Journal of Agricultural Science; Vol. 11, No. 5; 2019
ISSN 1916-9752 E-ISSN 1916-9760
Published by Canadian Center of Science and Education

Mathematical Modeling for Leaf Area Estimation From Papaya Seedlings 'Golden THB'

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Received: January 1, 2019 Accepted: March 3, 2019 Online Published: April 15, 2019

doi:10.5539/jas.v11n5p496 URL: https://doi.org/10.5539/jas.v11n5p496

Abstract

The aim of this study was to select the most suitable model for leaf area estimation from papaya seedlings cv. 'Golden THB' using linear dimensions of leaves with unilobular and trilobular morphology. It was used leaves of 60 seedlings with 30 days after sowing produced in nursery of the Fazenda Santa Teresinha which belongs to company Caliman Agrícola S.A., in the municipality of Linhares, state of Espírito Santo, in March 2016. The measurement of the length (L) was performed along the midrib, the maximum width (W) of the leaf blade, the product of the length by the width (LW) and the observed leaf area (OLA). From these results, first degree and power linear regression models was adjusted. From the proposed regression models, the validation was performed with a leaves sample of 60 seedlings produced in June 2016, obtaining, thus, the estimated leaf area (ELA). The following criteria were used to choose the best model: the highest coefficient of determination (R^2), the values do not significant of the comparison of means of OLA and ELA and values of MAE and RMSE closer to zero. The leaf area estimation from papaya seedlings cv. 'Golden THB' can be represented through equation ELA = -0.402619 + 0.612525(LW) for trilobular leaves and through equation ELA = 0.623355 + 0.610552(LW) for unilobular leaves.

Keywords: *Carica papaya* L., linear dimensions, non-destructive methods

1. Introduction

Papaya (*Carica papaya* L.) cv. 'Golden THB' is characterized by great planting uniformity, vigorous plants and high yield, whose destination is mainly to external Market (Serrano & Cattaneo, 2010).

Knowing the leaf area is fundamental to evaluate the plants growth and development, being important in works involving physiology, photosynthesis efficiency, perspiration and behavior related to fertilizer and irrigation (Blanco & Folegatti, 2005).

The leaf area may be measured by direct or indirect method, depending on the objective of the study. The direct methods are destructive because the plant leaves are removed, and this method, mostly, is expensive for requesting specific equipment. The indirect methods are non-destructive, allowing successive leaf area estimation, and less costly (Norman & Campbell, 1989).

One of the non-destructive and indirect methods to estimate leaf area is through mathematical equations from linear dimensions as leaf length and width, and both dimensions in combination, whose high degree of accuracy is shown in most cases (Gamiely, Randle, Milks, & Smittle, 1991; Blanco & Folegatti, 2005).

Mathematical models that aim the indirect leaf area estimation have been used for different plant species as cocoa (Asomaning & Lockard, 1963), *Cucumis sativus* L. (Cho, S. Oh, M. M. Oh, & Son, 2007), *Vicia faca* L. (Peksen, 2007), Tabebuia and Handroanthus (Monteiro et al., 2017), colza (Tian et al., 2017) and *Coffea canephora* (Schmildt, Amaral, Santos, & Schmildt, 2015; Espindula et al., 2018). Methods have been described to estimate leaf area of papaya from adult plants, as mentioned by Campostrini and Yamanishi (2001), Ayala, Tatis, and Causil (2009), and Posse, Sousa, Bernardo, Pereira, and Gottardo (2009), however, none mention was found for papaya seedlings, in which a few leaves have a single leaf blade, differently from adult plants, in which all the leaves have more than one lobule.

The existence of leaves with different morphology on the same plant has been also observed in other crops as canola (Tartaglia et al., 2016) and passionfruit (Schmildt, Oliari, Schmildt, Alexandre, & Pires, 2016).

Developing techniques that determine the papaya leaf area from non-destructive methods is important to avoid vegetal material losses. Thus, the objective of this study was to determine mathematical models for leaf area estimation from papaya seedlings 'Golden THB' from non-destructive method, using linear dimensions (length and width) of leaves with trilobular and unilobular morphology.

