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Estimation of Leaf Area by Linear Dimensions in *Coffea dewevrei*

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Authors' contributions

This work was carried out in collaboration among all authors. Authors OS, ENS, VSO, RRG and LCS designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors VSO, ERS, KTHS and GPS managed the analyses of the study. Authors ANMRS, SMS, CJF and SDA managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The objective of this research was to select the equation that best estimates the leaf area of the coffee tree Coffea dewevrei, from the linear dimensions of the leaves. For this purpose, 140 leaves of adult plants were collected from the Capixaba Institute for Research, Technical Assistance and Rural Extension, in the city of Linhares, North of the State of Espírito Santo, Brazil. The length (L), the width (W), the product of the multiplication between the length and width (LW) and the leaf area

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observed (OLA) were determined from all leaves. For the modeling, a 100 leaves sample was used, where OLA was used as a dependent variable in function of L, W and LW as independent variable, being obtained the following models: linear first degree, quadratic and power. For the validation, a sample of 40 leaves was used, where the values of L, W LW were substituted in the equations generated in the modeling, thus obtaining the estimated leaf area (ELA). A simple linear equation model was fitted for each modeling equation relating ELA in function of OLA. The hypotheses H0: β0 = 0 versus Ha: β0 ≠ 0 and H0: β1 = 1 versus Ha: β1 ≠ 1, were tested using Student's t test at 5% probability. The mean absolute error (MAE), root mean square error (RMSE) and Willmott's index d for all equations were also determined. The best model that estimates the area of Coffea dewevrei was chosen through the following criteria: β0 not different from zero, β1 not different from one, MAE and RMSE values closer to zero and index d closer to the unit. The area of the leaves can be determined by its greater width (W), through the quadratic model equation $ELA=-10.255+1.020(W)+1.293(W)^2$.

Keywords: Coffea dewevrei; non-destructive method; mathematical models.

1. INTRODUCTION

The coffee, originating in Africa and with a history of more than a thousand years, is a drink that every year surprises, gains fans, has its production increased and its quality improved [1].

In the literature for the coffee tree, 124 species are cataloged for the Coffea genus [2]. However, only *Coffea arabica* and *Coffea canephora* present significant economic importance. Other species such as *Coffea liberica*, *Coffea racemosa, Coffea dewevrei*, *Coffea eugenoides, Coffea congensis, Coffea stenophylla*, are of fundamental relevance in breeding programs [1]. In this context, the *Coffea dewevrei* species has important attributes, such as resistance to rust (*Hemileia vastatrix*), to some nematodes [3], and to *Leucoptera coffeella* [4], considered as one of the main phytosanitary problems of coffee [5], in addition to dry tolerance [6].

Coffee *Coffea dewevrei*, also known as Excelsa coffee, is self-incompatible [7] and highly productive [6]. The plants can reach eight to ten meters in height, and their leaves are large, measuring about 26 cm long and 13 cm wide, and coriaceous [8].

The amount of leaf area is indicative of crop productivity [9], and is also fundamental for physiological studies involving growth analysis, transpiration, and in research to quantify damage caused by pests and foliar diseases [10].

The measurement of leaf area can be done directly and indirectly [11]. In order to determine the leaf area directly, generally all the leaves of the plant are collected, characterizing the method as destructive and high labor, besides being considered expensive equipment, such as planimeters. However, the indirect and non-destructive methods allow successive evaluations in the same plant and rapidity in the evaluations [12], and are therefore more convenient and cheaper [13]. In the indirect methods, portable automatic planimeters are used, sometimes with the disadvantage that the larger leaves cannot be evaluated by limiting the reading area of the portable equipment [14], it is still used mathematical models, using leaf blade length and width [12], to which they generally involve the use of regression equations, as in *Coffea arabica* coffee trees [15,11,16], and *Coffea canephora* [17,15,18], however, in the literature there is no evidence of studies with *Coffea dewevrei*, therefore, it is important to obtain them, since it is known that temporal variation of leaf area in an agricultural crop depends on cultivar, edaphoclimatic conditions, and population density, among other factors [19].

In this work we aimed to select the equation that best fits the determination of the leaf area of the coffee tree *Coffea dewevrei*, rom the linear dimensions of the length, the maximum width and the product between them.

