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LEAF AREA ESTIMATION IN LITCHI BY MEANS OF ALLOMETRIC RELATIONSHIPS[1]

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ABSTRACT- Obtaining leaf area is critical in several agronomic studies, being one of the important instruments to assess plant growth. The aim of this study was to estimate equations and select the most appropriate in determining leaf area in litchi (*Litchi chinensis* Sonn.). From the linear dimensions of length (L) and maximum width (W) of leaf limb, equations were estimated using linear, quadratic, potential and exponential models. The linear regression equation using the product of the length by maximum width, given by $\hat{Y} = 0.2885 + 0.662$ (L.W) is the one that best expresses the leaf area estimation of litchi tree.
Index terms: *Litchi chinensis* Sonn., leaf dimension, non-destructive method.

ESTIMATIVA DA ÁREA FOLIAR EM LICHIEIRA POR MEIO DE RELAÇÕES ALOMÉTRICAS

RESUMO - A obtenção da área foliar é fundamental em vários estudos agronômicos, sendo um dos importantes instrumentos que avaliam o crescimento de uma planta. O objetivo do trabalho foi estimar equações e selecionar a mais apropriada na determinação não destrutiva da área foliar em Lichieira (*Litchi chinensis* Sonn.). A partir das dimensões lineares de comprimento (C) e largura máxima (L) do limbo foliar, as equações foram estimadas para os modelos linear, quadrático, potência e exponencial. A equação de regressão linear simples, utilizando o produto do comprimento pela máxima largura, dada por $\hat{Y} = 0{,}2885 + 0{,}662$ (C.L), é a que melhor expressa a estimativa da área foliar de Lichieira.
Termos para indexação: *Litchi chinensis* Sonn., dimensão foliar, método não destrutivo.

Litchi (*Litchi chinensis* Sonn.) is a plant of the Sapindaceae family, the same of guaraná, pitomba and rambutã, typical of subtropical climate. In Brazil, its introduction occurred in the year 1810 in Rio de Janeiro and, from then, its cultivation expanded to the southeastern region (SMARSI et al., 2011). In early 1970s, the first commercial plantations emerged in the state of São Paulo.

Leaves have very important functions in the plant, such as intercepting and absorbing light to perform photosynthesis, gas exchanges, transpiration (SPANN and HEEREMA, 2010) and to define the fungicide application technology to be used, since parameters such as coverage, density and drop deposition depend on leaf area data. Therefore, knowledge of leaf area is extremely important, especially for non-destructive measurements over time.

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Direct and indirect methods can be used to measure leaf area. Direct method can be destructive or not, and indirect is non-destructive. In the direct determination of leaf area, usually all leaves are collected, which characterizes the method as destructive and of high manpower use (SCHMILDT et al., 2014).

Indirectly, leaf area can be measured by area estimation models as a function of linear leaf dimensions, which is advantageous in relation to the direct destructive method because more than one measurement can be made in the same leaves over time, which is interesting in growth analysis studies (OLFATI et al., 2010).

Statistical modeling based on allometric measures of length, maximum width of leaf limb and the product between both has been investigated for several fruits, with the most recent studies for apple (BOSCO et al., 2012), passion fruit (MORGADO et al., 2013), pineapple (FRANCISCO et al., 2014), grape (PERMANHANI et al., 2014) and mango (SILVA et al., 2015).

The aim of this work was to estimate regression equations for different mathematical models and to select the most suitable for leaf area of litchi as a function of leaf length and width.

Leaves were collected in October 2014 from a clonal eight-year-old orchard propagated by the lavering method at Caliman Agrícola S.A. company located in the municipality of Linhares - ES, with geographic coordinates of 19º 11 ‘49 “ S and 40º 05 ‘52 “W and 30 m asl.

Leaves were collected at all stages of development from the middle third of each plant and in the four quadrants, provided they did not present deformations, damages or signs of diseases or pests. Leaves were placed in plastic bags, stored in a thermal box and transferred to the Laboratory of Plant Improvement of the University Center of Northern Espírito Santo (CEUNES), Federal University of Espírito Santo (UFES), located in the municipality of São Mateus.

