Floresta e Ambiente 2018; 25(2): e20170108
https://doi.org/10.1590/2179-8087.010817
ISSN 2179-8087 (online)

Original Article

Conservation of Nature

Leaf Area Estimate of *Erythroxylum simonis* Plowman by Linear Dimensions

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ABSTRACT

This research aimed to determine an equation to estimate the leaf area of *Erythroxylum simonis* using the length and width of leaf blades. Two hundred leaf blades of this species were collected in Mata do Pau-Ferro, a State Park located in Areia, PB, Brazil. Regression analyses were used to determine the estimation equations. The linear, linear without intercept, quadratic, cubic, power and exponential statistical models were used. The criteria used for model selection were based on an examination of the coefficient of determination, the Akaike information criterion and standard error of the estimate. All the equations presented can be used to estimate the leaf area of *E. simonis*. From a practical point of view, the linear regression equation without intercept involving the product between length and width is recommended, using the equation Y=0.6426*LW, which corresponds to 64.26% of the product between length and width, with a coefficient of determination of 0.9936.

Keywords: biometry, non-destructive method, *Erythroxylaceae*.

1. INTRODUCTION

Popularly known "guarda-orvalho", the *Erythroxylum simonis* Plowman (Erythroxylaceae) is an understory species, endemic to the Northeast region, being reported in the states of Paraíba, Ceará, Pernambuco, Sergipe, and Rio Grande do Norte, found in Atlantic Forest rainforests or in countryside forest environments known as "Altitude Marshes" (Loiola et al., 2007; Loiola & Costa-Lima, 2015). This species is extremely important for the preservation of genetic resources that are endemic to these regions and to ensure a food source for their fauna during different periods, cooperating with seed propagation, especially in disturbed environments such as the Altitude Marshes (Fabricante, 2013).

Due to this species' importance, it is necessary to perform ecophysiological studies of its traits in terms of growth, development and propagation. In most studies, determining leaf area, an element considered by some as the most important parameter to evaluate vegetation growth, is fundamentally important (Bianco et al., 1983; Benincasa, 1988). This is one of the most difficult variables to measure because it requires expensive equipment or employs destructive techniques (Bianco et al., 1983; Taiz & Zeiger, 2004).

There are many methods to determine the leaf area, which can be classified as destructive or non-destructive, direct or indirect (Marshall, 1968). The destructive methods, are usually simple and precise (Malagi et al., 2011) but can be more complicated, demanding time and labor (Marcolini et al., 2005), and also result in leaf destruction. Marshall (1968) states that it is important to employ a non-destructive method to measure leaf area because it allows several evaluations of the same plant with precision and speed. Therefore, the determination of the leaf area may be estimated using the dimensional parameters of the leaf (length, width, and length by width), which present good correlations with the leaf surface, adapting regression equations to obtain an estimate between the real leaf area and the linear dimensional parameters of the leaf without destroying the sample (Nascimento et al., 2002; Lizaso et al., 2003). This non-destructive method has been used successfully in several other studies, both in cultivated (Oliveira & Santos, 1995; Uzun & Çelik, 1999; Lizaso et al., 2003; Blanco & Folegatti, 2005; Demirsoy et al., 2005; Tsialtas & Maslaris, 2005; Antunes et al., 2008; Pompelli et al., 2012) and forest species (Silva et al., 2007, 2013; Cabezas-Gutiérrez et al., 2009; Queiroz et al., 2013; Mota et al., 2014; Keramatlou et al., 2015).

Therefore, the objective of the present study is to determine a regression equation to obtain an estimate of *Erythroxylum simonis* leaf area based on the linear dimensional parameters of the leaf blade.

2. MATERIAL AND METHODS

This study was developed in Mata do Pau-Ferro State Park, located 5 km west of the center of the city of Areia-PB, Northeast of Brazil, at a latitude of 6°58'12" S and longitude 35°42'15" W, totaling an approximate area of 608 ha (Figure 1). The region presents an altitude that varies between 400 and 600 m, an annual average temperature of 22°C (Ribeiro et al., 2018), and a tropical climate classified, according to Köppen (1936), as As.

