Use of modeling for studying the growth of *Tithonia diversifolia* collection 10

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The study was conducted for two years under dry conditions to describe the performance of some morphological components of the collection 10 of *Tithonia diversifolia*, through the use of different statistical criteria and to determine the models of best goodness of fit test. The indicators were determined every 14 d for 18 weeks, when cutting in each of those moments for each season. The 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) green matter (total weight 1 m GM) were studied in two moment of 2006 and 2007, in the periods June-October and January-June, respectively. The variables expressed in DM did not have proper goodness of fit in the models used. The Richards model was not adequate for describing the performance of the variables studied. In the rainy season, the model of best fit for the seedling height was the model of Gompertz, while the weight of 100 leaves GM, weight of the IP GM and total weight of 1 m GM showed square fits. The variable seedling height reached 175.23 cm of superior value in week 18, with weekly growth rate of 0.14 cm. The weight of 100 leaves GM and that of the integral plant had maximum values at 12 weeks, with 282.47 g and 133.99 g, respectively. The rest of the variables of weight and the total weight 1 m showed maximum values in week 12, with a Little bit more of 6000 g. During the dry season, there were no significant fits for most of the variables under study. The linear fit was considered for the seedling height; although its statistical significance was lower than 0.05. Only the weight of 100 leaves GM had significant fit to the exponential model. It is concluded that *Tithonia diversifolia*, green material 10, had the best growth characteristics during the rainy season up to week 12. However, there was no stability of the indicators under study in the dry season. The results show conditions for developing further studies, related with biomass production, even for cutting or for grazing, when knowing the performance of different plant components in time.

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

Mathematical modeling is a tool of great utility for the different disciplines of knowledge. In Cuba, this technique has developed in the animal branch (Torres *et al*. 2001). However, in studies with plants, specifically in grassland assessments, the studies have been more limited.

The Tithonia genus, with more than 10 species, is from Central America, but it is widely distributed in the tropical area of different continents, giving it a great ecological plasticity. Undoubtedly, it is a new feeding option that may be used to mitigate the lack of feeds, mainly on tropical countries, with insufficient incomes and resources (Pérez *et al*. 2010).

The great interest on this plant is considerable due to its use in animal feeding. Its genetic variability has been object of attention by the scientific community. So it is demonstrated by the study of Ruiz *et al*. (2010), who assessed 29 plant materials collected in Cuba. That is why assessing its characteristics on biomass production is so important.

The objective of this research was to describe the performance of some morphological components of collection 10 of *Tithonia diversifolia* through the use of different statistical and modeling criteria to determine the models of best goodness of fit.

Materials and Methods

A study conducted by Ruiz *et al*. (2010), where 29 plant materials of Tithonia were discriminated, five (23, 5, 10, 16 y 17) representatives of the four groups were selected, defined by their growth and development characteristics in stage 1, using the statistical model of Torres *et al*. (2008). The plant material 10, part of the group showing the intermediate indicators will be analyzed in this study.

Statistical methodology. Different linear and non-linear models were adjusted for plant material 10 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 years of study (2006 and 2007), in the periods June-October (rainy season) and January-May (dry season). The models used for the study were the followings:

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

Squeare 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)

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

In order to conduct the adjustment of linear models (linear and square), the least square 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 squares and those of the parameters like 1e-8.

The statistical criteria of 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 square of the error
3. Coefficient of determination R2.
4. Signification level of the model adjustment
5. Analysis of the residues

The processing was conducted during the two climatic seasons of the years cited. 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 (Visauta1998).

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. The research began after the successful establishment of the area, at 180 d.

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, under dry conditions. The measurements were every 14 d, for 18 weeks, in both years studied. The cuttings were four at 1 m in each interval for every climatic season, at a height of 15 cm.

Results and Discussion

Studying the literature available in different international data bases, indicates no results with modeling were informed on *Tithonia diversifolia* when studying the growth of this plant.

The experience on several studies shows the necessity of assessing the use and benefits of the trees in SPS in different regions (Grande and Maldonado 2011).