2. Method

This study used papaya seedlings leaves (*Carica papaya* L.) cv. 'Golden THB' produced in nursery of the Fazenda Santa Teresinha which belongs to company Caliman Agrícola S. A., in the municipality of Linhares, state of Espírito Santo, Brazil (19º23′28″ of latitude S and 40º04′20″ of longitude W).

The seedlings were prepared using tubes with volume of 50 cm^3 that were pre-sanitized by solution sodium hypochlorite 1% and filled with Bioplant® commercial substrate that presents the following chemical composition: N = 0.62%; P_2O_5 = 3.55%; K_2O = 0.53%; Ca = 1.84; Mg = 0.43%; S = 0.55%; Fe = 2.36%; Zn = 99.8 ppm; Cu = 75.0 ppm; Mn = 333.5 ppm; B = 34.5 ppm and Mo = 52.21%, added with Basacote mini 3M®, formulation NPK (mg) 13-06-16 (1,4) with 10% S, 0.05% Cu, 0.26% Mn and 0.015% Mo, whose proportion was of 10 kg m^{-3} (Paixão, Schmildt, Mattiello, Ferreguetti, & Alexandre, 2012).

Two seeds per tube were used to maximize the germination. The seedlings were put in trays containing 96 cells. At 15 days after planting, the thinning was performed, conducting only one seedling per tube. The seedlings were produced in March 2016.

The leaves used for leaf area modeling were obtained from seedlings with 30 days after sowing. All the leaves of 60 central seedlings of the tray were used, disregarding the border seedlings. All the 60 seedlings analyzed showed 314 leaves, being 173 leaves with trilobular shape and 141 leaves with unilobular shape.

At laboratory was made the measurement of the length (L, in cm) along the midrib and the maximum width (W, in cm) of the leaf blade. In both measures were used a graduated ruler in 1 mm (Figure 1). Then, the leaves were scanned by a Scanner HP Deskjet F4280®, whose images were saved in tif format with 75 dpi for posterior lecture of the leaf area using ImageJ® program (Schindelin, Rueden, Hiner, & Eliceiri, 2015), determining the observed leaf area (OLA, in cm^2). The product of the length by the width (LW) was obtained.

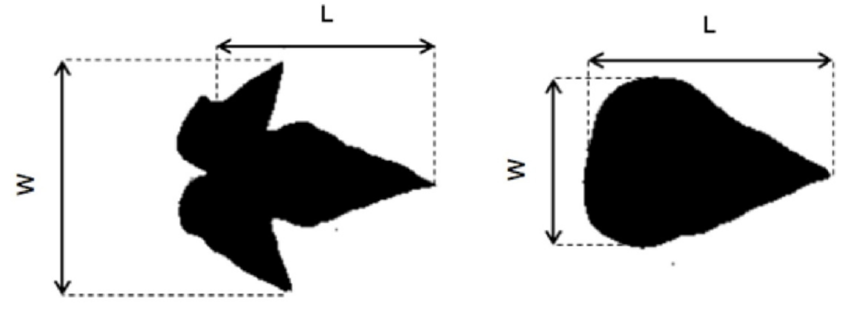

Figure 1. Representation of the measurement of length (L) and width (W) of trilobular and unilobular leaves of papaya seedlings cv. 'Golden THB'

Three regression models for each type of leaf were evaluated, the first degree linear model was represented by Equation 1, the quadratic model represented by Equation 2 and the power model was represented by Equation 3. The equations were resulted of the relation between the OLA used as dependent variable and L, W and LW used as independent variable, totaling nine equations for unilobular leaves and six equations for trilobular leaves.

