LEAF AREA OF *Erythrina velutina* Willd. (FABACEAE) BY USING ALLOMETRIC EQUATIONS

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Resumo

Area foliar de Erythrina velutina Willd. (Fabaceae) a partir de equações alométricas. A estimativa da área foliar é de fundamental importância para avaliar o crescimento, desenvolvimento e propagação das plantas. Este trabalho teve como objetivo ajustar e identificar modelos de regressão para estimar a área foliar de *Erythrina velutina* a partir das dimensões lineares do folíolo central das folhas. Duzentas folhas simples foram coletadas de árvores matrizes de *E. velutina* em fragmentos florestais no município de Mossoró, estado do Rio Grande do Norte, Nordeste do Brasil. A equação para estimativa da área foliar de *E. velutina* foi ajustada a partir de modelos de regressão linear, linear sem intercepto (0,0), quadrático, cúbico, potência e exponencial. As melhores equações foram aquelas com maior coeficiente de determinação (R²), coeficiente de correlação de Pearson (r), índice de Willmott (*d*) e índice CS (CS), e com o menor critério de informação de Akaike (AIC) erro absoluto médio (MAE) e erro quadrático médio (RMSE), e índice BIAS mais próximo de zero (BIAS). As equações ajustadas pelo produto comprimento pela largura (LW) apresentaram os melhores critérios para estimar a área foliar, portanto, se ajustam melhor aos modelos de regressão utilizados. Portanto, a equação ŷ = 1,4755*LW ajustada usando o modelo linear sem intercepto é a mais adequada para estimar a área foliar de *E. velutina* (R² = 0,9906; r = 0,9860; *d* = 0,9929; CS = 0,9790; AIC = 1402,7; MAE = 5,34; RMSE = 7,90; BIAS = 0,019).

Palavras-chave: biometria, Fabaceae, mulungu, método não destrutivo, modelos de regressão.

Abstract

Leaf area estimation is of fundamental importance to evaluate growth, development, and propagation of plants. This work aimed to adjust and identify regression models to estimate leaf area of *Erythrina velutina* from linear dimensions of the central leaflet of leaves. Two hundred simple leaves were collected from *E. velutina* mother plants in forest fragments in the municipality of Mossoró, Rio Grande do Norte state, Northeast Brazil. The equation for estimating leaf area of *E. velutina* was adjusted from linear, linear without intercept (0.0), quadratic, cubic, power, and exponential regression models. The best equations were those with the highest determination coefficient (R²), Pearson's correlation coefficient (r), Willmott's index (*d*) and CS index (CS), and with the lowest Akaike information criterion (AIC), mean absolute error (MAE), root mean square error (RMSE), and BIAS index closest to zero (BIAS). The equations fitted using the product of length by width (LW) showed the best criteria for estimating leaf area, thus best fitting the regression models used. Therefore, the equation ŷ = 1.4755*LW adjusted using the linear model without intercept is the most suitable for estimating leaf area of *E. velutina* (R² = 0.9906; r = 0.9860; *d* = 0.9929; CS = 0.9790; AIC = 1402.7; MAE = 5.34; RMSE = 7.90; BIAS = 0.019).

Keywords: biometrics, Fabaceae, mulungu, non-destructive method, regression models.

INTRODUCTION

Erythrina velutina Willd. is a xerophilous species native to Caatinga, occurring in the semiarid region of Brazil (ALVES JUNIOR *et al.*, 2016). The species belongs to the Fabaceae family, grows to 12 and 15 m in height, and it is characterized as an arboreal and deciduous plant occurring in forest fragments of Caatinga and Cerrado. Popularly known as 'mulungu', 'mulungu-velutina', 'canivete', 'corticeira' and 'suinã', the species is of economic importance in the production of wood artifacts, such as toys, rafts and crates, for medicinal and ornamental purposes, and widely used in agroforestry systems (MACÊDO *et al*., 2018).

Given the importance of this species, it is important to study the growth, propagation, morphology, and ecophysiology of the plant. Among these studies, the determination of leaf area is of fundamental importance to understand the plant responses to environmental factors, since the leaf is directly related to photosynthesis, irradiance interception, gas exchange, and biomass accumulation processes (HERNANDEZ-SANTANA *et al*., 2017).

Several methods have been used to determine leaf area, which are classified as direct and indirect, or destructive and non-destructive (MARSHALL, 1968). By direct methods (destructive and non-destructive), measurements are directly performed on the leaf surface, to determine leaf area in a simple and practical way. This method includes the use of millimetric paper, planimetric and gravimetric techniques, in addition to digital photographs and high-cost equipment, in which it is necessary to remove the leaves and other plant structures, making it impossible use for endangered species, and plants in early stages of development (ZHANG, 2020).

In turn, indirect (non-destructive) methods allow successive evaluations on plants throughout their growing period, in addition to providing fast and accurate measurements (ZHANG, 2020). The most used indirect methods are the automated infrared image system, interception of solar radiation, and leaf area estimation by linear dimensions of leaves (SAUCEDA-ACOSTA *et al*., 2017).

Estimating leaf area by linear dimensions of leaves using regression models is a simple and precise method, which facilitates using the method in any vegetative phase of the plant and under adverse environmental conditions (CARVALHO *et al*., 2017). This method was used in several forest species, such as *Hymenaea courbaril* L. (SANTOS *et al*., 2016), *Tabebuia roseoalba* (Ridl.) Sand. (MONTEIRO *et al*., 2017), *Bertholletia excelsa* Bonpl. (BOUVIÉ *et al*., 2020), and *Palicourea racemosa* (Aubl.) Borhidi (RIBEIRO *et al*., 2020a). Thus, the objective of this work was to adjust and identify regression models to estimate the leaf area of *E. velutina* plants through linear dimensions of the central leaflet of the leaf.

