Brazilian Journal of Experimental Design, Data Analysis and Inferential Statistics

Federal University of Rio de Janeiro
BJEDIS, Rio de Janeiro, Special Edition, v. 02, 2022
DOI: https://doi.org/10.55747/bjedis.v2i2.52835
E-ISSN: 2763-6925

Special Edition **Received 09/09/2022. Revised 10/27/2022. Accepted 11/03/2022. Published 11/23/2022.**

Mathematical models in determining leaf area in eggplant and scarlet eggplant seedlings

Leonardo Raasch Hell[1], Vinicius de Souza Oliveira[2], Karina Tiemi Hassuda dos Santos[3], Gleyce Pereira Santos[3], Omar Schmildt[3], Marcio Paulo Czepak[3], Sara Dousseau Arantes[4], Edilson Romais Schmildt[*3]

[1]Federal Institute of Espírito Santo, Campus Itapina, Colatina, Espírito Santo, Brazil; [2]Federal University of Espírito Santo, Center for Agricultural Sciences and Engineering, Alegre, Espírito Santo, Brazil; [3]Federal University of Espírito Santo, North University Center of Espírito Santo, São Mateus, Espírito Santo, Brazil; [4]Capixaba Institute for Research, Technical Assistance and Rural Extension, Regional Center for Rural Development, Brazil.

Abstract: The objective of this study was to obtain the best mathematical equation that estimates the leaf area seedlings of eggplant (*Solanum melongena*) and scarlet eggplant (*Solanum gilo* Raddi) through the linear dimensions of the leaves. Leaves of seedlings produced in a protected environment in the horticulture sector of the Instituto Federal do Espírito Santo – Campus Itapina, Colatina, in the Northwest region of the State of Espírito Santo, Brazil, were used. At 45 days after sowing, the length (L) along the midrib and the maximum width (W) of the leaf blade were determined, the product of the multiplication between the length and width (LW) and the observed leaf area (OLA). With the measurements in hand, the first degree linear model equations were obtained, potencyand its respective coefficient of determination. it was foundby analysis of covariance the possible adequacy of only one model to meet the two species. The models were validated, through a sample of leaves intended for this purpose, where their values of L, W and LW were substituted in the modeling equations, obtaining the estimated leaf area (ELA). A simple linear equation was fitted ELA and OLA. The hypotheses H_0: $\beta_0 = 0$ versus H_a: $\beta_0 \neq 0$ and H_0: $\beta_1 = 1$ versus H_a: $\beta_1 \neq 1$ were tested by Student's t test at 5% probability. The mean absolute error (MAE) and the root mean square error (RMSE) were also determined for all equations. The power ($\mathrm{ELA} = 0.3706(\mathrm{L})^{2.1846}$) and exponential ($\mathrm{ELA} = 0.5000(2.7937)^{\mathrm{W}}$) model equations better predicted the area of eggplant and scarlet eggplant leaves, being the most recommended for these species.

Keywords: *Solanum melongena*; *Solanum gilo* Raddi; non-destructive method; linear dimensions; leaf area estimate; statistical analysis.

Adherence to the BJEDIS' scope: This work is based on the statistical analysis of a sample of eggplant and scarlet eggplant seedling leaves that, through mathematical modeling, allows the adjustment of equations to determine the leaf area of these species in a non-destructive way.

*Address correspondence to this author at the Department of Agricultural and Biological Sciences/Plant Breeding Laboratory, North University Center of Espírito Santo, Federal University of Espírito Santo, Rodovia BR 101 Norte, Km 60, São Mateus, Brasil; Tel: +55-27-3312-1697; E-mails: edilson.schmildt@ufes.br; e.romais.s@gmail.com

1. INTRODUCTION

Knowing the leaf area is a fundamental practice in ecological, agronomic and ecophysiological studies, since its quantification allows the understanding of the behavior of the plant in relation to edaphoclimatic factors, which is a vital organ, directly responsible for the process of photosynthesis and the gas exchange of plants (1). In this sense, there are direct and indirect methods to measure the leaf area.

