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Economy

Use of mathematical models to estimate the total leaf area of banana

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Abstract - The objective of this work was to adjust and validate a mathematical equation to estimate the total leaf area of banana plants of the cultivars Maça BRS Princesa, Prata BRS Platina, Prata Gorutuba and Prata-Anã together, through the linear dimensions of the third leaf and the total number of leaves. For that, the linear first degree and power models were tested, where was used a dependent variable (y) the total leaf area (TLA) an independent variable (x) the multiplication of the length with the total number of leaves (LN), multiplication of the width with the total number of leaves (WN), and multiplying the length by the width with the total number of leaves (LWN). Analysis of covariance was used to test the possibility of using a single equation to estimate the total leaf area of the analyzed cultivars. For all equations, the mean absolute error, the root mean square error and the Willmott d index were obtained as validation criteria. The power model equation TLA = $3.9292(WN)^{1.5851}$ can be used simply and quickly to determine the total leaf area of plants of the four cultivars under study.

Index Terms: *Musa* spp., non-destructive method, linear dimension, validation.

Uso de modelos matemáticos para estimar a área foliar total de bananeiras

Resumo – O objetivo deste trabalho foi ajustar e validar uma equação matemática para estimar a área foliar total de bananeira das cultivares Maçã BRS Princesa, Prata BRS Platina, Prata Gorutuba e Prata-Anã, de forma conjunta, através das dimensões lineares da terceira folha e do número total de folhas. Para tanto, foram testados os modelos linear de primeiro grau e potência, sendo utilizada como variável dependente (y) a área foliar total (AFT) e como variável independente (x) a multiplicação do comprimento com o número total de folhas (CN), multiplicação da largura com o número total de folhas (LN) e multiplicação do comprimento com a largura, com o número total de folhas (CLN). Utilizou-se a análise de covariância para testar a possibilidade do uso de uma única equação para estimar a área foliar total das cultivares analisadas. Para todas as equações, foram obtidos o erro absoluto médio, a raiz do quadrado média do erro e o índice d de Willmott como critério de validação. A equação de modelo potência AFT = $3{,}9292(LN)^{1{,}5851}$ pode ser utilizada de maneira simples e rápida para determinar a área foliar total das plantas das quatro cultivares em estudo.

Termo para indexação: *Musa* spp., método não destrutivo, dimensões lineares, validação.

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Introduction

The Brazilian fruit industry has stood out in recent years with increments of new technologies used for the development of the activity. The culture of banana (*Musa* spp.) is one of the activities that make up the fruit agribusiness and exerts social and economic importance. Brazil appears as the 4th largest producer of bananas in the world, behind only India, China, and Indonesia (FAO, 2021). In 2020, Brazil produced 6,637,308 tons with a cultivated area of approximately 5.4 million hectares, with the main producer being the state of São Paulo with 1,000,732 tons (IBGE, 2022).

Leaves are the main organ that produces photoassimilates that supply the physiological needs of plants. In banana plants, they interfere with the development of daughter seedlings and can be a source of inoculum for pests and diseases (RODRIGUES et al., 2009). Therefore, the determination of leaf area is an important parameter for studying the interaction of the plant with the environment, allowing us to understand factors such as water loss through transpiration, absorption, and conversion of light energy, in addition to the response to irrigation and the use of fertilizers (BLANCO, FOLEGATTI, 2005). Thus, this characteristic is associated with the accumulation of dry mass, productivity, and crop quality (BUSATO et al., 2010).

The use of mathematical models allows estimating the leaf area of the most diverse species (ZUCOLOTO et al., 2008; OLFATI et al., 2010; CARVALHO et al., 2017; SCHMILDT, 2017; LAVANHOLE et al., 2018; OLIVEIRA et al., 2019; OLIVEIRA, 2020; TOGNERE et al., 2021). In addition, this is a non-destructive method that allows successive evaluations on the same plant, not requiring the use of machinery or specialized labor to carry out the measurements, accurately obtaining the area of the leaves of the cultivars under study (TOEBE et al., 2012).