$$ELA = \hat{\beta}_0 + \hat{\beta}_1 x \quad (1)$$

$$ELA = \hat{\beta}_0 + \hat{\beta}_1 x + \hat{\beta}_2 x^2 \quad (2)$$

$$\mathrm{ELA} = \hat{\beta}_0 x^{\hat{\beta}_1} \tag{3}$$

For the data validation, a new sample with 287 leaves was used, being 144 trilobular leaves and 143 unilobular leaves of 60 seedlings with 30 days after sowing produced in June 2016. The variables L, W, LW and OLA were measured according to previously proposed methodology. The estimated leaf area (ELA, in cm^2) was obtained replacing all the values of L, W and LW in the obtained equation for modeling. A simple linear regression for each proposed model was generated, as well as the respective coefficient of determination (R^2), where ELA was the dependent variable and OLA was the independent variable. The means of OLA and ELA were compared by Student t-test at 5% probability level. The mean absolute error (MAE) and root mean square error (RMSE) were determined by the following equations:

$$\mathrm{MAE} = \frac{1}{n-1} \sum_{i=1}^{n} \left| \mathrm{ELA} - \mathrm{OLA} \right| \tag{4}$$

$$\mathrm{RMSE} = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (\mathrm{ELA} - \mathrm{OLA})^2} \tag{5}$$

The choice of the best mathematical model that estimates the leaf area from papaya seedlings cv. 'Golden THB' as a function of the length (L) along the midrib, the maximum width (W) of the leaf blade or the product of the length by the width (LW) considered the value of coefficient of determination (R^2) closest to the unit, the values do not significant of the comparison of means of OLA and ELA and values of MAE and RMSE closer to zero. The statistical analyses were perfor¨using R software (R Core Team, 2018) with scripts developed by data package ExpDes.pt version 1.2 (Ferreira et al., 2018).

3. Results and Discussion

In table 1, it can be observed that in relation to the trilobular leaves used for the modeling, the value of the length (L) ranged from 1.600 to 6.200 cm, with a mean of 4.113 cm. The width (W) varied from 1.400 to 5.700 cm, average of 3.659 cm. The product of length and width (LW) varied from 2.240 to 35.340 cm^2 with an average of 15.958 cm^2 and the leaf area observed (OLA) varied from 1.200 to 20.700 cm^2 with a mean of 9.372 cm^2. For the unilobular leaves L values varied from 2.100 to 5.300 cm with an average of 3,446 cm. The W ranged from 1.700 to 4.500 cm with a mean of 2.703 cm. LW ranged from 3.780 to 23.850 cm^2 with a mean of 9.749 cm^2. OLA ranged from 1.900 to 15.100 cm^2 with an average of 6.576 cm^2. All variables of the leaf sample used for validation presented values close to those used for modeling, and this practice is recommended by Levine, Berenson, Krehbiel, and Stephan (2012), since the values used for the validation should not extrapolate those used for the modeling.

In relation to the coefficient of variation (CV) of the trilobular and unilobular leaves samples, used in modeling, it was observed that the values ranged from 21.98 to 46.75%, whose values are classified as high and very high, according to Pimentel-Gomes (2009). However, these values are recommended in works that aim the leaf area modeling for characterizing different plant growth stages (Pezzini et al., 2018).

Table 1. Minimum, maximum and mean coefficient of variation (CV) of the variables length (L), width (W), product of the length by the width (LW) and observed leaf area (OLA) for papaya seedlings trilobular and unilobular leaves cv. 'Golden THB'

Variable	Minimum	Maximum	Mean	CV (%)
Trilobular				
173 leaves used in modeling				
L	1.600	6.200	4.113	25.587
W	1.400	5.700	3.659	24.975
LW	2.240	35.340	15.958	43.032
OLA	1.200	20.700	9.372	45.695
144 leaves used in validation				
L	0.750	5.900	4.064	29.108
W	0.480	5.300	3.436	29.071
LW	0.360	29.680	15.064	47.505
OLA	0.230	18.800	9.007	49.379
Unilobular				
141 leaves used in modeling				
L	2.100	5.300	3.446	21.981
W	1.700	4.500	2.703	22.238
LW	3.780	23.850	9.749	46.751
OLA	1.900	15.100	6.576	42.679
143 leaves used in validation				
L	2.000	5.900	3.794	21.035
W	1.700	4.400	2.741	22.124
LW	3.990	25.370	10.844	43.788
OLA	2.300	16.100	7.349	39.071

The accuracy of the leaf area estimation depends on the equation model used (Borghezan, Gavioli, Pit, & Silva, 2010). According to Tsialtas, Koundouras, and Zioziou (2008), in a few cases the equations may be used to estimate the leaf area of leaves with different morphologies, however, the adjusts do not always show efficiency when a high degree of accuracy is desirable. Thus, obtaining individual equations for papaya seedlings leaves cv. 'Golden THB' with trilobular and unilobular shape become necessary.