Direct methods, although accurate, mostly require the destruction of leaves, in addition to the need to use specific equipment, making this type of analysis costly (2). Among the indirect methods, we highlight the mathematical modeling that relates the area with the linear measurements of the leaves, such as length, width or a combination of both, which allows, after an adequate calibration, to predict the leaf area with measurements of the leaves (3). Such mathematical models are simple to use, in addition to not requiring the destruction of leaves to perform the measurements (4).

The use of regression models generated from allometric measurements of leaves to estimate their area is a useful methodology in morphogenic studies (5), and has already been reported for several species such as *Helianthus annuus* L. (6), *Crambe abyssinica* (7), *Jatropha curcas* (2), *Passiflora mucronata* (8), *Litchi chinensis* Sonn. (9) and *Pyrus communis* L. (10). However, studies involving eggplant and eggplant were not found in the literature.

Thus, the objective of the present study was to obtain the best mathematical equation that estimates the leaf area of eggplant (*Solanum melongena*) and scarlet eggplant (*Solanum gilo Raddi*) seedlings through the linear dimensions of the leaves.

2. MATERIALS AND METHOD

In the present study, leaves of eggplant (*Solanum melongena*) and scarlet eggplant (*Solanum gilo* Raddi) seedlings produced in a protected environment in the Horticulture sector of the Federal Institute of Espírito Santo - Campus Itapina, Colatina, in the Northwest region of the State of Espírito Santo, were used. Brazil, located under the following geographical coordinates: 19° 32' 22'' South latitude and 40° 37' 50'' West longitude. The climate of the region according to the classification of köppen it is tropical type AW (11).

In the preparation of seedlings (Figure 1) expanded polystyrene trays with a capacity of 128 cells were used. Cells were filled with commercial Bioplant® substrate with the following chemical composition: N = 0.62%; P_2O_5 = 3.55%; K_2O = 0.53%; Ca = 1.84%; Mg = 0.43%; S = 0.55%; Fe = 2.36%; Zn = 99.8 ppm; Cu = 75.0 ppm; Mn = 333.5 ppm; B = 34.5 ppm. Organic matter = 52.21%. Two seeds were used per cell, after emergence, thinning was done keeping only one seedling per cell.

Figure **1.** Eggplant seedlings (*Solanum melongena*) used to model the leaf area.

At 45 days after sowing, all leaves of 128 eggplant seedlings and 128 scarlet eggplant seedlings were evaluated, obtaining the measurements of length (L) along the midrib and maximum width (W) of the leaf blade, both measurements were obtained with the help of a graduated ruler, in cm (Figure 2). Subsequently, the product of the multiplication between length and width (LW) was determined. The observed leaf area (OLA) was determined through scanned images of the leaves by a desktop scanner model HP Deskjet F4480®, saved in the Tag Image File Format (TIFF) with 75 dpi resolution and processed by the ImageJ® software, in the public domain. (12).

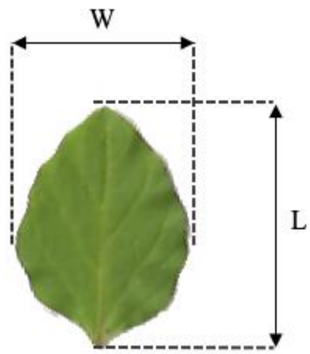

Figure **2.** Representation of the measurement of the length (L) along the midrib and maximum width (W) of the leaf blade of eggplant (*Solanum melongena*).

The data were submitted to descriptive statistics analysis, obtaining the average and minimum values, total amplitude (TA), standard deviation (SD) and coefficient of variation (CV) for all measurements obtained.