Two hundred *E. simonis* leaf blades were gathered. They did not present any deformities originating from external factors (healthy leaves), such as pests or diseases. Ten different-sized leaves were sampled in each individual, deposited in plastic bags and taken to the laboratory to determine their leaf blade length (L) and width (W) (Figure 2), and to calculate their real leaf area (LA). All leaf blades were digitalized with a table scanner, with the addition of a certain scale (Figure 3A and B). To perform the measurements, public domain *ImageJ®* (*Powerful Image Analysis*) software was employed. In *ImageJ*, the images were contrasted to facilitate the leaf area determination (Figure 3B) and then all measurements were performed. In Figure 3 (A and B), we can see different-sized, full *E. simonis* leaves and in digitalized images to perform the measurements.

To choose the adjusted equation that determines the *E. simonis* leaf area estimate, regression studies were performed, employing the following statistical models: linear, linear without intercept, quadratic, cubic, power, and exponential (Table 1). The Y value was estimated for X, in which the values were length (L), width (W), or the product (LxW). The best equations were chosen based on the greatest coefficient of determination

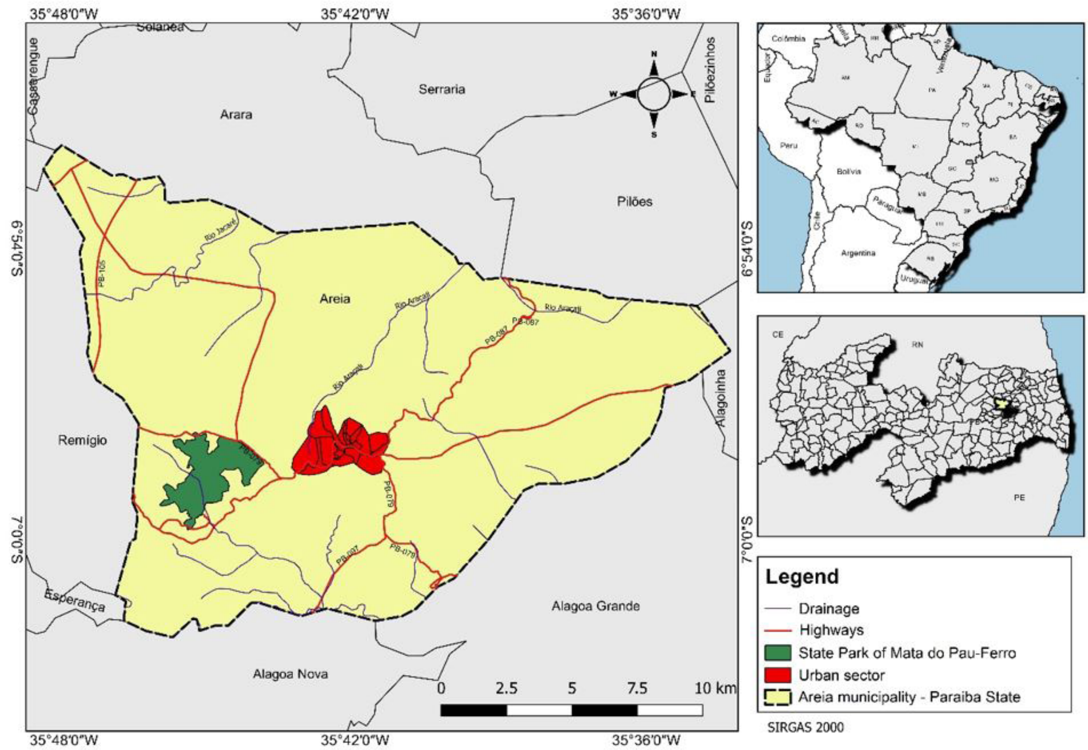

Figure 1. Geographic location of the State Park of Mata do Pau-Ferro, Areia, State of Paraíba, Northeast Brazil.

