The equations of $Y = 0.737x - 1.371$ for 'Summer Red' variety, $Y = 0.720x - 1.099$ for 'Mondial Gala', $Y = 0.675 \times ^{0.773}$ for 'Golden Delicious' and $Y = 0.657 \times ^{0.884}$ for 'Braeburn' variety can be used for the most accurate estimation of leaf area.

The results indicated that the estimation of plant leaf area can be achieved in an inexpensive, fast, and non-destructive manner using mathematical relationships obtained with high R^2 and low MSE values using leaf dimensions of each variety rather than using expensive measurement instruments.

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Author Contribution Selma Boyacı: Field studies, leaf area measurements, discussion. Hande Küçükönder: Statistical analysis.

Declarations

Conflict of interest S. Boyacı and H. Küçükönder declare that they have no competing interests.

Ethical standards *Consent for publication:* If the study is deemed appropriate, there is no objection to its publication.

Ethics approval: An ethical document is not required for this research.

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