Modelling of dry matter yield of *Pennisetum purpureum* cv. king grass with different cutting frequencies and N fertilizer dosages

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For predicting the productive performance of *Pennisetum purpureum* cv. king grass with different cutting frequencies and N fertilizer levels, a non-linear mixed regression model and another of categorical regression were adjusted. Data from a five-year experiment were taken in which the effect of cutting frequency and nitrogen dosage (N) on DM yield was evaluated. Literature data from the last 30 years were collected for selecting the variables of highest influence on DM yield. The Bootstrap re-sampling was used for generating a sample of 50 observations per cut. Five statistical criteria were assessed for selecting that of better adjustment in the variable studied. It was established that the non-linear mixed regression model was not adequate for predicting the performance of DM yield, since it showed coefficients of determination lower than 80 %. The categorical regression achieved to predict DM yield with high precision in the adjustment, according to the established statistical criteria that allowed identifying the variables and effects of greater importance in the rainy and dry periods. The cutting frequency was the one of highest incidence in both periods.

Key words: *non-linear, mixed effects, Bootstrap, DM yield*

Pasture growth can be described by means of mathematical functions that predict the performance of height and biomass production. These functions permit realizing evaluations on the production level in livestock enterprises and classifying in a simple way the productivity of a specific species in a given zone (Martínez 2007).

Also they allow calculating the maximum values and the medium and common growths. With these functions it can also be determined the cutting ages that allow obtaining the maximum economical benefit. They also supply information that admits carrying out feeding programming and of stocking rate capacity; also they allow measuring genetic changes from one generation to another, related to the production level (Agudelo *et al*. 2008).

The Gompertz model is within the mathematical functions mostly used with this objective besides others, as the linear and the polynomial (Thornley and France 2007). One of the main disadvantages of these functions is plant age, without taking into consideration other factors involved in their development, as the environmental, soil, fertilizer dosage, irrigation, among others (Romera *et al*. 2009).

The implementation of mixed effects offers the possibility of analyzing data with structures of dependency, non-balanced and, occasionally with lack of normality. It also facilitates modelling in a flexible way, complex data structures (El Halimi 2005).

In the same way, the categorical regression models (CatReg) allow to describe the relationships between one response variable and a set of effects and predictive variables (De Leeuw 2005). The purpose is, in essence, the same than any other analysis of regression. In this case, what is interesting is that the CatReg can be applied when the classical or standard analyses of regression fail.

The use of these models can represent a solution to the problem of estimating biomass production, from the main factors involved in their development. Therefore, this study has as objective to select the model that best estimate the DM yield of king grass, when different cutting frequencies and nitrogen (N) fertilizer dosage are applied.

Materials and Methods

Data from experiments conducted during five years by the Department of Pastures of the Institute of Animal Science, located in the municipality of San José de las Lajas, Mayabeque province, between the 22º 53' NL and the 82º 02' WL at 92 m a.s.l. For soil and climate data it is suggested to consult Herrera and Ramos (1990).

Data collection. For the adjustment of the non-linear mixed and categorical regression models, data were used from an experiment where the effects of cutting age and N dosage on yield components were evaluated.

For identifying the variables of greater influence on yield performance, experimental data from the last 30 years on king grass in the literature were gathered. A database was formed with 244 rows and 53 columns, gathering the main effects and variables influencing on DM yield. The absolute frequency and expert criteria were utilized to differentiate what columns were the most important. Cut, year, nitrogen x cut, potassium, phosphorus, minimum and maximum temperatures, rainfall and global radiation were selected.

Procedures. The experiment was established in the field in a split plot design with four replications. Treatments were: main plot, cutting age of 60, 80 and 120 d and sub-plots, nitrogen levels 0, 200 and 400 kg/ha/year. Plots measured 6 x 6 m (36 m^2) with a harvestable area of 25 m^2.

Pasture was sown and after its establishment a cutting was performed. Nitrogen was fractionated after each cutting and a basal fertilization of 50 and 100 kg/ha/season of P_2O_5 and K_2O, respectively were applied. During the dry season there was irrigation with 50 mm of water every 15 d. Plots were cut according to treatments. The plant was cut at 10 cm height from the soil.

