Models to estimate the growth dynamics of *Pennisetum purpureum* cv. Cuba CT-169

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Different regression models were used to study the growth dynamics of *Pennisetum purpureum* cv. Cuba CT-169 through the agronomic variables accumulated yield of dry matter, percentage of leaves, and plant height. The data of the experiments were from the Pastures Department at the Institute of Animal Science. Every 14 d, data of the pasture biomass accumulation were collected at twelve cut ages during the rainy season, and at ten ages in the dry season, without fertilization or irrigation. Three linear models (one-way, quadratic, and cubic) and three non-linear (logistic, Gompertz, and exponential) were fitted. Four statistical criteria were applied to select the models of best goodness of fit. The models accounted for most of the total variability, with coefficients of determination superior to 89 %, minimum residual variance, significant parameters and adequate values for the rest of the criteria. The models of best fit in the rainy season were the Gompertz, for the accumulated yield of dry matter and the height, and the exponential, for the leaf percentage. In the dry season, that of best fit was the logistic, for the accumulated yield of dry matter and the height; and the one-way linear, for the leaf percentage. In the conditions of this study, the forage cut at 70 and 106 d of age is recommended in the rainy and dry seasons, respectively. Deepening into the performance of the bromatological indices is suggested, as well as validating the proposed models in further researches to simulate the response of this pasture to different conditions.

Key words: *regression models, growth dynamics, Cuba CT-169, goodness of fit.*

Several species and varieties of creeping and standing growth have been used in Cuba for forage production (Herrera and Ramos 2006). Del Pozo (1998) analyzed the star grass (*C. nlemfuensis*) growth under cut and grazing conditions, with and without nitrogenous fertilizer for forage production from creeping and low standing grasses. In this variety, Torres *et al*. (1999) estimated a model to describe the growth under grazing conditions, but according to the resting time. These authors recommended similar studies in other tropical species with creeping and standing growth.

The Cuba CT-169 pasture is a clone obtained at the Institute of Animal Science from the genetic improvement of *Pennisetum purpureum* through tissue culture (Martínez *et al*. 1986, cited by Herrera and Martínez 2006). Due to its possibilities for forage utilization (Martínez 2007), it is recommended for animal feeding.

The CT-169 is characterized by robust stems and long internodes, with longer and wider leaves than king grass. The leaf ratio is superior at the first 100 d of age, thus the crude protein content in the biomass is superior in 3-5 %. The annual average yield of this pasture is 20 t DM, 10 % more than that of king grass. This provides it with the best characteristics for a forage plant (Martínez *et al*. 2009).

At present, the CT-169 is being introduced in different cattle regions in Cuba (Ramírez 2010). The purpose of its introduction is to produce better quality forage (Herrera and Martínez 2006), thereby being of great interest to know its growth dynamics under different edaphoclimatic conditions, with the aim of establishing mechanisms for its best utilization and management.

The mathematical models applied to plant growth permit estimating or predicting its seasonal behavior under different conditions (Thornley and France 2007). For its correct utilization, three fundamental aspects should be considered: a) goodness of fit of the data, b) capacity of biological interpretation, and c) computer requirements (Chacín 1998). Currently, this latter is not a limitation, due to the development in computer sciences.

A general growth function, relating certain pasture characteristics in time, may be expressed as $W=F(t)$, where,

F (t) denotes a functional relationship and t is the independent variable measured in time

The objective of this work was to model the growth dynamics of the Cuba CT-169 pasture in the rainy and dry seasons, according to its agronomic characteristics, accumulated yield of dry matter, plant height, and percentage of leaves.

Materials and Methods

Data were used from studies developed throughout one year by the Pastures Department at the Institute of Animal Science. This institution is located in the San José de las Lajas municipality, Mayabeque province, between 22º 53´ NL and 82º 02´ WL, at 92 m a.s.l. The average of rainfall from 2002 to 2009 was of 1071 mm in the rainy season, and of 200 mm in the dry season (García *et al*. 2010).

