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BIOLOGY

An allometric model to estimate total leaf area of banana plants of the cultivar Vitória (AAAB)

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ABSTRACT: *The plants physiological processes such as transpiration and photosynthetic efficiency are directly related to leaf area, which is difficult to quantify in a nondestructive manner. To generate a model to estimate the total leaf area of plants of banana cv. Vitória, simple and multiple linear regressions utilizing the length and width of the third leaf, the product of length and width of the third leaf, and the total number of leaves of 'Vitória' plants, were tested. The data to develop the model were obtained from 'Vitória' banana plants from different edafoclimatic conditions and management. The best performance of the model was obtained using stepwise multiple regression with* r^2*=0.93 and* r^2*= 0.94. Validation of the model resulted in an* r^2 *of 0.74.*
Key words: *Musa, genotype, regression, nondestructive method.*

Um modelo alométrico para estimativa da área foliar total de bananeiras da cultivar Vitória (AAAB)

RESUMO: *Processos fisiológicos das plantas como transpiração e eficiência fotossintética estão diretamente relacionados à área foliar, a qual é difícil quantificar de forma não destrutiva. Para gerar um modelo para estimar a área foliar total de plantas da cv. Vitória, foram testadas regressões lineares simples e múltiplas utilizando comprimento e largura da terceira folha, o produto comprimento e largura da terceira folha e número total de folhas. Os dados para desenvolver o modelo foram obtidos de cultivos com diferentes condições edafoclimáticas e de manejo. O melhor modelo foi obtido por meio de regressão múltipla stepwise com* r^2 *= 0,93 e* r^2 *= 0,94. A validação do modelo resultou em* r^2 *de 0,74.*
Palavras-chave: *Musa, genótipo, regressão, método não destrutivo.*

INTRODUCTION

Bananas have been used as food by humans since prehistory and currently are one of the principal products of the world fruit market, produced with a highly organized and developed industry in diverse countries. The fruit is considered to be of fundamental importance for nutritional security of millions of people serving as source of carbohydrates, potassium, and vitamin A (COSTA et al. 2008; DOTTO et al. 2018).

The production of bananas typically requires hot and humid environmental conditions, and they are widely produced in tropical and subtropical countries. Brazil is one of the world's largest producers of bananas, and is responsible for 10 % of the global production, of which 98 % is destined for domestic market. However, banana crop losses due to the incidence of diseases, as well as inadequate crop and post-harvest management in Brazil are estimated to be up to 40 % (VENTURA et al. 2005).

The banana cv. Vitória (BRS Vitória) is a hybrid tetraploid (AAAB) resulting from the cross of 'Pacovan' (AAB), of the subgroup Pome, with the diploid 'M53' (AA). 'Vitória' exhibits resistance to black Sigatoka and yellow Sigatoka, common and destructive leaf diseases of bananas caused by the fungi *Pseudocercospora fijiensis* and *Pseudocercospora musae*; respectively, as well as Panama disease an economically important banana disease caused by the fungus *Fusarium oxysporum* f.sp. *cubense* that infects the vascular system of the plants and alters foliar metabolism. The cv. Vitória was launched commercially in 2005 with objectives to

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minimize losses in the process of banana production. It is characterized by presenting development and yield superior to the ‘Prata Comum’ banana cultivar and flavor similar to the cultivar Pacovan. Chemical analysis demonstrates the excellent quality of fruits and great potential in the consumer market due to the longer durability of the fruits after harvest (VENTURA & GOMES, 2005; VENTURA et al. 2005; SANTOS et al. 2016).

For studies of plant physiology, phytopathology, and the comportment of banana plants in conventional production systems, and alternatives such as agroecological management and agroforestry systems, it is important to know the leaf area of the plants. Leaf area is used to determine the photosynthetic potential of plants and is an important parameter used for evaluation of responses of plants to environmental conditions such as light, temperature, availability of water, severity of diseases, and crop management (TURNER, 1998; STEVENS et al. 2020). However, determination of the total leaf area of plants is slow and a tedious work. Diverse methods have been utilized to determine leaf area, including destructive and nondestructive methods, and allometric models have been described for estimating leaf area including a nondestructive approach that reduces time required and other costs (JONCKHEERE et al. 2004). However, existing models have demonstrated limitations when utilized for different genotypes of bananas or in plants cultivated under conditions of biotic or abiotic stress (ZUCOLOTO et al. 2008; DONATO et al. 2020).