For the modeling, 398 eggplant leaves and 392 scarlet eggplant leaves were used, where OLA was used as a dependent variable in function of L, W and LW as an independent variable, obtaining the model linear first degree equations represented by $\mathrm{ELA} = \hat{\beta}_0 + \hat{\beta}_1 \mathrm{x}$, power represented by $\mathrm{ELA} = \hat{\beta}_0 \mathrm{x}^{\hat{\beta}_1}$ and exponential represented by $\mathrm{ELA} = \hat{\beta}_0 e^{\hat{\beta}_1 \mathrm{x}}$ with their respective coefficient of determination (R^2). The parameters $\hat{\beta}_0$ and $\hat{\beta}_1$ were estimated by the method of least squares, being the power and exponential models previously linearized. The constants $\hat{\beta}_0$ and the slope $\hat{\beta}_1$ were verified between the models proposed individually for each species by the analysis of covariance (13) through the test t Student at 5% probability. If the effect on $\hat{\beta}_0$ and $\hat{\beta}_1$ is significant, the best equation for each species individually will be indicated, if there is no effect on $\hat{\beta}_0$ and $\hat{\beta}_0$, the adjusted model with all 790 leaves together (398 of eggplant and 392 of scarlet eggplant) will be indicated.

The models were validated with a sample of 100 leaves (50 of eggplant and 50 of scarlet eggplant), where the values of L, W and LW were substituted in the modeling equations, obtaining the estimated leaf area (ELA). A simple linear equation was fitted ($\mathrm{AFE} = \hat{\beta}_0 + \hat{\beta}_1 \mathrm{x}$) between ELA in function of the OLA, obtaining linear ($\hat{\beta}_0$), angular ($\hat{\beta}_1$) and coefficient of determination (R^2).The hypotheses H_0: $\beta_0 = 0$ versus H_a: $\beta_0 \neq 0$ and H_0: $\beta 1 = 1$ versus H_a: $\beta_1 \neq 1$ were tested by Student's t test at 5% probability. The mean absolute error (MAE) and the root mean square error (RMSE) were also determined for all equations, using expressions 1 and 2.

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

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

Where: ELA are the estimated values of leaf area; OLA are the observed values of leaf area; n is the number of sheets used in the validation (n = 100 in the present study).

The best equations that estimate the leaf area of eggplant and scarlet eggplant were selected according to the following criteria: linear coefficient (β_0) not different from zero, slope (β_1) not different from one, in addition to MAE and RMSE closer to zero. Statistical analyzes were performed using the R software (14) and the graphics using Microsoft Office Excel (15).

3. RESULTS AND DISCUSSION

The analysis of descriptive statistics of the characteristic of the leaves of eggplant (Solanum melongena) and scarlet eggplant (*Solanum gilo Raddi*) seedlings used to generate the models are shown in Table 1. It is observed that the average values of length (L), width (w), product of length and width (LW) and observed leaf area (OLA) were similar, showing that the leaves of both species have a similar shape. The total amplitude (TA) of the 398 eggplant leaves and 392 scarlet eggplant leaves was also very close for all characteristics, with high values for both species, showing that the population sample is very representative.

It was found that for all the characteristics sampled, the coefficient of variation (CV) values varied from 19.81 to 38.25 % for eggplant leaves and from 21.71 to 43.60% for scarlet eggplant leaves. These values, according to Pimentel-Gomes (16) are between the range classified as high or very high. A high variability of the sample data is indicative of leaves of different sizes, obtained at different stages of plant growth and development, being more desired for the generation of mathematical models, since the equations can be used covering small, medium and large leaves (17). Thus, as long as the range of values used for modeling is respected (15) these equations can be used for seedlings in addition to plants of the same species grown under similar conditions (1).

Table **1.** Mean, minimum, maximum, total amplitude (TA), standard deviation (SD) and coefficient of variation (CV) of length (L, in cm), width (W, in cm), product between length and width (LW, in cm^2) of leaf blade and observed leaf area (OLA, in cm^2) of 398 leaves of eggplant seedlings (*Solanum melongena*) and 392 leaves of scarlet eggplant seedlings (*Solanum gilo Raddi*).

