Use of modeling to study the growth of the plant material 23 of *Tithonia diversifolia*

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A study was conducted under dry conditions for two years to describe, through different statistical criteria, the performance of some morphological components of the plant material 23 of *Tithonia diversifolia* and determine the models of best goodness of fit. The indicators were determined through the cut conducted every two weeks in the rainy and dry season. The experiment lasted 18 weeks during 2006 and 2007. The height of the tuft (cm) was measured, as well as the weight of 100 leaves, green matter (g) (weight 100 L GM), weight of the whole plant, green matter (g) (weight WP GM), and total weight of a linear meter (g) and green matter (total weight 1 m GM). The variables expressed in dry matter did not have proper goodness of fit in the models. Richards' model was not adequate for describing the performance of the variables. In the rainy season, the model of best fit was the linear for the tuft height and the total weight of 1 m, and the quadratic, for the weight of 100 leaves GM. The variables tuft height and total weight of 1 m reached the highest values at 18 weeks, with 174.98 cm and 4927.3 g, respectively. The maximum weight of 100 leaves GM was at 14 weeks, with 220.59 g. The weight of the whole plant weight kept increasing even at 18 weeks and reached 109.70 g. In the dry season, all the variables had significant fits for the exponential model, due to their low mean squares. The Gompertz model did not have numerical solution for the variables under analysis. The exponential dynamics showed slow performances during the first three weeks (4, 6 and 8) and increases from week 10 to 18. Since that time, they kept increasing, not reaching stable or maximum values. The total weight of 1 m GM reached more than 3000 g at 18 weeks and had considerable amount of leaves. It is concluded that the plant material 23 of *Tithonia diversifolia* reached the best growth characteristics during the rainy season up to week 14, while, in the dry season, its best growth was since week 10. This information allows further research related to biomass production, cutting or grazing, because performance of different plant components can be known.

Key words: *growth, modelling, Tithonia diversifolia.*

Tithonia diversifolia is an herbaceous tree species with attractive yellow flowers. It has great adaptation capacity. It can be found at sea level or at about 2 400-m height. It can grow in high- or low-fertility soils. It is used for animal feeding and has additional benefits to control erosion (Zapata and Silva 2010).

Mathematical modeling is a tool of great use in different knowledge fields. In Cuba, this technique has been developed in the animal branch (Torres *et al*. 2001). However, in plant studies, specifically in pasture evaluation, works are incipient and narrow.

Ruiz *et al*. (2010), by evaluating 29 plant materials collected in Cuba, noted the considerable interest in this plant, specially due to its genetic variability and as source in animal feeding. Thus, it is necessary in biomass production to assess its growth characteristics. The object of this research was to describe the performance of some morphological components of the plant material 23 of *Tithonia diversifolia* and determine, through statistical and modeling criteria, the models of best goodness of fit.

Materials and Methods

In a study of Ruiz *et al*. (2010) the discrimination of 29 plant materials of Tithonia was conducted, and 5 (23, 5, 10, 16 and 17) were selected, representing the four groups. Due to their growth and development characteristics, they were located in the stage 1. The statistical model of Torres *et al*. (2008) was used. In this research, the plant material 23 is analyzed, being part of the group that showed the highest indicators.

Statistical methodology. Different linear and non-linear models were fitted to know the performance of the variables height of the tuft (cm), weight of 100 leaves (g GM and DM), weight of the whole plant (green matter, g) and total weight of one linear meter (g green matter) during 2006 and 2007, from June to October (rainy season), and from January to June (dry season).

The models for the fit were the following:

Linear model: $C(t) = A + B(t) + \varepsilon$

Cuadratic model: $C(t) = A + B(t) + C(t)^2 + \varepsilon$

Logistic model: $C(t) = A/(1 + B\exp(-Ct) + \varepsilon$

Gompertz model: $C(t) = A\exp^{\frac{B(1-\exp(-Ct)}{C}} + \varepsilon$

Exponential model: $C(t) = (A\exp(Bt) + \varepsilon$

Richards model: $C(t) = A(1 + B\exp^{-Ct})^D + \varepsilon$

Where,

C (t): Dependent variables height and weight according to 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 mean zero and constant variance.

In order to conduct the fit of the linear models (linear and quadratic), the method of least squares was used. For the non-linear (logistic, Gompertz, exponential, and Richards), it was used the iterative procedure of estimation of the parameters of Levenberg-Marquardt. In this instance, work was started out of an initial solution of the parameters and the convergence of the sum of the squares of the error and of the parameters was pre-fixed as $1e^{-8}$.