Every 14 d (14, 28, 42, 56, 70, 84, 98, 112, 126, 140, 154, 168), biomass accumulation data were collected from the Cuba CT-169 pasture at twelve cut ages during the rainy season, and at ten ages during the dry season. The relations were established between the cut age and the value of the measurements in each cut for the variables accumulated yield of dry matter (AYDM), plant height, and percentage of leaves.

The experiment was conducted on red ferrallitic soil, without irrigation or fertilization, in twelve furrows, of 40 m of length and one of width. Every 14 d, six plots were cut, with 5 m of length per 1 m of width. The plots were six repetitions at every age. The pasture cut height was performed at 10 cm above the soil.

Six regression models were assessed to select that of best fit in each of the variables, as the pasture age increased. The models were the following:

Lineals
$$\begin{cases} W(t) = \beta_0 + \beta_1 t & \text{simple} \\ W(t) = \beta_0 + \beta_1 t + \beta_2 t^2 & \text{cuadratic} \\ W(t) = \beta_0 + \beta_1 t + \beta_2 t^2 + \beta_3 t^3 & \text{cibic} \end{cases}$$

Non lineals
$$\begin{cases} W(t) = \dfrac{\beta_1}{1 + \beta_2 e^{-\beta_3 t}} & \text{logistic} \\ W(t) = \beta_1 e^{-\beta_2 e^{-\beta_3 t}} & \textit{Gompertz} \\ W(t) = \beta_1 + \beta_2 e^{-\beta_3 t} & \text{exponential} \end{cases}$$

Where,

W(t) = variable representing the growth or development

βi = parameters of the models i= 1, 2, 3

t = time (d)

The selection of the model of best goodness of fit for each variable was conducted from four statistical criteria reported by Chacín (2000), Ortiz (2000), and Guerra *et al*. (2003). The following criteria of selection were analyzed: significance of the parameters, coefficient of determination (R^2), residual mean square (RMS) and residual analysis (Durbin-Watson).

The first and second derivative of the models of best fit were calculated, in the variables accumulated yield of dry matter and plant height to determine the maximum growth speed and the age of the inflexion point. The information was processed in the statistical software InfoStat (Di Rienzo *et al*. 2001) and Statgraphics Plus (Anon 1995).

Results and Discussion

Table 1 shows the result of the models that had the best fit for the variables under study, and the four criteria of comparison considered for their selection.

Different models were fitted for the rainy and dry seasons. The classical growth models, Gompertz for the rainy season and logistic for the dry season, were those of best fit for the variables accumulation of dry matter and plant height. This behavior is expected, considering that these models are characterized by forming a sigmoid curve that is fitted to the typical growth of the plants (Pérez *et al*. 2004 and Thornley and France 2007).

These models have been applied in different fields and constitute a common tool in the study of systems with diverse characteristics (Torres *et al*. 2009). In the field of animal science, these functions are among the most used to describe the growth of the individuals (Cayré *et al*. 2007, Casas *et al*. 2010 and Martínez *et al*. 2010). Besides, they have made possible the identification of the productive parameters of economic interest to implement programs of animal breeding improvement.

Studies of García *et al*. (2007) and Rodríguez *et al*. (2007) confirmed that the models of logistic growth and Gompertz had good fit as to the experimental data of yield and height of other pastures species and varieties, such as *Panicum maximun* cv. Mombaza and *Pennisetum purpureum* cv. Cuba CT-115. These varieties are characterized by a long growth cycle (more than 160 d).

The variable percentage of leaves did not respond to the sigmoid curve. For the rainy season, the exponential model was that of best results, and for the dry season the one-way linear.

Figures 1, 2, 3, 4, 5, and 6 show the fit of the models to the experimental data of the variables dry matter accumulation, plant height, and percentage of leaves at both seasons.

In general, in both seasons, and for all the variables under study, the parameters were significant. The variability explained by the models was high and similar, with coefficients of determination superior to 89 %. This indicated the accuracy of the models to account for the biological process.

The data were more variable (RMS) in the rainy season compared with the dry season as to the accumulation of dry matter and the plant height, respectively (table 1). This performance could be due to the fact that in the rainy season there are higher temperatures, higher soil humidity, and longer days, which propitiates plants accumulate larger biomass amount, and express their growth potential and variability in amore dynamic form.