Statistic	L	W	LW	OLA
		Eggplant		
Average	2.94	1.99	6.12	4.18
Minimum	1.04	0.62	0.71	0.47
Maximum	4.21	3.09	12.57	8.71
TA	3.17	2.47	11.86	8.24
SD	0.58	0.48	2.34	1.57
CV	19.81	24.27	38.25	37.60

		Scarlet eggplant		
Average	3.03	1.96	6.26	4.36
Minimum	1.48	0.62	1.11	0.73
Maximum	4.55	3.10	13.83	9.68
TA	3.07	2.48	12.72	8.95
SD	0.66	0.49	2.73	1.87
CV	21.71	25.28	43.60	42.98

The analysis of covariance in the slope ($\hat{\beta}_1$) verified a non-significant effect by the t test of student($p<0.05$) only in power model equations, where length (L) was used as an independent variable (Equation 12) and exponential models based on width (W) as an independent variable (Equation 24). This suggests that these equations can be used together to estimate the area of eggplant and scarlet eggplant leaves. The adjustment of a single equation model that aims to estimate the leaf area of several species is fundamental because it allows the researcher to be more agile in obtaining sample data and making decisions. These equations also showed a high degree of correlation, with values of coefficient of determination (R^2) exceeding 0.92, indicating that the independent variable explains 92% of the observed leaf area.

According to Maldaner et al. (18), equations fitted with only one dimension of the leaf surface are more effective, since these models reduce the number of measurements in the estimation of leaf area by 50%, compared to models fitted based on the combination of measurements, which for Oliveira et al. (10) makes the work easier to be carried out in the field. However, according to Espindula et al. (19) these models must be well calibrated so that there is no biased estimation by these equations. Thus, it is necessary to use adequate statistical criteria that validate and prove the legitimacy of the models.

Table **2.** Estimated equations and respective coefficients of determination (R^2) of the leaf area of seedlings of eggplant (*Solanum melongena*), scarlet eggplant (*Solanum gilo* Raddi) and set (eggplant and scarlet eggplant) as a function of length (L), width (W) and of the product length times width (LW) and p-value of the analysis of covariance

Equation	Culture	estimated equation	R2	p-value (1)
1	Eggplant	$\mathrm{ELA} = -3.3715 + 2.5683(\mathrm{L})$	0.9065	
2	Scarlet eggplant	$\mathrm{ELA} = -4.0271 + 2.7692(\mathrm{L})$	0.9437	
3	Set	$\mathrm{ELA} = -3.7187 + 2.6769(\mathrm{L})$	0.9268	<0.05
4	Eggplant	$\mathrm{ELA} = -2.1041 + 3.1471(\mathrm{W})$	0.9420	
5	Scarlet eggplant	$\mathrm{ELA} = -2.8628 + 3.6745(\mathrm{W})$	0.9487	
6	Set	$\mathrm{ELA} = -2.4806 + 3.4068(\mathrm{W})$	0.9336	<0.05
7	Eggplant	$\mathrm{ELA} = 0.1013 + 0{,}6653(\mathrm{LW})$	0.9850	
8	Scarlet eggplant	$\mathrm{ELA} = 0.0847 + 0{,}6831(\mathrm{LW})$	0.9892	
9	Set	$\mathrm{ELA} = 0.0823 + 0{,}6760(\mathrm{LW})$	0.9865	<0.05

10	Eggplant	$\text{ELA} = 0.3857(\text{L})^{2.1628}$	0.9134	
11	Scarlet eggplant	$\text{ELA} = 0.3519(\text{L})^{2.167}$	0.9358	
12	Set	$\text{ELA} = 0.3706(\text{L})^{2.1846}$	0.9252	0.1843
13	Eggplant	$\text{ELA} = 1.2639(\text{W})^{1.6761}$	0.9693	
14	Scarlet eggplant	$\text{ELA} = 1.2572(\text{W})^{1.7690}$	0.9732	
15	Set	$\text{ELA} = 1.2630(\text{W})^{1.7188}$	0.9569	<0.05
16	Eggplant	$\text{ELA} = 0.7168(\text{LW})^{0.9730}$	0.9852	
17	Scarlet eggplant	$\text{ELA} = 0.6733(\text{LW})^{1.0184}$	0.9888	
18	Set	$\text{ELA} = 0.6953(\text{LW})^{0.9953}$	0.9866	<0.05
19	Eggplant	$\text{ELA} = 0.3222e^{2.3098\text{ L}}$	0.8674	
20	Scarlet eggplant	$\text{ELA} = 0.3996e^{2.1185\text{ L}}$	0.8875	
21	Set	$\text{ELA} = 0.3661e^{2.1958\text{ L}}$	0.8683	<0.05
22	Eggplant	$\text{ELA} = 0.4886e^{2.7845\text{ W}}$	0.9192	
23	Scarlet eggplant	$\text{ELA} = 0.5084e^{2.8126\text{ W}}$	0.9437	
24	Set	$\text{ELA} = 0.5000e^{2.7937\text{ W}}$	0.9264	0.5790
25	Eggplant	$\text{ELA} = 1.0798e^{1.2266\text{ LW}}$	0.8585	
26	Scarlet eggplant	$\text{ELA} = 1.2627e^{1.1966\text{ LW}}$	0.8777	
27	Set	$\text{ELA} = 1.1795e^{1.2093\text{ LW}}$	0.8649	<0.05