Specifically, for bananas, Zucoloto et al. (2008) used linear measurements of the third leaf and the total number of leaves of the plant to adjust an equation that estimates the leaf area of the cultivar Prata-Anã. Viana et al. (2015), based on linear measurements of the leaf blade, fitted equations to estimate the individual and total leaf area of cultivars D'Angola belonging to the Plantain subgroup. Donato et al. (2020), adjusted equations to estimate the leaf area of the cultivars Prata-Anã and Platina in the phenological stage of lanceolate leaves. However, few works in the literature seek to adjust mathematical equations for more than one banana cultivar together.

Thus, the objective of this study was to adjust and validate an equation based on mathematical modeling that estimates the total leaf area of banana plants of the cultivars Maça BRS Princesa, Prata BRS Platina, Prata Gorutuba, and Prata-Anã together, through the linear dimensions of the length and width of the third leaf and the total number of leaves of the plants.

Material and methods

The study was carried out in the experimental area of the Center for Agricultural Sciences and Engineering of the Federal University of Espírito Santo (CCAE-UFES), located in the municipality of Alegre, State of Espírito Santo, Brazil, at coordinates 20º 44' 59.19" latitude. South and 41º 29' 14.73" West longitude with an altitude of 116 meters. The climate of the region according to the Köppen classification is humid subtropical Cwa, with dry winters and hot summers (ALVARES, 2014).

Plants of four banana cultivars were used: Maça BRS Princesa, Prata BRS Platina, Prata Gorutuba, and Prata-Anã. The plants were 3 years old and planting was carried out in 2018, with 3 m spacing between rows and 2 m between plants. Planting was carried out leaving the mother, daughter, and granddaughter plant in the row. The irrigation system used was located by microsprinkler. At the time of analysis, the plants had a fully formed bunch stage.

All leaves of plants of the four banana cultivars were collected, and the number of plants and leaves varied according to availability, totaling 57 plants and 408 leaves. The total number of plants sampled was defined according to the methodology adopted by Kumar et al. (2002) (Table 1).

All 408 leaves were measured using the Licor Model LI-3100 electronic meter, and the total leaf area (TLA) of each plant was determined. Also, the total number of leaves (N) per plant was counted. Subsequently, from the third leaf (the leaf that best represents the nutritional status of the plant), of each of the 57 plants, the maximum length (L) along the midrib and the maximum width (W) of the leaf blade were measured, both measurements taken with the help of a measuring tape graduated in centimeters. It was also determined the product of multiplying the length with the width (LW), the product of multiplying the length with the total number of leaves (LN), the product of multiplying the width with the total number of leaves (WN), and product of the multiplying the length by the width by the total number of leaves (LWN).

To adjust the modeling, the models linear first degree represented by $y = \hat{\beta}_0 + \hat{\beta}_1 x$ and power represented by $y \hat{\beta}_0 x^{\hat{\beta}1}$, where TLA was used as the dependent variable (y) in function of LN, WN and LWN as the independent variable (x) were tested. The possibility of using a single equation to estimate the total leaf area of the four banana cultivars was tested, for this, the parameters $\hat{\beta}_0$ and $\hat{\beta}_1$ of each of the equations based on the same characteristic were submitted to analysis of covariance by the student's t test at 5 % probability (ZHANG, LIU, 2010; CIRILLO et al., 2017). To perform the analysis of covariance, the power model was previously linearized with logarithmic base 10 (log) for the variables, dependent (y) and independent (x): $\log(y)_= (\hat{\beta}_0) + \hat{\beta}_1 \log(y)$. Thus, if the equations are not significant, a single equation would be adjusted for the four cultivars. If there was a significant difference between the cultivars, an equation would be adjusted for each one of the cultivars individually. All equations were fitted by the least squares method. The coefficient of determination (R^2) for all equations was also obtained (KVALSETH, 1985).

