Estimating leaf area of basil cultivars through linear dimensions of leaves

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10.1590/0034-737X202269020003

ABSTRACT

Ocimum basilicum L. (basil) is an annual herb belonging to the Lamiaceae family that has economic importance for many regions around the world. Thus, ecophysiological studies are needed to assess this species growth and dispersal. This work aimed to obtain equations from regression models that meaningfully estimate the leaf area of basil cultivars using linear dimensions of leaves. For this purpose, 300 leaves from ‘Italiano Roxo’ and 500 leaves from ‘Folha Fina’ cultivar were collected from plants cultivated in a greenhouse. Then, the length, width, and leaf area of each leaf were measured, and product of length by width were calculated. The equations were adjusted using the simple linear, linear without intercept, quadratic, cubic, power, and exponential regression models. Criteria for selecting the best equations were highest determination coefficient and Willmott’s agreement index, lowest Akaike information criterion and root mean square error, and BIAS index closest to zero. All the equations fitted using the product of length by width (L.W) can estimate the leaf area of basil cultivars. Thus, basil leaf area can be estimated through a non-destructive method using linear dimensions of leaves. However, the equation w = 0.8175*lw^{0.9307} is the most suitable for ‘Italiano Roxo’ and w = 0.6335*lw for ‘Folha Fina’.

Keywords: Ocimum basilicum; biometry; allometric equations; Lamiaceae; leaf blade.

INTRODUCTION

Ocimum basilicum L., popularly known as basil, and as manjeriço, alfavaca, basilico and alfavaca-cheirosa in Brazil, is an annual herb belonging to the Lamiaceae family. Reaching 30 to 60 cm in height under ideal environmental conditions (Minami et al., 2007), the plant is native to India and other Asian regions and cultivated in several countries, where the raw material is used to produce essential oils rich in linalool (Pinheiro et al., 2017). In addition to having biological properties, such as antibacterial and insecticidal, the essential oil is used as flavoring and condiment in the food and pharmaceutical industry (Luz et al., 2009; Machado et al., 2012). Also, basil is used in all countries for culinary, medicinal, ornamental, and aromatic purposes (Hussain et al., 2008). In traditional medicine, basil leaves are freshly consumed or after infusion as analgesic, soothing, expectorant, invigorating, sedative, and tonic (Ribeiro et al., 2014; Sakurai et al., 2016).

Many basil varieties have been exploited commercially for presenting desirable characteristics, such as high essential oil content and greater biomass production. ‘Italiano Roxo’ (Ocimum basilicum var. purpurascens Benth.) is a basil cultivar that grows to 50 and 60 cm in height, and produces greenish-purple leaves, long inflorescences, and erect stem (Kamada et al., 1999). ‘Folha Fina’ (Ocimum basilicum var. minimum L.) has an erect and branched stem, grows to 40 and 50 cm in height, and produces short and white inflorescences (Matos, 2002).

Given the importance of this species, studies on its growth, physiology, development, reproduction, and propagation are of great interest. Leaf area measurement
is of fundamental importance because leaves are responsible for multiple functions in plants, such as light interception and absorption for photosynthetic processes, gas exchange, and stomatal opening, thus directly affecting the plant biomass production (Spann & Heerema, 2010; Taiz et al., 2017).

Leaf area can be determined by different methods, classified according to Marshall (1968) as direct and indirect, or destructive and non-destructive. Direct methods (destructive or not) are simple to measure but cost time and labor, in addition to being unfeasible for endangered species and plants in the early stages of development, and because it requires plants to be destroyed (Mota et al., 2014). On the other hand, indirect (non-destructive) methods allow quick and accurate evaluations, permitting successive measurements on the same plant, based on regression models using leaf dimensions (length and width), without destroying the sample (Pompelli et al., 2012; Sousa & Amaral, 2015; Ribeiro et al., 2019a).

Regression models for estimating leaf area have been used by several authors in other species, such as Capsicum annuum L. (Padrón et al., 2016), Smallanthus sonchifolius (Poeppl.) H. Rob. (Erlacher et al., 2016), Salvia hispanica L. (Mack et al., 2017), Theobroma cacao L. (Salazar et al., 2018), Erythroxylum citrifolium A.St.-Hil. (Ribeiro et al., 2019a), Psychotria carthagenensis Jacq. and Psychotria hoffmannseggiana (Willd. ex Schult.) Müll.Arg. (Ribeiro et al., 2019b), Erythroxylum simonis Plowman (Ribeiro et al., 2018), Mesophaerum suaveolens (L.) Kuntze (Ribeiro et al., 2020a), and Erythroxylum pauperrense Plowman (Ribeiro et al., 2020b). Therefore, this work aimed to obtain equations from regression models that meaningfully estimate leaf area of basil cultivars (‘Italiano Roxo’ and ‘Folha Fina’) through linear dimensions of leaves.

