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Comprehensive study of a *Thithonia diversifolia* material using mathematical modeling

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Graphical Abstract

Abstract.

Is describing and the morphological behavior of components of the plant material 23 *Tithonia diversifolia* and using statistical criteria for modeling, are selected the models best goodness of fit. Different linear and non-linear models were adjusted to know the behavior of the variables height of the seedling (cm), weight of 100 leaves (g MV), weight of the whole plant (green matter, g) and total weight of a linear meter (g green matter) during the rainy and dry seasons in the Granma province in Cuba. The data was processed in the softwares Statistical Infostat (2001) and IBM - SPSS (V22). In step rainy indicators seedling height and weight of 1m is better linear model adjusted, reaches higher values at 18 weeks, with 174.98 cm and 4927.3 g, respectively, while the weight of 100 sheets MV it was adjusted to the quadratic model with the highest value at 14 weeks, with 220.59 g. The weight of the whole plant continued to increase at 18 weeks, reaching 109.70 g. In the dry season, the variables presented significant adjustments for the

	exponential model and expressed slow behavior during the first three measurements, increasing from week 10 to 18. Weight of 100 green leaves increased to values above 300 g at 18 weeks. Is reports for the first time about the growth of plant material 23 of *T. diversifolia* in the eastern part of Cuba.

Introduction

The integral study of the potential of *Tithonia diversifolia* this shrub plant in silvopastoral systems contributing to the biodiversity and sustainability and productive in tropical livestock has been carried out by different authors in Cuba, among them [1-3] and in other countries of the Southern Cone such as Colombia.

The materials of *T. diversifolia were* evaluated for their adaptive, botanical, growth characteristics, chemical, nutritional and productive constituents. It has also been addressed using mathematical modeling. It has been a useful methodology for the evaluation of this forage shrub species. In the eastern region of Cuba, evaluations of different materials of this plant have been carried out and their modeling has allowed the comparison of their behavior using the statistical criteria described by [4]

In a previous investigation [2], made the discrimination of 29 *Tithonia* plant materials through the Statistical Model of Impact Measurement [5], selecting 5 (23, 5, 10, 16 and 17), representative of four groups according to this methodology and recommended as plant materials intended for food by the options offered for the production of biomass .

The objective of this research was to describe the behavior of some morphological components of the plant material 23 of *T. diversifolia* to determine, through the use of statistical and modeling criteria, the best fit models for different yield components.

Materials and Methods

In this investigation, plant material 23 was analyzed, a member of the group of materials that showed the greatest indicators of biomass production.

Statistical methodology. Different linear and non-linear models were adjusted to know the behavior of the variables height of the seedling (cm), weight of 100 leaves (g MV), weight of the whole plant (green matter, g) and total weight of a linear meter (g green matter) during 2006 and 2007, from June to October (rainy season), and from January to June (rainy season) of the Granma province in Cuba. The adjusted models were linear, quadratic, cubic, Gompertz, Logistic and Exponential as a function of time. The criteria described by [4] were used to select the best fit models .presented the criteria to be considered and clarifies that they are essential

The models used in the adjustment of the variables were the following:

Linear model: C (t) = A + B (t) + ε

Quadratic model: C (t) = A + B (t) + C (t) 2 + ε

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

GompertzModel : C (t) = A expB (1-exp (- Ct) + ε

Exponential model: C (t) = (A exp (Bt) + ε

Where: C (t): Dependent variables based on t.

A, B and C are model parameters

t is the variable measured in time

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

To select the best fit models Torres et al (2012) presented the criteria that should be considered and clarifies that they are essential

1. R^2 determination coefficient
2. CMEP statistic (mean square of the prediction error)
3. PRESS statistic (sum of squares of the prediction error)
4. Mean square, corresponding to the fitted model
5. Standard estimation error
6. Standard error of parameter estimators
7. Coefficient of variation of the estimators
8. Confidence limits of the parameters
9. Parameter redundancy test
10. Diagnosis of multicollinearity (Durbin- Watson)
11. Correlation coefficients between predicted and actual results
12. Analysis of residual by means of:

Average absolute error (EAM)

Average absolute error rate (PEAM)

Mean Error (MS)

Average error percentage (PEM)

Later clarifies this same author that are essential to make a correct selection of models criteria 1, 2, 5, 6 and 12

The processing was performed for the two weather stations. The information was organized in Excel databases to determine the statisticians and to plot the data. Subsequently, the statistical software Infostat (2001) and IBM-SPSS (V 22) were used to adjust the models.