For banana plants, the product of maximum length and width of the third leaf and the number of leaves is a method that has been used for indirect estimation of total leaf area (KUMAR et al. 2002; TURNER, 2003). However, the method is not applicable for all cultivars and stages of development of plants (TURNER, 2003). An allometric equation to estimate the total leaf area of ‘Prata-Anã’ (AAB) banana plants was obtained from simple linear regression considering total leaf area as a function of the length and width of the third leaf, the product of the length and width of the third leaf, and the number of leaves of the plant, and based on the highest coefficient of determination (ZUCOLOTO et al. 2008).

During the development of banana plants there is a change in the shape of leaves that reflects the transition from an initial vegetative stage of slow growth of the plant to a stage of rapid growth. The alteration in the form of the leaves signals the end of the hormonal inhibition of production of suckers by the mother plant (DONATO et al. 2020). The form and extent of these changes have a strong relationship with the plant cultivar or genotype and the edaphoclimatic conditions under which the plants are cultivated, requiring adjustments in methods and models for estimation of the leaf area for new cultivars that have been developed (TURNER, 1998; 2003).

To obtain a mathematical model for estimation of the total leaf area of banana plants of the cv. Vitória, simple and multiple linear regressions were tested utilizing the parameters of data of banana crops with plants cultivated with different practices of management and in different edaphoclimatic conditions in the state of Espírito Santo, Brazil.

MATERIALS AND METHODS

Collection of plants and leaves

Measurements of leaves of banana plants for this study were made in ‘Vitória’ banana crops planted at four sites under different environmental and management conditions, including conventional production and intercropped agroforestry systems in the State of Espírito Santo, Brazil as follows:

Sooretama Experimental Farm (SEF), Incaper

Located at the Incaper Sooretama Experimental Farm (SEF) in the municipality of Sooretama, in the northern region of the state of Espírito Santo (19° 07’ 05” S; 40° 04’ 59” W) with a ‘Vitória’ banana crop area at 63 m of altitude. The crop was grown without irrigation or fertilization in an experimental area planted in 2008 with 3 m x 3 m plant spacing. The climate in the region is tropical, hot and humid, with rainy summers and dry winters, characterized as Aw (Köppen classification). The mean annual temperature of the area is 23.3 °C, varying between a mean minimum of 14.8 °C and a mean maximum of 34.2 °C. The mean annual precipitation is 1,202 mm, with large variations between years (https://meteorologia.incaper.es.gov.br/).

Bananal do Norte Experimental Farm (BNEF), Incaper

Located at the Incaper Bananal do Norte Experimental Farm (BNEF) in the municipality of Cachoeiro de Itapemirim (20° 45’ 19” S; 41° 16 ‘55” W) at 102 m altitude, the area of the planting is an integrated system of production established in 2012 in which ‘Vitória’ bananas (3 m x 4 m) were interplanted with mangosteen (*Garcinia mangostana*) spacing of 6 m x 8 m. Fertilization was according to the recommended agronomic practices for banana in Espírito Santo (VENTURA & GOMES, 2005;

VENTURA et al. 2005). In the region, the mean annual temperature is 24.9 °C, with minimum varying between 11.8 °C and 18 °C and maximum varying between 30.7 °C and 34 °C, and the mean annual precipitation is 1,293 mm (https://meteorologia.incaper.es.gov.br/).

Alfredo Chaves Experimental Farm (ACEF), Incaper

Located in the municipality of Alfredo Chaves, Espírito Santo (20° 38' 10" S; 40° 44' 33" W), 'Vitória' bananas were planted in 2002 in an area at 16 m altitude. The suckers were planted with a spacing of 3 m x 3 m and maintained without irrigation. Fertilizer was applied at planting, and from the first year onwards, lime was applied annually at a rate of 1.5 tons of limestone per hectare. The mean annual temperature of the region is 24.9 °C, with the highest monthly mean in January (27.2 °C) and lowest in July (22.4 °C). Mean annual precipitation in the area is 1,549 mm with rain predominantly between the months of September and April (https://meteorologia.incaper.es.gov.br/).

