Use of modeling for studying the growth of *Tithonia diversifolia* collection 17

T.E. Ruiz, Verena Torres, G. Febles, H. Díaz and J .González

Mayabeque, Cuba

Email: teruizv@ica.co.cu

This study was conducted under dry conditions to describe the performance of some morphological components of the collection 17 of *Tithonia diversifolia*, through the use of different statistical criteria and to determine the models of best goodness of fit. The indicators were determined every two weeks for 16 weeks. In two moments of 2006 and 2007, from June to October and from January to June respectively, a sampling for each climatic season was conducted: seedling height (cm), weight of 100 leaves green matter (g) (weight 100 L GM), weight of the integral plant green matter (g) (weight IP GM), total weight of a linear meter (g) and green matter (total weight 1 m GM). The variables expressed in DM did not have proper goodness of fit with the models used. The Richards model was not adequate for describing the performance of the variables studied. In the rainy season, the seedling height was adjusted to a logistic model, while the weight of 100 leaves GM had a quadratic performance and that of IP GM was exponential. The weight of 1 m GM did not have significant adjustment for the models considered. The seedling height reached a little bit more than 200 cm in week 18, with a fortnightly growth rate of 0.21 cm. the weight of 100 leaves GM achieved the maximum increase at week 12. The diminishing of the leaves weight was rapid from this time on. The weight of the integral plant showed a tendency to keep increasing after week 18, with value of 87.41 in the last week. During the dry season, the linear model explained the seedling height, and the quadratic that of 100 leaves GM. The exponential referred the IP of the plant GM, and the total weight 1 m GM. The linear dynamics of the seedling height explained an increase of 3.0 cm weekly and 62 cm, as superior height at 18 weeks. The weight of 100 leaves and that of the integral plant reached very low values up to week 18, when both variables increased rapidly, reaching higher values of almost 250 and 100 g. It is concluded that *Tithonia diversifolia* plant material 17 had the best growth characteristics during the rainy season between weeks 12 and 14, including the last. In the dry season, its best growth was from week 12 on. The information allows further studies based on biomass production, even for cutting or grazing, when knowing the performance of different plant components in time.

Key words: *growth, modeling*, *Tithonia diversifolia*

Tithonia diversifolia is a species of great interest for producers as cattle feeding due to its wide adaptation ranges. It has also other benefits in agricultural exploitations (Zapata and Silva 2010).

From the interest on this plant for animal nutrition, and considering its genetic variability, trait referred by Ruiz *et al*. (2010) when assessing 29 plant materials collected in Cuba, the objective of this research was to describe the performance of some morphological components of *Tithonia diversifolia* collection 17 from the use of different statistical criteria and to determine the models of best goodness of fit.

Materials and Methods

In a study of Ruiz *et al*. (2010), where the discrimination of 29 plant materials of Tithonia was conducted, five of them were selected: 23, 5, 10, 16 and 17. They represent the four groups defined in stage 1, where the statistical model developed by Torres *et al*. (2008) was applied. Plant material 17 was analyzed in this research.

Statistical methodology. Different linear and non-linear models were adjusted for this plant material to know the performance of seedling height (cm), weight of 100 leaves (g GM and DM), weight of the whole plant (green material, g) and total weight of a linear meter (g green material) in two moments of 2006 and 2007), from June to October and from January to May.

The models adjusted were:

Linear model 1. $C(t) = A + Bt + \varepsilon$

Quadratic model. $C(t) = A + Bt + \varepsilon$

Logistical model. $C(t) = A\,(1 + Bexp^{(-CT)} + \varepsilon$

Gompertz model. $C(t) = Aexp\ \frac{B(1 - exp(-Ct)}{C} + \varepsilon$

Exponencial model. $C(t) = Aexp\ (Bt) + \varepsilon$

Richards model. $C(t) = A(1 + Bexp^{-Ct})^{D} + \varepsilon$

Where:

C (t): dependant variables height and weight in function of t.

A, B, C and D: Parameters of the models

t: variable measured in time (from 2 to 18 weeks)

ε : random error, normally distributed with zero mean and constant variance.

In order to conduct the adjustment of linear models (linear and quadratic), the least quadratic method was applied. For the non-linear models (logistic, Gompertz, exponential and Richards) the iterative procedure for the estimation of the parameters of Levenberg-Marquardt was used. The beginning was with an initial solution of the parameters and the convergence of the sum of the error quadratics and those of the parameters like 1e-8.