When we analyzed the behavior of the first degree linear model for the trilobular leaves we saw that the lowest value of R^2 was obtained using W as independent variable and the highest value was used for LW. In relation to the behavior of equations with quadratic adjustment and power for trilobular leaves, the lowest value of R^2 was observed based on W, and the highest value was used as an independent variable (Table 2). Although the largest values of R^2 for quadratic and power adjustments were observed using L as the independent variable, the values were not very different from those found on the basis of LW as an independent variable. Montero, Juan, Cuesta, and Brasa (2000), studying non-destructives methods for leaf area estimation of *Vitis vinifera* L., verified that the use of only one variable such as the width, for instance, shows an inconstant method with the vegetative growth, being necessary making adjusts for different phenological stages.

Thus, models used to determine leaf area that takes into consideration only one linear dimension show lower degree of efficiency, being used only in a few cases. Thus, equations based on the set of dimensions and several leaves size, such as the product of the length by the width, are more desired for showing better adjusts for leaf area estimation (Espindula et al., 2018).

For the behavior of the proposed models for the unilobular leaves (Table 2), it was observed that the highest values of R^2 were achieved using LW as independent variable and the lowest values were obtained based on W as independent variable for all the equations. Schmildt et al. (2015), studying allometric model for leaf area estimation of *Coffea canephora*, also found higher values of R^2 using LW as independent variable, verifying that this characteristic better represents the modeling for this species and shows better adjust in the first degree linear model.

In general, all the models used to estimate leaf area from trilobular and unilobular leaves show high values of R^2, higher than 0.88. However, according to Antunes, Pompelli, Carretero, and Damatta (2008), for the estimation of folia area should not choose the equation only by the high values of R^2 because this practice for generating oversized measurements. Thus, validation of data through appropriate methodologies becomes essential.

Table 2. Equation with first degree, quadratic and power linear adjust and the respective coefficient of determination (R^2), using the observed leaf area (OLA) as dependent variable as a function of the length (L), width (W) and the product of the length by the width (LW) for papaya seedlings trilobular and unilobular leaves cv. 'Golden THB'

Model	Equation	R^2
Trilobular		
Linear	ELA = -6.95005 + 3.96763(L)	0.9510
Linear	ELA = -6.7563 + 4.4080(W)	0.8847
Linear	ELA = -0.402619 + 0.612525(LW)	0.9647
Quadratic	ELA = -0.30103 + 0.02556(L) + 0.53081$(L)^2$	0.9725
Quadratic	ELA = -3.3861 + 2.2175(W) + 0.3267$(W)^2$	0.8913
Quadratic	ELA = -0.675085 + 0.657280(LW) – 0.001465$(LW)^2$	0.9651
Power	ELA = 0.4743$(L)^{2.0617}$	0.9722
Power	ELA = 0.7855$(W)^{1.8765}$	0.8811
Power	ELA = 0.5267$(LW)^{1.0386}$	0.9633
Unilobular		
Linear	ELA = -5.82953 + 3.59984(L)	0.9440
Linear	ELA = -5.83127 + 4.58922(W)	0.9665
Linear	ELA = 0.623355 + 0.610552(LW)	0.9832
Quadratic	ELA = 1.46712 – 0.42682(L) + 0.52868$(L)^2$	0.9574
Quadratic	ELA = -1.7703 + 1.7612(W) + 0.4675$(W)^2$	0.9715
Quadratic	ELA = 0.309506 + 0.670162(LW) – 0.002311$(LW)^2$	0.9835
Power	ELA = 0.6671$(L)^{1.8206}$	0.9569
Power	ELA = 1.0831$(W)^{1.7808}$	0.9711
Power	ELA = 0.8251$(LW)^{0.9148}$	0.9836

Validating the data through the sample of trilobular and unilobular sheets, it is verified that all the equations that used LW as independent variable presented the highest values R^2 (Figures 2 and 3), attesting a high degree of correlation between ELA and OLA, being these same equations that presented high values of R^2 in modeling. It was also observed that the values of ELA and OLA differed statistically by Student's t-test ($p < 0.05$) only for the equation of the quadratic model based on L as independent variables. However, it is worth mentioning that the highest values for both trilobular leaves and unilobular leaves were verified based on LW as independent variable, indicating a greater similarity between ELA and OLA in the use of this variable.