Among the 500 sampled leaves, 400 were randomly selected to obtain equations and 100 leaves were used to validate them. Measurements were made with maximum widths (W, in cm), in the medial position of the limb, perpendicular to lines of the largest lengths, as well as lengths (L, in cm) on the main vein, considering the insertion point from the limb on the petiole to the apex (SCHIMILDT et al., 2014). With L and W data, the product between L and W was also determined (L.W, in cm^2).

All leaves were scanned in their natural color with the aid of an HP Deskjet F4280®scanner. Images were processed by the public domain ImageJ® version 1.32j software (Wayne Rasband National Institute of Health, USA) to obtain the observed leaf area (OLA, in cm²). Central tendency and variability measures were also calculated.

The following models were used to model OLA (dependent variable = Y_i) as a function of L, W or L.W of the 400 leaves, as independent variables (x_i): simple linear ($Y_i = \beta_0 + \beta_1 x_i + e_i$), exponential ($Y_i = \beta_0 \beta_1^{xi} + e_i$), quadratic polynomial ($Y_i = \beta_0 + \beta_1 x_i + \beta_2 x_i^2 + e_i$) and potential ($Y_i = \beta_0\, xi^{\beta 1} + e_i$), and their respective determination coefficients (R^2). Parameters β_0 and β_1 were estimated by the least squares method and the potential and exponential functions were previously linearized.

The validation of leaf area estimation models was performed based on values estimated by the model ($\hat{Y}_i$) and observed values (Y_i), in 100 leaves. In each model, a simple linear regression ($\hat{Y}_i = \beta_0 + \beta_1 X_i$) of the leaf area estimated by the model (dependent variable) as a function of the observed leaf area (independent variable) was initially adjusted.

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 means of the Student t test, at 5% probability. The mean error ($\bar{E}$), mean absolute error (EAM), root mean square error (RQME) and Willmott's d index (WILLMOTT, 1981) were also determined for all equations by means of the following expressions:

$$\bar{E} = \frac{\sum_{1=1}^{n}\left(\hat{Y}_i - Y_i\right)}{n};\ EAM = \frac{\sum_{i=1}^{n}\left|\hat{Y}_i - Y_i\right|}{n};$$

$$RQME = \sqrt{\frac{\sum_{i=1}^{n}\left(\hat{Y}_i - Y_i\right)^2}{n}};\ d = 1 - \left[\frac{\sum_{i=1}^{n}\left(\hat{Y}_i - Y_i\right)^2}{\sum_{i=1}^{n}\left(\left|\hat{Y}_i - \overline{Y}\right| + \left|Y_i - \overline{Y}\right|\right)^2}\right]$$

where: $\hat{Y}_i$ is the estimated leaf area values $\hat{Y}$ is the observd leaf area values; $\overline{Y}$ is the mean of observed values; n is the number of leaves.

The criteria used to select equations that best estimate leaf area as a function of L, W or L.W were: linear coefficient (β_0) not different from zero, angular coefficient (β_1) not different from one, EAM, RQME and $\bar{E}$ more close to zero, and Willmott's d index (WILLMOTT, 1981) closer to one. Statistical analyses were performed using the Microsoft Office Excel software (LEVINE et al., 2012).

The leaves collected presented considerable variability for length (L), maximum width (W) and length times maximum width (L.W) and observed leaf area (OLA), and this variability was greater for leaves used to obtain equations with sample of 400 leaves in relation to those used for the validation of models, with sample of 100 leaves (Table 1). High variability in allometric measurements is important to obtain the regression equations of each mathematical model, since the equation to be selected can be used for leaves of different sizes within limits of evaluated values. Levine et al. (2012) reported that when using regression models for estimates, the values of the independent variable to be estimated should not extrapolate the values used in the construction of the regression equation.

The estimated regression equations are presented in Table 2. It was verified that in general, there was a good fit between OLA and allometric measurements, with R^2 higher than 0.98, when length times maximum width (L.W) was used as independent variable in the linear and quadratic model. OLA adjustments as a function of L and W were not appropriate, as they presented lower R^2 values, around 0.85, similar to that verified by Francisco et al. (2014) in the modeling of pineapple leaves. It should be noted that a model should not be selected solely by the high R^2value, and it is appropriate to adopt validation measures (FASCELLA et al., 2013).