The statistical criteria of Guerra *et al*. (2005) and Torres *et al*. (2001) were used for analyzing the goodness of fit and selecting the best models:

1. Standard error of the estimators of the parameters.
2. Mean quadratic of the error.
3. Coefficient of determination R^2.
4. Signification level of the model adjustment.
5. Analysis of the residues.

The processing was conducted in different stages. The data were organized in the data base Excel to determine the statigraphs and plot the data. Later, the statistical software Infostat (2001) and SPSS (V 11.5) were used for adjusting the models.

Experimental procedure. The study was conducted on a red ferralic soil of rapid drought, clayish and deep over limestone (Hernández *et al*. 1999), equivalent (Duran and Pérez 1994) to the sub-type rodic ferralic cambisol (FAO-UNESCO). The soil was prepared with ploughing and two harrowings. The sowing was conducted in the rainy season, in furrows separated at 3.0 m in the experimental area of Zaldivar, belonging to the Department of Pastures and Forages of the Institute of Animal Science of the Republic of Cuba, located in the western part of the country. Sticks taken from the middle part of the stem were used for the sowing, with 80 d of age and 50 cm length, in furrows of 15 cm depth. The area was kept cleaned of weeds, and on dry conditions. The measurements were every two weeks, for 16 weeks. The cuttings were four at 1 m in each climatic season, at a height of 15 cm in the two years of study.

Results and Discussion

The reaserches with *Tithonia diversifolia* have been addressed mainly to the agronomical, bromatological and nutritional studies, for their application on cutting systems or as green manure mainly. References on this respect may be found in international databases (Scielo, EBSCO and Science Direct) and in journals with high impact indexes.

The results of the statistical criteria for plant material 17 and each season are following presented. A table is shown with the error mean quadratic of the analysis of variance and the signification for each model and variable analyzed, to select the models with best goodness of fit. Later, the information of the models selected is completed with the determination coefficient (R^2), the estimated parameters and their corresponding standard errors.

The variables expressed in DM did not have proper goodness of fit with the models used, hence no results for these variables are informed. The model of Richards is not referred as it was not proper for describing the performance of the variables studied.

In the rainy season, for plant material 17 (table 1) the first two criteria considered for selecting the models of better fit are presented. The seedling height was adjusted to a logistical model, while the weight of 100 leaves GM had a quadratic performance. That of the IP GM was exponential. The weight of 1 m GM did not have significant adjustment for the models considered.

According to the models adjusted, the assessment of the seedling height reached 160 cm in week 18. This material started with a height of 40 cm. During the first weeks, its dynamics was slow and, from week 8 on, it increased rapidly and reached 160 cm in week 18, with fortnightly growth rate of 0.21 cm. The weight of 100 leaves GM reached the maximum increase at week 12 and its diminish was rapid from that moment on. It ended at 18 weeks with 168 g. The weight of the integral plant had a similar performance to the seedling height, but its increase was from week 14 on. It showed a tendency to keep increasing after the 18 weeks, with value of 87.41 in the last (table 2 and figure 1).

Table 1. Criteria CME and signification for each model and variable studied for the plant material 17

Lineal	CMe	Sign
Seedling height	158.77	***
Weight of 100 green leaves (g)	8347.69	NS
Weight IP GM (g)	115.55	**
Total weight of 1 m (g) GM	490281	NS
Quadratic		
Seedling height	165.56	NS
Weight of 100 green leaves (g)	2835.81	*
Weight IP GM (g)	63.19	*
Total weight of 1 m (g) GM	575243.22	NS
Logistic		
Seedling height	133.59	*
Weight of 100 green leaves (g)	72273.19	NS
Weight IP GM (g)	47.93	NS
Total weight of 1 m (g) GM	14682.39	NS
Gompertz		
Seedling height	150.46	NS
Weight of 100 green leaves (g)	7632.67	NS
Weight IP GM (g)	57.12	NS
Total weight of 1 m (g) GM	33240.24	NS
Exponential		
Seedling height	178.36	**
Weight of 100 green leaves (g)	11007.71	NS
Weight IP GM (g)	38.35	**
Total weight of 1 m (g) GM	24158.22	NS

$^*P< 0.05$ $^{**}P< 0.01$ $^{***}P<0.001$

Dry season. In table 3, the criteria for selecting the models of best adjustment show that the linear model referred the seedling height and the quadratic referred the weight of 100 leaves GM. The exponential one was applied for the IP GM and the total weight 1 m GM.