According to del Pozo (1998), pastures growth and quality may vary considerably depending on the management, with favorable effects or not according to the plant species and the edaphoclimatic conditions. Other factors such as age, cut height, and mineral fertilization are among the most determinant components in the tropical conditions.

For the variable percentage of leaves, this situation was different. The data dispersion was lower in the

Table 1. Models of best goodness of fit between the variables accumulated yield of dry matter, plant height, percentage of leaves and the pasture cut age

Season	Variables	Model of best fit	Statistical criteria			
			Significance of the parameters	R^2 (%)	RMS	Durbin Watson
Rainy	Accumulated yield of dry matter (t ha^{-1})	Gompertz	β_1 P<0.001 β_2 P<0.05 β_3 P<0.001	97.50	5.80	1.92
	Height (cm)	Gompertz	β_1 P<0.001 β_2 P<0.001 β_3 P<0.001	98.65	118.00	2.32
	Leaves (%)	Exponential	β_1 P<0.001 β_2 P<0.001 β_3 P<0.001	98.69	5.38	2.45
Dry	Accumulated yield of dry matter (t ha^{-1})	Logistic	β_1 P<0.05 β_2 P<0.01 β_3 P<0.01	98.00	00.15	1.98
	Height (cm)	Logistic	β_1 P<0.001 β_2 P<0.001 β_3 P<0.001	98.00	37.58	2.99
	Leaves (%)	One-way linear	β_0 P<0.001 β_1 P<0.001	89.00	24.95	1.51

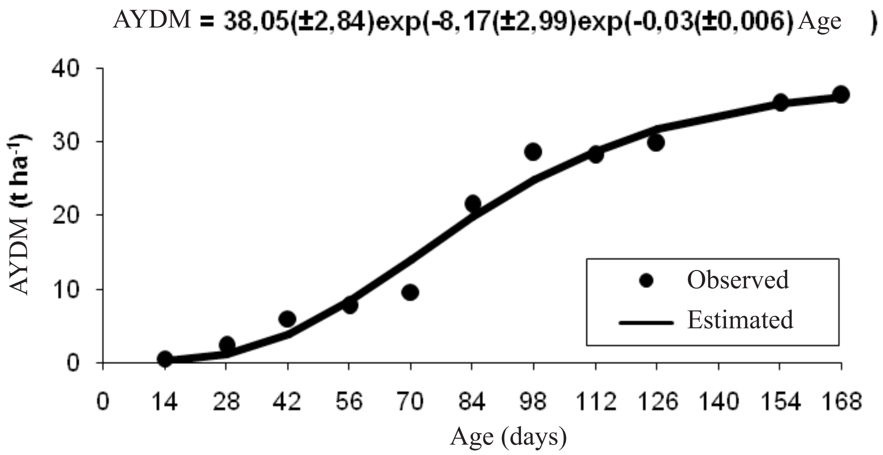

Figure.1 Gompertz model fitted to the accumulated yield of dry matter in the rainy season

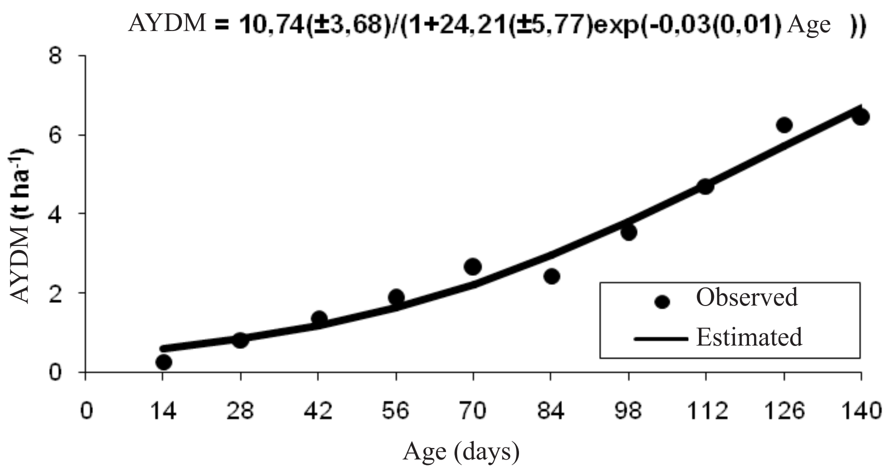

Figure 2. Logistic model fitted to the accumulated dry matter yield in the dry season