When validating based on sample of another 100 Litchi leaves, it was observed that of the 12 equations evaluated, only four are adequate, according to criteria of linear coefficient statistically equal to zero and angular coefficient statistically equal to one (Table 3). Among these four equations, the most appropriate is the simple linear, which presents lower mean error ($\overline{E}$), mean absolute error (EAM) and root mean square error values (RQME) and Willmott's d index (WILLMOTT, 1981) value closer to unity. Figure 1 represents the equation selected and the validation representation.

In several other leaf area modeling studies, the equation estimated based on simple linear regression was also indicated, as in apple (BOSCO et al., 2012), Arabica coffee (SCHMILDT et al., 2014) and pigeon pea (CARGNELUTTI FILHO et al., 2015).

Thus, it is concluded that the equation that uses length (L) and maximum leaf width (W), given by $\hat{Y} = 0.285 + 0.662$ (L.W) is the most appropriate to estimate Litchi leaf area (*Litchi chinensis* Sonn.).

TABLE 1 - Minimum, maximum, mean values and variation coefficient (VC, in %) of length (L in cm^2), maximum width (W in cm^2) and length times maximum width (L.W, in cm^2), leaf limb and observed leaf area (OLA, in cm^2) of Litchi (*Litchi chinensis* Sonn.).

Variable	Minimum	Maximum	Mean	VC
Sample of de 400 leaves to obtain estimation equations				
L	6.00	18.00	12.68	15.91
W	2.1	6.00	3.89	16.26
L.W	12.5	102.6	50.36	29.76
OLA	8.00	67.40	33.63	29.80
Sample of de 100 leaves to obtain estimation equations				
L	10.00	18.00	13.93	13.40
W	2.70	5.30	4.094	14.12
L.W	28.35	90.00	57.83	24.94
OLA	18.88	58.77	39.09	24.41

TABLE 2 - Equations for leaf area determination using length (L), width (W) and length times width (L.W) as independent variables (x) and determination coefficient (R^2) based on 400 Litchi leaves (*Litchi chinensis* Sonn.)

Model	x	Equation	R^2
Linear	L	$\hat{Y} = -24.943 + 4.6196x$	0.8646
Linear	W	$\hat{Y} = -23.089 + 14.561x$	0.8470
Linear	L.W	$\hat{Y} = 0.2885 + 0.662x$	0.9803
Exponential	L	$\hat{Y} = 4.9614(1.158)^x$	0.8701
Exponential	W	$\hat{Y} = 5.4421(1.577)^x$	0.8213
Exponential	L.W	$\hat{Y} = 11.527(1.020)^x$	0.9155
Quadratic	L	$\hat{Y} = -2.2615 + 0.9231x + 0.1467x^2$	0.8720
Quadratic	W	$\hat{Y} = -15.251 + 10.5054x + 0.5112x^2$	0.8515
Quadratic	L.W	$\hat{Y} = -1.1665 + 0.7205x + 0.0005x^2$	0.9806
Potential	L	$\hat{Y} = 0.3351x^{1.8053}$	0.8904
Potential	W	$\hat{Y} = 2.9544x^{1.7714}$	0.8515
Potential	L.W	$\hat{Y} = 0.647x^{1.0079}$	0.9155

TABLE 3 - Linear ($\hat{\beta}_0$), angular ($\hat{\beta}_1$) and determination coefficients (r^2) obtained in the adjusted regression between estimated (dependent variable) and observed leaf area (independent variable), mean error ($\bar{E}$) mean absolute error (EAM), root mean square error (RQME) and Willmott's d index (d) calculated based on estimated and observed leaf area of 100 Litchi leaves (*Litchi chinensis* Sonn.)