2. MATERIALS AND METHODS

The determination of the coffee leaf area (*Coffea dewevrei*) was made in leaves from adult plants, at the initial stage of grain formation. These leaves were collected in May 2019 at the headquarters of the Capixaba Institute for Research, Technical Assistance and Rural Extension, in the municipality of Linhares, in the north of the State of Espírito Santo, Brazil, located at the geographical coordinates 19°25' 03" south latitude and 40°04'50" west longitude.

The leaves were harvested from six year old plants. A total of 140 leaves of different growth sizes were collected, obeying the four cardinal points (north, south, east and west) distributed in the lower, middle and upper third of the plant.

The length (L, in cm), along the central midrib and greater width (W, in cm) of the leaf blade were measured from all leaves (Fig. 1), both measurements were made with ruler graduated in millimeters. The product of multiplication between length and width (LW, in cm^2) was also calculated. The observed leaf area (OLA, in cm^2) was obtained with the LI-COR® portable analyzer model LI-3000C (Fig. 2).

For the generation of the models that estimate the leaf area, a 100 leaf sample was used, where OLA was used as a dependent variable in function of L, W and LW as independent variable, and the following models were obtained: linear first degree ($\mathrm{ELA} = \hat{\beta}_0 + \hat{\beta}_1 x$), quadratic ($\mathrm{ELA} = \hat{\beta}_0 + \hat{\beta}_1 x + \hat{\beta}_2 x^2$) and power ($\mathrm{ELA} = \hat{\beta}_0 x^{\hat{\beta}_1}$) and its respective coefficient of determination (R^2), totaling nine equations for the estimation of the leaf area of *Coffea dewevrei*.

The validation of the models was based on a sample of 40 sheets specially designed for this purpose. For this, the values of L, W LW were substituted in the equations generated in the modeling, thus obtaining the estimated leaf area (ELA, in cm^2) for each equation. Subsequently, a simple linear equation model ($\mathrm{ELA} = \hat{\beta}_0 + \hat{\beta}_1 x$) was adjusted for each modeling equation relating ELA in function of OLA. The hypotheses H_0: $\beta_0 = 0$ versus H_a: $\beta_0 \neq 0$ and H_0: $\beta_1 = 1$ versus Ha: $\beta_1 \neq 1$, were tested using Student's t test at 5% probability. The mean absolute error (MAE), root mean square error (RMSE) and Willmott's index d [20] for all equations were also determined by equations 1, 2 and 3.

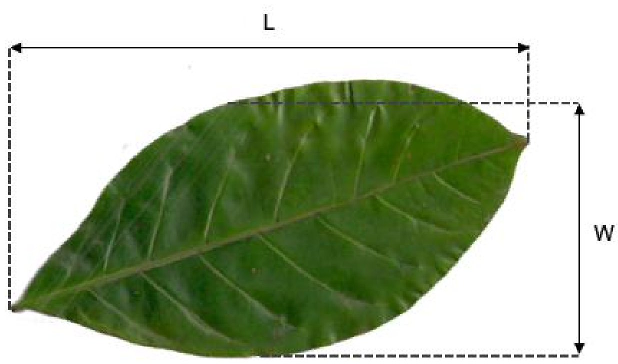

Fig. 1. Representation of the length (L) along the midrib and the maximum width (W) of leaves of *Coffea dewevrei*