In addition, the LW based equations presented MAE and RMSE values closer to zero (Table 3), the values being very similar between first degree linear model, quadratic and power, indicating that any of these models can be used to estimate the leaf area of seedlings of papaya cv. 'Golden THB'. In practice, using models take takes into consideration only one linear dimension is less costly, allowing greater agility in the data collection in field, however, show lower accuracy when compared with models that relate more than one dimension (Borghezan et al., 2010).

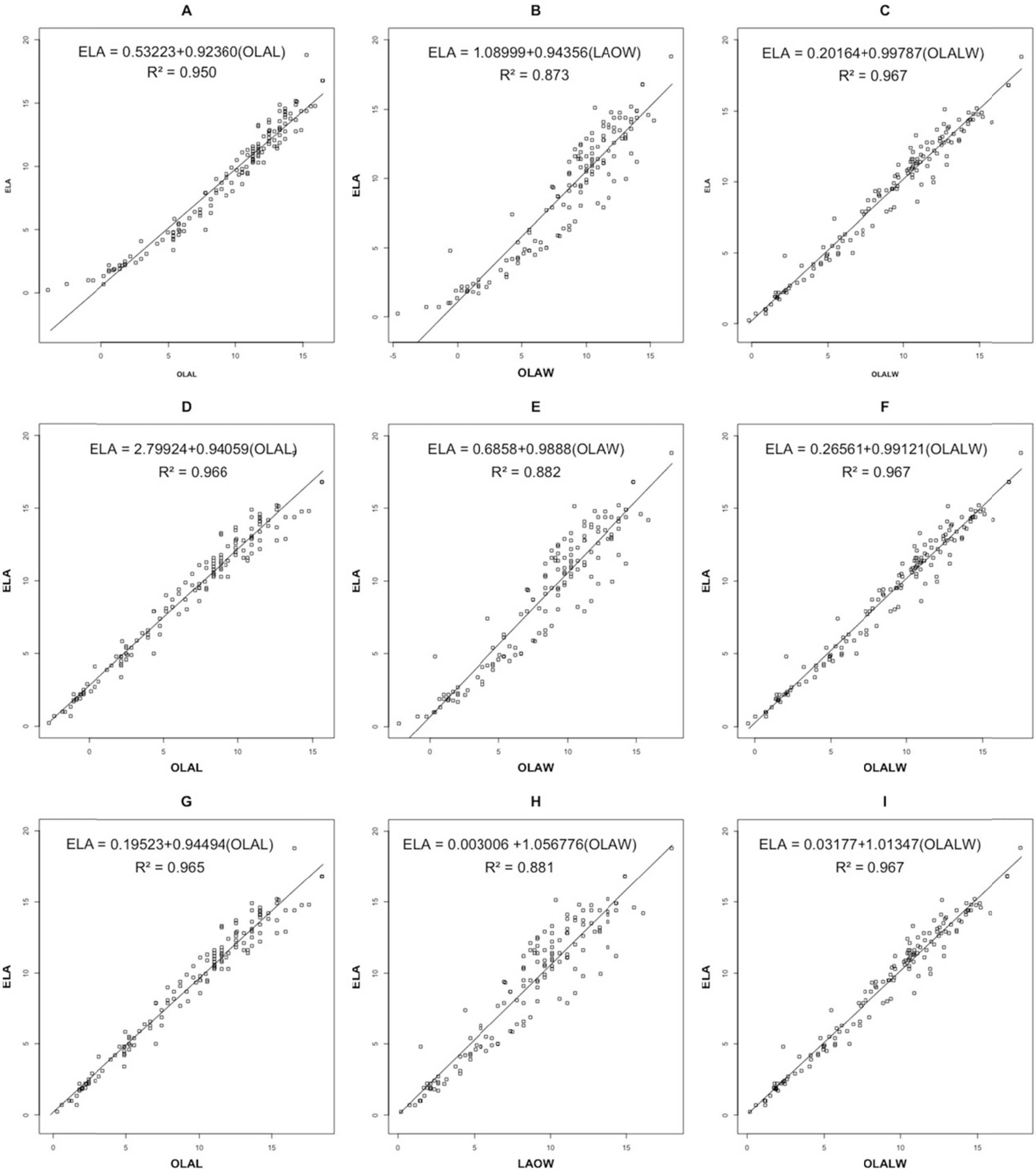

Figure 2. Validation equation with first degree linear adjust and the respective coefficient of determination (R^2), using the estimated leaf area (ELA) as dependent variable as a function of the observed leaf area of the length (OLAL), width (OLAW) and the product of the length by the width (OLALW) based on the first degree linear model (A, B and C), quadratic (D, E and F) and power (G, H and I) for papaya seedlings trilobular leaves cv. 'Golden THB'