Argeo Denadai Farm (ADF)

Located in the municipality of Alfredo Chaves, Espírito Santo, a conventional crop system was used for 'Vitória' bananas grown on a private property located 15 km from the city of Alfredo Chaves (20° 31' 33" S; 40° 42' 42" W) at an altitude of 360 m. The cropped was established in 2007 with a 3 m x 3 m plant spacing. Fertilization included application of 2 tons of dolomitic lime per hectare every 2 years, and simple superphosphate with 3 applications of 200 g year^{-1} plant. Mean annual temperature is 24.9 °C with highest values of 22 °C and lowest of 18 °C. Mean annual rainfall is 1,564.5 mm (https://meteorologia.incaper.es.gov.br/).

Development of the model

To develop a mathematical model to estimate the total leaf area of 'Vitória' banana plants, collection and measurement of the leaf area of all functioning leaves of one group of 20 plants consisting of five randomly selected plants collected from each of the four study sites (plots) of cv. Vitória banana plants was conducted.

The plants were evaluated during the phase of inflorescence when leaf development stabilizes and there is no production of new leaves. The individual collected leaves were photographed with a digital camera and the leaf imagens (72 dpi) were vectorized, utilizing the program AutoCAD (AUTODESK, 2011), to obtain measurements of length along the midvein, maximum leaf width, and the actual area of each leaf (MORAES et al. 2013).

The regression analyses were based on the total leaf area of the plant (TLA), in square meters, as a dependent variable, and the parameters of length of the third leaf (L3), in meters, maximum width of the third leaf (W3), in meters, the product of L3 and W3 (L3W3), and the total number of leaves of the plant (NL) as independent variables. Simple linear regression (SLR) and multiple linear regression (MLR) models were tested, using different combinations with the independent variables (L3, W3, L3W3, NL). From the multiple linear regression with all variables, the stepwise method was used to simplify the model. Results of the coefficient of determination (r^2), root-mean square error (RMSE) and standard error (SE) were used to compare the linear regression models.

Validation of the models

The validation of the models obtained accounted with an independent sample with a set of 15 plants collected specifically for this purpose, from a banana plantation located at the Alfredo Chaves Experimental Farm. Models of linear regression were applied to estimate the total leaf area (TLA) of the 15 plants based on measures of the third leaf length and width by using the AutoCAD program (AUTODESK, 2011), and counting the total number of leaves of the plants. The r^2, RMSE and SE calculation allowed defining the model that best fit.

RESULTS AND DISCUSSION

The total number of functional leaves per plant of the cv. Vitória banana plants utilized in the generation of the model varied between 8 and 15. Edaphoclimatic conditions and methods of management of the crops evaluated influenced the number of leaves ($P = 0.01$) and the dimensions of the third leaf ($P < 0.0001$) of the plants. The lowest mean values of length and width of leaves of 1.75 m (SE = 0.12) and 0.54 m (SE = 0.02), respectively, were observed under the conditions of relatively high temperature, and without irrigation and fertilization of the 'Vitória' banana crop located at the Sooretama Experimental Farm (Table 1). Considering that the plants evaluated were in approximately the same stage of development, the occurrence of a smaller number of leaves, as well as smaller dimensions in length and width of the leaves, and lower total leaf area of the 'Vitória' banana plants obtained in the banana crops located at the Sooretama Experimental

Table 1 - Mean values (in meters), standard error (SE) and coefficient of variation (CV) of the parameters total leaf area (TLA), total number of leaves of the plant (NL), length of the 3rd leaf (L3), width of the 3rd leaf (W3) and product of length and width of the 3rd leaf (L3W3) obtained in the crops located at the Sooretama Experimental Farm (SEF), Bananal do Norte Experimental Farm (BNEF), Alfredo Chaves Experimental Farm (ACEF) and Argeo Denadai Farm (ADF).