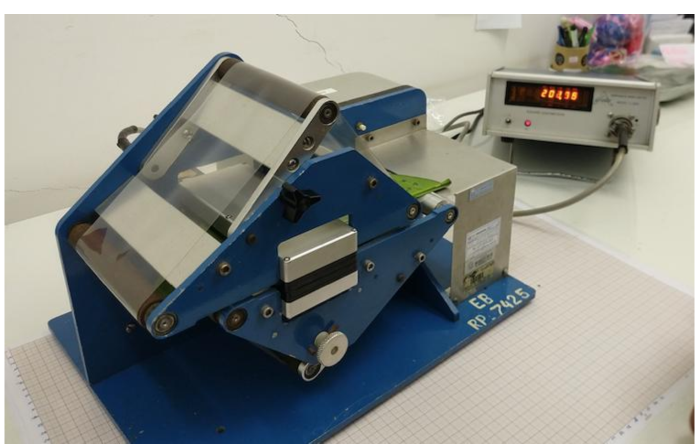

Fig. 2. Representation of the LI-COR® portable analyzer model LI-3000 C

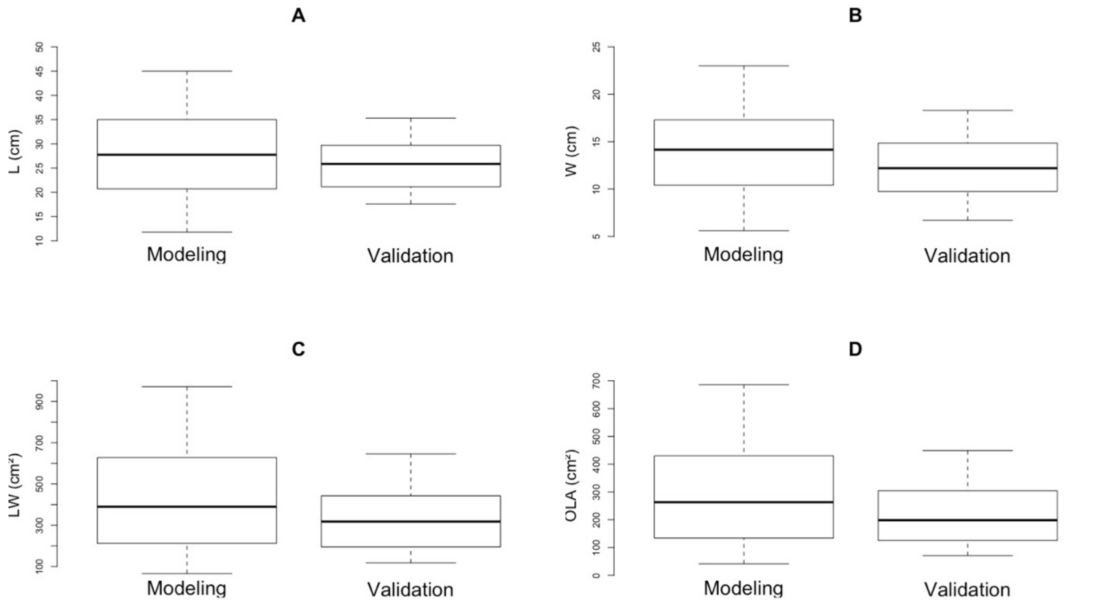

Fig. 3. Values of the measurements of the length (L) (A), width (W) (B), product of length with width (LW) (C) and observed leaf area (OLA) (D) of leaves used for modeling and validation

$$\mathrm{MAE} = \frac{1}{n-1}\sum_{i=1}^{n}|\mathrm{ELA} - \mathrm{OLA}| \quad (1)$$

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

$$d = 1 - \left[\frac{\sum_{i=1}^{n}(\mathrm{ELA}_i - \mathrm{OLA}_i)^2}{\sum_{i=1}^{n}(|\mathrm{ELA}_i - \overline{\mathrm{OLA}}| + |\mathrm{OLA}_i - \overline{\mathrm{OLA}}|)^2}\right] \quad (3)$$

Where, ELA represents the estimated leaf area; OLA the observed value of leaf area; $\overline{\mathrm{OLA}}$ is the average of the leaf area values observed; and n is the number of sheets sampled for validation (n = 40 in the present study).

The best model that estimates the area of *Coffea dewevrei* was chosen through the following criteria: linear coefficient (β_0) not different from zero, angular coefficient (β_1) not different from one, MAE and RMSE values closer to zero and index d closer to the unit. For the statistical analyzes, the software R [21] was used, with the aid of the data package ExpDes.pt version 1.2 [22].

3. RESULTS AND DISCUSSION

The values of the measurements of the length (L), width (W), product of length with width (LW) and observed leaf area (OLA) of the leaves used for modeling (100 leaves) and validation (40 leaves) are shown in Fig. 3. It was verified that for all the variables under study the values of the sample used in the validation were between the range of the values of the sheets sampled for the adjustment of the modeling, according to Levini et al. [23] is adequate since the values used in the validation should not extrapolate the values of the modeling since this practice can lead to erroneous estimation by the equations. The results also show a high amplitude in the values obtained for the modeling indicating the use of leaves of different sizes with the presence of leaves of different development stages, being a well representative sample, which allows the use of the equations throughout the crop cycle [24,25].