Results and Discussion

To facilitate the discussion, the results with the plant material 23 is analyzed for each climatic season. A table is presented first with the mean squares of the error of the analysis of variance of the model and the significance of this, for each model and variable analyzed to make their selection with better goodness of fit. Subsequently, the information of the selected models is completed with the coefficient of determination (R^2), the estimated parameters and their corresponding standard errors.

Rainy **.**The indicators of seedling height and total weight of 1m were better adjusted to the linear model, while the weight of 100 MV sheets was more adjusted to the quadratic model. The weight of the entire plant achieved a better fit to the exponential model (table 1). Although this variable did not have an important significance, the 10% level was considered to determine the trend of the variable over time.

From the application of the selected models it was found that the height of the seedling and the total weight of 1m (table 2) (figure 1) reached the highest values at 18 weeks, with 174.98 cm and 4927.3 g, respectively.

These variables increased by 6.13 cm and 216.38 g on average. The maximum weight of 100 MV sheets was at 14 weeks, with 220.59 g. The weight of the whole plant continued to increase at 18 weeks, reaching 109.70 g.

Table 1. CME criteria and significance for each model and variables studied for plant material 23

Linear	**Cme**	**Sign**
Seedlingheight	**27.84**	*****
P that of 100 MV sheets (g)	2166.41	NS
Weight PI MV (g)	837.65	*
Total weight of 1 m (g) MV	**262555.89**	****

Quadratic	Cme	Sign
Seedlingheight	30.44	NS
Weight of 100 MV sheets (g)	**1064.89**	***
Weight PI MV (g)	719.47	NS
Total weight of 1 m (g) MV	314518.37	NS

Logistics	Cme	Sign
Seedlingheight	43.51	*
weight of 100 leaves Green (g)	41145.3	NS
Weight PI MV (g)	719.47	NS
Total weight of 1 m (g) MV	411453.12	NS

Gompertz	Cme	Sign
Seedlingheight	32.57	**
weight of 100 leaves Green (g)	1303.51	NS
Weight PI MV (g)	711.59	NS

Total weight of 1 m (g) MV	404080.69	NS

Exponential	Cme	Sign
Seedlingheight	44.83	***
weight of 100 leaves Green (g)	2883112.68	***
Weight PI MV (g)	**970.47**	**NS +**
Total weight of 1 m (g) MV	33773417	**

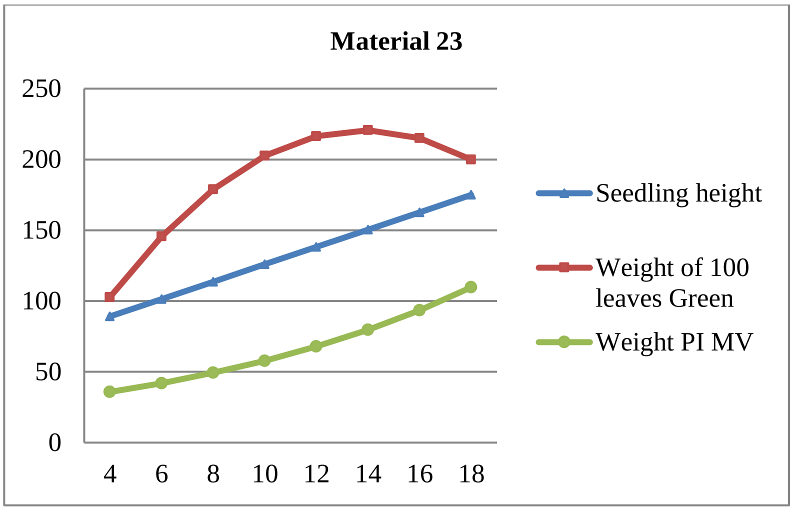

Figure 1. Dynamics of the variables height, weight of 100 MV sheets and weight of the entire MV plant material 23

Figure 2 shows the behavior of the total weight in 1 m linear. The adjusted model was the linear one, which explained the increase of this variable until 18 weeks. The average biweekly increase was 216.38 (table 1).

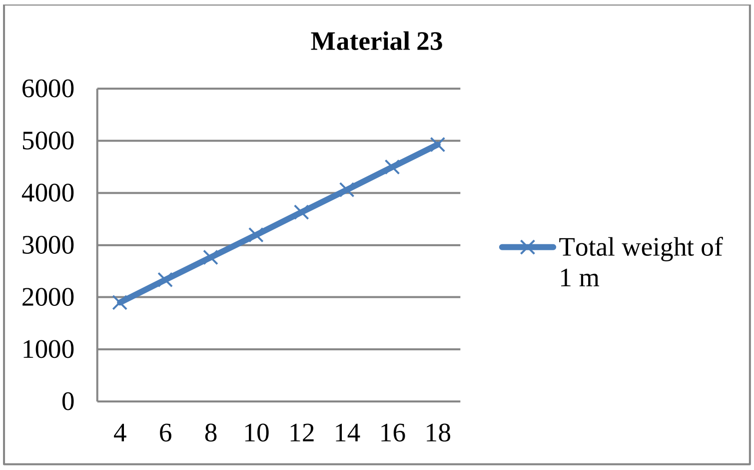

Figure 2. Dynamics of the 1 m total weight variable for plant material 23.