In order to analyze the goodness of fit and selecting the best models, the statistical criteria of Guerra *et al*. (2005) and Torres *et al.* (2001) were applied:

1. Standard error of the estimators of the parameters
2. Mean square of the error
3. Coefficient of determination R^2.
4. Significance level of the fit of the model
5. Analysis of the residues

The processing was carried out for the two seasons. The information was organized in Excel databases to determine the statistics and for the plot of the data. Later, the statistical software Infostat (2001) and SPSS (V 11.5) were used in the fit of the models (Visuata 1998).

Experimental procedure. The work was conducted on red ferrallitic soil, of fast drying, clayish and deep on limestone (Hernández *et al*. 1999), equivalent (Duran and Pérez 1994) to the rodic ferrallic cambisol subtype (FAO-UNESCO) with preparation of plowing and two harrow passes. Tithonia was planted in the rainy season, in furrows 3.0 m apart, in the experimental area of Zaldívar in the Department of Pastures and Forages at the Institute of Animal Science in Cuba, located in the western part of the country. The study was started after the satisfactory establishment of the area.

The plantation was performed in furrows of 15 cm depth. Cuttings of the middle part of the stem were used. They had 50cm of length and were 80 d old. The area was kept free of weeds and under dry conditions.

The measures were performed every two weeks, for a period of 18 weeks. Thus, the cut was performed four times, 1 m linear, at a height of 15 cm in every season during the two years under study.

Results and Discusion

The explanation and comparison of the results was difficult and complex, because the available information in international databases such as Scielo, EBSCO, and Science Direct and in journals with high impact indices shows that the studies on *Tithonia diversifolia* has been focused, mainly, on agronomic, bromatological and nutritional studies for its utilization in systems of cut and carry or as green fertilizer.

Medina *et al*. (2009) studied in Tithonia some growth variables, such as the plant height, the number of sprouts, the number, length and diameter of the branch, leaves per branch, among others. However, this was only related to the characteristics of the stems used for the plantation of this shrub, and not to the biomass production.

In order to facilitate the discussion, in each season, the results of two years of research are shown for the statistical criteria of the 23 plant material. First, a table with the mean squares of the error of the analysis of variance of the model and its significance is presented for each model and variable to make their selection with best goodness of fit. Later, the information of the selected models is fulfilled with the coefficient of determination (R^2), the estimated parameters and their correspondent standard errors.

In this research, the variables expressed in dry matter did not have adequate goodness of fit when applying the models, thus, results are not presented for these variables. The model of Richards was not reported, because it was not adequate to describe the performance of the variables.

Rainy season. The indicators tuft height and total weight of 1m were better fitted to the linear model, whereas the weight of 100 leaves GM was better fitted to the quadratic model. The weight of the whole plant attained better fit to the exponential model (table 1). Although this variable did not have great significance, the level of 10 % was considered to know the trend of the variable in time.

Out of the application of the models selected, it was proved that the tuft height and the total weight of 1m (table 1) (figure 1) reached the highest values at 18 weeks, with 174.98 cm and 4927.3 g, respectively. These variables were increased in 6.13 cm and 216.38 g as average in every 15-day period. The maximum weight of 100 leaves GM was at 14 weeks, with 220.59 g. The weight of the whole plant continued increasing at 18 weeks, reaching 109.70 g.

Figure 2 presents the performance of the total weight in 1 m linear. The fitted model was the linear, accounting for the rise of this variable up to 18 weeks. The average 15-day period increment was of 216.38 (table 2).

When making the integral analysis of the results of the measures fitted to the models, although they had, in general, their highest values at 18 weeks, it should be taken into account that the measure of the weight of 100 green leaves did not have the same performance. Its highest value was found at week 14, and, since this week, it decreased. This result shows that higher weight of whole plant can be obtained, and not per linear meter, but the biomass produced could have lower content of leaves. This aspect is of great importance for the animal feeding, even more

Table 1. MSE and significance criteria for each model and variables under study for the plant material 23