The adjusted equations were validated with a sample of leaves obtained from five plants of each cultivar collected specifically for this purpose, in which the values of LN, WN and LWN were substituted in the equations proposed in the modeling, thus obtaining the estimated total leaf area (ETLA) for each equation. As a validation criterion was calculated, the Lin concordance correlation coefficient (CCC) (LIN, 1989), the mean absolute error (MAE), the root mean square error (RMSE) and the Willmott index (d) (WILLMOTT, 1981)for all models through the expressions 1, 2 and 3.

$$\text{(1)} \qquad \text{MAE} = \frac{\sum_{i=1}^{n}|\text{ETLA} - \text{TLA}|}{n}$$

$$\text{(2)} \qquad \text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(\text{ETLA} - \text{TLA})^2}{n}}$$

$$\text{(3)} \qquad d = 1 - \left[\frac{\sum_{i=1}^{n}(\text{ETLA} - \text{TLA})^2}{\sum_{i=1}^{n}(|\text{ETLA} - \overline{\text{TLA}}| + |\text{TLA} - \overline{\text{TLA}}|)^2}\right]$$

where, ETLA are the values of the total leaf area estimated by the equations; $\overline{\text{TLA}}$ are the values of the total leaf area of each plant; TLA are the average values of the total leaf area of each plant; and n is the plant number used for validation.

To select the best model to estimate the leaf area of banana cultivars, the following criteria were adopted: higher CCC, MAE and RMSE values closer to zero, and Willmott's d index closer to one.

All statistical analyzes and graphic representations were prepared with the help of the R language (R CORE TEAM, 2022), with commands performed through the ExpDes.pt package version 1.2 (FERREIRA et al., 2018) and DescTools version 0.99.45 (SIGNORELL et al., 2022).

Results and discussion

The analysis of covariance by the student's t-test at 5% probability (Table 2) showed that models 6 and 8 presented values of linear coefficient ($\hat{\beta}_0$) and angular coefficient ($\hat{\beta}_1$) statistically not different for all cultivars. In these models, it is possible to adjust a single equation that estimates the total leaf area of the cultivars, therefore, the data of the four cultivars were grouped. For the other models, the adjustment of a single equation was discarded, since they did not meet this criterion.

The two models were adjusted to jointly estimate the total leaf area of the banana cultivars and the values of the validation criteria are shown in Table 3. It is noted that, although model 6 presents a higher value of the coefficient of determination (R^2), model equation 8 had a lower mean absolute error (MAE), root mean square error (RMSE), Willmott index (d) with greater proximity to a and higher Lin concordance correlation coefficient (CCC). This finding allows us to say that the model equation 5 (Figure 1) produces less error, being more accurate in estimating the total leaf area of the banana cultivars Maça BRS Princesa, Prata BRS Platina, Prata Gorutuba, and Prata-Anã together.

Differently from what was found by Zucoloto et al. (2008), when they reported that the total leaf area of the Prata-Anã banana can be estimated by the model linear first degree with multiplying the length by the width of the third leaf with the total number of leaves of the plant, the results found in this research show that it is possible to estimate the banana leaf area of the cultivars studied with only a linear measure of the leaf blade. This fact may be related to the difference in leaf length between the cultivars, which ranged from 234.80 cm for Maça BRS Princesa to 201.90 cm for Prata Gorutuba. About width, the variation was smaller, from 79.80 cm for Prata-Anã to 72.20 cm for Maça BRS Princesa evidencing more similarity in width between the four cultivars. Another important fact to mention is that the cultivar BRS Princesa is of the 'Maça' type with a higher size, which implies larger leaves than the other cultivars of the 'Prata' type (ROSA, 2016).