**MATERIAL AND METHODS**

The experiment was carried out under greenhouse at the Center for Agrarian Sciences, Department of Phytotechnics and Environmental Sciences, Federal University of Paraíba, Campus II, Areia city, Paraíba state, Brazil (6°58′1.3″S, 35°42′49.09″O, 400 to 600 m altitude), where the climate is As type, hot and humid with autumn-winter rains (Alvares et al., 2013). During the experimental period, the average temperature was 28.4 °C and relative humidity was 54.8%, which were monitored using a digital thermo-hygrometer (MT-241A, Minipa).

Basil seeds from ‘Italiano Roxo’ and ‘Folha Fina’ cultivars were purchased at the local market. Then, seedlings were produced in polyethylene bags with 1.3 dm³ capacity filled with a substrate composed of latosol, washed sand, and tanned cattle manure at the 3:1:1 ratio (Table 1).

At 55 days after planting, beginning of flowering, 300 leaves from ‘Italiano Roxo’ and 500 leaves from ‘Folha Fina’, of different sizes and shapes, were randomly collected. Only healthy leaves without injuries caused by pests, diseases, and other factors were selected. Then, the leaves were packed in plastic bags and transported to Plant Ecology Laboratory, at Federal University of Paraíba, Campus II. At the laboratory, the maximum length (L, cm) and width (W, cm) (Figure 1) of each leaf were measured using a millimetric ruler. Then, the product of length by width (L.W, cm²) was calculated. Also, the real leaf area (LA, cm²) was determined by digital photocopies obtained using a scanner (P-215II, Canon), and the images were analyzed in ImageJ® v.1.51j8 (Powerful Image Analysis) software.

A descriptive analysis was performed to determine the minimum, maximum, mean, amplitude, median, variance, standard deviation, standard error, and coefficient of variation of L, W, LW, and LA. Then, equations for estimating the leaf area were adjusted using the simple linear, linear without intercept (0.0), quadratic, cubic, power, and exponential regression models (Table 2). Subsequently, the equations that meaningfully estimated leaf area of the basil cultivars were selected by checking the highest determination coefficient (R²) and Willmott’s agreement index (d) (Willmott, 1981) (Equation 1), lowest Akaike information criterion (AIC) (Akaike, 1974) (Equation 2) and root mean square error (RMSE) (Janssen & Heuberger, 1995) (Equation 3), and BIAS index closest to zero (Leite & Andrade, 2002) (Equation 4). Statistical analyzes were performed in R® v.4.0.0 software (R Core Team, 2020), using the package hydroGOF (Zambrano-Bigiarini, 2020).

\[
d = 1 - \frac{\sum_{i=1}^{n} (y_i - \bar{y})^2}{\sum_{i=1}^{n} (|y_i| - |\bar{y}|)^2} \quad (1)
\]

\[
AIC = -2 \ln L(x; \hat{\theta}) + 2(p) \quad (2)
\]

\[
RMSE = \sqrt{\frac{\sum_{i=1}^{n} (y_i - \hat{y}_i)^2}{n}} \quad (3)
\]

\[
BIAS = \frac{\sum_{i=1}^{n} (\hat{y}_i - y_i)^2}{\sum_{i=1}^{n} (\hat{y}_i)^2} \quad (4)
\]

Where \( \hat{y}_i \) is the estimated leaf area, \( y_i \) is the observed leaf area, \( \hat{\theta} \) is the mean of the observed values (\( \hat{\theta}_i = \hat{y}_i - \hat{y} \); \( y_i = y_1 \); \( \hat{\theta} \)), L (x; \( \theta \)) is the maximum likelihood function that is defined as the product of the density function, \( p \) is the number of coefficients in the equation, and \( n \) is the number of observations.