	MSE	Sign.
Linear		
Tuft height	27.84	***
Weight of 100 leaves GM (g)	2166.41	NS
Weight WP GM (g)	837.65	*
Total weight of 1 m(g) GM	262555.89	**
Quadratic		
Tuft height	30.44	NS
Weight of 100 leaves GM (g)	1064.89	*
Weight WP GM (g)	719.47	NS
Total weight of 1 m(g) GM	314518.37	NS
Logistic		
Tuft height	43.51	*
Weight of 100 green leaves (g)	41145.30	NS
Weight WP GM (g)	719.47	NS
Total weight of 1 m(g) GM	411453.12	NS
Gompertz		
Tuft height	32.57	**
Weight of 100 green leaves (g)	1303.51	NS
Weight WP GM (g)	711.59	NS
Total weight of 1 m(g) GM	404080.69	NS
Exponential		
Tuft height	44.83	***
Weight of 100 green leaves (g)	2883112.68	***
Weight WP GM (g)	970.47	NS+
Total weight of 1 m(g) GM	33773417.00	**

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

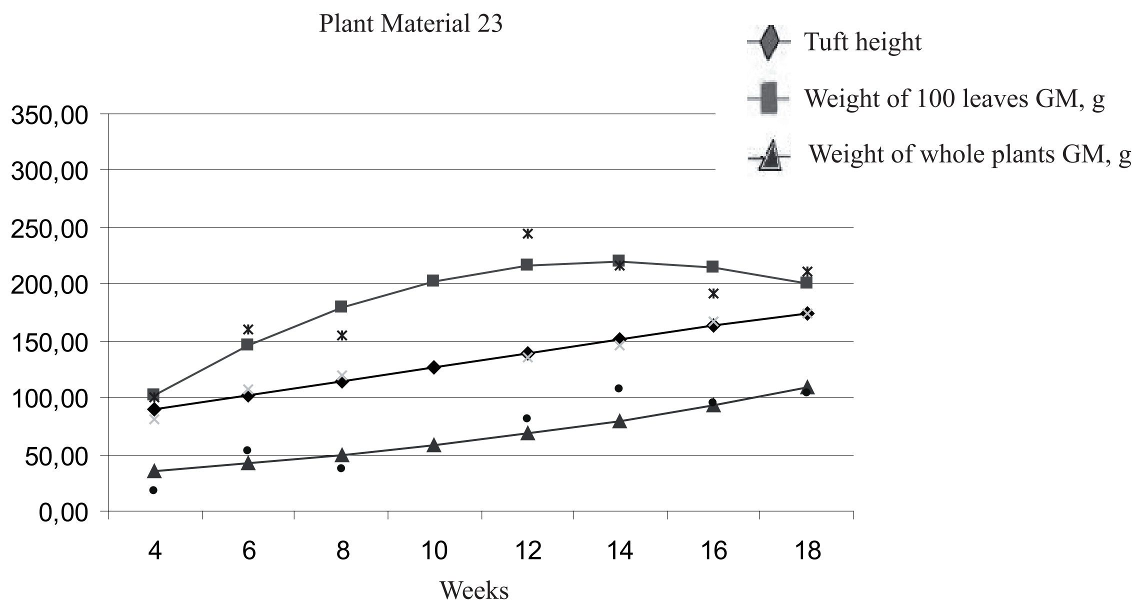

Figure 1. Dynamics of the variables height, weight of 100 leaves GM and weight of the whole plant GM for the plant material 23