(1) p-value of the analysis of covariance in which it was verified whether the cultivar has an effect on the slope ($\hat{\beta}_1$).

In both models generated together with eggplant and eggplant leaves, the linear coefficient ($\hat{\beta}_0$) was statistically equal to zero, indicating that when the values of the observed leaf area of the plant are null, the values estimated by the models will also be close to zero. The coefficient angular ($\hat{\beta}_1$) in both models it also had satisfactory results being statistically equal to one, suggesting that as the observed leaf area increases by 1 cm^2, the models will increase by 1 cm^2 in the estimated leaf area. Thus, it can be said that both the models present reliable results in the estimation of the leaf area (3). In addition, these equations also presented values of the mean absolute error (MAE), root mean square error (RMSE) and coefficient of determination (R^2) very similar to each other when validated using a sample of 100 leaves, which indicates similar accuracy between these two models.

Studying leaf area modeling Schmildt et al. (8) indicated the potency model for the species *Passiflora mucronata*, Rouphael et al. (6) obtained a better fit for *Helianthus annuus* L. in the simple linear model and Toebe et al. (7) concluded that for *Crambe abyssinica* the quadratic and geometric models were more accurate. In all these studies, the leaf area was better predicted by equations obtained with only one measure of the leaf surface, corroborating the results found in the present study, showing the efficiency of these adjustments for these species.

Table **3.** Linear coefficients ($\hat{\beta}_0$), angular ($\hat{\beta}_1$), coefficient of determination (R^2), obtained in the adjusted regression between the estimated leaf area (dependent variable) and observed (independent variable), mean absolute error (MAE) and, root mean square error (RMSE) in the validation of equations obtained for seedlings of set eggplant (*Solanum melongena*) and scarlet eggplant (*Solanum gilo* Raddi).

Variable	$\hat{\beta}_0$ (1)	$\hat{\beta}_1$ (2)	R^2	MAE	RMSE
Length	-0.0920ns	1.0549ns	0.9235	0.3484	0.4643
Width	0.0688us	0.9510us	0.9213	0.3343	0.4280

(1)ns Constant does not differ from zero, by Student's t test, at 5% level
(2)ns Intercept does not differ from one, by Student's t test, at 5% level

Thus, the power model represented by the equation $\text{ELA} = 0.3706(\text{L})^{2.1846}$, based on length (L) as an independent variable whose validation lines and 1:1 adequacy line can be seen in Figure 3A and the exponential model represented by the equation , in which $\text{ELA} = 0.5000e^{2.7937\,\text{W}}$ the largest width (W) as an independent variable whose validation lines and 1:1 adequacy line can be seen in Figure 3B, better predicted the leaf area of eggplant and scarlet eggplant together. Thus, considering that these models met all the statistical criteria established in this study, due to their simplicity, requiring the measurement of only one dimension of the leaf surface, these equations are the most recommended in the estimation of leaf area of these two species.