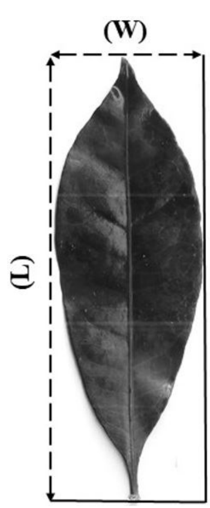

Figure 2. Length (L) and width (W) of the leaf blade used to create models to estimate the leaf area in *Erythroxylum simonis*.

estimated (R^2), lowest Akaike information criterion (AIC), and the lowest standard error of the estimate (Peressin et al., 1984). The regression analyses were obtained through the *Datafit v. 9.1.32* software (Oakdale Engineering, Oakdale, PA, USA).

Table 1. Denomination and representation of equation models adjusted to estimate the leaf area of *Erythroxylum simonis*.

Denomination of equation	Representation of equation
Linear	$y = ax + b$
Linear without intercept (0.0)	$y = bx$
Quadratic	$y = ax^2 + bx + c$
Cubic	$y = ax^3 + bx^2 + cx + d$
Power	$y = ax^B$
Exponential	$y = ab^X$

3. RESULTS AND DISCUSSION

E. simonis leaf blades presented an average length (L) of 4.81 cm, varying from 1.12 to 9.38 cm. Regarding the width (W), they presented a variation of 0.58 to 4.01 cm, with an average value of 2.00 cm. The real leaf area values varied from 0.51 to 23.4 cm^2, with an average of 6.98 cm^2 (Table 2).

Regarding the data variability, lower variation coefficients were registered for the linear dimensions of width and length (CV = 33.13 and 34.14%, respectively), and greater variability for the product (LxW) and leaf

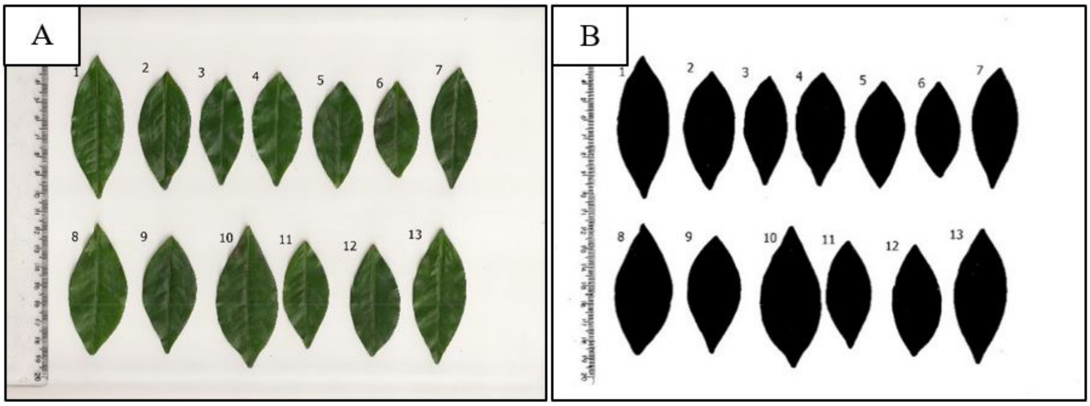

Figure 3. (A) *Erythroxylum simonis* scanned leaves of different sizes used to determine the leaf area, using *ImageJ* software; (B) Scanned leaves with contrasting background used to determine the leaf area, using *ImageJ* software.

Table 2. Minimum, maximum, mean, median, standard deviation, standard error, and coefficient of variation (C.V.) for length (L), width (W), length by width (LxW), and leaf area (LA) of 200 *Erythroxylum simonis* leaf blades.

Statistical	Length (cm)	Width (cm)	LxW (cm^2)	Leaf area (cm^2)
Minimum	1.120	0.580	0.640	0.516
Maximum	9.380	4.010	37.650	23.479
Mean	4.819	2.007	10.703	6.983
Median	4.795	1.940	9.185	5.886
Standard deviation	1.596	0.685	6.783	4.372
Standard error	0.113	0.048	0.480	0.309
C.V. (%)	33.130	34.140	63.370	62.620

area (CV = 63.37 and 62.62%) (Table 2). Other studies also presented greater variability for LxW regarding the L and W dimensions (Cargnelutti et al., 2012, 2015; Toebe et al., 2012).