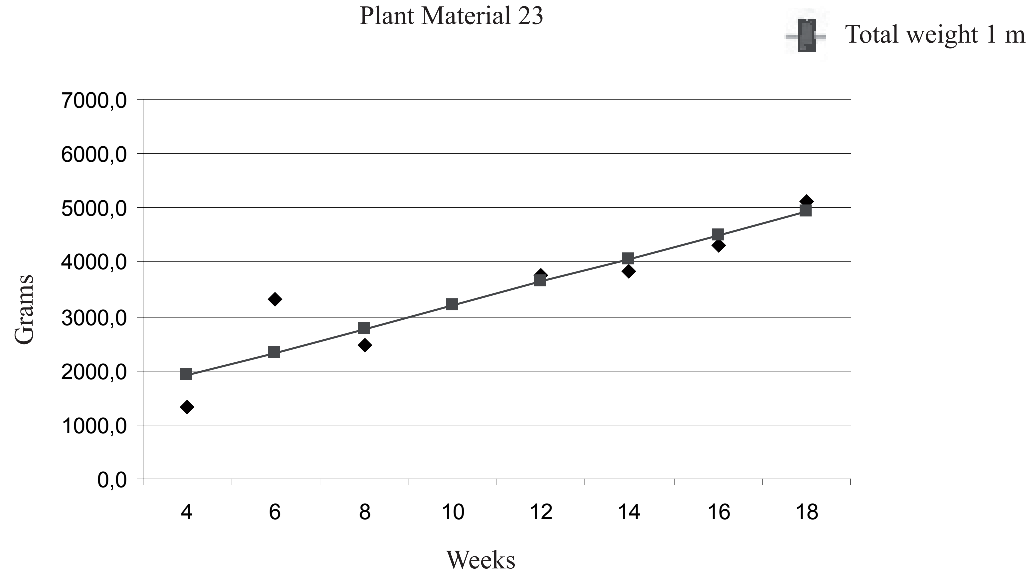

Figure 2. Dynamics of the variable total weight 1 m for the plant material 23

Table 2. Selected models for the variables that had important criteria of goodness of fit in the plant material 23.

Models	Variables	R²	MSE	Sign models	Parameters		
						b	c
Linear	Tuft height	0.97	27.84	***	64.64	6.13	
SE ±					4.85	0.41	
Quadratic	Weight of 100 green leaves (g)	0.83	1064.89	*	-12.06	33.56	-1.21
SE ±					54.19	11.39	0.51
Exponential	Weight WP GM (g)	0.81	970.47	NS+	25.99	0.08	
SE ±					8.42	0.02	
Linear	Total weight of 1 m(g) GM	0.83	262555.89	**	1032.46	216.38	
SE ±					471.09	39.53	

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

in this type of plant that would be the principal feeding source.

Dry season. The criteria for the material 23 (table 3) evidenced that, in this case, the model of Gompertz did not have numeric solutions either for the variables under analysis.

All the variables had significant fits for the exponential model, due to their lower mean squares.

The exponential dynamics for the plant material 23 (table 4) expressed slow behavior during the first three measures (4, 6 and 8 weeks) (figure 3). They increased from week 10 up to 18, and continued with this behavior not reaching stable or maximum values. Out of the three variables, the weight of 100 green leaves was increased with values superior to the 300 g at 18 weeks (figure 3).

The total weight of 1 m GM of the material 23 reached more than 3000 g at 18 weeks (figure 4) and had considerable amount of leaves.

The growth characteristics of this plant were completely different in the dry season compared with the rainy. The model of best fit was always the exponential. It showed that the material 23 has slow growth in the dry season, but it reached considerable values in the leaves.

In a study made in Cuba, Ruiz and Febles (2000) proved the use of modeling, when evaluating the models of best fit to study the growth of a group of tropical tree species. They determined the best model when sowing at two times of the rainy season. This allowed more accurate recommendations in this regard.

With this study it is reported for the first time the growth of materials collected from *Tithonia diversifolia* in different areas of Cuba. This information will be of great use to better exploit this species.

It is concluded that *Tithonia diversifolia*, plant material 23, had the best growth characteristics during the

Figure 2. Dynamics of the variable total weight 1 m for the plant material 23

	MSE	Sign
Linear		
Tuft height	197.46	**
Weight of 100 leaves GM (g)	3900.22	**
Weight WP GM (g)	4112.21	*
Total weight of 1 m(g) GM	459454.31	**
Quadratic		
Tuft height	88.11	**
Weight of 100 leaves GM (g)	2526.06	NS
Weight WP GM (g)	45.81	**
Total weight of 1 m(g) GM	57936.45	**
Logistic		
Tuft height	No fit	
Weight of 100 leaves GM (g)	2100.25	NS
Weight WP GM (g)	27.22	NS
Total weight of 1 m(g) GM	59368.36	NS
Gompertz		
Tuft height	No solution	
Weight of 100 leaves GM (g)	No solution	
Weight WP GM (g)	No solution	
Total weight of 1 m(g) GM	No solution	
Exponential		
Tuft height	69.13	**
Weight of 100 leaves GM (g)	2529.92	*
Weight WP GM (g)	21.76	*
Total weight of 1 m(g) GM	50506.97	**

*P < 0.05 **P < 0.01

Table 4. Selected models for the variables that had important criteria of goodness of fit in the plant material 23

