Numerical and regression models for the leaf area of tomato seedlings

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Abstract

The determination of the leaf area of plants is important in studies related to their growth and development because in the leaves are synthesized the carbohydrates that will be distributed to the other organs of the plant. In this paper, the authors want to apply new modeling methodologies and compare them with the usual techniques to obtain information of the leaf area considering the explanatory variables length and width and the effect of the container size variable.

The first objective is to determine regression and numerical models, and their comparison to the estimate of the leaves of tomato seedlings (*Solanum lycopersicum* L.), using as explanatory variables the maximum length and width of the sheet. For linear regression models it has identified four types of models: a) a regression model in the variable length b) a regression model in the variable width c) a regression model across the variable and d) a model regression in the variable product of length and width. From the obtained models are selected those that best explain the leaf area.

A new numerical method is also applied for obtaining models of the leaf area and inferring its value from the values of the width and length, which are compared with the regression models. The second objective is to consider the different types of container classified by their size: small, medium and large. Finally, we analyzed the effect of container size on leaf area development of seedlings
Keywords: leaf area, plants, container size, regression models, numerical models.

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1 Introduction

The determination of the leaf area of plants is important in studies related to their growth and development because in the leaves are synthesized the carbohydrates that will be distributed in the other organs of the plant. The photosynthesis capacity of the plants is directly related to the leaf surface and it is expressed as leaf area index [1, 2]. Furthermore the leaf is an important index in the in nutrition studies and plant growth, and it determines dry matter accumulation, carbohydrate metabolism and the yield and quality of harvest [3].

Although the determination of the leaf area is an essential part in the classical analysis of growth and it is necessary in many physiological studies [4], not always there are simple methodologies to estimate it. It have been used several methods to obtain the leaf area that we can be classified in destructive and non destructive and direct and indirect. Among indirect methods are important those which use allometric correlations between magnitudes of leaves and leaf area, measurements of the degree of soil cover or the relation of penetration of radiation and structure of vegetation cover [5].

The direct method use leaf area meters which are instruments designed for this purpose and have an order of resolution of mm^2. Leaf area was determined using Licor LI-3000; Lincoln, Nebraska, USA or CI-203 Area Meter.

The direct measurement is more accurate but need it high cost equipment. Also it has the disadvantage to be a method that not always can be applied with success, especially in those species with large leaves (Cucurbits or composite) and/or deeply lobed (tomato). Among the indirect methods for estimating leaf area, allowing operational overcome this difficulty are those based on allometric correlations.

The leaf area keeps fairly close relationship with its linear parameters, large and width, ant this relation can be described by mathematical models as regression models [6, 7]. In this sense, Pire and Valenzuela [8] find highly significant relationships between large, width and the leaf area through regressions models calculated in different stages of the grape plants. Other studies, using lineal parameters, have obtained regression models to estimate the leaf area in melon plants [9] and paprika [10].

But these methods are not appropriate for some species, for example some vegetables whose compound leaves (tomato) prevent recording the large and width of the leaf. In these cases it can be used an alternative method what is based in the use of images [11], developed a nondestructive method to obtain the leaf area of the tomato, using photographic patterns of sheets of different developmental stages.

To better analyse the behavior of the plants' leaf area by their relation to growth and development, it desirable to get models which can obtain simulations from experimental data in the same conditions of the obtained models. For this reason, in this paper are generated models that estimate the leaf area of the seedlings sheets in tomatoes and considering the large and width as explicative variables. For this, on the one hand are generated regression models and on the other it is applied a new numerical [11, 12], comparing both methodologies and results. The numerical methodology gets us to do simulations in the same way that in the regression models but the way how to get the values inferred is different. Furthermore the effect from the container size in the development of seedlings' leaf area has been analyzed.

The test was achieved, in the period September−December 2000, in the city of Azul to the 45'S 36th and 59th and 57'W to 137 m above sea level, in the province of Buenos Aires, in a greenhouse type double Chapel.

For this test was used the hybrid "Diamond". The seeds were planted in has been analyzed, with different number and shape of the cell: G (big) 59.5 cm^3; M (medium) 45.66 cm^3 and CH (small) 16.79 cm^3. These were placed in a greenhouse on a chinlink table. As substratum was used vermiculite due to its characteristics and to the type of material. It was watered with foliar fertilizer consisting of NPK (nitrogen, phosphorus and potassium) and micronutrients.