**RESULTS AND DISCUSSION**

The length (L) of the ‘Italiano Roxo’ (IR) leaves varied from 1.100 to 10.738 cm, with 4.133 cm on average and 9.638 cm amplitude, while width (W) varied from 0.493 to 9.638 cm amplitude, while width (W) varied from 0.493 to 9.638 cm amplitude.
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6.066 cm, with 2.391 cm on average and 5.573 cm amplitude. The product of length by width (L.W) ranged from 0.634 to 65.137 cm², with 12.229 cm² on average and 64.503 cm² amplitude, and real leaf area (LA) ranged from 0.256 to 37.933 cm², with 8.179 cm² on average and 37.677 cm² amplitude (Table 3). In turn, the length of ‘Folha Fina’ (FF) leaves differed from 0.403 to 3.495 cm, 1.663 cm on average and 3.092 cm amplitude, whereas width (W) ranged between 0.180 and 2.294 cm, 0.901 cm on average and 2.114 cm amplitude. The product length by width (L.W) varied from 0.079 to 7.889 cm², 1.774 cm² on average and 7.810 cm² amplitude. Finally, real leaf area (LA) was from 0.063 to 4.640 cm², 1.154 cm² on average and 4.577 cm² amplitude (Table 3).

Regarding variability in basil leaf dimensions, the lowest coefficients of variation were those from length (46.1% for IR and 41.21% for FF) and width (54.8% for IR and 48.61% for FF), whereas the highest coefficients of variation were those from the product of length by width (97.4% for IR and 89.90% for FF) and real leaf area (91.5% for IR and 85.69% for FF) (Table 3). High values of amplitude, standard deviation, standard error, and coefficient of variation are of fundamental importance for studies aimed at estimating leaf area from regression models, allowing measurements on leaves of different sizes and plants on different phenological stages (Pezzini et al., 2018). Therefore, the number of leaves used in the present study was adequate for estimating the basil leaf area through linear dimensions of leaves. Other studies also reported high variability in product of length by width (LW) and real leaf area (LA) as compared to L and W values (Leite et al., 2017; Ribeiro et al., 2018; Ribeiro et al., 2020c; Ribeiro et al., 2020d).

Regarding leaf size classes, 32.3% of ‘Italiano Roxo’ leaf area (n = 300) was in the range of 0.25 and 3.00 cm², and 37.4% of ‘Folha Fina’ leaf area was in the range of 0.51 and 1.00 cm², which shows these cultivars have high leaf area variation (Figure 2).

The regression models and allometric equations obtained from the relationship between real leaf area (w) and linear dimensions of leaf blades (L, W, and L.W) are shown in Table 4. The determination coefficients (R²) were greater than 0.87, indicating that at least 87% of the variation in leaf area was explained by the equations adjusted using linear dimensions of leaves (Table 4).

The equations adjusted using the product of leaf length by width (LW) showed satisfactory assumptions for estimating leaf area, best fitting all the regression models (Assis et al., 2015; Oliveira et al., 2017; Lucena et al., 2019).

### Table 1: Chemical characterization of the substrate used in the experiment

| pH | OM (g kg⁻¹) | P (mg kg⁻¹) | K⁺ (cmol dm⁻³) | Ca²⁺ | Mg²⁺ | Na⁺ | BS | H⁺ + Al³⁺ | Al³⁺ | CEC |
|----|-------------|-------------|----------------|------|------|-----|-----|------------|------|-----|
| 7.8 | 22.2 | 85.5 | 693.6 | 2.9 | 1.59 | 0.23 | 6.5 | 0.0 | 0.0 | 6.5 |

OM: organic matter; BS: base saturation; CEC: cation exchange capacity.

**Figure 1:** Linear dimensions [length (L) and width (W)] of leaves of ‘Italiano Roxo’ (A) and ‘Folha Fina’ (B) basil cultivars used to estimate leaf area.
al., 2018; Ribeiro et al., 2018). Except for the equation adjusted using the exponential model, which showed best indexes when just using leaf width, as was also reported by Silva et al. (2017).

Following the criteria for selecting the equations that meaningfully estimated the leaf area of basil cultivars through linear dimensions of leaves, it was found that the power model and linear model without intercept, both fitted using the product of length by width, as was also reported by Silva et al. (2017). These equations showed the highest $R^2$ (0.9945 and 0.9894) and $d$ (0.9979 and 0.9942), lowest RMSE (0.695 and 0.150) and AIC (609.6 and 76.9), and BIAS index closest to zero (-0.0064 and 0.0301) (Table 4). Therefore, the equation $w = 0.8175* LW^{0.9307}$ is the most suitable for estimating the leaf area of 'Italiano Roxo' and 'Folha Fina' basil cultivars, respectively.