MATERIAL AND METHODS

The study was carried out on forest fragments of Caatinga, in the municipality of Mossoró, located in Mossoró microregion, Oeste Potiguar mesoregion, state of Rio Grande do Norte, Northeast Brazil (5°11'S and 37°20'W) (Figure 1). The average temperature in the region is 28ºC, rainfall from around 695 mm, and the altitude is 18 m. The climate of the region is dry and very hot, with a dry and rainy season, and classified as BSh according to the Köppen classification (ALVARES *et al*., 2013).

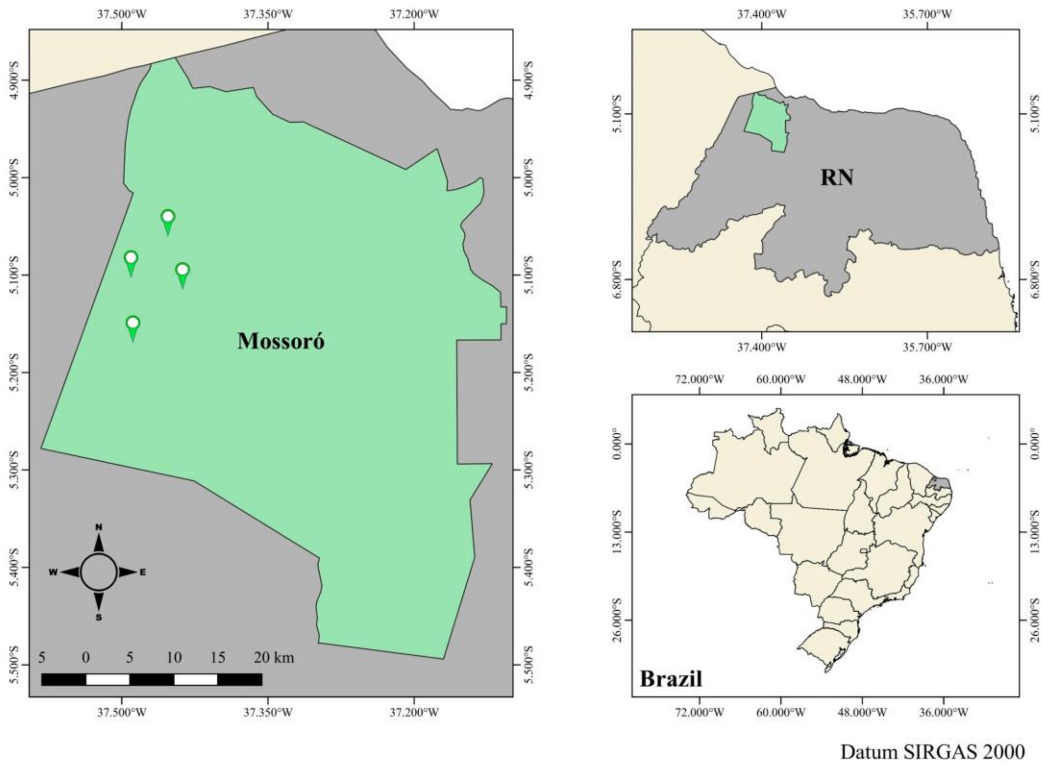

Figure 1. Geographic location of the municipality of Mossoró, Rio Grande do Norte, Northeast Brazil.
Figura 1. Localização geográfica do município de Mossoró, Rio Grande do Norte, Nordeste do Brasil.

For performing measurements, 200 leaves of different shapes and sizes were collected from 20 mother plants of *E. velutina* (herbarium EAN, Federal University of Paraiba, Campus II-CCA, voucher number 17654), and then packed them in thermal containers to avoid dehydration. Only fully expanded leaves without deformation caused by pests, diseases and other factors were selected.

On each of the 200 leaves, the maximum length (L) and width (W) of the central leaflet limb (Figure 2) were measured using a millimetric ruler. Length was measured as the distance from the petiole insertion until the opposite distance of the leaf; and width as the largest measure perpendicular to the central leaf vein. Then, the product of length by width (LW), length by length (LL), and width by width (WW) were calculated. Thus, leaf area (LA) of the 200 leaves was determined by digital photocopies obtained using a scanner (L395 Epson), and the images were processed individually in ImageJ® v.1.51j8 software (Powerful Image Analysis).