Model(1)	$\hat{\beta}_0$ (2)	$\hat{\beta}_1$ (3)	r^2	$\bar{E}$	EAM	RQME	d
Simple Linear 1	6.4834**	0.8654**	0.8685	1.3637	3.0562	3.6177	0.9578
Exponential 1	-1.0442^{ns}	1.0789^{ns}	0.8476	1.9580	3.5051	4.7153	0.9433
Quadratic 1	4.0659**	0.9332^{ns}	0.8646	1.5251	3.1082	3.7723	0.9574
Potential 1	3.7188**	0.9389^{ns}	0.8672	1.3952	3.0557	3.7310	0.9585
Simple Linear 2	5.9363**	0.8040**	0.7871	-1.5160	3.4422	4.5281	0.9316
Exponential 2	2.8074^{ns}	0.8808**	0.7619	-1.7258	3.8263	4.9887	0.9254
Quadratic 2	5.7669**	0.8077**	0.7856	-1.5460	3.4537	4.5547	0.9312
Potential 2	4.1794**	0.8460**	0.7811	-1.6765	3.5814	4.6863	0.9307
Simple Linear 3	0.5136^{ns}	1.0004^{ns}	0.9468	0.5315	1.5302	2.2546	0.9853
Exponential 3	-5.720**	1.1722**	0.9204	0.8293	2.3438	3.6564	0.9677
Quadratic 3	0.6073^{ns}	1.0020^{ns}	0.9467	0.6844	1.5894	2.3005	0.9975
Potential 3	-0.0571^{ns}	1.0174^{ns}	0.9468	0.6040	1.5755	2.3142	0.9848

(1) Indices 1, 2 and 3 indicate length, width, length x width, respectively.

(2) ^{ns} Linear coefficient does not differ from zero by the test t at 5% error probability. ** Angular coefficient differs from zero by the t test at 1% error probability.

(3) ^{ns} Angular coefficient does not differ from one by the t-test at 5% error probability. ** Angular coefficient differs from one by the t test a 1% error probability.

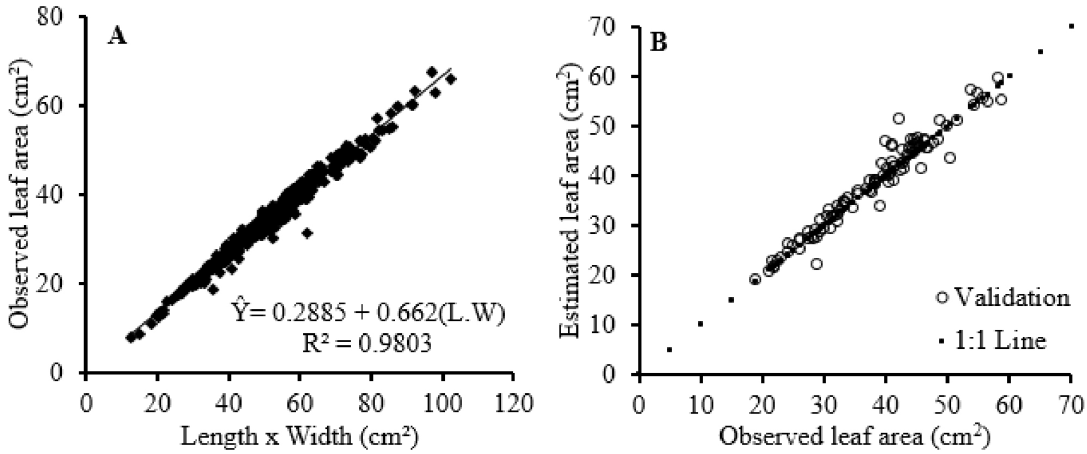

FIGURE 1 - Litchi leaf area representation (*Litchi chinensis* Sonn.) in the linear model for the product between length and maximum width (L.W) of leaves: A = equation estimated based on 400 leaves; B = model validation using 100 leaves.

REFERENCES

BOSCO, L.C.; BERGAMASCHI, H.; CARDOSO, L. S.; PAULA, V. A.; CASAMALI, B. Seleção de modelos de regressão para estimar a área foliar de macieiras 'Roayal Gala' e 'Fuji Suprema' sob tela antigranizo e em céu aberto. **Revista Brasileira de Fruticultura**, Jaboticabal, v.34, n.2, p.504-514, 2012. Disponível em: <http://www.scielo.br/pdf/rbf/v34n2/24.pdf >.

CARGNELUTTI FILHO, A. C.; TOEBE, M.; ALVES, B.; BURIN, C. Estimativa da área foliar de feijão guandu por dimensões foliares. **Ciência Rural**, Santa Maria, v.45, n.1, p.1-8, 2015. Disponível em: <http://www.scielo.br/pdf/cr/v45n1/0103-8478-cr-45-01-00001.pdf >.