Table 2: Models and equations used to estimate leaf area of basil through linear dimensions of leaves

| Model                                      | Equation                                      |
|--------------------------------------------|-----------------------------------------------|
| Linear                                     | $\hat{y} = b_0 + b_1 * L + \epsilon_i$       |
| Linear                                     | $\hat{y} = b_0 + b_1 * W + \epsilon_i$       |
| Linear                                     | $\hat{y} = b_0 + b_1 * LW + \epsilon_i$      |
| Linear without intercept (0.0)             | $\hat{y} = b_1 * LW + \epsilon_i$            |
| Quadratic                                  | $\hat{y} = b_0 + b_1 * L + b_2 * L^2 + \epsilon_i$ |
| Quadratic                                  | $\hat{y} = b_0 + b_1 * W + b_2 * W^2 + \epsilon_i$ |
| Quadratic                                  | $\hat{y} = b_0 + b_1 * LW + b_2 * LW^2 + \epsilon_i$ |
| Cubic                                      | $\hat{y} = b_0 + b_1 * L + b_2 * L^2 + b_3 * L^3 + \epsilon_i$ |
| Cubic                                      | $\hat{y} = b_0 + b_1 * W + b_2 * W^2 + b_3 * W^3 + \epsilon_i$ |
| Cubic                                      | $\hat{y} = b_0 + b_1 * LW + b_2 * LW^2 + b_3 * LW^3 + \epsilon_i$ |
| Power                                      | $\hat{y} = b_0 * L^{b_1} + \epsilon_i$       |
| Power                                      | $\hat{y} = b_0 * W^{b_1} + \epsilon_i$       |
| Power                                      | $\hat{y} = b_0 * LW^{b_1} + \epsilon_i$      |
| Exponential                                | $\hat{y} = b_0 * W^{b_1} + \epsilon_i$       |
| Exponential                                | $\hat{y} = b_0 * L^{b_1} + \epsilon_i$       |
| Exponential                                | $\hat{y} = b_0 * LW^{b_1} + \epsilon_i$      |

Table 3: Minimum, maximum, mean, amplitude, median, variance, standard deviation, standard error, and coefficient of variation of length (L), width (W), product of length by width (LW), and leaf area (LA) of leaf blades of ‘Italiano Roxo’ and ‘Folha Fina’ basil cultivars

| Statistics               | Italiano Roxo (n = 300 leaf blades) | Folha Fina (n = 500 leaf blades) |
|--------------------------|-------------------------------------|----------------------------------|
|                          | L (mm)                              | W (mm)                           | LW (mm²)                          | LA (mm²)                         |
| Minimum                  | 1.100                               | 0.493                            | 0.634                             | 0.256                            |
| Maximum                  | 10.738                              | 6.066                            | 65.137                            | 37.933                            |
| Mean                     | 4.133                               | 2.391                            | 12.229                            | 8.179                            |
| Amplitude                | 9.638                               | 5.573                            | 64.503                            | 37.677                            |
| Median                   | 3.883                               | 2.179                            | 8.394                             | 5.933                             |
| Variance                 | 3.631                               | 1.717                            | 141.969                           | 56.047                            |
| Standard deviation       | 1.906                               | 1.310                            | 11.915                            | 7.486                             |
| Standard error           | 0.113                               | 0.078                            | 0.707                             | 0.444                             |
| Coefficient of variation | 46.10                               | 54.80                            | 97.40                             | 91.50                             |

Rev. Ceres, Viçosa, v. 69, n.2, p. 139-147, mar/apr, 2022
area of ‘Italian Roxo’, and the equation \( w = 0.6335 \times LW \) for ‘Folha Fina’ (Table 4).

Despite the linear patterns, the power regression model was the best adjustment for predicting ‘Italiano Roxo’ leaf area, which was also recommended for other species, such as Vigna unguiculata (L.) Walp. (Oliveira et al., 2015), Theobroma cacao L. (Schmidt et al., 2017), Stizolobium cinereum Piper & Tracy (Cargnelutti Filho et al., 2018), and Manihot esculenta Crantz (Guimarães et al., 2019). In turn, the linear model indicated to estimate ‘Folha Fina’ leaf area was also recommended for species such as Moringa oleifera Lamarck (Macário et al., 2020), Allium cepa L. (Córcoles et al., 2015), and Commelina difusa Burm.f. (Carvalho et al., 2017).

According to the proposed equations to estimate the basil cultivars leaf area, data showed low dispersion from the regression line in the scatterplot and residues were homogenously distributed, showing that variances were homogeneous, and residues were normally distributed (Figure 3A and B).