The adjusted equations for the estimation of the area of the leaves of *Coffea dewevrei*, as well as their respective coefficient of determination (R^2), are presented in Table 1. Note that, in general, there was a satisfactory adjustment between OLA and leaf surface measurements (L, W or LW), with R^2 exceeding 0.94 for all models, indicating that the characteristics have a good correlation with more than 94% of the area leaf being explained by the linear measurements of the leaf. However, the choice of the best fit should not only be based on the high values of R^2, since this practice can lead to imprecise estimates of the leaf area [15], and it is necessary to verify the models by suitable validation criteria [26].

The criteria used to validate the nine adjusted equations are shown in Table 2. The validation is important to confirm the accuracy of the equations allowing its use in estimation of field leaf area [27]. In this way, note that of the nine equations tested, only the linear first degree and quadratic models generated from the width (W) presented a linear coefficient $(\widehat{\beta}_0)$ statistically equal to zero and angular coefficient ($\widehat{\beta}_1$) statistically equal to one. This finding is very important because, according to Toebe et al. [28] indicates precision of these models in the estimated leaf area, once the observed leaf area is zero, the values estimated by the equation will also be zero and as 1 cm^2 of the observed leaf area increases, the equation will add 1 cm^2 in the estimated leaf area. However, considering these two equations, the quadratic model presented values of mean absolute error (MAE) and root mean square error (RQME) closest to zero, in addition to the value of the index d closest to the unit, which suggests a more predictive leaf area of *Coffea dewevrei* by this model.

Notoriously, several authors have reported in the literature models of mathematical equations that estimate the leaf area of several coffee varieties [15,18,29,16]. In specific cases, the model adjusted for a given variety can be used to estimate leaf area of other varieties [30]. However, for most species each variety presents a pattern of different leaf morphology requiring different equations [27], as observed by Espindula et al. [29] for the coffee tree.

For this reason, in this work we indicate the quadratic model equation represented by $\mathrm{ELA} = -10.255 + 1.020(\mathrm{W}) + 1.293(\mathrm{W})^2$ obtained from the largest width of the leaf surface, whose behavior can be seen in Fig. 4, for being the most accurate in the estimation of the leaf area of *Coffea dewevrei*. The use of these equations in practice, allows the measurement of leaf area for studies related to physiology, agronomic performance and evaluation of phytosanitary damages [27]. In addition, this is a non-destructive method where the leaf area can be measured by simply measuring the length of the leaf without the use of specific and expensive equipment, which can be obtained with the help of a ruler.