In order to make the discussion easier, the average results of the statistical criteria in the plant material 10 are indicated for each season during two years of research. A table with the error mean squares of the analysis of variance of the model and its significance is presented, according to each model and variable analyzed, to select those of best goodness of fit. Later, the information was completed with the information of the models selected with the coefficient of determination (R^2), the parameters estimated and their corresponding standard error.

With the models used, the variables expressed in dry matter did not have proper goodness of fit, hence the information for these variables is not reported. Likewise, the model of Richards was not informed as it was not adequate for describing the performance of the variables studied.

Rainy season. Table 1 presents the criteria for collection 10. The model of best adjustment for the seedling height was that of Gompertz, while the weight of 100 leaves GM, weight WP GM and total weight of 1 m GM had square adjustments. However, the first did not reach important significance, although the level of 10 % was considered for knowing the tendency of the variable in time.

When assessing the biological expression of the models of best adjustment, it was determined that the seedling height reached higher value in week 18, with 175.23 cm, with a weekly growth rate of 0.14 cm. The weight of 100 leaves GM and that of the whole plant had maximum values at week 12, with 282.47 g and 133.99 g, respectively (table 2 and figure 1).

Like the rest of the important variables, the total weight of 1 m for this collection was adjusted to a square model. This showed maximum values in week 12, with a little bit more than 6000 g (figure 2).

The height reached values over 80 cm at week four. Its performance began stabilizing since week 14. However, the weight of 100 green leaves and that of the whole plant GM increased up to week 12 and from that time its declination began.

This material increased its values for this measurement up to week 12. Its dimnishing began rapidly after this moment.

Dry season. The material assessed did not reach significant adjustments for most of the variables under study (table 3). The linear adjustment was considered for the seedling height; although its statistical significance was lower than $P<0.05$. Only the weight of 100 leaves GM had significant adjustment to the exponential model.

Figure 3 and table 4 show that the linear adjustment of the seedling did not represent properly the performance of this variable, from week 14 to 18, when the values were superior. That is why the low determination coefficient of this model (0.64) showed an underestimation for this variable. The height of the plant did not surpass 50 cm.

Tabl 1. Criteria CME and significnace for each model and variables studied for the plant material 10 during the rainy season

Models and variables	Cme	Sign.
Linear		
Seedling height	70.26	***
Weight of 100 leaves GM(g)	3948.17	NS
Weight WP GM (g)	1115.74	NS
Total weight of 1 m GM (g)	2517850.02	NS
Square	Cme	Sign
Seedling height	45.95	NS
Weight of 100 leaves GM(g)	1823.91	NS+
Weight WP GM (g)	261.86	*
Total weight of 1 m GM (g)	153984.56	**
Logistic	Cme	Sign
Seedling height	52.23	*
Weight of 100 leaves GM(g)	1842.17	NS
Weight WP GM (g)	205.18	NS
Total weight of 1 m GM (g)	Sin solución	
Gompertz	Cme	Sign
Seedling height	45.13	*
Weight of 100 leaves GM(g)	1856.21	NS
Weight WP GM (g)	1401.37	NS
Total weight of 1 m GM (g)	Sin solución	
Exponential	Cme	Sign
Seedling height	110.62	***
Weight of 100 leaves GM(g)	1856.21	NS
Weight WP GM (g)	1219.03	NS
Total weight of 1 m GM (g)	150277.31	NS

*P < 0.05 **P < 0.01 ***P < 0.001

Table 2. Models selected for the variables with important goodness of fit for the plant material 10 during the rainy season.

Models	Variables	R^2	CMe	Model Sign.	Parameters		
					a	b	c
Gompertz	Seedling height	0.97	45.13	*	196.12	1.40	0.14
SE					19.24	0.22	0.05
Square	Weight of 100 green leaves (g)	0.72	1823.91	NS+	-67.57	55.93	-2.23
SE					94.68	19.27	0.85
Square	Weigth WP GM (g)	0.88	261.86	*	-83.33	34.19	-1.34
SE					35.87	7.30	0.32
Square	Total weight of 1 m (g) GM	0.96	153984.56	**	-3617.24	1644.76	-69.03
SE					869.94	177.04	7.83

*P < 0,05 **P < 0.01 ***P < 0.001

Like other collections studied, the weight of 100 leaves GM reached slowly superior values after week 10, with numbers inferior to 300 g, at week 18 (figure 3).