When carrying out the integral analysis of the results of the measures adjusted to the models, although they generally presented their highest values at 18 weeks, it should be considered that the weight measure of 100 green leaves did not have the same behavior. Its highest value was found in week 14, and from this it decreased.

Table 2. Selected models for the variables that had criteria of goodness of important adjustments. Plant material 23

Models	Variables	R^2	CMe	Sign model	**Parameters** a	**b**	**c**
Linear	Seedlingheight	0.97	27.84	***	64.64	6.13	
EE(±)					4.85	0.41	
Quadratic	weight of 100 leaves Green (g)	0.83	1064.89	*	-12.06	33.56	-1.21
EE(±)					54.19	11.39	0.51
Exponential	Weight PI MV (g)	0.81	970.47	NS +	25.99	0.08	
EE(±)					8.42	0.02	
Linear	Total weight of 1 m (g) MV	0, 83	262555.89	* *	1032.46	216.38	
EE(±)					471.09	39.53	

This result indicates that you can have greater weight of the whole plant and per linear meter, but the biomass produced could have lower leaf content. This aspect is very important for animal feed, especially in this type of plant that would be the main source of food.

***Rainy few*.** The criteria for plant material 23 (table 3), show that in this case neither the Gompertz model presented numerical solutions for the variables analyzed.

All variables presented significant adjustments for the exponential model and linear but due to their lower square means the first selected. The exponential dynamics for material 23 (table 4) expressed slow behavior during first measurements (4, 6 and 8 weeks) (figure 3).

Table 3. CME Criteria and Significance for each model and variables studied. Plant material 23.

Linear	**CMe**	**Sign**
Seedlingheight	197.46	**
P that of 100 MV sheets (g)	3900.22	**
Weight PI MV (g)	4112.21	*
Total weight of 1 m (g) MV	459454.31	**
Quadratic		
Seedlingheight	88.11	**
Weight of 100 MV sheets (g)	2526.06	NS
Weight PI MV (g)	45.81	**
Total weight of 1 m (g) MV	57936.45	**
Logistics		

Seedlingheight	Without solution	
weight of 100 leaves Green (g)	2100.25	NS
Weight PI MV (g)	27.22	NS
Total weight of 1 m (g) MV	59368.36	NS

Gompertz	
Seedlingheight	Without solution
P that of 100 MV sheets (g)	Without solution
Weight PI MV (g)	Without solution
Total weight of 1 m (g) MV	Without solution

Exponential		
Seedlingheight	**69.13**	**
Weight of 100 MV sheets (g)	**2529.92**	*
Weight PI MV (g)	**21.76**	*
Total weight of 1 m (g) MV	**50,506.97**	**

They increased from week 10 to 18, and continued with this behavior without reaching stable or maximum values. Of the three variables, the weight of 100 green leaves increased with values greater than 300 g at 18 weeks (Figure 3).

The total weight of 1 m MV of plant material 23 reached more than 3000 g at 18 weeks (figure 4) and presented a considerable amount of leaves. The characteristics of the growth of this plant were totally different in the dry season with respect to the rainy season. The best fit model is always the exponential. This indicated that the material presents slow growth in the rainy season, although it reached appreciable values in the leaves.

In a work carried out in Cuba, Ruiz and Febles (2000), found the usefulness of modeling, when evaluating the best fit models to study the growth ofa group of tropical tree species. They determined the best model when sowing in two moments of the rainy period. This enabled recommendationsmore precise about it.