Leaf area estimated by the proposed equations was positively correlated with real leaf area, with determination coefficients (\( R^2 \)) of 0.9913 and 0.9894, showing the high quality of the adjustments (Figure 4A and B). Therefore,
Table 4: Regression models, allometric equations, determination coefficient (R²), Willmott’s agreement index (d), Akaike information criterion (AIC), root mean square error (RMSE), and BIAS index of 300 leaves of ‘Italiano Roxo’ and 500 leaves of ‘Folha Fina’ basil cultivars

### ‘Italiano Roxo’

| Model         | x    | R²   | AIC    | RMSE  | d     | BIAS  | Equation               |
|---------------|------|------|--------|-------|-------|-------|------------------------|
| Linear        | L    | 0.8997 | 1306.0 | 2.367 | 0.9730 | 0.2752 | $\hat{y} = -7.224 + 3.727*L$ |
| Linear        | W    | 0.9463 | 1128.6 | 1.734 | 0.9860 | 0.2583 | $\hat{y} = -5.110 + 5.558*W$ |
| Linear        | L.W  | 0.9903 | 640.6  | 0.737 | 0.9978 | 0.1883 | $\hat{y} = 0.5325 + 0.6253*LW$ |
| Linear (0.0)  | L.W  | 0.9914 | 703.2  | 0.825 | 0.9790 | 0.1593 | $\hat{y} = 0.6476* LW$ |
| Quadratic     | L    | 0.9515 | 1101.7 | 1.648 | 0.9874 | 0.1638 | $\hat{y} = 0.2591 - 0.1629*L + 0.4149*L^2$ |
| Quadratic     | W    | 0.9686 | 978.0  | 1.327 | 0.9920 | 0.1508 | $\hat{y} = -1.0851 + 2.0488*W + 0.5871*W^2$ |
| Quadratic     | L.W  | 0.9913 | 611.2  | 0.699 | 0.9796 | -0.0242 | $\hat{y} = 0.2126 + 0.6844* LW - 0.00138* LW^2$ |
| Cubic         | L    | 0.9550 | 1082.7 | 1.589 | 0.9884 | 0.1742 | $\hat{y} = 4.0019 - 3.0819*L + 1.0576*L^2 - 0.0417*L^3$ |
| Cubic         | W    | 0.9686 | 979.8  | 1.326 | 0.9920 | 0.1629 | $\hat{y} = 0.86917 + 1.7403*W + 0.7068*W^2 - 0.01315*W^3$ |
| Cubic         | L.W  | 0.9914 | 610.3  | 0.696 | 0.9797 | -0.0086 | $\hat{y} = 0.2482 + 0.6743* LW - 0.0008* LW^2 - 0.000007* LW^3$ |
| Power         | L    | 0.9514 | 1100.2 | 1.650 | 0.9874 | -0.0945 | $\hat{y} = 0.3863*L^{2.0138}$ |
| Power         | W    | 0.9686 | 976.0  | 1.327 | 0.9919 | 0.1198 | $\hat{y} = 1.699*W^{1.642}$ |
| Power         | L.W  | 0.9945 | 609.6  | 0.695 | 0.9797 | -0.0064 | $\hat{y} = 0.8175* LW^{0.917}$ |
| Exponential   | L    | 0.9036 | 1323.1 | 2.440 | 0.9690 | -0.4478 | $\hat{y} = 1.8565 + 1.3794*L$ |
| Exponential   | W    | 0.9353 | 1197.4 | 1.957 | 0.9812 | -0.2824 | $\hat{y} = 2.217* 1.605^W$ |
| Exponential   | L.W  | 0.9552 | 1438.0 | 1.957 | 0.9812 | -0.2824 | $\hat{y} = 4.669* 1.04^LW$ |