It should be considered that in this season, the biological performance could have been influenced by environmental factors that limited its development, as no stability was achieved in any variable. This suggests that this collection could not express its maximal potential.

This study presents for the first time, data about the growth of material 10 collected from *Tithonia diversifolia* in Cuba. The information will be of great utility for improving the exploitation of this species.

It is concluded that the plant material 10 of *Tithonia diversifolia* had the best growth characteristics during the rainy season up to week 12. However, in the dry season, it did not achieve the stability on the

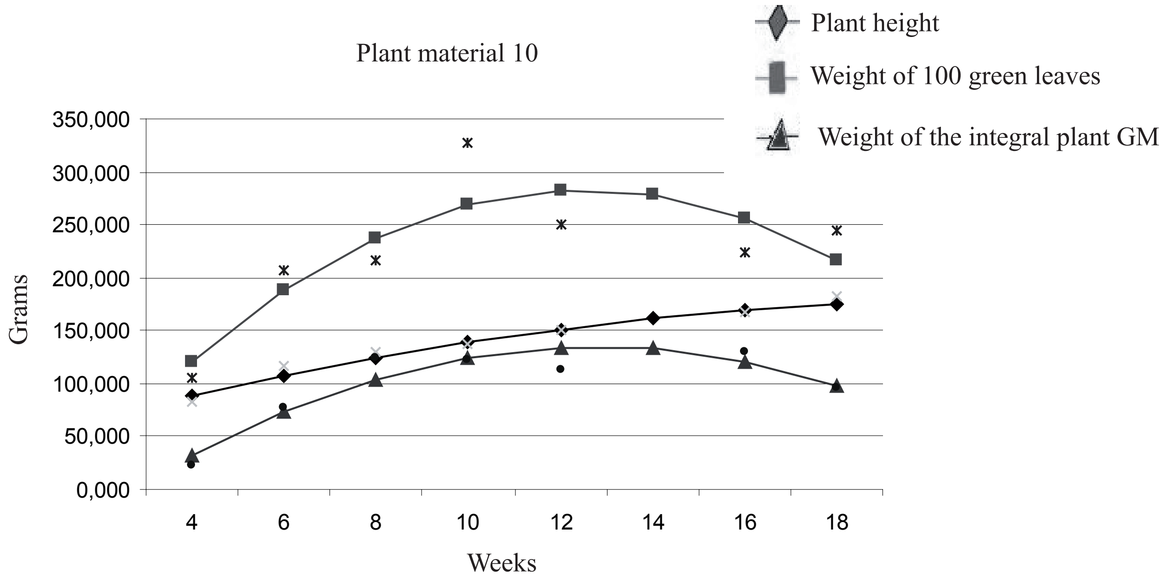

Figure 1. Dynamics of the variables height, weight of 100 leaves GM and weight of the whole plant GM for the plant material 10 during the rainy season.