Table 4. Selected models for the variables that had criteria of goodness of important adjustments. Plant material 23

Models	Variables	R^2	CMe	Sign model	Parameters **a**	**b**	c
Exponential	Seedlingheight	0.97	69.13	**	16.51	0.12	
EE					3.05	0.01	

Exponential	weight of 100 MV sheets (g)	0.91	2529.92	*	23.69	0.15
EE					13.23	0.03
Exponential	Weight PI MV (g)	0.98	21.76	*	0.89	0.26
EE					0.32	0.02
Exponential	Total weight 1 m MV (g)	0.98	50,506.97	**	32.37	0.26
EE					15.45	0.03

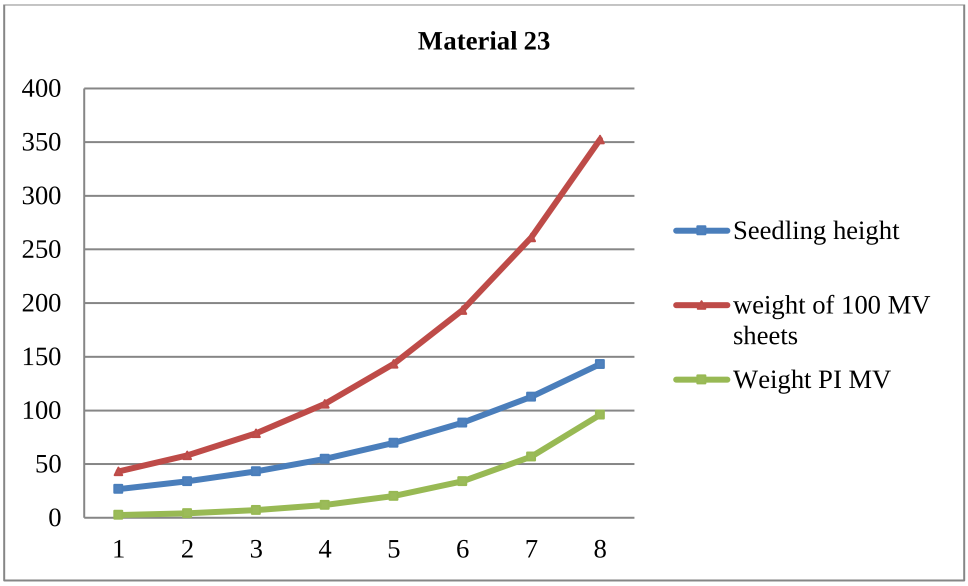

Figure 3. Dynamics of the variables height, weight of 100 MV sheets and weight of the entire MV plant. Plant material 23.

For this plant material 23 the exponential dynamics (table 4), express slow behaviors in the first 3 weeks (4, 6 and 8) and an increase from week 10 to 18 where they continue to increase without reaching values that show stabilization or maximum. Of the three variables the weight of 100 green leaves increases to values above 300 g. at 18 weeks.

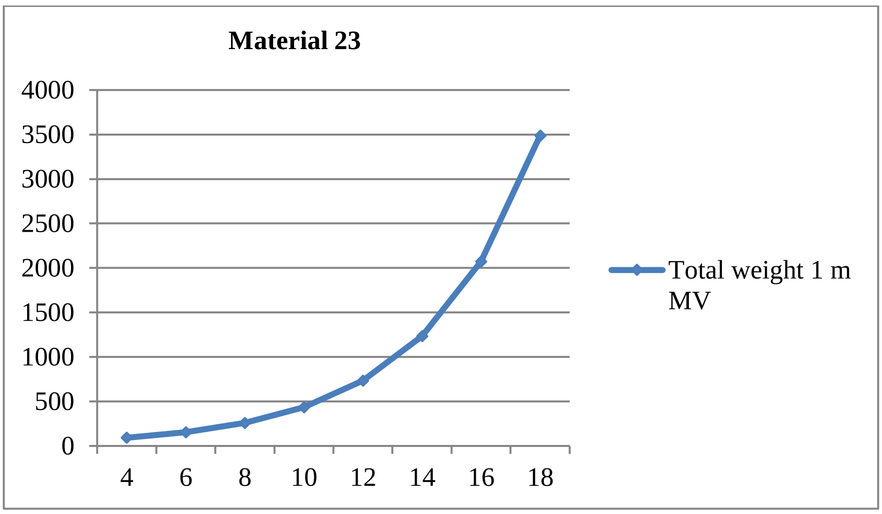

Figure 4. Dynamic variable total weight 1m MV. Plant material 23.

The total weight of 1 m MV of this collection 23 were much higher because they reach more than 3000 g at 18 weeks. The material 23 exceeds almost 1,000 g to other collections, especially considering that the heights of the plant are similar.

This study reports for the first time about the growth of materials 23 of *Tithoniadiversifolia*in different areas of Cuba. This information will be very useful to exploit better species.

Conclusions

It is concluded that *Tithonia diversifolia*, plant material 23, presented the best growth characteristics during the rainy season until week14. In the rainy season, the best growth was from week 10.

Knowing the behavior of different components of the plant over time allows the development of future work related to the production of biomass, whether for cutting or grazing.

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