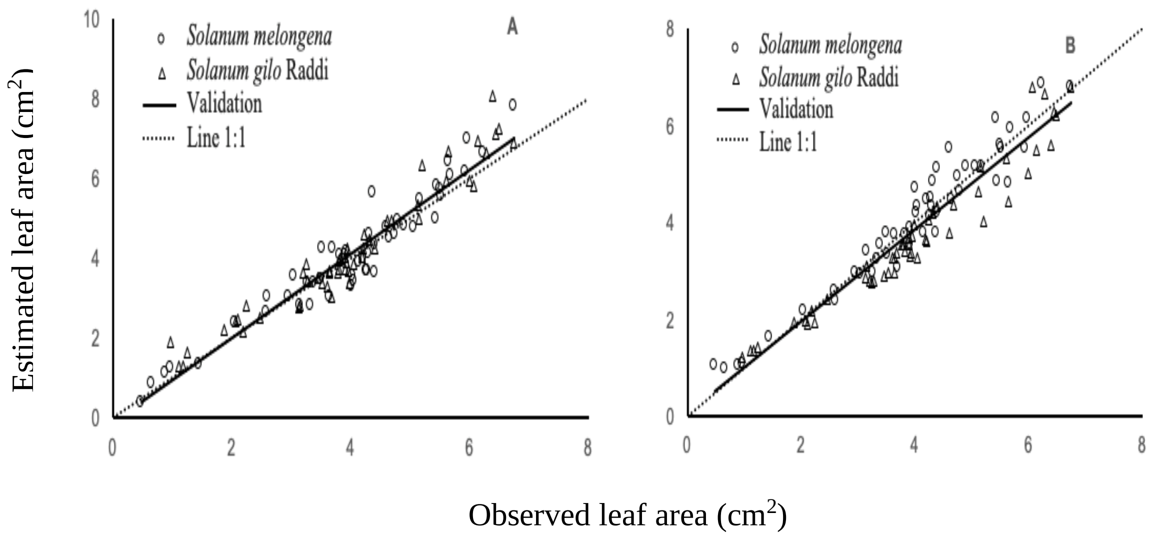

Figure **3.** Validation of models for estimating leaf area in eggplant (*Solanum melongena*) and scarlet eggplant (*Solanum gilo* Raddi) seedlings obtained from measurements of length (L) and width (W). Models: A – eggplant and scarlet eggplant, $\text{ELA} = 0.3706(\text{L})^{2.1846}$; B – eggplant and scarlet eggplant, $\text{ELA} = 0.5000e^{2.7937\,\text{W}}$

4. CONCLUSION

The leaf area of eggplant and Scarlet eggplant seedlings can be efficiently determined jointly from the allometric measurements of length (L) and/or width (W). The power ($\mathrm{ELA} = 0.3706(\mathrm{L})^{2.1846}$) and exponential ($\mathrm{ELA} = 0.5000e^{2.7937\,\mathrm{W}}$) model equations better predicted the area of eggplant and scarlet eggplant leaves, being the most recommended for these species.

CONFLICT OF INTEREST

There is no conflict of interest.

ACKNOWLEDGEMENTS

This work was supported with the award of scholarships by the Coordination for the Improvement of Higher Education Personnel (Capes), the National Council for Scientific and Technological Development (CNPq) and Foundation for Support to Research and Innovation of Espírito Santo (FAPES).

Author statement

Leonardo Raasch Hell: conducted the experimente, and designed the study, **Vinicius de Souza Oliveira:** designed the study, performed the statistical analysis, and managed the writing of the manuscript, **Karina Tiemi Hassuda dos Santos:** conducted the experiment, **Gleyce Pereira Santos:** conducted the experiment, **Omar Schmildt:** conducted the experiment, **Marcio Paulo Czepak:** conducted the experiment, **Sara Dousseau Arantes:** conducted the experiment, **Edilson Romais Schmildt:** designed the study, performed the statistical analysis, and managed the writing of the manuscript.

REFERENCES

1. SANTOS, Ronaldo O., SOARES, Rubiene N., PIMENTEL, Mickelly,P. Q., ABREU, Jadso, C., LIMA, Robson B., SILVA, Breno M. S. Modeling the leaf area of *Ormosia paraenses* Ducke by statistical models and artificial neural networks. **Chilean Journal Of Agricultural Research**. v.78, n.4, p.511-520, 2018. DOI 10.4067/S0718-58392018000400511. Available from: http://dx.doi.org/10.4067/S0718-58392018000400511. Accessed 08 july 2022.