Site	-----------TLA-----------			----------NL-----------			-------------L3-------------			------------W3------------			---------L3W3--------		
	Mean	SE	CV	Mean	SE	CV	Mean	SE	CV	Mean	SE	CV	Mean	SE	CV
SEF	6.3[1]a	0.6	22.5	9.80a	0.6	13.3	1.7a	0.06	8.3	0.54a	0.02	8.8	0.94a	0.04	10.4
BNEF	17.7b	1.8	22.7	11.8a	0.9	16.3	2.8b	0.2	15.8	0.67b	0.03	8.8	1.95b	0.2	22.9
ACEF	16.0b	0.7	9.76	9.80b	0.5	11.2	2.9b	0.06	4.2	0.73b	0.03	8.1	2.16b	0.1	10.9
ADF	19.9b	1.9	21.4	12.6b	0.5	9.0	3.1b	0.1	7.3	0.74b	0.02	4.7	2.31b	0.1	10.4

[1]Means followed by the same lower case letter in the column do not differ significantly ($P < 0.05$).

Farm may have been influenced by the adverse environmental conditions, principally related to the soil fertility and absence of management of the culture. In contrast, the greater number and size of leaves was observed in the banana crops with conventional intensive management evaluated at the Argeo Denadai Farm in the municipality of Alfredo Chaves, with environmental conditions considered optimal for the production of 'Vitória' bananas. The influence of environmental factors, particularly temperature, soil fertility, and water availability in banana plant biomass production has also been demonstrated in other studies (THOMAS & TURNER, 2001; MELO et al. 2009).

The allometric models obtained from MLR provided better performance compared to the SLR models, demonstrating a better relationship between the dependent variable and the diverse independent variables. The models of MLR, that utilize more than one independent variable, presented the best performances with r^2 greater than 0.90, RMSE less than 1.90 and SE less than 0.50 (Table 2). A strong positive correlation between the measured and estimated data was obtained in generation of the stepwise RLM model ($r^2 = 0.93$; RMSE = 1.86 and SE = 0.43) developed from 'Vitória' banana cultivated in different environmental and management conditions. The correlation between the values of TLA observed (measured) and the values of TLA predicted (estimated) from the parameters NL, L3, W3 and L3W3, varied with the equations, with the highest values of r^2 equal to 0.93 and 0.94 (Figure 1).

The use of the stepwise method enabled the simplification of the proposed MLR model without significant reduction in the coefficient of determination (BUDIARTO et al. 2021). The stepwise analysis indicated that the parameters total number of leaves of the plant (NL) and product of the length

Table 2 - Models obtained, coefficients of determination (r^2), root-mean square error (RMSE) and standard error (SE) from linear regressions to estimate the total leaf area of 'Vitória' banana plants considering the total leaf area (TLA), the number of leaves (NL), the length of the 3rd leaf (L3) and the width of the 3rd leaf (W3) and the product of the length of the 3rd leaf and the width of the 3rd leaf (L3W3).

Model	r^2	RMSE	SE
TLA = -18.37 + 3.02 NL	0.57	4.75	1.09
TLA = -10.92 + 10.13 L3	0.74	3.68	0.84
TLA = -26.52 + 63.46 W3	0.80	3.28	0.75
TLA = -2.48 + 10.07 L3W3	0.81	3.18	0.73
TLA = -13.46 + 1.64 NL - 2.96 L3 -1.58 W3 + 10.75 L3W3	0.94	1.82	0.42
TLA = -16.88+1.63 NL+7.77 L3W3	0.93	1.86	0.43