The linear dynamics of the seedling height (table 4) explained the increase of 3.0 cm weekly, and 62 cm as superior height at 18 weeks. Therefore, it was characterized as low. The weight of 100 green leaves hardly varied from week 4 to week 10. It kept in 60 g, and, from that time on, it increased sustainably up to week 18, when reaching 240 units. The weight of the integral plant had very low values up to week 12, when it increased faster, with superior values of almost 100 g of weight approximately, in week 18 (figure 2).

When assessing the three indicators of best adjustment during the rainy season, it ws found between the weeks 10 and 14. This should be considered in further researches on this green material for studies related with biomass production.

In the dry season, the three indicators of best adjustment increased their values in time, although with low growth rate up to weeks 10 and 12. The best values were reached in week 18, so it should be studied for a longer period in further studies. Besides, the values for the whole plant were similar, between weeks 1 and 18 compared with those of the rainy season, adding the weight of 100 leaves. This analysis proves it is a plant material of good performance in the dry season and further studies are suggested.

This study reports, for the first time, the growth of *Tithonia diversifolia* materials collected in different areas of Cuba, allowing a better exploitation of this species.

It is concluded that *Tithonia diversifolia*, plant material 17, had the best growth characteristics during the rainy season up to week 12 and 14. In the dry season, the best growth was from week 12 on.

The information found allows developing further

Table 2. Models selected for the variables with important criteria of goodness of fit for plant material 17

Models	Variables	R^2	CMe	Sign model	Parameters		
					a	b	c
Logistic	Seedling height	0.95	133.59	*	215.44	13.18	0.21
SE					68.02	4.06	0.07
Quadratic	Weight of 100 leaves GM(g)	0.78	2835.81	*	-233.94	90.59	-3.69
SE					122.12	25.37	1.13
Exponential	Weight IP GM (g)	0.95	38.35	**	8.42	0.13	
SE					1.84	0.014	

*P < 0.05 **P < 0.01

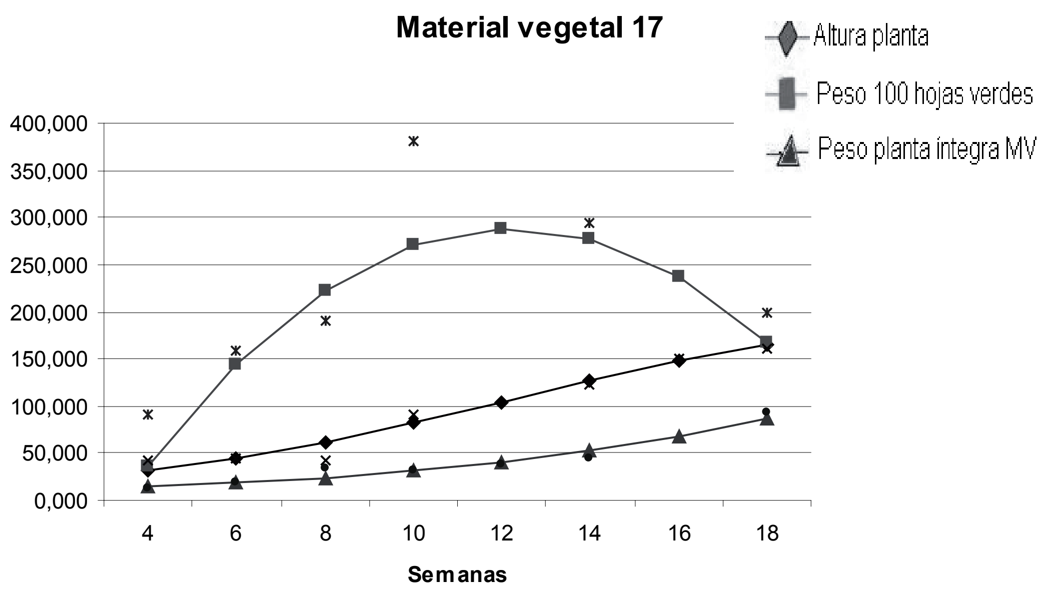

Figure 1. Performance of the models adjusted for the variables studied in plant material 17