2. POMPELLI, Marcelo F., ANTUNES, Werner C., FERREIRA, Débora T. R. G., CAVALCANTE, Polyana G. S., WANDERLEY FILHO, H. C. L., ENDRES, Laurício. Allometric models for non-destructive leaf area estimation of *Jatropha curcas*. **Biomass and Bioenergy**, v.36, n.1, p.77-85, 2012. DOI: 10.1016/j.biombioe.2011.10.010. Available from: https://doi.org/10.1016/j.biombioe.2011.10.010. Accessed 08 july 2022.

3. TOEBE, Marcos, SOUZA, Rafael R., MELLO, Anderson C., MELO, Patrícia J., SEGATTO, Alexandre, CASTANHA, Ana C. Leaf area estimation of squash 'Brasileirinha' by leaf dimensions. **Ciência Rural**. v.49, n.4, p.1-11, 2019. DOI: 10.1590/0103-8478cr20180932. Available from: https://doi.org/10.1590/0103-8478cr20180932. Accessed 08 july 2022.

4. LEITE, Maurício L. M. V., LUCENA, Leandro R. R., CRUZ, Manoela G., SÁ JÚNIOR, Eduardo H., SIMÕES, Vicente J. L. P. Leaf area estimate of *Pennisetum glaucum* by linear dimensions. **Acta Scientiarum Animal Sciences**. v.41, p.1-7, 2019. DOI: 10.4025/actascianimsci.v41i1.42808. Available from: https://doi.org/10.4025/actascianimsci.v41i1.42808. Accessed 08 july 2022.

5. ACHTEN, Wouter M. J., MAES, Wouter H., REUBENS, Bert, MATHIJS, Erik, SINGH, Virendra P., VERCHOT, Louis, MUYS, Bart. Biomass production and allocation in *Jatropha curcas* L. seedlings under different levels of

drought stress. **Biomass and Bioenergy,** v.34: p.667-676, 2010. DOI: 10.1016/j.biombioe.2010.01.010. Available from: https://doi.org/10.1016/j.biombioe.2010.01.010. Accessed 08 july 2022.

6. ROUPHAEL, Youssef, COLLA, Giuseppe, FANASCA, S., KARAM, Fadi. Leaf area estimation of sunflower leaves from simple linear measurements. **Photosynthetica**, v.45, n.2, p.306–308, 2007. DOI: 10.1007/s11099-007-0051-z. Available from: https://ps.ueb.cas.cz/pdfs/phs/2007/02/25.pdf. Accessed 08 july 2022.

7. TOEBE, Marcos, BRUM, Betânia, LOPES, Sidinei J., CARGNELUTTI FILHO, Alberto, SILVEIRA, Tatiani R. Estimate leaf area of *Crambe abyssinica* for leaf discs and digital photos. **Ciência Rural**. v.40, n.2, p.445-448, 2010. DOI: 10.1590/S0103-84782010000200036. Available from: https://doi.org/10.1590/S0103-84782010000200036. Accessed 08 july 2022.

8. SCHMILDT, Edilson R., OLIARI, Layane S., SCHMILDT, Omar, ALEXANDRE, Rodrigo S., PIRES, Fábio R. Determinação da área foliar de *Passiflora mucronata* a partir de dimensões lineares do limbo foliar. **Revista Agro@mbiente On-line**, v.10, n.4, p.351-354, 2016. DOI: 10.18227/1982-8470ragro.v10i4.3720. Available from: https://pdfs.semanticscholar.org/bebb/b17391b314c8c27e0117e4a917b9acedc242.pdf. Accessed 08 july 2022.

9. OLIVEIRA, Pablo S., SILVA, Wilton, COSTA, Adriana A. M., SCHMILDT, Edilson R., VITÓRIA, Edney L. Leaf area estimation in litchi by means of allometric relationships. **Revista Brasileira de Fruticultura**. v.39, p.1-6, 2017. DOI: 10.1590/0100-29452017403. Available from: https://doi.org/10.1590/0100-29452017403. Accessed 08 july 2022.