To determine of the leaf area of the seedlings leaves was used the processing program and image analysis SCION image, which it is based in the NIH Image for platform Macintosh.

The measuring unit has been centimeter (cm) with a scale of 9,8425 pixels/cm and the measurement were performed at 8 weeks of planted seedlings.
Firstly, a variance analysis was made of the variables: area, large and width of the seedlings using a completely randomize design with a factor (Anova): containers size.

To estimate the leaf area in seedlings from three types of containers, it was generated models applying two methods.

Regressions were determined for each type of container using the following types of models:

$$\textit{Model 1: } y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \varepsilon$$

$$\textit{Model 2: } y = \beta_0 + \beta_1 x_1 + \varepsilon$$

$$\textit{Model 3: } y = \beta_0 + \beta_2 x_2 + \varepsilon$$

$$\textit{Model 4: } y = \beta_0 + \beta_1 x_1 x_2 + \varepsilon$$

where x_1 is the sheet length; x_2 the sheet width

Furthermore it has been applied the numerical methodology developed in [11, 12]. Using geometric models of finite elements, families of models can be obtained and the most suitable to improve the models in relation with the reality have been selected.

2 Results and discussions

Analysis of variance of the variables: area, length and width of sheets, using a completely randomize design with the factor: containers size shows that in some cases there are highly significant differences. Table 1 shows the values obtained to compare the average of the variables from the Duncan test. In the three analyzed variables there are not significant differences between the obtained values, for the seedling produced in medium and large containers. However seedlings from containers small show values for the area, length and large much lower than the others. In general the development of the green matter planted seedlings in small container is half of that obtained in big and medium containers.

Table 1: Comparison of the averages of the different container.

Variable	Average container		
	Small	Medium	Big
Area	0.920 (b)	2.330 (a)	2.371 (a)
Length	1.9848 (b)	3.3812 (a)	3.2785 (a)
Width	0.8434 (b)	1.5915 (a)	1.5524 (a)

The parameters estimates of the regression models, their coefficients of variation (CV) and the percentage of the variance explained by the model (R^2) are showed in tables 2, 3, 4 and 5, for the four types of models.

The parameter estimation, in the model type 1, is shown in the following table:

Table 2: Parameter estimation of the model 1.

Container	Intercept	Length	Width	R^2	CV
Small	-0.56465	0.40096	0.81620	0.897	15.84
Medium	-1.41928	0.62740	1.02302	0.857	19.35
Big	-1.23350	0.61978	1.01269	0.854	14.88

The models chosen are the following:

$$y = -0.56465 + 0.40096x_1 + 0.81620x_2$$
$$y = -1.23350 + 0.61978x_1 + 1.01269x_2$$

The parameter estimation, in the model type 2, is shown in the following table:

Table 3: Parameter estimation of the model 2.

Container	Intercept	Length	R^2	CV
Small	-0.126685	0.527124	0.55	33.12
Medium	-1.61582	1.16706	0.67	29.10
Big	-1.249841	1.104287	0.60	24.63

The parameter estimation, in the model type 3, is shown in the following table:

Table 4: Parameter estimation of the model 3.

Container	Intercept	Width	R^2	CV
Small	0.05062	1.030344	0.60	30.92
Medium	-0.31503	1.54902	0.75	25.61
Big	0.16115	1.423218	0.72	20.50

The parameter estimation, in the model type 4, is shown in the following table:

Table 5: Parameter estimation of the model 4.

Container	Intercept	Length * Width	R^2	CV
Chico	0.21607	0.40526	0.89	16.28
Mediano	0.44467	0.32809	0.87	18.57
Big	0.63824	0.32734	0.84	15.21

The parameter estimation, in the model type 5, is shown in the following table:

Table 6: Parameter estimation of the model 4.

Container	Intercept	Length * Width	R^2	CV
Chico	0.21607	0.40526	0.89	16.28
Mediano	0.44467	0.32809	0.87	18.57
Big	0.63824	0.32734	0.84	15.21

The model chosen is the following:

$$y = 0.44467 + 0.32809 x_1 x_2$$

The tables above show that models 1 and 4 are the best to explain the area. Also it can be seen that the estimations in big and medium containers are similar but different of the small ones.

With the numerical methodology [11, 12], models for each type of container have been generated. The models improve the results obtained in the regression models and enhance the tendency especially regarding experimental data. Below are shown the results obtained for each container and model type.