### ‘Folha Fina’

| Model         | x    | R²   | AIC    | RMSE  | d     | BIAS  | Equation               |
|---------------|------|------|--------|-------|-------|-------|------------------------|
| Linear        | L    | 0.8798 | 253.3  | 0.342 | 0.9672 | 0.2614 | $\hat{y} = -1.097 + 1.354*L$ |
| Linear        | W    | 0.9234 | 238.5  | 0.273 | 0.9798 | 0.2433 | $\hat{y} = -0.8011 + 2.170*W$ |
| Linear        | L.W  | 0.9769 | 122.0  | 0.150 | 0.9941 | 0.1983 | $\hat{y} = 0.067 + 0.613* LW$ |
| Linear (0.0)  | L.W  | 0.9894 | 76.9   | 0.150 | 0.9942 | 0.0301 | $\hat{y} = 0.6335* LW$ |
| Quadratic     | L    | 0.9296 | 82.7   | 0.262 | 0.9815 | 0.1638 | $\hat{y} = 0.1702 - 0.2030*L + 0.4086*L^2$ |
| Quadratic     | W    | 0.9495 | 114.4  | 0.222 | 0.9870 | 0.1508 | $\hat{y} = -0.0798 + 0.5636* W + 0.7235* W^2$ |
| Quadratic     | L.W  | 0.9769 | 152.4  | 0.156 | 0.9942 | 0.0327 | $\hat{y} = 0.0542 + 0.6279* LW - 0.0025* LW^2$ |
| Cubic         | L    | 0.9295 | 84.4   | 0.261 | 0.9815 | 0.1811 | $\hat{y} = 0.24934 - 0.36038*L + 0.5005*L^2 - 0.0160*L^3$ |
| Cubic         | W    | 0.9505 | 85.7   | 0.219 | 0.9873 | 0.1832 | $\hat{y} = 0.1747 - 0.3563* W + 1.6694* W^2 - 0.2819* W^3$ |
| Cubic         | L.W  | 0.9769 | 151.8  | 0.150 | 0.9938 | -0.0965 | $\hat{y} = 0.0364 + 0.6612* LW - 0.0158* LW^2 + 0.0014* LW^3$ |
| Power         | L    | 0.9293 | 85.1   | 0.263 | 0.9815 | 0.0896 | $\hat{y} = 0.3465* L^{0.2021}$ |
| Power         | W    | 0.9502 | 83.1   | 0.221 | 0.9871 | 0.1255 | $\hat{y} = 1.213*W^{0.693}$ |
| Power         | L.W  | 0.9769 | 452.3  | 0.150 | 0.9941 | -0.0625 | $\hat{y} = 0.6792* LW^{0.948}$ |
| Exponential   | L    | 0.9132 | 193.4  | 0.294 | 0.9755 | -0.0259 | $\hat{y} = 0.2116* 2.4684^L$ |
| Exponential   | W    | 0.9187 | 169.1  | 0.287 | 0.9765 | -0.0333 | $\hat{y} = 0.2982* 3.7314^W$ |
| Exponential   | L.W  | 0.9188 | 310.0  | 0.287 | 0.9765 | -0.0333 | $\hat{y} = 0.5931* 1.3627^W$ |
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The equations $w = 0.8175 \times LW^{0.9307}$ ('Italiano Roxo') and $w = 0.6335 \times LW$ ('Folha Fina') allow quickly and accurately estimate basil leaf area through the product of leaf length by width (L.W) of leaf blades by the equations indicated to estimate leaf area. The residual dispersion is shown in the inserted chart. The proposed equations can contribute to studies on basil growth, development, and physiology since leaf area estimation is of fundamental importance for these studies.

CONCLUSIONS

Basil leaf area can be quickly and accurately estimated through a non-destructive method using linear dimensions of leaves.

Equations adjusted using the product of leaf length by width (L.W) can meaningfully estimate basil leaf area.

The equation $w = 0.8175 \times LW^{0.9307}$ adjusted using the power model (for 'Italiano Roxo' cultivar) and $w = 0.6335 \times LW$ adjusted using the linear model without intercept (for 'Folha Fina' cultivar) are the most suitable for estimating the leaf area basil cultivars.

ACKNOWLEDGEMENTS, FINANCIAL SUPPORT AND FULL DISCLOSURE

The authors would like to thank to Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (financing code 001) by scholarships awarded to the authors.
REFERENCES

Alvares CA, Stape JL, Sentelhas PC, Gonçalves JLM & Sparovek G (2013) Köppen’s climate classification map for Brazil. Meteorologische Zeitschrift, 22:711-728.

Akahe H (1974) A new look at the statistical model identification. IEEE Transactions on Automatic Control, 19:716-723.

Assis JP, Linhares PFC, Souza RP, Pereira FMS & Almeida AMB (2015) Estimação da área foliar da “jiitiana” (Merremia aegyptia (L.) Urban), através de modelos de regressão para Mossoró-RN. Revista Verde de Agroecologia e Desenvolvimento Sustentável, 10:75-81.

Cargnelutti Filho A, Toebe M, Burin C, Neu IMM & Alves BM (2018) Número de folhas para modelar a área foliar de mucuna cinza por dimensões foliares. Revista de Ciências Agroveterinárias, 17:571-578.

Carvalho LB, Alves EA, & Bianco S (2017) Non-destructive model to predict Commelina diffusa leaf area. Planta Daninha, 35:1-5.

Córcoles J, Domínguez A, Moreno M, Ortega J & De Juan J (2015) A non-destructive method for estimating onion leaf area. Irish Journal of Agricultural and Food Research, 54:17-30.