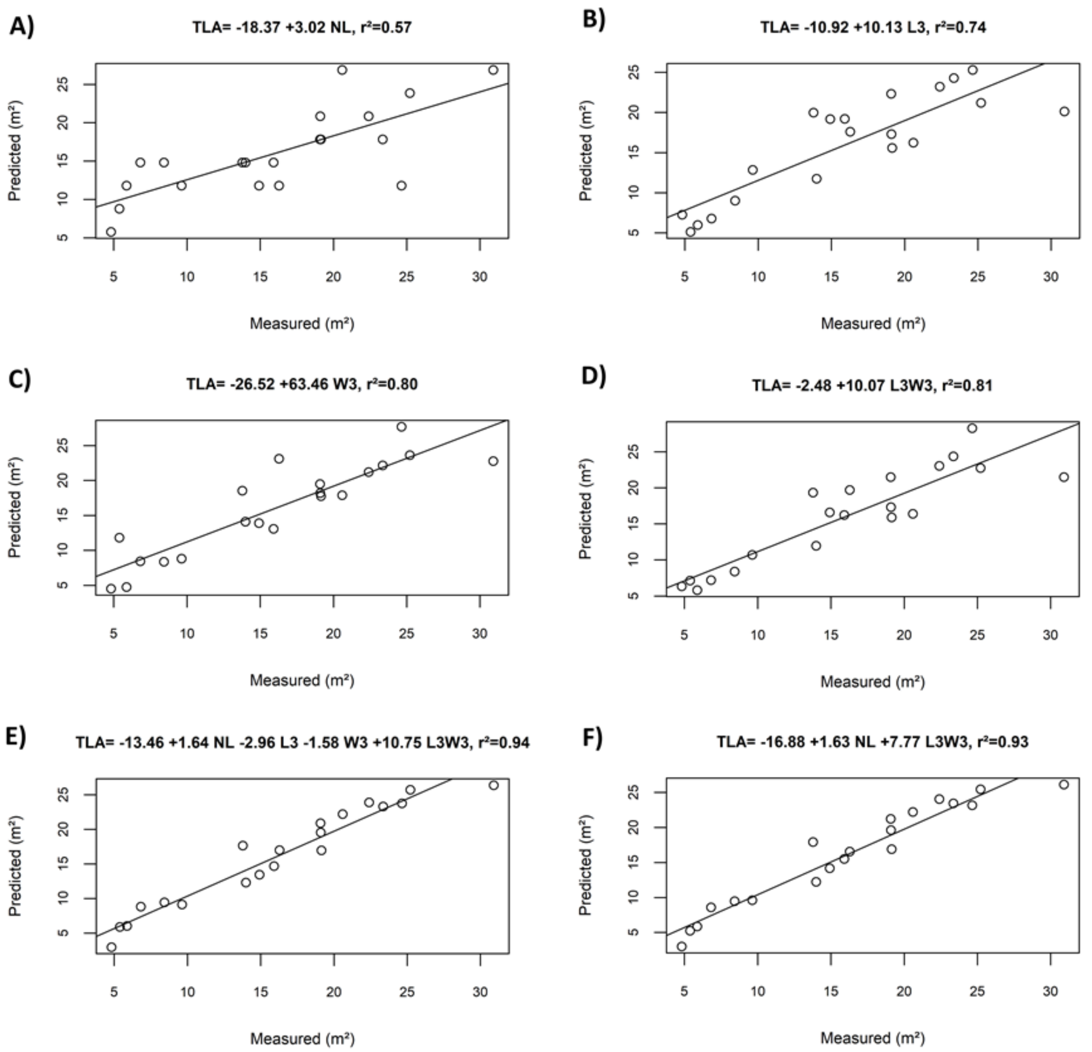

Figure 1 - Correlation between values of the total leaf area (TLA) observed and predicted from the models of linear regression as a function of the parameters: number of leaves NL (a); length of the 3rd leaf (L3) (b); width of the 3rd leaf (W3) (c); product of length and width of the 3rd leaf (L3W3) (d); the combination of all of the parameters (NL, L3, W3, L3W3) (e); and, combination of the number of leaves and product of length and width of the 3rd leaf (f); obtained in the process of modeling the total leaf area of 'Vitória' banana plants.

and width of the third leaf (L3W3) as independent variables were sufficient to estimate the total leaf area of the banana plants. Although, the coefficient of determination was used as a criterion in the definition of the model that best fit to estimate the total leaf area of 'Vitória' bananas, the mean squared error and the standard error were also considered aiming to avoid a false perception of the model's accuracy and precision (BOSCO et al. 2012; RAMOS et al. 2015).