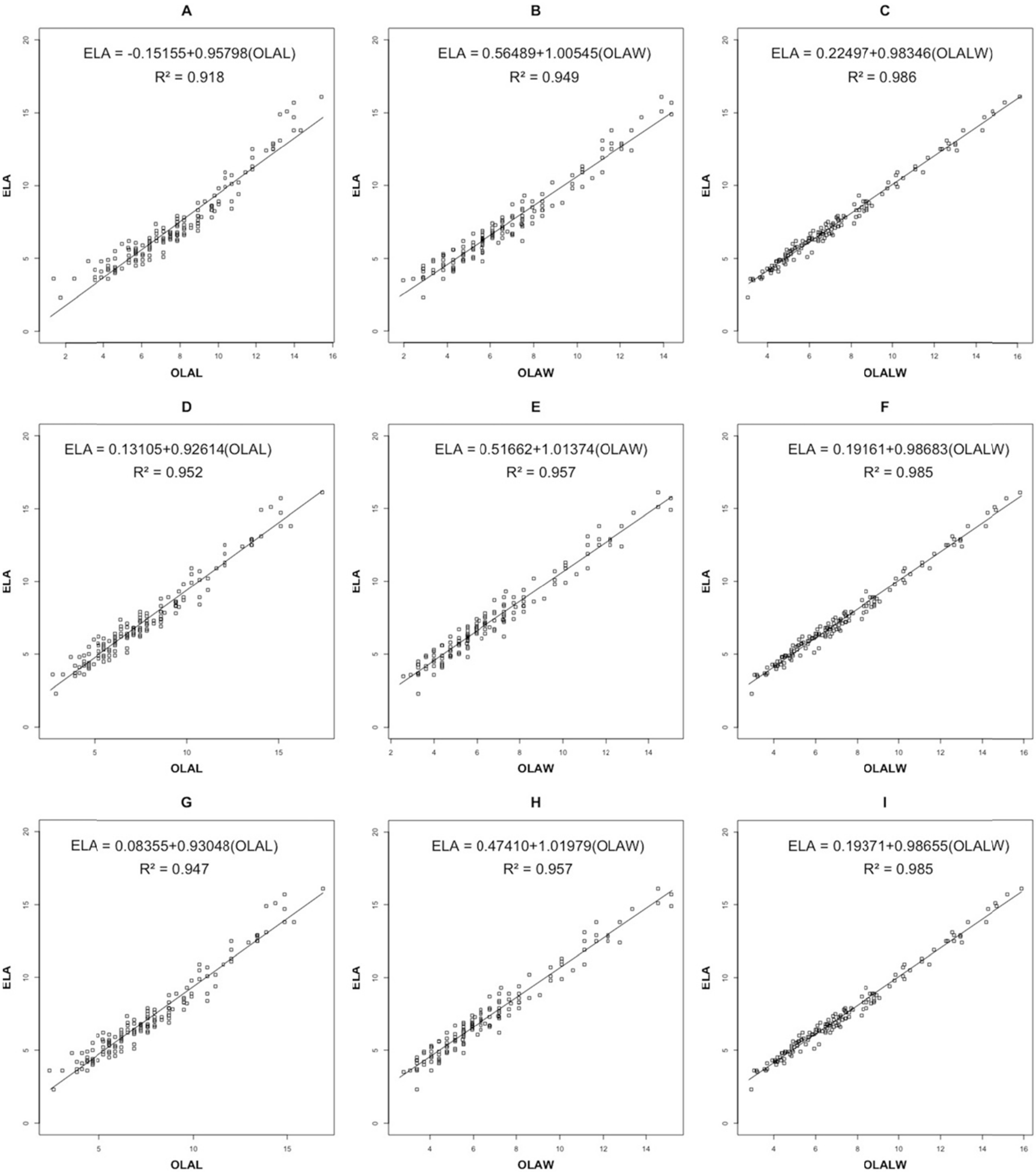

Figure 3. Validation equation with first degree linear adjust and the respective coefficient of determination (R^2), using the estimated leaf area as dependent equation as a function of the observed leaf area of the length (OLAL), width (OLAW) and the product of the length by the width (OLALW), based on the first degree linear model (A, B and C), quadratic (D, E and F) and power (G, H and I) for papaya seedlings unilobular leaves cv. 'Golden THB'

Table 3. Observed leaf area (OLA) and estimated leaf area (ELA) of first degree, quadratic and power linear equations for the independent variables length (L), width (W), product of the length by the width (LW), beyond the *p* value, mean absolute error (MAE) and root mean square error (RMSE) for papaya seedlings trilobular and unilobular leaves cv. 'Golden THB' used in validation

Model	Variable	OLA	ELA	p* value	MAE	RMSE
Trilobular						
Linear	L		9.176	0.754	0.8422	1.0699
Linear	W		8.391	0.238	1.3771	1.7215
Linear	LW		8.824	0.725	0.6148	0.8276
Quadratic	L		6.600	0.00001034	2.4280	2.5659
Quadratic	W	9.007	8.4154	0.2479	1.2970	1.6376
Quadratic	LW		8.8192	0.7189	0.6176	0.8289
Power	L		9.325	0.552	0.6720	0.9245
Power	W		8.521	0.327	1.2667	1.6263
Power	LW		8.856	0.770	0.6103	0.8257
Unilobular						
Linear	L		7.8299	0.1582	0.7843	0.9574
Linear	W		6.7476	0.0730	0.7337	0.8835
Linear	LW		7.2442	0.7582	0.2977	0.3602
Quadratic	L		7.793962	0.2036	0.6626	0.7989
Quadratic	W	7.3493	6.740143	0.06896	0.7122	0.8539