In practice, the prediction of the leaf area with only one measure of the leaf blade makes the operation easier to be carried out when compared to equations that use more than one leaf dimension, in this way, the work becomes less onerous since there is a 50% reduction in the number of measures necessary to obtain the leaf area (SANTOS et al., 2016; OLIVEIRA et al., 2019), without losing the high precision in its estimation (BUTTARO et al., 2015). Another advantage associated with the equation adjusted in the present study is that it is possible to contemplate several cultivars, making it more interesting, as it favors data collection and allows its use by researchers and/or producers in places where there is a large number of cultivars (OLIVEIRA, 2020).

It is noteworthy that for the accomplishment of the present study it was necessary to use specific meters to obtain the area of the banana leaves, these equipment demand time for the execution of the measures. In addition, as it is necessary to remove the leaves from the plant, they may not look good for reading, and maybe damaged or lose their turgidity. Another disadvantage of this equipment is the limitation for carrying out experiments, especially those in the field, and the difficulty in collecting and transporting the number of samples to the place where the analyzes will be carried out (LUCENA et al., 2011). However, after adjusting the equation, it is not necessary to use specific equipment, and the total leaf area of the plants can be obtained without the use of more elaborate equipment, requiring only a ruler or a measuring tape. Despite the leaf anatomy of the most diverse banana cultivars being very similar, we only indicate the use of the adjusted equation for the cultivars Maça BRS Princesa, Prata BRS Platina, Prata Gorutuba, and Prata-Anã.

Table 1. Banana cultivars and their respective number of plants and number of leaves used for modeling

Cultivar	Number of plants	Number of Leaves
Maça BRS Princesa	20	164
Prata BRS Platina	18	144
Prata Gorutuba	9	46
Prata-Anã	10	54

Table 2. Presentation of the p value in the analysis of covariance of the linear coefficients ($\hat{\beta}_0$) and angular coefficient ($\hat{\beta}_1$) of the equations of model linear first degree and power fitted with the total leaf area (TLA) in function of the product of the length with the total number of leaves (LN), product of the width with the total number of leaves (WN) and product of the length with the width and the total number of leaves (LWN) of the banana cultivars Maça BRS Princesa, Prata BRS Platina, Prata Gorutuba, and Prata-Anã.

Model	Cultivar	Covariant	p Value	
			$\hat{\beta}_0$	$\hat{\beta}_1$
(4) $TLA = \hat{\beta}_0 + \hat{\beta}_1 LN$	Princesa	Platina	0.053	<0.05
	Princesa	Gorutuba	0.349	0.279
	Princesa	Prata-Anã	0.291	0.174
	Platina	Gorutuba	<0.05	<0.05
	Platina	Prata-Anã	<0.05	<0.05
	Gorutuba	Prata-Anã	0.937	0.916
(5) $TLA = \hat{\beta}_0 + \hat{\beta}_1 WN$	Princesa	Platina	0.505	0.907
	Princesa	Gorutuba	0.136	<0.05
	Princesa	Prata-Anã	0.247	0.059
	Platina	Gorutuba	0.055	<0.05
	Platina	Prata-Anã	0.102	0.065
	Gorutuba	Prata-Anã	0.510	0.494
(6) $TLA = \hat{\beta}_0 + \hat{\beta}_1 LWN$	Princesa	Platina	0.132	0.193
	Princesa	Gorutuba	0.697	0.261
	Princesa	Prata-Anã	0.924	0.279
	Platina	Gorutuba	0.106	0.068
	Platina	Prata-Anã	0.151	0.055
	Gorutuba	Prata-Anã	0.632	0.675
(7) $TLA = \hat{\beta}_0 (LN)^{\hat{\beta}_1}$	Princesa	Platina	0.184	0.172
	Princesa	Gorutuba	0.071	0.073
	Princesa	Prata-Anã	0.115	0.120
	Platina	Gorutuba	<0.05	<0.05
	Platina	Prata-Anã	0.003	0.003
	Gorutuba	Prata-Anã	0.543	0.541
(8) $TLA = \hat{\beta}_0 (WN)^{\hat{\beta}_1}$	Princesa	Platina	0.416	0.433
	Princesa	Gorutuba	0.073	0.065
	Princesa	Prata-Anã	0.141	0.120
	Platina	Gorutuba	0.058	0.056
	Platina	Prata-Anã	0.131	0.122
	Gorutuba	Prata-Anã	0.571	0.576
(9) $TLA = \hat{\beta}_0 (LWN)^{\hat{\beta}_1}$	Princesa	Platina	0.416	0.433
	Princesa	Gorutuba	0.079	0.073
	Princesa	Prata-Anã	0.529	0.493
	Platina	Gorutuba	<0.05	<0.05
	Platina	Prata-Anã	0.081	0.075
	Gorutuba	Prata-Anã	0.200	0.203