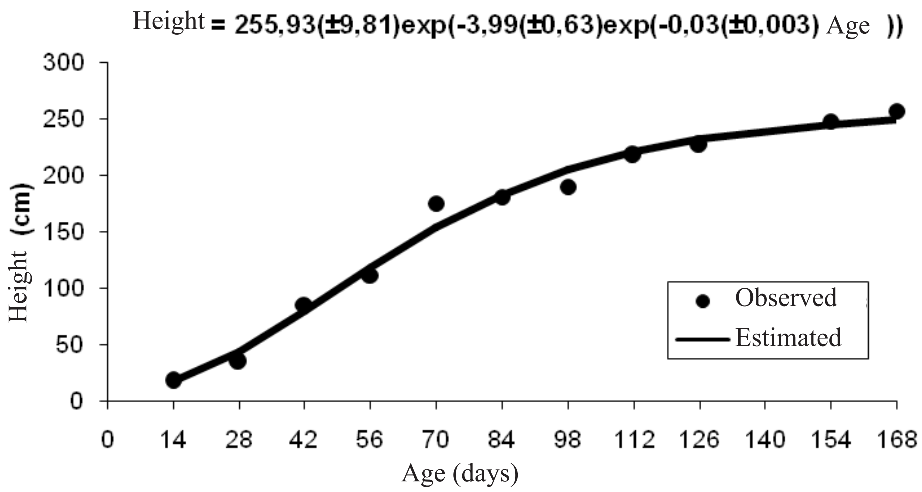

Figure 3. Gompertz model fitted tot he plant height in the rainy season

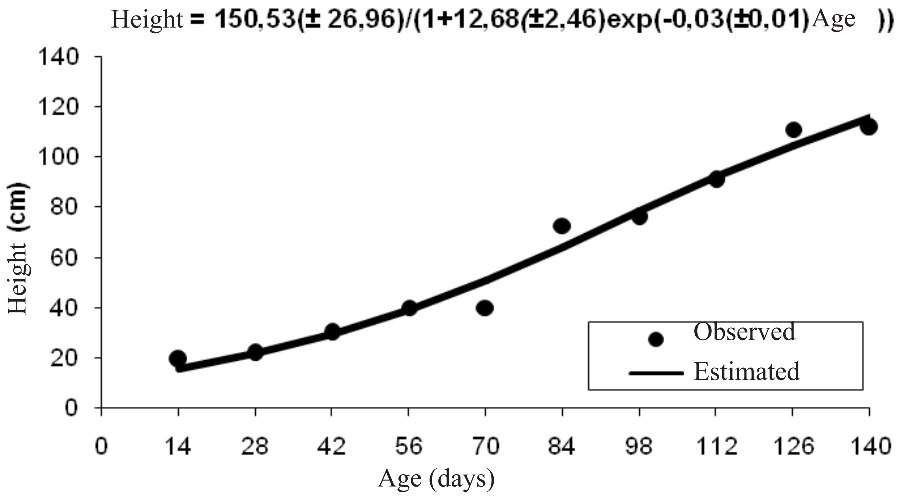

Figure 4. Logistic model fitted to the plant height in the dry season

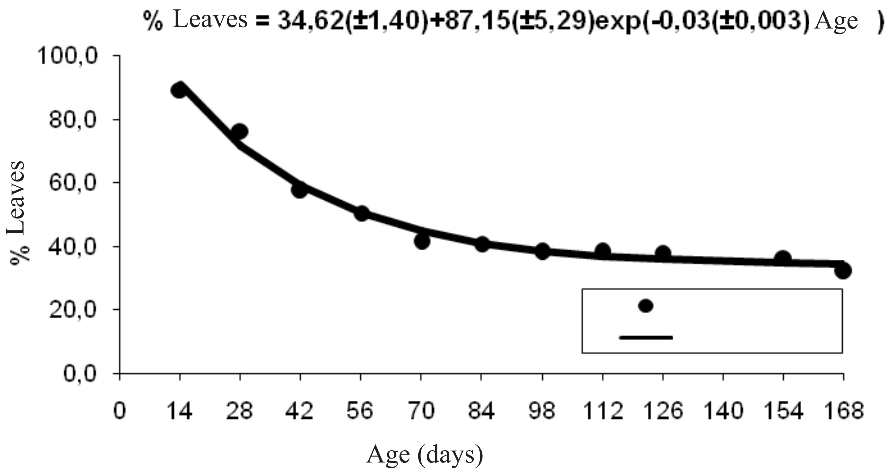

Figure 5. Exponential model fitted to the percenatge of leaves in the rainy season

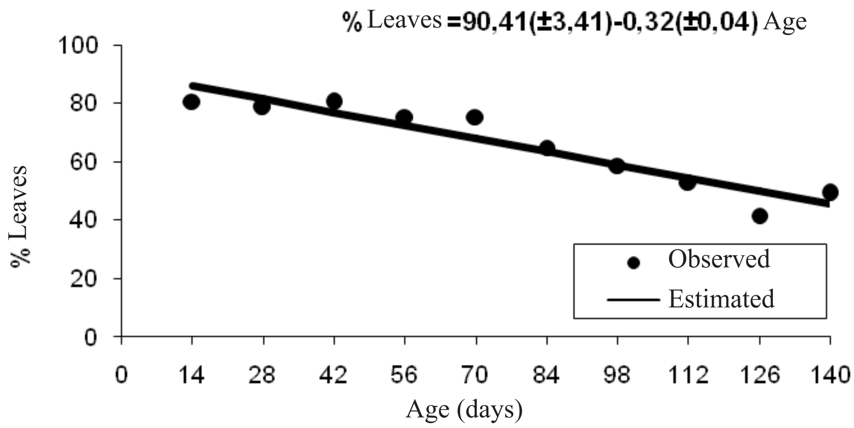

Figure 6. One-way linear model fitted to the percentage of leaves in the dry season

rainy season, and the highest in the dry season. This is explained because there is an inverse relationship biologically between the development and growth of the plant and its percentage of leaves. In the dry season, this indicator is higher and more variable.

In the rainy season, the leaf ratio decreased exponentially with the pasture age, with great variability between cut ages (figure 5). On the contrary, in the dry season, the leaf ratio was also reduced, but constantly, at a rate of 0.32 percent units per day (figure 6).

In all the instances, the test of Durbin-Watson evidenced absence of correlation of the errors (Montgomery *et al*. 2005), regardless the observations were ordered in function of the time (Abreu *et al*. 2004).

Table 2 shows the rates of variation of the growth and the age at the inflexion point of this clone in both seasons.

In the rainy season, this cultivar experiences higher speed rate, expressed in the variables dry matter yield and height. It reached the inflexion point for the accumulated yield of dry matter at 70 d, with growth rate of 0.42 t $ha^{-1}d^{-1}$, and for the height at 46 d with 1.92 cm d^{-1}.

These results explained why in the rainy season forage cut frequencies of 60 to 70 d of age are recommended, which coincided with better quality of the product. This corroborated the report of Martínez *et al*. (2009) for this cultivar.

In Costa Rica, Chacón and Vargas (2009) found out similar results in king grass, when studying three cut ages (60, 75, and 90). Although these authors did not model the growth dynamics, they recommended that the optimum cut age for king grass harvest should be 60 d, time in which the best pasture quality was shown.

As to Machado *et al*. (1983), in most of the assays with tropical grasses, the longer cut frequencies, not harming the pasture quality, are the most favorable and provide greater pasture stability.