Quadratic	LW		7.253287	0.7781	0.3050	0.3653
Power	L		7.8086	0.1873	0.6886	0.8300
Power	W		6.7418	0.0689	0.7080	0.8528
Power	LW		7.2532	0.7779	0.3024	0.3628

Note. **P* values higher than 0.05 indicate that the observed leaf area (OLA) and the estimated leaf area (ELA) do not differ by Student t-test.

Therefore, based on the R2 value of the mathematical models and the validation equations closest to the unit, the non-significant valuesof the comparison of the means of ELA and OLA, besides the values of MAE and RMSE closer to zero, the models of linear equation of first degree, quadratic and power using LW as independent variable are the most suitable to estimate leaf area of papaya seedlings of cv. 'Golden THB' for trilobular and unilobular shaped sheets, attesting to a high degree of accuracy and efficiency. However, due to the ease of the calculations, the first degree linear model, represented by the ELA = -0.402619 + 0.612525 (LW) and ELA = 0.623355 + 0.610552 (LW) equations for trilobular and unilobular leaves, respectively, is recommended.

6. Conclusion

The leaf area estimation from papaya seedling cv. 'Golden THB' can be determined with accuracy by the first degree linear model taking into consideration the product of the length by the width for trilobular leaves through equation ELA = -0.402619 + 0.612525(LW) and for unilobular leaves through equation ELA = 0.623355 + 0.610552(LW).

Acknowledgements

CNPq, CAPES and FAPES for financial support.

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