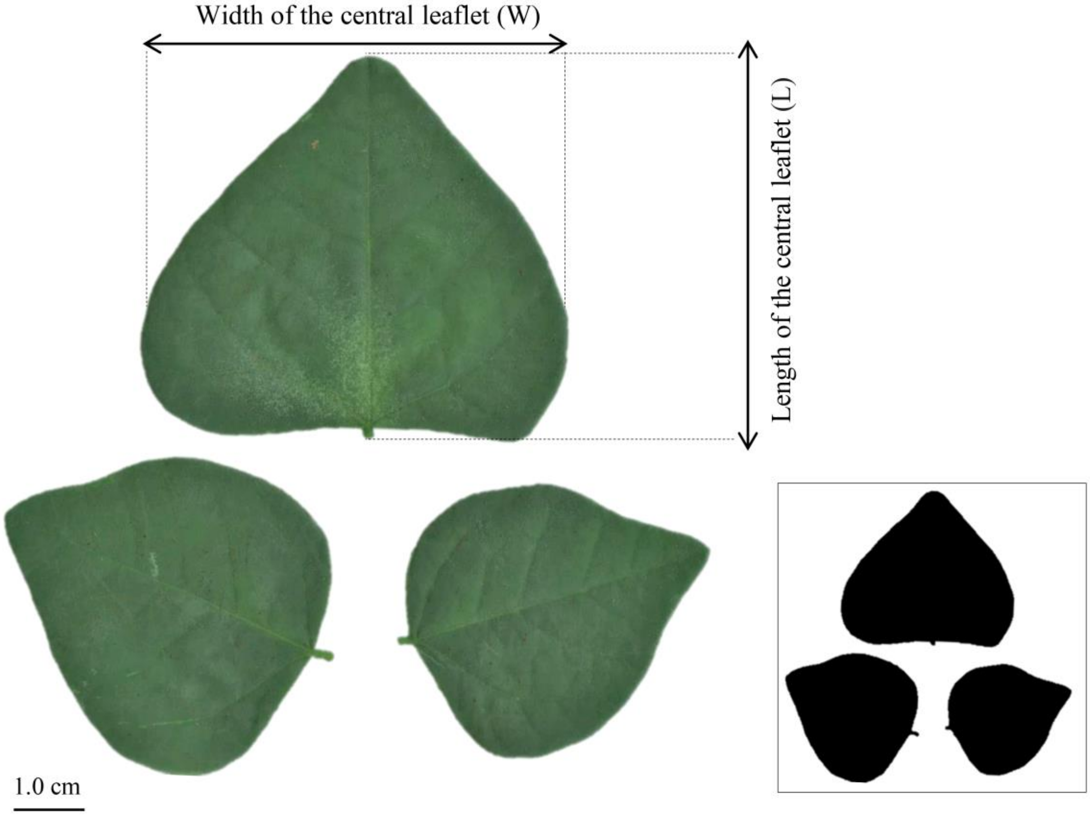

Figure 2. Linear dimensions [maximum length (L) and maximum width (W)] of the central leaflet of *Erythrina velutina* used to estimate leaf area of complete leaves.

Figura 2. Dimensões lineares [comprimento máximo (L) e largura máxima (W)] do folíolo central de *Erythrina velutina* utilizadas para estimar a área foliar de folhas completas.

From L, W, LW, LL, WW and LA of the 200 leaves, we calculated the minimum and maximum values, mean, amplitude, median, standard deviation, standard error, coefficient of variation, asymmetry, kurtosis and normality by the Shapiro-Wilk test (SHAPIRO; WILK, 1965). Also, histograms of frequency and dispersion graphs were plotted with the L, W, LW, LL, WW and LA values.

The equation for estimating the leaf area of *E. velutina* was adjusted using the following regression models: linear, linear without intercept (0.0), quadratic, cubic, power and exponential (Table 1). In these equations, $\hat{y}$ estimated leaf area (LA) as a function of x, whose values were represented by the linear dimensions of leaves (L, W, LW, LL and WW).

Table 1. Models and equations used to estimate leaf area of *Erythrina velutina* from the linear dimensions of 200 leaves.

Tabela 1. Modelos e equações usados para estimar a área foliar de *Erythrina velutina* a partir das dimensões lineares de 200 folhas.

Model	Equation
Linear	$\hat{y} = \beta_0 + \beta_1 * L + \varepsilon_i$
Linear	$\hat{y} = \beta_0 + \beta_1 * W + \varepsilon_i$
Linear	$\hat{y} = \beta_0 + \beta_1 * LW + \varepsilon_i$
Linear without intercept (0.0)	$\hat{y} = \beta_1 * LW + \varepsilon_i$
Linear	$\hat{y} = \beta_0 + \beta_1 * LL + \varepsilon_i$
Linear	$\hat{y} = \beta_0 + \beta_1 * WW + \varepsilon_i$

Quadratic	$\hat{y} = \beta_0 + \beta_1 * L + \beta_2 * L^2 + \varepsilon_i$
Quadratic	$\hat{y} = \beta_0 + \beta_1 * W + \beta_2 * W^2 + \varepsilon_i$
Quadratic	$\hat{y} = \beta_0 + \beta_1 * LW + \beta_2 * LW^2 + \varepsilon_i$
Quadratic	$\hat{y} = \beta_0 + \beta_1 * LL + \beta_2 * LL^2 + \varepsilon_i$
Quadratic	$\hat{y} = \beta_0 + \beta_1 * WW + \beta_2 * WW^2 + \varepsilon_i$
Cubic	$\hat{y} = \beta_0 + \beta_1 * L + \beta_2 * L^2 + \beta_3 * L^3 + \varepsilon_i$
Cubic	$\hat{y} = \beta_0 + \beta_1 * W + \beta_2 * W^2 + \beta_3 * W^3 + \varepsilon_i$
Cubic	$\hat{y} = \beta_0 + \beta_1 * LW + \beta_2 * LW^2 + \beta_3 * LW^3 + \varepsilon_i$
Cubic	$\hat{y} = \beta_0 + \beta_1 * LL + \beta_2 * LL^2 + \beta_3 * LL^3 + \varepsilon_i$
Cubic	$\hat{y} = \beta_0 + \beta_1 * WW + \beta_2 * WW^2 + \beta_3 * WW^3 + \varepsilon_i$
Power	$\hat{y} = \beta_0 * L^{\beta_1} + \varepsilon_i$
Power	$\hat{y} = \beta_0 * W^{\beta_1} + \varepsilon_i$
Power	$\hat{y} = \beta_0 * LW^{\beta_1} + \varepsilon_i$
Power	$\hat{y} = \beta_0 * LL^{\beta_1} + \varepsilon_i$
Power	$\hat{y} = \beta_0 * WW^{\beta_1} + \varepsilon_i$
Exponential	$\hat{y} = \beta_0 * {\beta_1}^{L} + \varepsilon_i$
Exponential	$\hat{y} = \beta_0 * {\beta_1}^{W} + \varepsilon_i$
Exponential	$\hat{y} = \beta_0 * {\beta_1}^{LW} + \varepsilon_i$
Exponential	$\hat{y} = \beta_0 * {\beta_1}^{LL} + \varepsilon_i$
Exponential	$\hat{y} = \beta_0 * {\beta_1}^{WW} + \varepsilon_i$

The equation that meaningfully estimated the leaf area of *E. velutina* from linear dimensions of leaves was selected by checking the determination coefficient (R²), Pearson's correlation coefficient (r), Willmott's index (d) (Eq. 1), CS index closest to one (Eq. 2), the lowest Akaike information criterion (AIC) (Eq. 3), mean absolute error (MAE) (Eq. 4), root mean square error (RMSE) (Eq. 5), and BIAS index closest to zero (Eq. 6). Data analyses were performed in R® v.4.0.2 software.