p Values greater than 0.05 indicate that the linear coefficients (β_0) and the angular coefficient do not differ between the equations by Student's t-test.

Table 3. Adjusted equations of the model linear first degree and power for estimating the total leaf area jointly of the banana cultivars Maça BRS Princesa, Prata BRS Platina, Prata Gorutuba, and Prata-Anã, in addition to the coefficient of determination (R^2), mean absolute error (MAE), root mean square error (RMSE), Willmott index (d) and Lin's concordance correlation coeficiente (CCC).

Equation	R^2	MAE	RMSE	d	CCC
TLA = -12141.89057 + 0.81988(LWN)	0.9097	97896.43	106193.1	0.0798	0.0258
$TLA = 3.9292\ (WN)^{1.5851}$	0.8251	25162.84	37341.83	0.8508	0.7366

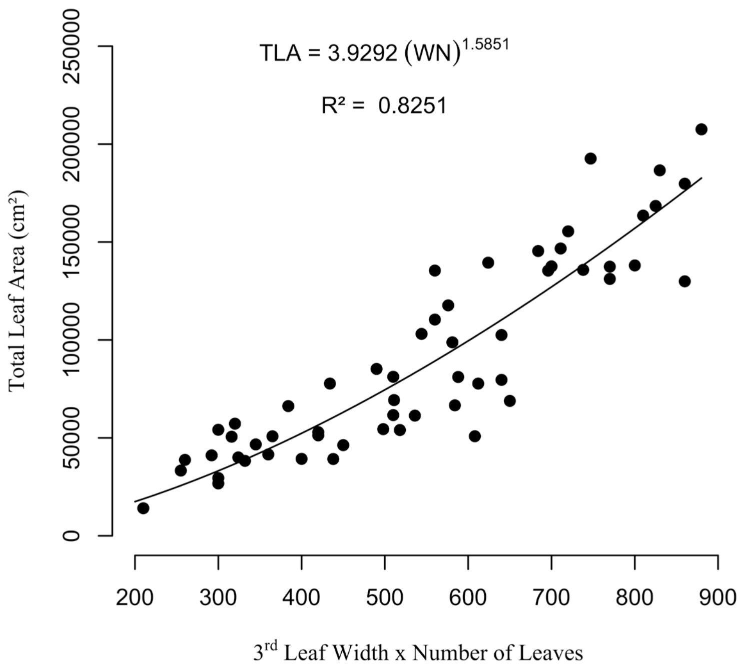

Figure 1. Power model equation fitted using total leaf area (TLA) in function of the product of the width with the total number of leaves (WN) and coefficient of determination (R^2) to estimate the total area of leaves of the banana cultivars Maça BRS Princesa, Prata BRS Platina, Prata Gorutuba, and Prata-Anã.

Conclusions

The total leaf area (TLA) of banana plants of the cultivars Maça BRS Princesa, Prata BRS Platina, Prata Gorutuba and Prata-Anã can be estimated through the equation $TLA = 3.9292(WN)^{1.5851,}$ using the value obtained by multiplying the width of the third leave with the total number of leaves (WN).

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