The values of the coefficients of determination of multiple linear regression models for the estimation of the total leaf area (TLA) of cv. Vitória banana plants, (AAAB), obtained in this research, were superior to those obtained by ZUCOLOTO et al. (2008) for the cv. Prata-Anã (AAB) (r^2 = 0.89). A comparison of the models of ZUCOLOTO et al. (2008) and the present study demonstrates the influence of different genomic groups of bananas in the estimation of total leaf area. Plants of the cv. Prata-Anã are of the group AAB, with consequent differences in leaf size and rates of leaf development compared to 'Vitória' banana plants, which are tetraploids of the group AAAB and typically produce larger leaves than those of other banana cultivars. The greater number of leaves per plant in the crops of 'Vitória' banana plants is related to resistance of this cultivar to yellow Sigatoka and black Sigatoka (VENTURA & GOMES, 2005).

The correlation analysis presented in the model validation confirmed the better performance of the MLR model and indicated reliability in the result obtained with r^2 of 0.74, RMSE of 2.09 and SE of 0.56 (Table 3). The results of the analysis of correlation between values observed (measured) and values predicted (estimated) in the process of validation of the model for estimation of the total leaf area of 'Vitória' banana plants presented r^2 greater for the combination of all of the parameters (0.75) and for the combination of the number of leaves and product of length and width of the 3rd leaf (0.74). The lowest value of r^2 resulted from the total leaf area as a function of the parameter length of the 3rd leaf (0.16) (Figure 2). The validation process by using an independent sample of plants, collected specifically for this purpose, in a different environmental condition reinforced the reliability of the model. The analytical method utilized to develop the model enabled the generation of a sound and robust model that can be widely applied in the obtaining total leaf area and facilitate future research related to the physiological processes of this cultivar.

The new model for estimating banana leaf area developed in this research was effective even in crops of cv. Vitória bananas affected by lack of management and conditions of high temperatures and low water availability as observed in the north of Espírito Santo (Sooretama). The mean length and width of the leaves and total leaf area were lower than on the other locations studied. Therefore, we suggest the estimation of the total leaf area (TLA) of 'Vitória' banana plants utilizing the total number of leaves of the plant (NL) and the product of the measurement of the length and width of the 3rd leaf (C3L3) with application of the equation: TLA = -16.88 + 1.63 NL + 7.77 L3W3. The simplified model obtained from the adjustment of equations of multiple linear regression (MLR) with analysis by the stepwise method resulted in improved model performance.

CONCLUSION

The present study provided a mathematical model for estimation of leaf area that was never reported before for tetraploid banana plants (AAAB). Also, results contributed to fill the gap in information needed for an allometric model, effective and simple to perform, to estimate the total leaf area of banana cv. Vitória. The model obtained in banana plantations under different edaphoclimatic and management conditions, resulted from the adjustment of equations of multiple linear regression (MLR) with analysis by the stepwise method that represents an improvement on the methods previously utilized for estimating banana leaf area.

The simplified model obtained will contribute to studies of plant physiology, phytopathology, and the comportment of banana plants in conventional production systems, agroecological management and agroforestry systems in which knowledge of the leaf area of the plants is necessary.

Table 3 - Models utilized, coefficients of determination (r^2), root mean square error (RMSE) and standard error (SE) in the validation of the equations obtained for estimation of the total leaf area of the 'Vitória' banana plants.

Model	r^2	RMSE	SE
TLA = -18.37 + 3.02 NL	0.58	2.94	0.79
TLA = -10.92 + 10.13 L3	0.16	3.45	0.92
TLA = -26.52 + 63.46 W3	0.28	4.01	1.07
TLA = -2.48 + 10.07 L3W3	0.24	3.96	1.06
TLA = -13.46 + 1.64 NL - 2.96 L3 -1.58 W3 + 10.75 L3W3	0.75	2.16	0.58
TLA = -16.88+1.63 NL+7.77 L3W3	0.74	2.09	0.56