1- Small container. The regression model selected is of type model 1, and has a coefficient determination, R^2 =0.897. The model equation is:

$$y = -0.56465 + 0.40096 x_1 + 0.81620 x_2$$

The numerical method generates a model with determination coefficient R^2 = 0.938 and improve tendency regarding experimental data.

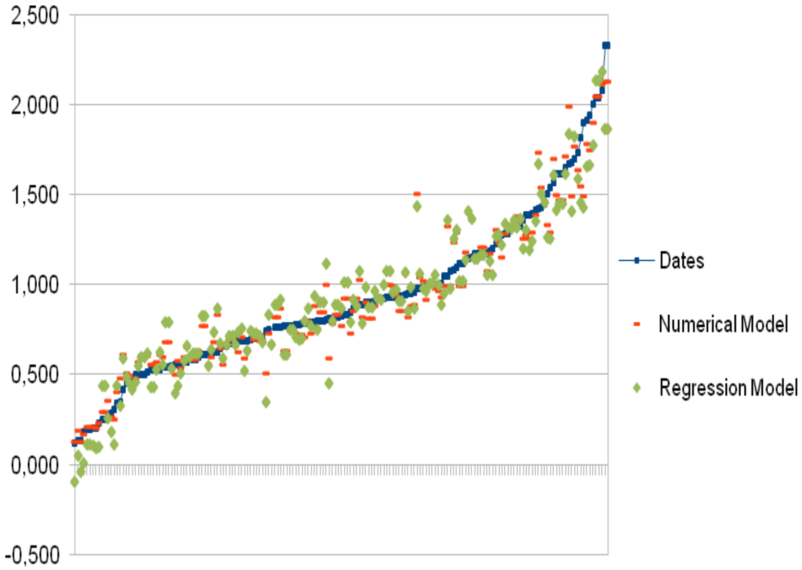

Figure 1: Numerical model, regression of type model 1 and experimental data.

2- Medium container. The regression model selected is of type model 4, and has a coefficient determination, R^2 =0.87. The model equation is:

$$y = 0.44467 + 0.32809 x_1 x_2$$

The numerical method generates a model which determination coefficient R^2 = 0.9295 and improve tendency regarding experimental data as it is shown in the following figure:

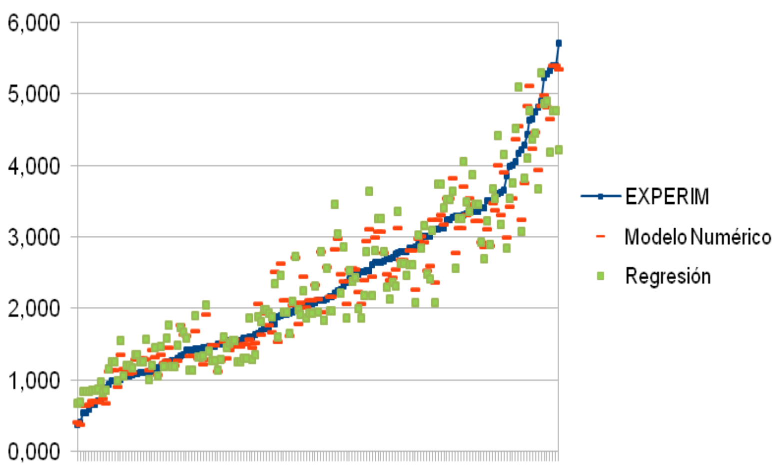

Figure 2: Numerical model, regression of type model 4 and experimental data.

3- Big container. The regression model selected is of type Model 1, and has a coefficient determination R^2 =0.854. The model equation is:

$$y = -1.23350 + 0.61978x_1 + 1.01269x_2$$

The numerical method generates a model which determination coefficient R^2 = 0.943 and improve tendency regarding experimental data as it is shown in the following figure:

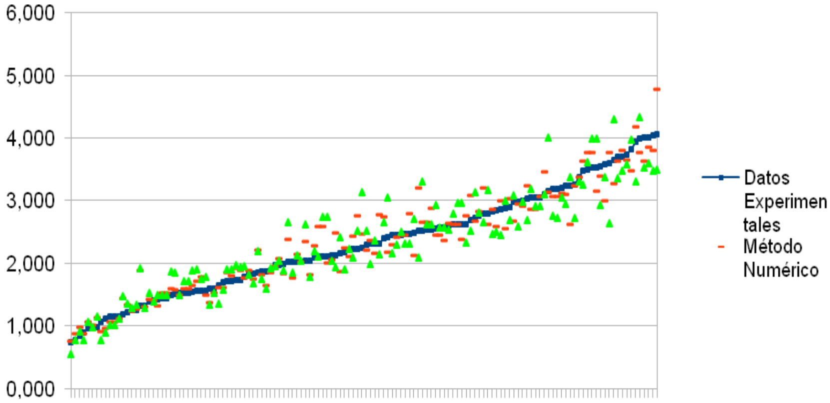

Figure 3: Numerical model, regression of type model 1 and experimental data.