Table 3 presents the percentage distribution of the 200 *E. simonis* leaf blades regarding their size range. We notice that 59.5% of the leaf area is related to leaves that vary from 0.05 to 7.0 cm^2, which indicates that most leaves of that plant are small.

The results with the equations obtained from the regression analysis linking the real leaf area (Y) and the linear parameters of length (L), width (W), and the product of length and width (LxW) are presented in Table 4. We can also notice that all regression equations presented allow us to satisfactorily estimate this species' leaf area, with every coefficient of determination (R^2) greater than 0.84, which indicates that at least 84% of the variations of the *E. simonis* leaf areas were explained by the determined equations, using this species' leaf dimensions.

The R^2 value varied from 0.8434 to 0.9939; the lower value corresponds to the exponential model in which the length and width product was employed as the calculation base to estimate the leaf area of *E. simonis* leaves, while the greatest value of R^2 was obtained with the product data (LxW), through the quadratic model (R^2 = 0.9939) (Table 4). The AIC varied from 639.95 to 1957.93. The lower value corresponds to the linear model without intercept, while the highest value obtained corresponds to the exponential model, both using the product data (LxW). Therefore, from a more practical perspective, the linear equation without intercept that presents a line crossing its origin (R^2 = 0.9939 and AIC = 639.95) is the most recommended because it is easier to use, which simplifies the calculation. Consequently, the *E. simonis* leaf area estimate may be obtained through

Table 3. Percentage distribution of the real leaf area (LA) of 200 *Erythroxylum simonis* leaf blades, in relation to different size ranges.

LA (cm^2)	(%)
[0.50-3.50]	25.0
[3.51-7.0]	34.5
[7.01-10.0]	16.0
[10.01-13.0]	14.5
[13.01-16.0]	7.0
[16.01-24.0]	3.0

Table 4. Estimated equations, estimated standard error, coefficients of determination and Akaike information criterion as a function of linear measurements of leaf blade of *Erythroxylum simonis*.

Model	X[(1)]	S.E.[(2)]	R^{2}[(3)]	AIC[(4)]	Estimated equation
Linear	L	113.27	0.9328	1182.17	$Y = -5.7666 + 2.646x$
Linear	W	0.969	0.9509	1198.09	$Y = -5.5060 + 6.226x$
Linear	LxW	0.350	0.9936	671.69	$Y = 0.1053 + 0.6426x$
Linear (0.0)	LxW	0.350	0.9936	639.95	$Y = 0.6426x$
Quadratic	L	0.845	0.9626	994.82	$Y = -0.2440 + 0.1717x + 0.2483x^2$
Quadratic	W	0.705	0.9739	996.95	$Y = -0.7084 + 1.1006x + 1.2211x^2$
Quadratic	LxW	0.342	0.9939	673.41	$Y = -0.0013 + 0.6769x - 0.062x^2$
Cubic	L	0.847	0.9624	996.42	$Y = 0.2373 - 0.1714x + 0.3223x^2 - 0.0049x^3$
Cubic	W	0.706	0.9738	992.56	$Y = -0.1233 + 0.1251x + 1.7092x^2 - 0.0751x^3$
Cubic	LxW	0.343	0.9938	666.73	$Y = -0.0102 + 0.6605x - 0.000009x^2 - 0.000025x^3$
Power	L	0.843	0.9627	992.80	$Y = 0.2975x^{1.9461}$
Power	W	0.705	0.9739	997.08	$Y = 1.7279x^{1.8774}$
Power	LxW	0.345	0.9937	671.98	$Y = 0.6885x^{0.9793}$
Exponential	L	110.10	0.9253	1169.57	$Y = 0.6965*0.4323^{X}$
Exponential	W	104.56	0.9285	1113.05	$Y = 0.7384*1.0092^{X}$
Exponential	LxW	82.74	0.8434	1957.93	$Y = 1.9769*0.0971^{X}$

[(1)]Linear measurements: length (L) and width (W); [(2)]Estimated standard error; [(3)]Coefficients of determination; [(4)]Akaike information criterion.

the equation Y = 0.6426*LW, that is, it corresponds to 64.26% of the product between the leaf blade's length and width, or 64.26% of the area given by the product (LxW) (Figure 4).