Erlacher WA, Oliveira FL, Fialho GS, Silva DMN & Carvalho LB, Alves EA, & Bianco S (2017) Non-destructive model for estimating onion leaf area. Horticultura Brasileira, 34:422-427.

Guimarães MM, Coelho Filho MA, Gomes Junior FA, Silva MM, Alves CVO & Lopes I (2019) Modelos matemáticos para a estimativa da área foliar de mandioca. Revista de Ciências Agrárias, 62:1-5.

Hussain AL, Anwar F, Sherazi STH & Przybylski R (2008) Chemical composition, antioxidant and antimicrobial activities of basil (Ocimum basilicum) essential oils depends on seasonal variations. Food Chemistry, 108:986-995.

Janssen PHM & Heuberger PSC (1995) Calibration of process models. Ecological Modelling, 83:55-66.

Kamata T, Casali VWD, Barbosa LCA, Fortes ICP & Finger FL (1999) Plasticidade fenotípica do óleo essencial em acessos de manjericão (Ocimum sp.). Revista Brasileira de Plantas Medicinais, 1:13-22.

Leite HG & Andrade VCL (2002) Um método para condução de inventários florestais sem o uso de equações volumétricas. Revista Árvore, 26:321-328.

Leite MLMV, Lucena LRR, Sá Júnior EH & Cruz MG (2017) Estimativa da área foliar em Urochloa mosambicensis por dimensões lineares. Revista Agropecuária Técnica, 38:9-16.

Leite MLMV, Lucena LRR, Cruz MG & Sá Júnior EH (2018) Estimativa da área foliar em Urochloa mosambicensis por dimensões foliares e imagens digitais. Archivos de Zootecnia, 67:408-413.

Luz JMQ, Morais TPS, Blank AF, Sodré ACB & Oliveira GS (2009) Teor, rendimento e composição química do óleo essencial de manjericão sob doses de cama de fumo. Horticulura Brasileira, 27:349-353.

Macário APS, Ferraz RLS, Costa PS, Brito Neto JM, Melo AS & Dantas Neto J (2020) Allometric models of estimating Moringa oleifera leaflets area. Ciência e Agrotecnologia, 44:1-10.

Machado TF, Nogueira NAP, Pereira RCA, Sousa CT & Batista VCY (2012) Atividade antimicrobiana do óleo essencial de manjericão contra patógenos e deterioradores de alimentos. Fortaleza, Embrapa Agroindústria Tropical. 16p.

Mack L, Capezzone F, Munz S, Piepho HP, Clauepin W, Phillips T & Graeff-Hönninger S (2017) Nondestructive leaf area estimation for Chia. Agronomy Journal, 109:1960-1969.

Marshall JK (1968) Methods of leaf area measurement of large and small leaf samples. Photosynthetic, 2:41-47.

Mats FIA (2002) Farmácias vivas: sistema de utilização de plantas medicinais projetado para pequenas comunidades. 4th ed. Fortaleza, Editora UFC. 267p.

Minami K, Suguino E, Mello SC & Watanabe AT (2007) A cultura do manjericão. Piracicaba, ESALQ - Divisão de biblioteca e documentação. 25p.

Mota CS, Leite HG & Cano MAO (2014) Equações para estimar área foliar de folíolos de Acerocorma aucteula. Pesquisa Florestal Brasileira, 34:217-224.

Oliveira RLL, Moreira AR, Costa AV, Souza LC, Lima LGS & Silva RTL (2015) Modelos de determinação não destrutiva de área foliar de feijão caupi Vigna unguiculata (L.). Global Science and Technology, 8:17-27.

Oliveira PS, Silva W, Costa AAM, Schmidli ER & Vitória EL (2017) Leaf area estimation in litchi by means of allometric relationships. Revista Brasileira de Fruticultura, 39:1-6.

Padrón RAR, Lopes SJ, Swarowsky A, Cerquera RR, Nogueira CU & Maffei M (2016) Non-destructive models to estimate leaf area on bell pepper crop. Ciência Rural, 46:1938-1944.

Pezzini RV, Cargnelutti Filho A, Alves BM, Follmann DN, Leinpaul JA, Wartha CA & Silveira DL (2018) Models for leaf area estimation in dwarf pigeon pea by leaf dimensions. Bragantia, 77:221-229.

Pinheiro PF, Chaves BV, Silva PI, Lucia SMD, Saraiva SH & Pinheiro CA (2017) Óleos essenciais de manjericão e gengibre na aromatização de azeite de oliva. Nucleus, 14:189-196.