$$d = 1 - \frac{\sum_{i=1}^{n} (\hat{y}_i - y_i)^2}{\sum_{i=1}^{n} (|\hat{y}'_i| + |y'_i|)^2} \qquad (1)$$

$$CS = r \times d \qquad (2)$$

$$AIC = -2 ln\, L(x\backslash\hat{\theta}) + 2(p) \qquad (3)$$

$$MAE = \frac{\sum_{i=1}^{n} |\hat{y}i - yi|}{n} \qquad (4)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (\hat{y}i - yi)^2}{n}} \qquad (5)$$

$$BIAS = \frac{\sum_{i=1}^{n} (\hat{y}i - yi)}{\sum_{i=1}^{n} (yi)} \qquad (6)$$

where: $\hat{y}_i$ are the estimated values of the leaf area; y_i are the observed values of the leaf area; $\bar{y}_i$ is the mean of the observed values; $\hat{y}'_i = \hat{y}_i - \bar{y}$; $y'_i = y_i - \bar{y}$; $L(x\backslash\hat{\theta})$ is the maximum likelihood function, defined as the product of the density function; p is the number of model parameters; n is the number of observations.

RESULTS

The length (L) of the central leaflet of *E. velutina* varied from 1.269 to 13.109 cm, with 6.074 cm on average and 11.84 cm amplitude, while width (W) varied from 1.036 to 14.892 cm, with 6.681 cm on average and 13.856 cm amplitude. In turn, the product of length by width (LW) ranged from 1.315 to 195.219 cm², with 46.173 cm² on average and 193.904 cm² amplitude; product of length by length (LL) ranged from 1.610 to 171.846 cm², with 41.737 cm² on average and 170.236 cm² amplitude; and product of width by width (WW) ranged from 1.073 to 221.772 cm², with 51.560 cm² on average and 220.699 cm² amplitude (Table 2). Real leaf area (LA) of complete leaves ranged between 1.803 and 282.000 cm², 68.798 cm² mean and 280,197 cm² amplitude (Table 2). Also, the lowest coefficients of variation were observed for length (36.30%) and width (39.46%), whereas the highest coefficients were those from product of length by width (70.21%), product of length by length (68.42%), product of width by width (73.23%), and real leaf area (69.13%) (Table 2).

The coefficient of kurtosis (*k*) of L, W, LW, LL, WW and LA indicated that these variables had a platykurtic distribution because the value was less than 3 ($k < 3$), expected for a normal distribution (Table 2). Also, according to the Shapiro-Wilk test, LW, LL, WW and LA were not normally distributed ($p<0.05$) (Table 2).

Table 2. Minimum, maximum, mean, amplitude, median, standard deviation, standard error, coefficient of variation (CV), asymmetry, kurtosis and Shapiro-Wilk test for length (L), width (W), product of length by width (LW), product of length by length (LL), product of width by width (WW), and real leaf area (LA) of 200 leaves of *Erythrina velutina*.

Tabela 2. Mínimo, máximo, média, amplitude, mediana, desvio padrão, erro padrão, coeficiente de variação (CV), assimetria, curtose e teste de Shapiro-Wilk para comprimento (L), largura (W), produto comprimento por largura (LW), produto do comprimento por comprimento (LL), produto da largura por largura (WW), e área foliar real (LA) de 200 folhas de *Erythrina velutina*.

Descriptive statistics	**L**	**W**	**LW**	**LL**	**WW**	**LA**
Minimum	1.269	1.036	1.315	1.610	1.073	1.803
Maximum	13.109	14.892	195.219	171.846	221.772	282.000
Mean	6.074	6.681	46.173	41.737	51.560	68.798
Amplitude	11.84	13.856	193.904	170.236	220.699	280.197
Median	6.176	6.719	41.665	38.143	45.146	62.192
Standard Deviation	2.205	2.636	32.419	28.556	37.758	47.562
Standard Error	0.156	0.186	2.292	2.019	2.669	3.363
CV (%)	36.30	39.46	70.21	68.42	73.23	69.13
Assimmetry [a]	0.182	0.187	1.32	1.339	1.306	1.187
Kurtosis + 3 [b]	3.189	2.965	5.694	5.780	5.416	5.196
Shapiro-Wilk	0.106^{ns}	0.245^{ns}	$< 0.001^{**}$	$< 0.001^{**}$	$< 0.001^{**}$	$< 0.001^{**}$

[a] Asymmetry differs from zero by the t-test at 5% probability;
[b] Kurtosis differs from three by the t-test at 5% probability;
** Significant at 1% probability;
^{ns} Non-significative.

Scatterplots between length (L), width (W), product of length by width (LW), product of length by length (LL), product of width by width (WW), and real leaf area (LA) indicate different relationships between them, suggesting adjustments of linear and non-linear models (Figure 3).