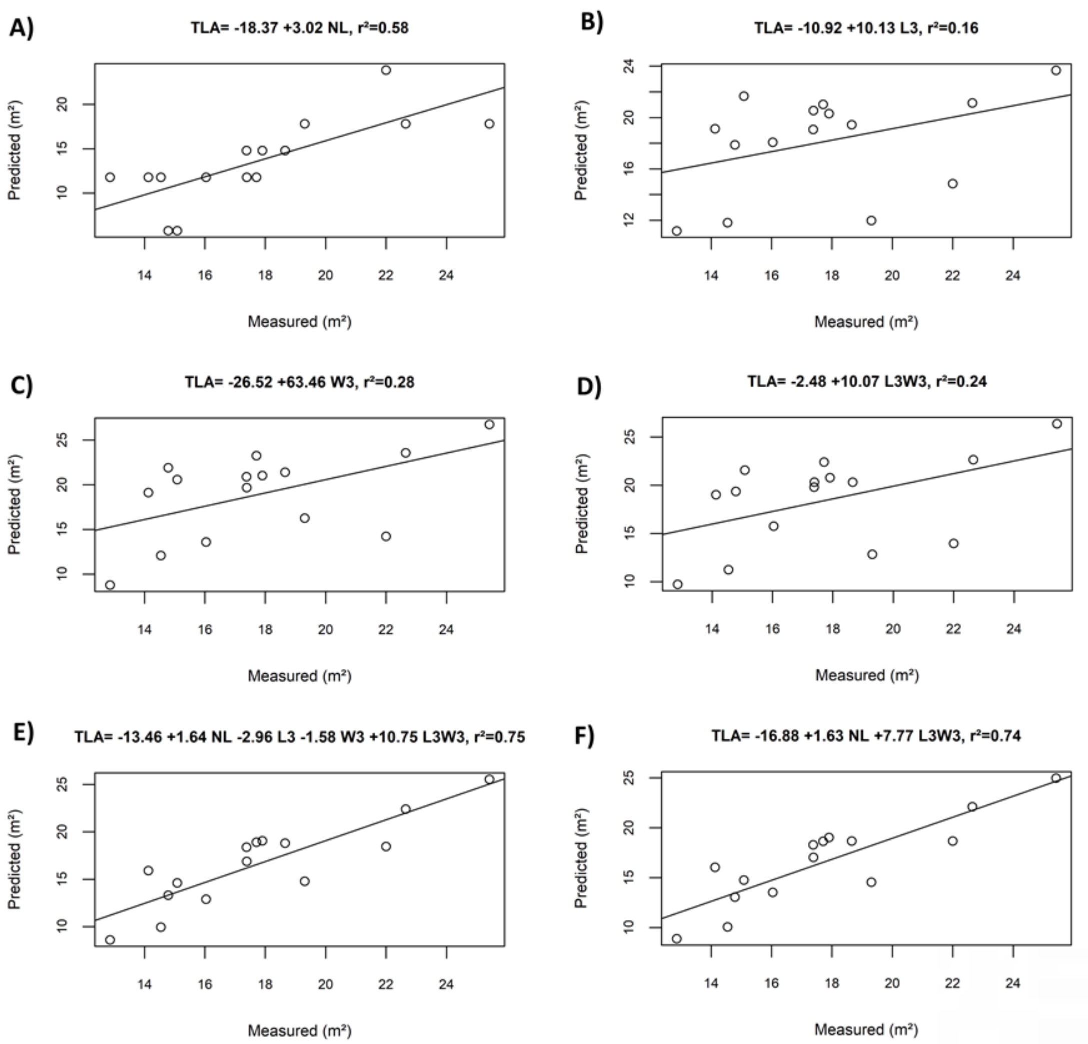

Figure 2 - Correlation between values of the total leaf area (TLA) observed and predicted by the models of regression linear, as a function of the parameters number of leaves - NL (a), length of the 3rd leaf - L3 (b), width of the 3rd leaf - W3 (c), product of length and width of the 3rd leaf - L3W3 (d), combination of all of the variables (e) and combination of number of leaves and product of length and width of the 3rd leaf (f) obtained in the process of validation of the models of regression linear of the total leaf area of 'Vitória' banana plants.

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DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

AUTHORS' CONTRIBUTIONS

The authors equally contributed to the manuscript.

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