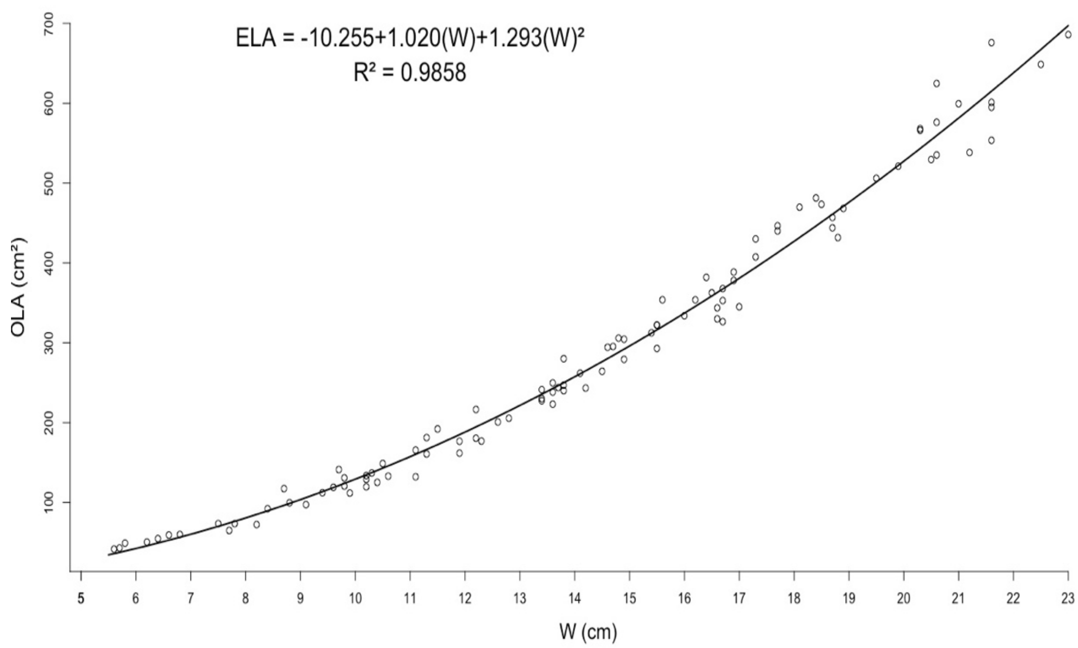

Fig. 4. Equation of quadratic model and determination coefficient (R^2), using the foliar area observed (OLA) as dependent variable, in function of the width (W) of leaves *Coffea dewevrei*

Table 1. Equation with linear adjustment of first degree, quadratic and power and its respective coefficient of determination (R^2) using the observed leaf area (OLA) as dependent variable, in function of length (L), width (W), product of length with width (LW) of leaves *Coffea dewevrei*

Model	Equation	R^2
Linear	$\mathrm{ELA} = -240.2285 + 19.1133(\mathrm{L})$	0.9438
Linear	$\mathrm{ELA} = -242.9450 + 37.6048(\mathrm{W})$	0.9607
Linear	$\mathrm{ELA} = -7.9437 + 0.6904\ (\mathrm{LW})$	0.9923
Quadratic	$\mathrm{ELA} = 6.6028 - 0.8532(\mathrm{L}) + 0.3629(\mathrm{L})^2$	0.9700
Quadratic	$\mathrm{ELA} = -10.255 + 1.020(\mathrm{W}) + 1.293(\mathrm{W})^2$	0.9858
Quadratic	$\mathrm{ELA} = -1.84249928 + 0.65569642(\mathrm{LW}) + 0.00003585(\mathrm{LW})^2$	0.9925
Power	$\mathrm{ELA} = 0.3030(\mathrm{L})^{2.0356}$	0.9700
Power	$\mathrm{ELA} = 1.2518(\mathrm{W})^{2.0174}$	0.9856
Power	$\mathrm{ELA} = 0.5409(\mathrm{LW})^{1.034\ 7}$	0.9925

Table 2. Linear coefficient ($\widehat{\beta}_0$), angular coefficient ($\widehat{\beta}_1$) and determination coefficient (R2), obtained from equations with first line linear adjustment between Observed Leaf Area (OLA) and Estimated Leaf Area (ELA) by length (L), width (W) and length product with the width (LW) of leaves *Coffea dewevrei* used for validation, besides the Mean Absolute Error (MAE), Root Mean Square Error (RMSE) and Willmott d Index

Model	Variable	$\beta_0^{(1)}$	$\beta_1^{(2)}$	R^2	MAE	RMSE	d
Linear	L	77.22202*	0.81777*	0.7993	49.9785	61.8682	0.9138
Linear	W	5.42754ns	0.98986ns	0.7804	47.6024	58.1432	0.9339
Linear	LW	31.71138*	0.85933*	0.8159	39.6977	47.3674	0.9487
Quadratic	L	64.95468*	0.79508*	0.8088	40.1321	52.0069	0.9350
Quadratic	W	20.80696ns	0.90213ns	0.8071	42.4635	49.5631	0.9465
Quadratic	LW	33.37097*	0.84877*	0.8160	39.5509	47.2243	0.9484
Power	L	65.19517*	0.79474*	0.8088	40.1915	52.0804	0.9348
Power	W	12.76778ns	0.87648*	0.8050	45.0336	51.3635	0.9348
Power	LW	32.1960*	0.85341*	0.8163	39.5838	47.2339	0.9487

(1) ns Value of β_0 does not differ from zero by Student's t-test, at a level of 5%
*(1) * Value of β_0 differs from zero by Student's t-test, at a level of 5%*
(2) ns Value of β_1 does not differ from one, by Student's t-test, at a level of 5%
*(2) * Value of β_1 differs from one, by Student's t-test, at a level of 5%*

4. CONCLUSION

The area of the leaves of *Coffea dewevrei* can be determined by its greater width (W), through the equation of quadratic model represented by $\mathrm{ELA} = -10.255 + 1.020\ (\mathrm{W}) + 1.293(\mathrm{W})^2$, precise and non-destructive way.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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