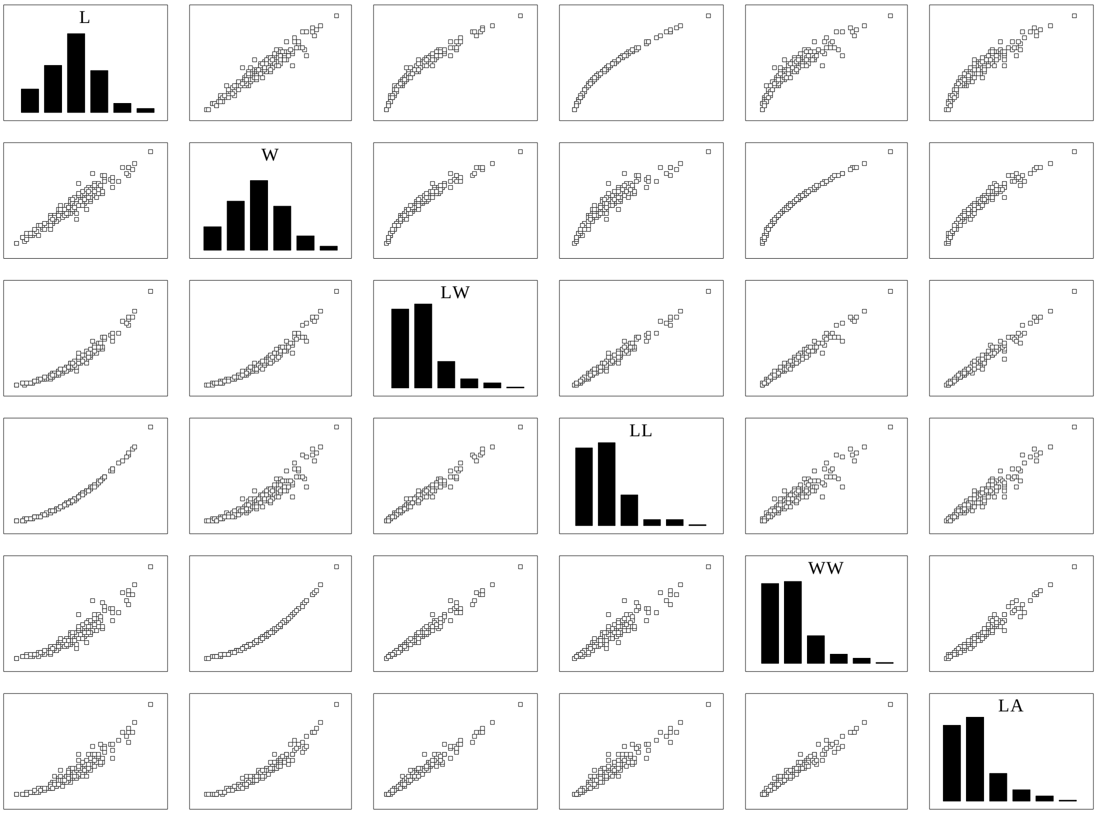

Figure 3. Scatterplots and histograms between length (L), width (W), product of length by width (LW), product of length by length (LL), product of width by width (WW), and real leaf area (LA).

Figura 3. Gráficos de dispersão e histogramas entre comprimento (L), largura (W), produto comprimento por largura (LW), produto comprimento por comprimento (LL), produto largura por largura (WW) e área foliar real (LA).

The regression models and equations obtained from the relationship between real leaf area (ŷ) and linear dimensions of the central leaflets (L, W, LW, LL and WW) are presented in Table 3. Following the criteria for selecting the equation that meaningfully estimated the leaf area of *E. velutina* from linear dimensions of leaves, it was found that the linear model without intercept adjusted with the product of length by width (LW) showed the highest determination coefficient (R^2) (0.9906), Pearson's correlation coefficient (r) (0.9860), Willmott's index (*d*) (0.9929) and CS (CS) index (0.9790), and the lowest Akaike information criterion (AIC) (1402.7), mean absolute error (MAE) (5.34), root mean square error (RMSE) (7.90), and BIAS index (BIAS) (0.019) (Table 3). Therefore, the equation ŷ = 1.4755*LW is the most suitable for estimating leaf area of *E. velutina.*

Table 3. Regression models, equations, determination coefficient (R^2), Pearson's correlation coefficient (r), Willmott index (*d*), CS index (CS), Akaike information criterion (AIC), mean absolute error (MAE), root mean square error (RMSE), and BIAS index (BIAS) calculated from 200 leaves of *Erythrina velutina*.

Tabela 3. Modelos de regressão, equações, coeficiente de determinação (R^2), coeficiente de correlação de Pearson (r), índice de Willmott (*d*), índice de CS (CS), critério de informação de Akaike (AIC), erro absoluto médio (MAE), raiz quadrada média erro (RMSE) e índice BIAS (BIAS) calculado a partir de 200 folhas de *Erythrina velutina*.

Model	**Equation**	**R^2**	**r**	***d***	**CS**	**AIC**	**MAE**	**RMSE**	**BIAS**
Linear	ŷ = - 54.70 + 20.33*L	0.8884	0.9426	0.9697	0.9140	1678.8	12.21	15.84	0.073
Linear	ŷ = - 47.14 + 17.35*W	0.9253	0.9619	0.9802	0.9429	1598.5	9.65	12.96	0.054
Linear	ŷ = 2.036 + 1.446 *LW	0.9713	0.9855	0.9927	0.9783	1407.2	5.54	8.03	0.035
Linear (0.0)	ŷ = 1.4755*LW	0.9906	0.9860	0.9929	0.9790	1402.7	5.34	7.90	0.019
Linear	ŷ = 1.768 + 1.606*LL	0.9297	0.9642	0.9815	0.9464	1586.3	9.16	12.57	0.052