10. OLIVEIRA, Vinicius S., SANTOS, Karina T. H., MORAIS, Andréia L., SANTOS, Gleyce P., SANTOS, Jéssica S. H., SCHMILDT, Omar, CZEPAK, Marcio P., GONTIJO, Ivoney, ALEXANDRE, Rodrigo S., SCHMILDT, Edilson R. Non-destructive Method for Estimating the Leaf Area of Pear cv. 'Triunfo'. **Journal of Agricultural Science**. v.11, n.7, p.14- 21, 2019. DOI: 10.5539/jas.v11n7p14. Available from: https://www.ccsenet.org/journal/index.php/jas/article/view/0/39326. Accessed 08 july 2022.

11. ALVARES, Clayton A., STAPE, José, L., SENTELHAS, Paulo C., GONÇALVES, José L. M., SPAROVEK, Gerd. Köppen's climate classification map for Brazil. **Meteorologische Zeitschrift**. v.22, n.6, p.711-728, 2014. DOI: 10.1127/0941-2948/2013/0507. Available from: http://www.lerf.eco.br/img/publicacoes/Alvares_etal_2014.pdf. Accessed 08 july 2022.

12. SCHINDELIN, Johannes, RUEDEN, Curtis T., HINER, Mark C., ELICEIRI, Kevin W. The ImageJ Ecosystem: An Open Platform for Biomedical Image Analysis. **Molecular Reproduction and Development**. v.82, p.518–529, 2015. DOI: 10.1002/mrd.22489. Available from: https://onlinelibrary.wiley.com/doi/10.1002/mrd.22489. Accessed 08 july 2022.

13. ZHANG, Lin, LIU, Xin S. Non-destructive leaf-area estimation for *Bergeria purpurascens* across timberline ecotone, southeast Tibet. **Annales Botanici Fennici**. v.47, n.5, p.346-352, 2010. Available from: http://www.sekj.org/PDF/anbf47/anbf47-346.pdf. Accessed 08 july 2022.

14. R CORE TEAM. **R: a language and environment for statistical computing**. Vienna: R Foundation for Statistical Computing, 2022.

15. LEVINE, David M., STEPHAN, David F., SZABAT, Kathryn A. **Estatistic for managers using Microsoft Excel: global edition**. 8th ed. London: Person. 2017, 728p.

16. PIMENTEL-GOMES, Frederico. **Curso de estatística experimental**. 15th ed. Piracicaba, SP: Fealq. 2009.

17. PEZZINI, Rafael V., CARGNELUTTI FILHO, Alberto, ALVES, Bruna M., FOLLMANN, Diego N., KLEINPAUL, Jéssica A., WARTHA, Cleiton A., SILVEIRA, Daniela L. Models for leaf area estimation in dwarf pigeon pea by leaf dimensions. **Bragantia**. v.77, n.2, p.221-229, 2018. DOI: 10.1590/1678-4499.2017106. Available from: https://doi.org/10.1590/1678-4499.2017106. Accessed 08 july 2022.

18. MALDANER, Ivan C., HELDWEIN, Amo B., LOOSE, Luis H., LUCAS, Dionéia D. P., GUSE, Fabricio I., BORTOLUZZI, Mateus P. Modelos de determinação não-destrutiva da área foliar em girassol. **Ciência Rural**. v.39, n.5, p.1356-1361, 2009. DOI: 10.1590/S0103-84782009000500008. Avaliable from: https://doi.org/10.1590/S0103-84782009000500008. Accessed 08 july 2022.

19. ESPINDULA, Marcelo C., PASSOS, Alexandre M.A., ARAÚJO, Larissa F.B., MARCOLAN, Alarto L., PARTELLI, Fábio L., RAMALHO, André R. Indirect estimation of leaf area in genotypes of 'Conilon' coffee (*Coffea canephora* Pierre ex A. Froehner). **Australian Journal of Crop Science**. v.12, n.6, p.990-994, 2018. DOI: 10.21475/ajcs.18.12.06.PNE1090. Available from: https://www.cropj.com/araujo_12_6_2018_990_994.pdf. Accessed 08 july 2022.