In the dry season there were very low growth rates, expressed in yield and height. In the conditions of this experiment, with the growth rates obtained (0.08 t $ha^{-1}d^{-1}$), the inflexion point occurs at 106 d. This corroborated the difficulties in the forage production, being motivated by low temperatures, low soil humidity, and the duration of the days.

It was concluded that the fitted models explained most of the total variability, with coefficients of determination higher than 89 %, minimum residual variance, and significant parameters. The Gompertz model for the rainy season and the logistic for the dry season were the ones that best accounted for the growth dynamics of Cuba CT-169 through the variables dry matter accumulation and plant height. For the variable percentage of leaves, the best model was the exponential for the rainy season, and the one-way linear for the dry season.

In the conditions of this study, the cut of the forage is recommended at the age of 70 and 106 d in the rainy and dry seasons, respectively. Deepening into the performance of the bromatological indicators is recommended, as well as validating the models proposed in further researches to simulate the behavior of this pasture in different conditions.

References

Abreu, U.G., Cobuci, J.A., da Silva, M.V.G.V. & Sereno,

Table 2. Rate of time variation of the variables accumulated yield of dry matter and plant height

Season	Rate of maximum growth variation		Age at the Inflexion point	
	Accumulated yield of dry matter (t $ha^{-1}d^{-1}$)	Height (cm d^{-1})	Accumulated yield of dry matter (d)	Height (d)
Rainy	0.42	1.92	70.0	46.0
Dry	0.08	1.13	106.0	84.6

J.R.B. 2004. Use of non lineal models for the adjustment of growth curve of bovine pantaneiros. Rev. Archivos Zootecnia 53:370

Anon 1995. Software estadístico Statgraphics Plus, versión 5.1 sobre Windows.

Casas, G., Rodríguez, D. & Afanador, G. 2010. Propiedades matemáticas del modelo de Gompertz y su aplicación al crecimiento de los cerdos. Available: <http://rccp.udea.edu.co/index.php/ojs/article/view/455/561> [Consulted: January 3, 2011]

Cayré, M.E., Vignolo, G.M. & Garro, O. A. 2007. Selección de un modelo primario para describir la curva de crecimiento de bacterias lácticas y *Brochothrix thermosphacta* sobre emulsiones cárnicas cocidas. Available: <http://www.scielo.cl/scielo.php?pid=S0718-07642007000300004&script=sci_arttext> [Consulted: January 3, 2011]

Chacín, F. 1998. Análisis de regresión y superficie de respuesta. Ed. R. Cásares, A. Segovia, D. Gaskin. Facultad de Agronomía. Universidad Central de Venezuela. 111 pp.

Chacín, F. 2000. Diseño y análisis de experimento I. Ed. Universidad Central de Venezuela. Caracas. Venezuela. p. 338

Chacón, P.A. &Vargas, C. F. 2009. Digestibilidad y calidad del *Pennisetum purpureum* cv. king grass a tres edades de rebrote. Nota Técnica. Agronomía Mesoamericana 20:399

Del Pozo, P.P. 1998. Análisis del crecimiento del pasto estrella (*C. nlemfuensis*) bajo condiciones de corte y pastoreo. PhD Thesis. Instituto de Ciencia Animal. La Habana, Cuba

Di Rienzo, J.A., Balzarini, M., Casanoves, F., González, L., Tablada, M., Guzmán, W. & Robledo, C.W. 2001. Software estadístico InfoStat. Estadística y Biometría. Facultad de Ciencias Agropecuarias. Universidad Nacional de Córdoba

García, M., Herrera, R.S., Cruz., A.M. & Romero, A. 2010. ¿Conoce usted el régimen de precipitaciones en dos áreas del Instituto de Ciencia Animal?. XVI Fórum de Ciencia y Técnica. Instituto de Ciencia Animal. Cuba. p. 5

García, C.R., Martínez, R.O., Tuero, R., Cruz, A.M., Romero, A., Estanquero, L. & Noda, 2007. Caracterización de la dinámica de crecimiento y calidad del *Panicum maximum* vc. Mombaza en un suelo ferralítico de provincia La Habana. II Congreso de Producción Animal Tropical. Eds. M.F. Díaz, R.S. Herrera, T. Ruíz. Cuba. p. 231

Guerra, C.W., Cabrera, A. & Fernández, L. 2003. Criteria for the selection of statistical models in scientific research. Cuban J. Agric. Sci. 37:3

Herrera, R.S. & Ramos, N. 2006. Factores que influyen en la producción de biomasa y la calidad. In: *Pennisetum purpureum* para la ganadería tropical. Eds. R.S. Herrera, G. Febles, G. Crespo. Instituto de Ciencia Animal. La Habana. Cuba. 79 pp.