FASCELLA, G.; DARWICH, S.; ROUPHAEL, Y. Validation of a leaf area prediction model proposed for rose. **Chilean Journal of Agricultural Research**, Chillán, v.73, n.1, p.73-76, 2013. Disponível em: <http://www.scielo.cl/pdf/chiljar/v73n1/at11.pdf>.

FRANCISCO, J. P.; DIOTTO, A. V.; FOLEGATTI, M. V.; SILVA, L. D. B. da.; PIEDADE, S. M. de S. Estimativa da área foliar do abacaxizeiro cv. Vitória por meio de relações alométricas. **Revista Brasileira de Fruticultura**, Jaboticabal, v.36, n.2, p.285-293, 2014. Disponível em: <http://www.scielo.br/pdf/rbf/v36n2/v36n2a03.pdf>.

LEVINE, D. M. STEPHAN, D.F.; KREHBIEL, T.C.; BERENSON, M. L. **Estatística**: teoria e aplicações usando Microsoft Excel em português. 6. ed. Rio de Janeiro: LTC, 2012. 832 p.

MORGADO, M.A.D.; BRUCKNER, C.H.; ROSADO, L.D.S.; ASSUNÇÃO, W.; SANTOS, C. E. M. Estimação da área foliar por método não destrutivo, utilizando medidas lineares das folhas de espécies de *Passiflora*. **Revista Ceres**, Viçosa, v.60, n.5, p.662-667, 2013. Disponível em: <http://www.scielo.br/pdf/rceres/v60n5/09.pdf>.

OLFATI, J.A.; PEYVAST, G.H.; SHABANI, H.; NOSRATIE-RAD, Z. An estimation of individual leaf area in cabbage and broccoli using non-destructive methods. **Journal of Agricultural Science and Technology**, Tehran, v.12, p. 627-632, 2010. Disponível em: <http://jast.modares.ac.ir/article_4670_1f495e44b648784764761ecf54d4c5f0.pdf

PERMANHANI, M.; VASCONCELLOS, A. A. da S.; SOUZA, R. T. de; MARTELLETO, L. A. P. Estimativa de área foliar da videira 'Niagara Rosada' conduzida em sistema de latada, região norte Fluminense. **Revista Brasileira de Fruticultura**, Jaboticabal, v.36, n.4, p.1034-1040, 2014. Disponível em: < http://www.scielo.br/pdf/rbf/v36n4/a32v36n4.pdf>.

SCHMILDT, E. R.; AMARAL, J. A. T.; SCHMILDT, O.; SANTOS, J. S. Análise comparativa de equações para estimativas da área foliar em cafeeiros. **Coffee Science**, Lavras, v.9, n.2, p.155-167, 2014. Disponível em: <https://coffeescience.ufla.br/index.php/Coffeescience/article/view/573/pdf_81>.

SILVA, S.F. da; CABANEZ, P.A.; MENDONÇA, R.F. de; PEREIRA, L.R.; AMARAL, J.A.T. do. Modelos alométricos para estimativa da área foliar de mangueira pelo método não destrutivo. **Revista Agro@ambiente On-line**, Porto Velho, v.9, n.1, p.86-90, 2015. Disponível em: <http://revista.ufrr.br/index.php/agroambiente/article/view/2134/1516>.

SMARSI, R. C.; OLIVEIRA, G. F.; REIS, L. L.; CHAGAS, E. A.; PIO, R.; MENDONÇA, V.; CHAGAS, P. C.; CURI, P. N. L. Efeito da adubação nitrogenada na produção de mudas de lichieira. **Revista Ceres**, Viçosa, MG,v. 58, n.1, p.129-131, 2011. Disponível em: <http://www.scielo.br/pdf/rceres/v58n1/a20v58n1.pdf>.

SPANN, T.M.; HEEREMA, R.J. A simple method for nondestructive estimation of total shoot leaf area in tree fruit crops. **Scientia Horticulturae**, Amsterdam, v.125, n.3, p.528-533, 2010. Disponível em: <http://www.sciencedirect.com/science/article/pii/S0304423810001883>.

WILLMOTT, C. J. On the validation of models. **Physical Geography**, Norwich, v.2, p.184-194, 1981.