Linear	$\hat{y} = 4.830 + 1.241*WW$	0.9700	0.9849	0.9923	0.9774	1415.8	5.55	8.21	0.033
Quadratic	$\hat{y} = - 6.873 + 2.928*L + 1.387*L^2$	0.9309	0.9648	0.9818	0.9473	1585.1	9.08	12.47	0.040
Quadratic	$\hat{y} = - 3.396 + 2.572*W + 1.067*W^2$	0.9713	0.9856	0.9927	0.9784	1408.9	5.37	8.03	0.035
Quadratic	$\hat{y} = - 0.0110 + 1.5365*LW - 0.0006728*LW^2$	0.9720	0.9859	0.9928	0.9788	1404.7	5.35	7.94	0.029
Quadratic	$\hat{y} = - 0.7109 + 1.7257*LL - 0.000987*LL^2$	0.9306	0.9647	0.9817	0.9470	1585.9	9.03	12.50	0.039
Quadratic	$\hat{y} = 2.8401 + 1.3211*WW - 0.000529*WW^2$	0.9707	0.9852	0.9925	0.9779	1413.3	5.44	8.12	0.037
Cubic	$\hat{y} = - 6.8042 + 2.8859*L + 1.394*L^2 - 0.00035*L^3$	0.9309	0.9648	0.9818	0.9473	1587.1	9.08	12.47	0.039
Cubic	$\hat{y} = - 7.1835 + 4.721*W + 0.732*W^2 + 0.01511*W^3$	0.9715	0.9856	0.9927	0.9784	1410.1	5.41	8.01	0.039
Cubic	$\hat{y} = - 1.533 + 1.65*LW - 0.002*LW^2 + 0.000008*LW^3$	0.9722	0.9859	0.9927	0.9786	1406.5	5.41	8.03	0.035
Cubic	$\hat{y} = - 3.75 + 1.983*LL - 0.0058*LL^2 + 0.000022*LL^3$	0.9315	0.9652	0.9820	0.9478	1585.2	9.03	12.41	0.040
Cubic	$\hat{y} = - 0.19 + 1.53*WW - 0.003*WW^2 + 0.00001*WW^3$	0.9719	0.9859	0.9928	0.9788	1404.7	5.35	7.94	-0.022
Power	$\hat{y} = 1.923 * L^{1.924}$	0.9306	0.9647	0.9816	0.9469	1584.1	9.15	12.50	-0.246
Power	$\hat{y} = 1.825 * W^{1.850}$	0.9712	0.9855	0.9927	0.9783	1407.7	5.54	8.04	-0.022
Power	$\hat{y} = 1.743 * LW^{0.9618}$	0.9720	0.9855	0.9928	0.9785	1407.2	5.43	7.94	-0.153
Power	$\hat{y} = 1.922 * LL^{0.9619}$	0.9306	0.9647	0.9816	0.9469	1584.1	9.15	12.50	-0.246
Power	$\hat{y} = 1.824 * WW^{0.9252}$	0.9712	0.9855	0.9927	0.9783	1407.7	5.39	8.04	-0.030
Exponential	$\hat{y} = 14.538 * 1.267^{L}$	0.8968	0.9470	0.9689	0.9175	1672.5	12.41	15.60	-1.707
Exponential	$\hat{y} = 15.329 * 1.228^{W}$	0.9408	0.9699	0.9823	0.9528	1567.2	9.48	11.98	-1.693
Exponential	$\hat{y} = 37.886 * 1.011^{LW}$	0.8331	0.8968	0.9015	0.8085	1708.5	13.47	16.54	-1.902
Exponential	$\hat{y} = 22.848 * 1.011^{LL}$	0.8018	0.8639	0.8966	0.7746	1782.1	15.49	18.90	-1.982
Exponential	$\hat{y} = 27.815 * 1.012^{WW}$	0.8396	0.9049	0.9012	0.8155	1768.4	12.68	14.82	-1.891

Regarding the proposed equation to estimate the leaf area of *E. velutina*, data showed low dispersion from the regression line in the scatterplot, showing that variances were homogeneous and residues were normally distributed (Figure 4). Also, the estimated leaf area using the proposed equation positively correlated with the real leaf area, with a determination coefficient (R^2) of 0.9713, indicating a significant relationship between them (Figure 5). Thus, the equation $\hat{y} = 1.4755*LW$ can meaningfully estimate the leaf area of *E. velutina* using the product of length by width (LW) in a precise and fast way.

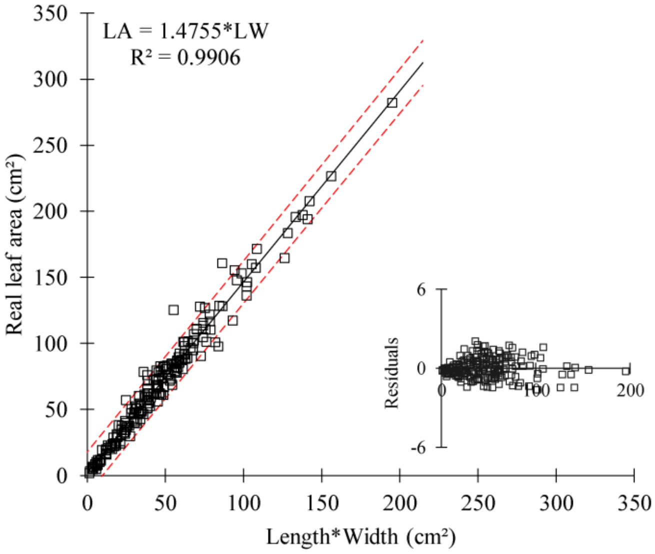

Figure 4. Relationship between the real leaf area (LA) and the product of length (L) by width (W) of leaves of *Erythrina velutina* using the equation $\hat{y} = 1.4755*LW$. The residual dispersion for this model is shown in the inserted chart.

Figura 4. Relação entre a área foliar real (LA) e o produto do comprimento (L) pela largura (W) das folhas de *Erythrina velutina* usando a equação $\hat{y} = 1{,}4755 * LW$. A dispersão residual para o modelo é mostrada no gráfico inserido.

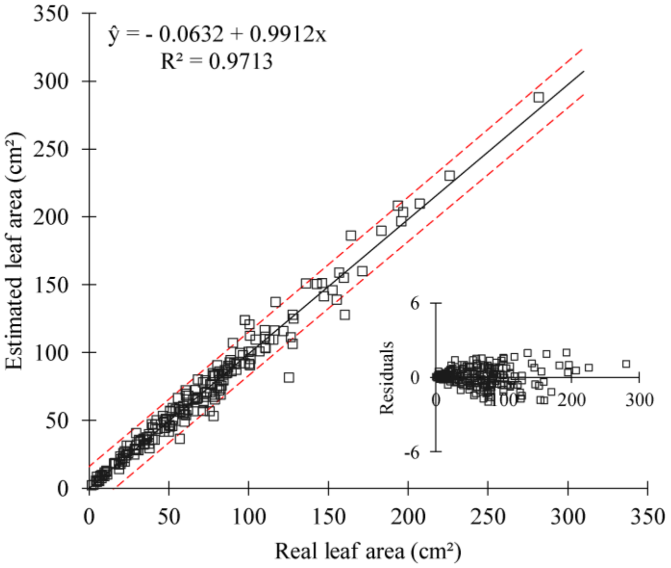

Figure 5. Relationship between the real leaf area and leaf area estimated by the equation ŷ = 1.4755*LW. The residual dispersion is shown in the inserted chart.