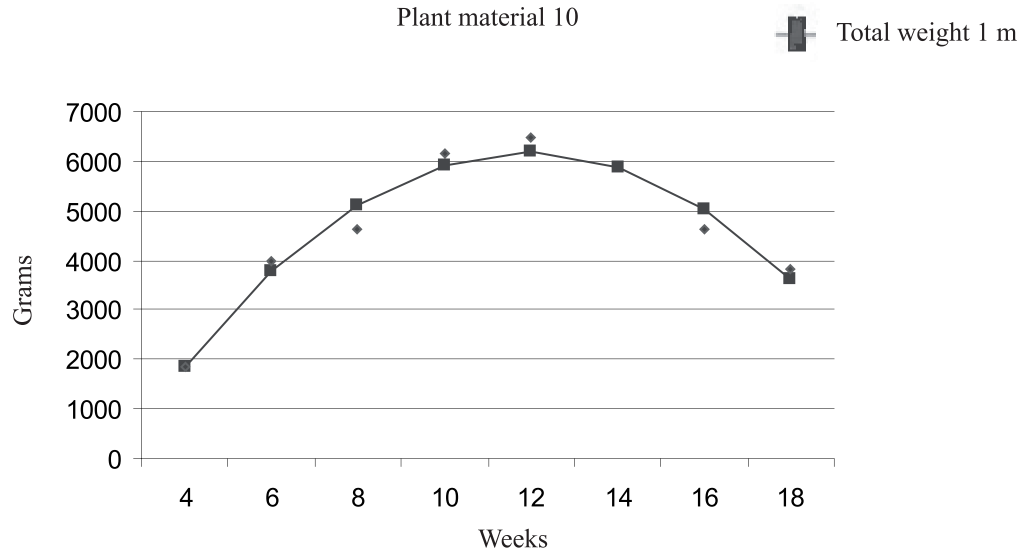

Figure 2. Dynamics of the variable total weight 1 m for the plant material 10 during the rainy season

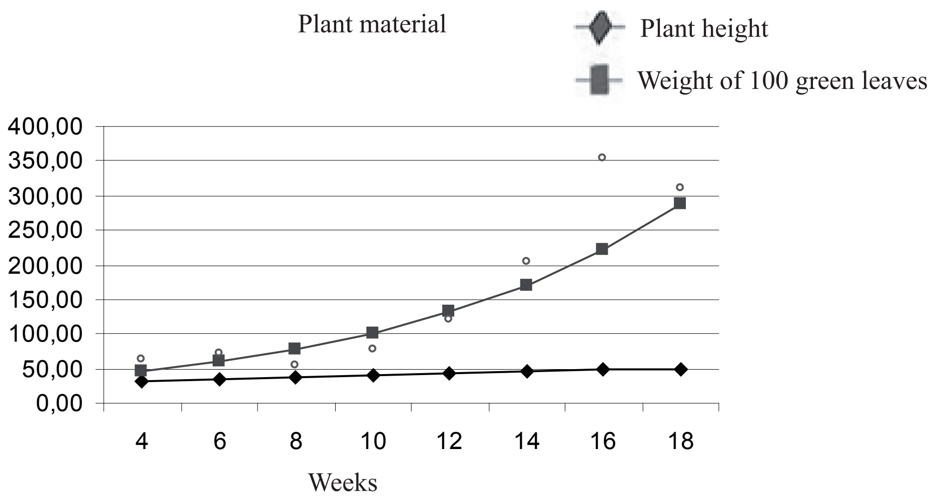

Figure 3. Dynamics of the variables seedling height and weight of 100 leaves GM of the plant material 10 during the dry season.

Table 3. Criteria CME and significnace for each model and variables studied for the plant material 10 during the dry season

Models and variables	CMe	Sign.
Linear		
Seedling height	24.64	NS+
Weight of 100 leaves GM(g)	2146.06	*
Weight WP GM (g)	44.86	NS
Total weight of 1 m GM (g)	2542.49	NS
Square		
Seedling height	18.38	NS
Weight of 100 leaves GM(g)	2200.06	NS
Weight WP GM (g)	48.02	NS
Total weight of 1 m GM (g)	2959.15	NS
Logistic		
Seedling height	12.37	NS
Weight of 100 leaves GM(g)	2302.3	NS
Weight WP GM (g)	54.88	NS
Total weight of 1 m GM (g)	3389.73	NS
Gompertz		
Seedling height	12.41	NS
Weight of 100 leaves GM(g)	2384.8	NS
Weight WP GM (g)	55.45	NS
Total weight of 1 m GM (g)	No ajustó	
Exponential		
Seedling height	27.45	NS
Weight of 100 leaves GM(g)	1810.01	*
Weight WP GM (g)	41.16	NS
Total weight of 1 m GM (g)	2542.74	NS

*P < 0.05

Table 4. Models selected for the variables with important goodness of fit test for the plant material 10 during the dry season

Models	Variables	R^2	CMe	Model Sign.	Parameters		
					a	b	c
Linear	Seedling height	0.64	24.64	NS +	25.63	1.37	
SE					5.21	0.51	
Exponential	Weight of 100 leaves GM (g)	0.72	1810.10	*	27.59	0.13	
SE					16.08	0.04	

*P < 0.05

indicators studied. The results found conditioned the development of further studied related with biomass production, even for cutting or grazing, as they offer data related with the performance of different plant components in time.

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