The analysis on the variables: area, length and width of the seedling leaves reveal that there are highly significant differences in some cases. For the three variables analyzed they are not significant differences between the obtained values in seedling produced in medium and big containers. However seedling from small containers shown values in the area, width and length lower than the others containers. We can say that in general the development of green matter of the seedlings planted in small containers is half that obtained in medium and big containers.

The best models for the small and big containers are those which consider as independent variables: the large and the width. In the medium container the best independent variable is the product of the length and the width. Furthermore the models obtained are tools to do simulations. It will be necessary to generate new data to analyze the efficiency of the models and needed to verify whether the improvements of the numerical model correspond to an improvement in the study and inference of leaf area.

Future research will need to consider new variables that may affect the leaf area by identifying and validating new models, which should be compared with those analyzed in this article.

It is possible to have a good estimate of the mean leaf area of the plant of tomato simply by measuring the width and length of the leaf. Equations that use only width or length showed good relationships with leaf area, which demand less effort and time in the measurement at field because just one dimension could be measured.

References

[1] Kozlowski, T., Kramer, P. and Pallardy, S. 1991. The physiological ecology of woody plants. Academic Press. New York.

[2] Leopold, A. and Kriedemann, P.E. 1975. Plant growth and development. McGraw Hill. New York.

[3] Ibarra, W.E. 1985. Comparación y validación de métodos de estimación de área foliar en ocho cultivares de sorgo granífero (*Sorghum bicolor* (L.) Moench) U.C.V. Facultad de Agronomía. Maracay. Tesis de grado.

[4] Sanoja, B., M.J. 1983. Estimación de área foliar de dos variedades de papa (Solanum tuberosum) en las localidades de Mariara, Estado Carabobo y Tucutunemo, Estado Aragua. U.C.V. Facultad de Agronomía. Maracay. Tesis de grado.

[5] Kucharik, C.J., Norman, J.M. and Gower, S.T. 1998. Measurements of branch area and adjusting indirect leaf area index measurements. Agric. For. Meteorol. 91, pp. 69-88.

[6] Manivel, L., Weaver, R.J. 1974.Biometric correlations between leaf area and length measurements of ‘Grenache’ grape leaves. HortScience, v. 9, n. 1, pp. 27-28.

[7] Sepúlveda, G., Kliewer, W.M. **1983**. Estimation of leaf area of two grapevines cultivars (Vitis vinifera L.), using laminae linear measurements and fresh weight. Am. J. Enol. Vitic. 34, pp. 221-226.

[8] Pire, R. and Valenzuela, E.I. 1995. Estimación del área foliar en Vitis vinifera L. ‘French Colombard’ a partir de mediciones lineales en las hojas. Agronomía Tropical 45(1): 143-154.

[9] Chirinos, T.L., Chirunos-Torres, J., Geraud-Pouey, F., Fernández, R., Mármol, L., Chirinos-Torres, D. 1997. Modelos para estimar el área foliar del melón híbrido ‘Durango’. Revista de la Facultad de Agronomía (LUZ) 14(2), pp. 163-171.

[10] Ray, R. and Singh, P. 1989. Leaf area estimation in Capsicum (Capsicum annunn L.) Scientia Horticulturae 39(3) pp. 181-188.

[11] Willians, R.F. 1953 Estimation of leaf area for agronomic and plat physiological studies. Australian Journal Agricultural Research, 5: 235-24.

[12] Villacampa, Y.; Navarro-González, F.J.; Llorens, J. (2009). A geometric model for the generation of models defined in Complex Systems. A geometric model for the generation of models defined in Complex Systems. 978-1-84564-194-8 – pp. 71-82.

[13] Navarro-González F.J. and Villacampa Y. A new methodology for complex systems using n-dimensional finite elements. Advances in Engineering Software 48 (2012) 52-57.