Figura 5. Relação entre a área foliar real e a área foliar estimada pela equação ŷ = 1,4755*LW. A dispersão residual é mostrada no gráfico inserido.

DISCUSSION

High values of amplitude, standard deviation, standard error, and coefficient of variation indicate wide data variability, which is of great importance for studies aimed at estimating leaf area from regression models (CARGNELUTTI FILHO *et al*., 2018). Such high variability in data indicates the reliability of the regression models, indicating that the equations can predict leaf area from large, medium, and small leaves, and in plants on different phenological stages (PEZZINI *et al*., 2018). Therefore, the number of leaves (200 leaves) used in this study was adequate to estimate the leaf area of *E. velutina* through linear dimensions of the central leaflet. Other studies also reported high variation in product of length by width, product of length by length, product of width by width, and real leaf area (RIBEIRO *et al*., 2020b).

Deviations observed in the coefficients of asymmetry and kurtosis of LW, LL, WW and LA indicate these variables were distant from a normal distribution, as compared to L and W. This behavior, as well as the adjustments to linear and non-linear models, were also observed in previous studies with other plant species (SILVA *et al.*, 2017; RIBEIRO *et al.*, 2019a).

As compared to the equations fitted using length or width, those equations adjusted using the product of length by width (LW) showed the best assumptions for estimating leaf area, thus best fitting the regression models (RIBEIRO *et al.*, 2019b). Except for the equation adjusted using the exponential model, which showed the best indexes when using leaflet width (W) (RIBEIRO *et al*., 2020b).

The linear model without intercept was also recommended to estimate leaf area of other forest species, such as *Crotalaria juncea* L. (LA = 0.7390LW; CARVALHO *et al*., 2017), *Tectona grandis* L. f. (LA = 0.4449*LW; BRAGA *et al*., 2018), *Erythroxylum simonis* Plowman (LA = 0.6426*LW; RIBEIRO *et al*., 2018), *Erythroxylum pauferrense* Plowman (LA = 0.6740*LW; RIBEIRO *et al*., 2020b), and *Ceiba glaziovii* (Kuntze) K. Schum. (LA = 0.4549*LW; RIBEIRO *et al*., 2020c).

The equation obtained in this study will contribute to future studies on the growth, development, propagation, and reproduction of *E. velutina*, thus being of fundamental importance for the preservation and conversation of the species in forest fragments of Caatinga and Cerrado.

CONCLUSIONS

- Leaf area of *E. velutina* can be accurately estimated through a non-destructive method using linear dimensions of leaves.
- The equation adjusted using the product of length by width (LW) can meaningfully estimate the leaf area of *E. velutina*.

- The equation ŷ = 1.4755*LW adjusted using the linear model without intercept is the most suitable to estimate quickly and accurately the leaf area of *E. velutina*.
- The proposed equation is of great importance for future studies, thus aiding in the preservation and conservation of the species in forest fragments of Caatinga and Cerrado.

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REFERENCES

ALVARES, C. A.; STAPE, J. L.; SENTELHAS, P. C.; GONÇALVES, J. L. M.; SPAROVEK, G. Köppen's climate classification map for Brazil. **Meteorologische Zeitschrift**, Stuttgart, v. 22, n. 6, p. 711 - 728, 2013.

ALVES JUNIOR, C.; VITORIANO, J. O.; SILVA, D. L. S.; FARIAS, M. L.; DANTAS, N. B. L. Water uptake mechanism and germination of *Erythrina velutina* seeds treated with atmospheric plasma. **Scientific Reports**, London, v. 6, p. 1 - 7, 2016.

BOUVIÉ, L.; SILVA, A. C.; BORELLA, D. R.; SILVA, C. C.; PIZZATTO, M. Área do limbo foliar da castanheira-do-Brasil por medidas lineares. **Nativa**, Sinop, v. 8, n. 3, p. 381 - 389, 2020.

BRAGA, N. S.; ARAÚJO, A. C. A.; ARAÚJO, I. D. A.; SOUZA, A. A. S.; CUNHA, D. S.; GIL, V. J. G.; ROCHA, I. S.; ALMEIDA, J. V. S.; SILVA, J. T. L. Modelos matemáticos para estimativa de área foliar de teca (*Tectonas grandis* L. f.). **Nucleus**, Ituverava, v. 15, n. 2, p. 331 - 339, 2018.

CARGNELUTTI FILHO, A.; TOEBE, M.; BURIN, C.; NEU, I. M. M.; ALVES, B. M. Número de folhas para modelar a área foliar de mucuna cinza por dimensões foliares. **Revista de Ciências Agroveterinárias**, Lages, v. 17, n. 4, p. 571 - 578, 2018.

CARVALHO, J. O.; TOEBE, M.; TARTAGLIA, F. L.; BANDEIRA, C. T.; TAMBARA, A. L. Leaf area estimation from linear measurements in different ages of *Crotalaria juncea* plants. **Anais da Academia Brasileira de Ciências**, Rio de Janeiro, v. 89, n. 3, p. 1851 - 1868, 2017.

FASCELLA, G.; CRISTOFORI, V.; RIVERA, C. M.; ROUPHAEL, Y. A simple and accurate model for the non-destructive estimation of leaf areas in genotypes of *Plumeria rubra* L. **Journal of Horticultural Science and Biotechnology**, United Kingdom, v. 90, n. 3, p. 267 - 272, 2015.

HERNANDEZ-SANTANA, V.; FERNANDEZ, J. E.; CUEVAS, M. V.; PEREZ-MARTIN, A.; DIAZ-ESPEJO, A. Photosynthetic limitations by water deficit: Effect on fruit and olive oil yield, leaf area and trunk diameter and its potential use to control vegetative growth of super-high density olive orchards. **Agricultural Water Management**, Amsterdam, v. 184, p. 9 - 18, 2017.