Herrera, R.S. & Martínez, R.O. 2006. Mejoramiento genético por vías no clásicas. In: *Pennisetum purpureum* para la ganadería tropical. Eds. R.S. Herrera, G. Febles, G. Crespo. Ed. Instituto de Ciencia Animal. La Habana. Cuba. p. 25

Machado, R., Caceres, O. & Miret, R. 1983. *Pennisetun purpureum* cvs, Taiwan A-144, A-146, A-148, y 801-4. Rev. Pastos y Forrajes 6:143

Martínez, R.O. 2007. Características de los clones de hierba elefante Cuba CT-115, Cuba CT-169 y Cuba OM-22 (*Pennisetum Sp*.) liberados por el Instituto de Ciencia Animal. II Congreso de Producción Animal Tropical. Eds. M.F. Díaz, R.S. Herrera, T. Ruíz. Cuba. 208 pp.

Martínez, R.O., Herrera, R.S., Tuero, R. & Padilla, C.R. 2009. Hierba elefante. Variedades Cuba CT-115, Cuba CT- 169 y Cuba OM-22 (*Pennisetum Sp.*). Rev. ACPA. 2:44

Martínez, C. A., Rodríguez, A.P., Jiménez, A. & Manrique, C. 2010. Descripción matemática de la función Gompertz aplicada al crecimiento de animales. Available: <http://www.revistas.unal.edu.co/index.php/remevez/article/view/16169> [Consulted: January 10, 2010]

Montgomery, D.C., Peck, E.A. & Vining, G.G. 2005. Otros temas acerca del uso del análisis de regresión. In: Introducción al análisis de regresión lineal. Tercera edición. Ed. Continental. México. Pp. 441-446

Ortiz, R.J. 2000. Modelación y simulación matemática del reciclaje de N, P y K en sistemas de pastoreo vacuno. PhD Thesis. Instituto de Ciencia Animal. La Habana, Cuba

Pérez, J.A., García, E., Enríquez, J.F., Quero. A.R., Pérez, J. & Hernández, A. 2004. A growth analisys, specific leaf area and leaf nitrogen concentration in "mulato" grass (*Brachiaria híbrido*, cv). Rev. Téc. Pec. Méx. 42:447

Ramírez, J.L. 2010. Rendimiento y calidad de cinco gramíneas en el Valle del Cauto. PhD Thesis. Instituto de Ciencia Animal, La Habana, Cuba. 121 pp.

Rodríguez, L., Torres, V., Martínez, O., Herrera, M., Noda, A. & Jay, O. 2007. Modelación matemática de la dinámica de producción del pasto *Pennisetum purpureum* Cuba CT-115 en época de lluvia. II Congreso de Producción Animal Tropical. Eds. M.F. Díaz, R.S. Herrera, T. Ruíz. 368 pp.

Thornley, J.H.M. & France, J. 2007. Growth functions. In: Mathematical Models in Agriculture. Quantitative methods for the plant, animal and ecological sciences. 2nd Ed. Cromwell Press, Trowbridge. pp. 136-171

Torres, V., Lazo, J., Ruiz, T.E. & Noda, A. 1999. Mathematical modeling to estimate *C. nlemfuensis* pasture availability. Cuban J. Agric. Sci. 33:343

Torres, V., Sampaio, I. & Fundora, O. 2009. Stochastic model of the productive performance in the growing stage of water buffaloes in Cuba. Cuban J. Agric. Sci. 43:111

Received: June 20, 2011