Table 3. Criteria CME and signification for each model and variable studied for the plant material 17

Lineal	CMe	Sign
Seedling height	106.92	**
Weight of 100 green leaves (g)	1719.87	*
Weight IP GM (g)	585.84	NS
Total weight of 1 m (g) GM	203728.82	NS
Quadratic		
Seedling height	128.288	NS
Weight of 100 green leaves (g)	693.47	**
Weight IP GM (g)	243.21	*
Total weight of 1 m (g) GM	122689.99	NS
Logistic		
Seedling height	126.33	NS
Weight of 100 green leaves (g)	Not adjusted	
Weight IP GM (g)	Not adjusted	
Total weight of 1 m (g) GM	Not adjusted	
Gompertz		
Seedling height	127.34	NS
Weight of 100 green leaves (g)	1158.13	NS
Weight IP GM (g)	115.88	*
Total weight of 1 m (g) GM	9722.54	NS
Exponential		
Seedling height	113.44	*
Weight of 100 green leaves (g)	878.2	*
Weight IP GM (g)	86.87	**
Total weight of 1 m (g) GM	9467.83	**

$^{*}P < 0.05$ $^{**}P < 0.01$

Table 4. Criteria CME and signification for each model and variables studied in plant material 17

Models	Variables	R^2	CMe	Sign. model	Parameters		
					a	b	c
Linear	Seedling height	0.70	106.92	**	8.26	3.00	
SE					9.51	0.80	
Quadratic	Weight of 100 leaves GM(g)	0.90	693.47	**	141.82	-23.44	1.60
SE					56.27	11.36	0.51
Exponential	Weight IP GM (g)	0.89	115.88	*	0.035	0.44	
SE					0.06	0.10	
Exponential	Total weight of 1 m (g) GM	0.92	23788.90	*	0.000037	0.98	
SE					0.0002195	0.33	

$^{*}P < 0.05$ $^{**}P < 0.01$

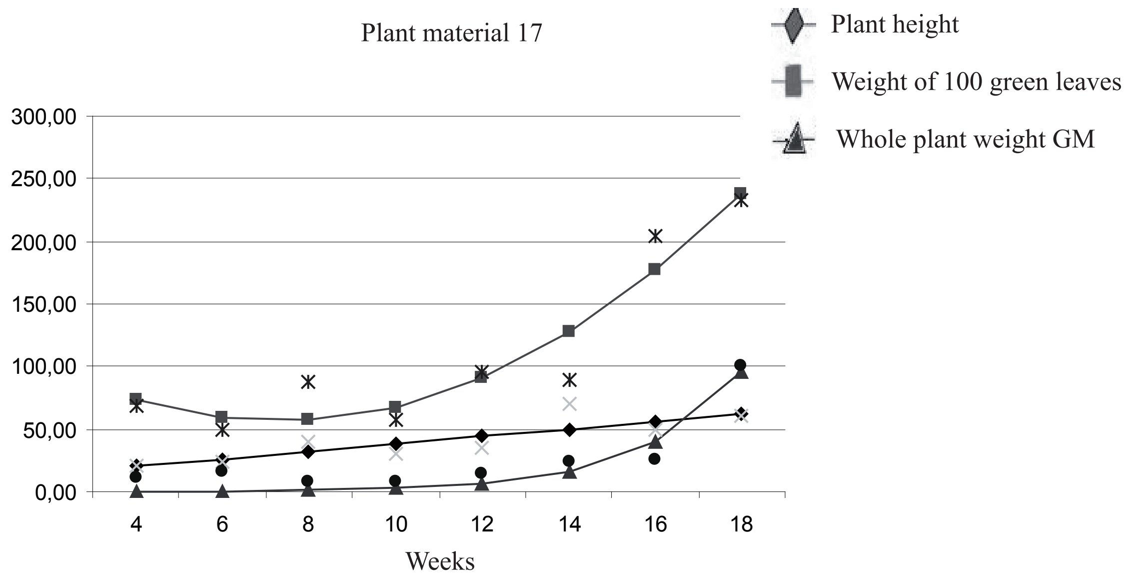

Figure 2. Dynamics of height, weight of 100 leaves GM and weight of the integral plant GM in plant material 17

studies related with biomass production, even for cutting or grazing, as the performance of different components of the plant in time is known.

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