Models	Variables	R^2	MSE	Sign model	Parameters		
					a	b	c
Exponential	Tuft height	0.97	69.13	**	16.51	0.12	
SE ±					3.05	0.01	
Exponential	Weight of 100 leaves GM (g)	0.91	2529.92	*	23.69	0.15	
SE ±					13.23	0.03	
Exponential	Weight WP GM (g)	0.98	21.76	*	0.89	0.26	
SE ±					0.32	0.02	
Exponential	Total weight 1 m GM (g)	0.98	50506.97	**	32.37	0.26	
SE ±					15.45	0.03	

*P < 0.05 **P < 0.01

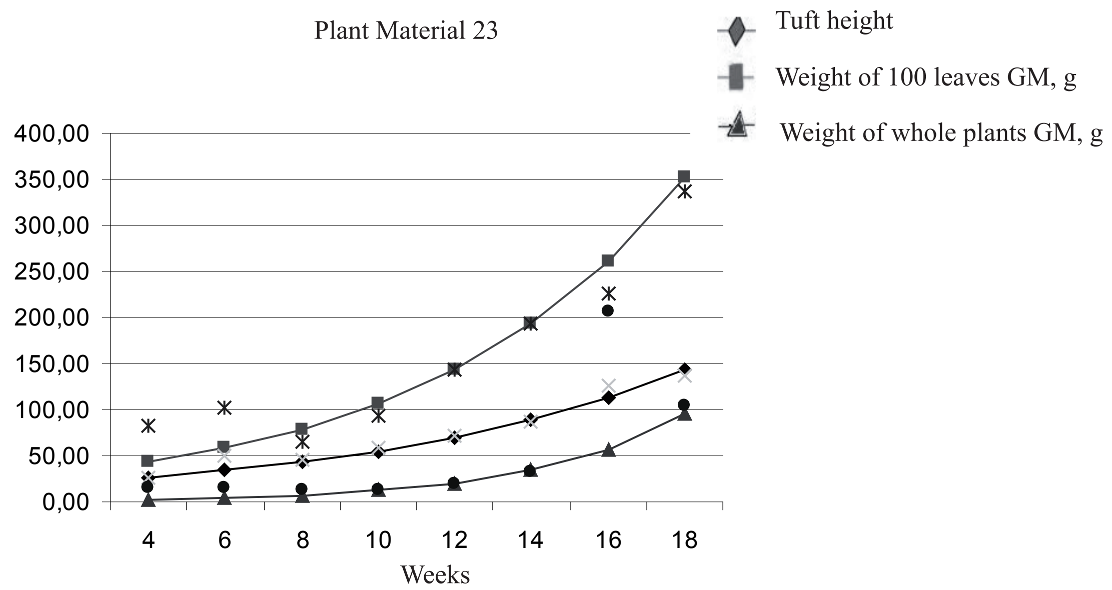

Figure 3. Dynamics of the variables height, weight of 100 leaves GM and weight of the whole plant GM in the plant material 23.

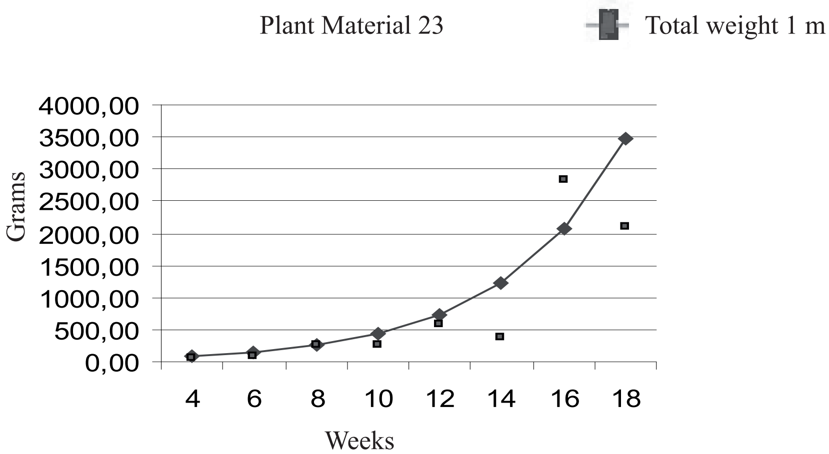

Figure 4. Dynamics of the variable total weight 1 m GM in the plant material 23.

rainy season up to week 14. In the dry season, the best growth was since week 10.

Knowing the performance of different plant components in time permits the development of further research related to the biomass production, whether for cut or grazing.

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