There was little data dispersion regarding the resulting line. Therefore, the Y = 0.6426*LW equation may represent the real leaf area very satisfactorily (Figure 4). Identical models were obtained to estimate other forest species leaf area, such as *Ziziphus joazeiro* (Y = 0.7931*LW) (Maracajá et al., 2008), *Manihot pseudoglaziovi*i and *Manihot piauhyensis* (Y = 0.533*LW) (Pinto et al., 2007), *Combretum leprosum* (0.7103*LW) (Candido et al., 2013), and *Ageratum conyzoides* (Y = 0.6789*LW) (Bianco et al., 2008). On the other hand, Kumar (2009) noticed that the most recommended model to estimate the *Crocus sativus* L.'s leaf area was the exponential ($Y = 191.33^{*(W)0.0037}$).

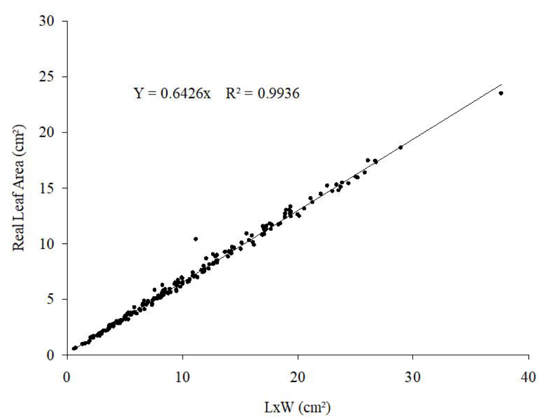

Figure 4. Relation between real leaf area of *Erythroxylum simonis* leaves as a function of the product of length (L) by width (W) of leaf blade, by the regression equation indicated to estimate the leaf area.

The equations that depend on the product (LxW) present higher coefficients of determination, lower AIC and lower standard error of the estimate for regression models in comparison with those observed for equations elaborated with L or W, except for the exponential model, in which the coefficient of determination was lower and the AIC was greater than the others (R^2 = 0.8434 and AIC = 1957.93) (Table 4). Similar results were found in the literature for other forest species, such as *Amburana cearenses*, *Caesalpinia ferrea*, and *Caesalpinia pyramidalis* (Silva et al., 2013), *Schinopsis brasiliensis* and *Tabebuia aurea* (Queiroz et al., 2013), *Acrocomia aculeata* (Mota et al., 2014) or even for cultivation species, such as *Crambe abyssinica* (Toebe et al., 2010), *Mangifera indica* (Lima et al., 2012), *Malus domestica* (Bosco et al., 2012) and *Arachis hypogae* (Cardozo et al., 2014), etc.

The estimated leaf area, obtained through the use of the indicated equation (Y = 0.6426*LW), ensures a satisfactory proximity to the real leaf area, since the coefficient of determination obtained through the relation between these two factors was of 0.9921, as seen in Figure 5.

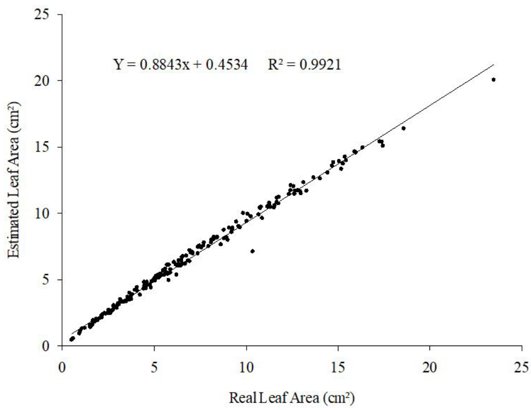

Figure 5. Relation between real leaf area and estimated leaf area by the regression equation Y = 0.6426*LW.

4. CONCLUSIONS

From a practical perspective, the *E. simonis* leaf area may be estimated using the equation Y = 0.6426*LW.

The exponential model is less recommendable because it presented a lower coefficient of determination and a greater AIC.

ACKNOWLEDGEMENTS

We thank to the CAPES (Coordination for the Improvement of Higher Education Personnel) for the scholarship of the first and second author.

SUBMISSION STATUS

Received: 15 june, 2017
Accepted: 11 aug., 2017

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