Pompelli MF, Antunes WC, Ferreira DTRG, Cavalcante PGS, Wanderley Filho HCL & Endres L (2012) Allometric models for non-destructive leaf area estimation of Jatropha curcas. Biomass and Bioenergy, 36:77-85.

R Core Team (2020) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available at: http://www.R-project.org/. Accessed on: January 15th, 2021.

Ribeiro DA, Macêdo DG, Oliveira LGS, Saraiva ME, Oliveira SF, Souza MMA & Menezes IRA (2014) Potencial terapêutico e uso de plantas medicinais em uma área de Caatinga no estado do Ceará, nordeste do Brasil. Revista Brasileira de Plantas Medicinais, 16:912-930.

Ribeiro JES, Barbosa AJS & Albuquerque MB (2018) Leaf Area Estimate of Erythroxylum simoniflorum Plowman by Linear Dimensions. Floresta e Ambiente, 25:1-7.

Ribeiro JES, Coelho ES, Figueiredo FRA, Lopes SF & Albuquerque MB (2019a) Estimation of leaf area of Erythroxylum citrifolium from linear leaf dimensions. Bioscience Journal, 35:1923-1931.

Ribeiro JES, Coelho ES, Figueiredo FRA, Pereira WE & Albuquerque MB (2019b) Leaf area estimation for Psychotria cattage-nensis and Psychotria hoffmannseggiana as a function of linear leaf dimensions. Acta Scientiarum. Biological Sciences, 41:1-8.

Ribeiro JES, Nóbrega JS, Figueiredo FRA, Ferreira JTA, Pereira WE, Bruno RLA & Albuquerque MB (2020a) Estimativa da área foliar de folíolos de Mesosphaerum suaveolens a partir de relações alométricas. Rodriguésia, 71:1-9.

Ribeiro JES, Coelho ES, Figueiredo FRA & Melo MF (2020b) Non-destructive method for estimating leaf area of Erythroxylum pauferrense (Erythroxylaceae) from linear dimensions of leaf blades. Acta Botanica Mexicana, 127:1-12.

Ribeiro JES, Figueiredo FRA, Coelho ES, Pereira WE & Albuquerque MB (2020c) Leaf area estimation of Palicourea racemosa (Aubl.) Borhidi from linear measurements. Floresta e Ambiente, 27:1-7.
Estimating leaf area of basil cultivars through linear dimensions of leaves

Ribeiro JES, Figueiredo FRA, Coêlho ES, Pereira WE & Albuquerque MB (2020d) A non-destructive method for estimating leaf area of *Ceiba glaziovii* (Kuntze) K. Schum. Floresta, 50:1063-1070.

Sakurai FN, Estrela KCA, Tamayo MS, Casseb MO & Nakasato M (2016) Caracterização das propriedades funcionais das ervas aromáticas utilizadas em um hospital especializado em cardiopneumologia. Demetra 11:1097-1113.

Salazar JCS, Muñoz LMM, Bautista EHD, Rienzo JAD & Casanoves F (2018) Non-destructive estimation of the leaf weight and leaf area in cacao (*Theobroma cacao* L.). Scientia Horticulturae, 229:19-24.

Schmidt ER, Belique ETM & Schmildt O (2017) Modelos alométricos para determinação da área foliar de cacau e ‘PH-16’ em sombreamento e pleno sol. Revista Agroambiente Online, 11:47-55.

Silva SF, Pereira LR, Cabanez PA, Mendonça RF & Amaral JAT (2017) Modelos alométricos para estimativa da área foliar de boldo pelo método não destrutivo. Agrarian, 10:193-198.

Sousa MC & Amaral CL (2015) Non-destructive linear model for leaf area estimation in *Vernonia ferruginea* Less. Brazilian Journal of Biology, 75:152-156.

Spann TM & Heerema RJ (2010) A simple method for nondestructive estimation of total shoot leaf area in tree fruit crops. Scientia Horticulturae, 125:528-533.

Taiz L, Zeiger E, Møller IM & Murphy A (2017) Fisiologia e desenvolvimento vegetal. Artmed. Porto Alegre, Brasil. 888p.

Willmott CJ (1981) On the validation of models. Physical Geography, 2:184-194.

Zambrano-Bigiarini M (2020) Package ‘hydroGOF’: Goodness-of-fit functions for comparison of simulated and observed hydrological time series. Available at: https://cran.r-project.org/web/packages/hydroGOF/hydroGOF.pdf. Accessed on: June 24th, 2021.