MACÊDO, M. J. F.; RIBEIRO, D. A.; SANTOS, M. O.; MACÊDO, D. G.; MACEDO, J. G. F.; ALMEIDA, B. V.; SARAIVA, M. E.; LACERDA, M. N. S.; SOUZA, M. M. A. Fabaceae medicinal flora with therapeutic potential in Savanna areas in the Chapada do Araripe, Northeastern Brazil. **Revista Brasileira de Farmacognosia**, Curitiba, v. 28, n. 6, p. 738 - 750, 2018.

MARSHALL, J. K. Methods of leaf area measurement of large and small leaf samples. **Photosynthetica**, v. 2, p. 41 - 47, 1968.

MONTEIRO, E. B.; SILVA, A. C.; SOUZA, A. P.; SILVA, C. C.; KAZAMA, V. S.; TANAKA, A. A. Statistical parameters to estimate the leaf area of native forest seedlings of genus *Tabebuia* and *Handroanthus*. **Bioscience Journal**, Uberlândia, v. 33, n. 4, p. 956 - 967, 2017.

PEKSEN, E. (2007) Non-destructive leaf area estimation model for faba bean (*Vicia faba* L.). **Scientia Horticulturae**, Amsterdam, v. 113, n. 4, p. 322 - 328, 2007.

PEZZINI, R. V.; CARGNELUTTI FILHO, A.; ALVES, B. M.; FOLLMANN, D. N.; LEINPAUL, J. A.; WARTHA, C. A.; SILVEIRA, D. L. Models for leaf area estimation in dwarf pigeon pea by leaf dimensions. **Bragantia**, Campinas, v. 77, n. 2, p. 221 - 229, 2018.

RIBEIRO, J. E. S.; BARBOSA, A. J. S.; ALBUQUERQUE, M. B. Leaf area estimate of *Erythroxylum simonis* plowman by linear dimensions. **Floresta e Ambiente**, Seropédica, v. 25, n. 2, p. 1 - 7, 2018.

RIBEIRO, J. E. S.; COÊLHO, E. S.; FIGUEIREDO, F. R. A.; LOPES, S. F.; ALBUQUERQUE, M. B. Estimation of leaf area of *Erythroxylum citrifolium* from linear leaf dimensions. **Bioscience Journal**, Uberlândia, v. 35, n. 6, p. 1923 - 1931, 2019a.

RIBEIRO, J. E. S.; COÊLHO, E. S.; FIGUEIREDO, F. R. A.; PEREIRA, W. E.; ALBUQUERQUE, M. B. Leaf area estimation for *Psychotria carthagenensis* and *Psychotria hoffmannseggiana* as a function of linear leaf dimensions. **Acta Scientiarum. Biological Sciences**, Maringá, v. 41, p. 1 - 8, 2019b.

RIBEIRO, J. E. S.; FIGUEIREDO, F. R. A.; COÊLHO, E. S.; PEREIRA, W. E.; ALBUQUERQUE, M. B. Leaf area estimation of *Palicourea racemosa* (Aubl.) Borhidi from linear measurements. **Floresta e Ambiente**, Seropédica, v. 27, n. 4, p. 1 - 7, 2020a.

RIBEIRO, J. E. S.; COÊLHO, E. S.; FIGUEIREDO, F. R. A.; MELO, M. F. Non-destructive method for estimating leaf area of *Erythroxylum pauferrense* (Erythroxylaceae) from linear dimensions of leaf blades. **Acta Botanica Mexicana**, Michoacán, v. 127, p. 1 - 12, 2020b.

RIBEIRO, J. E. S.; FIGUEIREDO, F. R. A.; COÊLHO, E. S.; PEREIRA, W. E.; ALBUQUERQUE, M. B. A non-destructive method for estimating leaf area of *Ceiba glaziovii* (Kuntze) K. Schum. **Floresta**, Curitiba, v. 50, n. 1, p. 1063 - 1070, 2020c.

SANTOS, J. C. C.; COSTA, R. N.; SILVA, D. M. R.; SOUZA, A. A.; MOURA, F. B. P.; SILVA JÚNIOR, J. M.; SILVA, J. V. Use of allometric models to estimate leaf area in *Hymenaea courbaril* L. **Theoretical and Experimental Plant Physiology**, London, v. 28, p. 357 - 369, 2016.

SILVA, S. F.; PEREIRA, L. R.; CABANEZ, P. A.; MENDONÇA, R. F.; AMARAL, J. A. T. Modelos alométricos para estimativa da área foliar de boldo pelo método não destrutivo. **Agrarian**, Dourados, v. 10, n. 37, p. 193-198, 2017.

SAUCEDA-ACOSTA, C. P.; GONZALEZ-HERNANDEZ, V. A.; SANCHEZ-SOTO, B. H.; SAUCEDA-ACOSTA, R. H.; RAMIREZ-TOBIAS, H. M.; QUINTANA-QUIROZ, J. G. MACF-IJ, automated method for measuring color and leaf area through digital images. **Agrociencia**, Texcoco, v. 51, n. 4, p. 409 - 423, 2017.

SHAPIRO, S. S.; WILK, M. B. Analysis of variance test for normality (complete samples). **Biometrika**, Oxford, v. 52, n. 3/4, p. 591 - 611, 1965.

YESHITILA, M.; TAYE, M. Non-destructive prediction models for estimation of leaf area for most commonly grown vegetable crops in Ethiopia. **Science Journal of Applied Mathematics and Statistics**, New York, v. 4, n. 5, p. 202 - 216, 2016.

ZHANG, W. Digital image processing method for estimating leaf length and width tested using kiwifruit leaves (*Actinidia chinensis* Planch). **PLoS ONE**, London, v. 15, n. 7, p. 1 - 14, 2020.