Statistical analysis. The annual biomass production curve of *Pennisetum purpureum* cv. king grass was created from the database utilized by Rodríguez *et al*. (2013) (unpublished data) for obtaining the models of biomass accumulation in the rainy and dry periods. This was considered as pattern curve for estimating the DM yield of the variety, when influenced by different factors. It was represented by the following expression:

$DM = \alpha\, e^{-(\beta) e^{-(\gamma\, cut)}}$

where:

DM: dependent variable dry matter yield

α, β y γ: parameters of the model

cut: independent variable

Formulation of the non-linear mixed and categorical regression models. Data for adjusting the models of non-linear mixed and categorical regression were re-sampled by means of the Bootstrap method, with magnitude Bootstrap B = 50 to generate 50 observations for each cut in the variable DM yield, according the criteria of Efron (1979), Hinkley and Winstead (1988) and Efron and Tibshirani (1993). These authors described the basic steps of this method. The models set out in table 1 were adjusted.

where:

Model (1):

DM: dependent variable dry matter yield

Year: random effect

Fert: N dosage, fixed effect

Alpha, beta and gamma are parameters of the model

Cut: independent variable

Models (2) and (3):

DMd: dependent variable dry matter yield in the dry period

DMrp: dependent variable dry matter yield in the rainy period

A_i and B_i: parameters of the models

X_i: effects and categorical variables

Kindness of fit test of the models. In order to prove the kindness of fit of the models, the statistical criteria of Kiviste *et al*. (2002), Guerra *et al*. (2003) and Torres and Ortiz (2005) were used. These criteria comprise the coefficient of determination (R^2 %), significance of the model (p value), significance of the parameters (p value), graphic of the residues and concordance test between the observed and estimated values (Legates and McCabe 1998 and Romera *et al*. 2010) through a simple linear regression model:

$Yreal = a + b * Yestimated$

The accuracy of the model was proved through the hypothesis tests in the parameters a and b of the line. The model was considered valid if achieving the null or of equality hypothesis of cases 1 and 2. This is equal to say that:

$Yreal_i = Y\,estimated + \varepsilon_i$

ε: random variable to be distributed $\varepsilon i \sim N(0,\sigma^2)$

Case 1 Case 2

H0 : $a = 0$ H0 : $b = 1$

H1 : $a \neq 0$ H1: $b \neq 1$

In general, the information was processed with the software SAS (2007), Infostat (Balzarini *et al*. 2008) and SPSS (2010).

Results and Discussion

The value of the parameters obtained in the estimation of the annual yield curve of *Pennisetum purpureum* vc. king grass by the model of Gompertz is shown in table 2. The coefficient of determination explained at about 85 % of yield variability. All parameters were significant ($P < 0.001$).

The standard error of the parameter estimations were sufficiently small, reason by which this model can be used as pattern curve for estimating yield, including fixed and random terDM, as demonstrated in the estimation of the parameters and adjustment statistics of the non-linear mixed regression model:

$DM = (25.561) - year)\, e^{-(4.3457 + fert)\, e^{-(3.3584)\, cut)}}$

R^2 (%)Sign. 70.67***

The model and the parameters were significant

Table 1. Expressions of the adjusted non-linear mixed regression and categorical regression models

Adjusted model	Expression of the model
Non-linear of fixed and random effects (mixed) model	$DM = (\alpha - year)\, e^{-(\beta + fert)\, e^{-(\gamma\, cut)}}$ (1)
Model CatReg Dry season	$DMdp = \sum_{i=1}^{n} A_i X_i$ (2)
Model CatReg Rainy season	$DMrp = \sum_{i=1}^{n} B_i X_i$ (3)

Table 2. Adjustment statistics and parameters of the model for the curve of annual biomass production.

Parameter	Value	SE(±)	Significance	R^2 (%)
α	34.4973	3.8778	P < 0.001	84.77
β	3.7443	0.1735	P < 0.001	
γ	0.0120	0.00138	P < 0.001	

(P < 0.001) with R^2 accounting for 70.67 % of the total yield variability. This value is considered moderate, according to Draper and Smith (2002) for its use for predictive purposes.

The equation of simple linear regression proves the agreement between the true values and those estimated by the non-linear mixed regression model. It can be observed that there is a linear relationship between both variables (P < 0.0001) from the information on the coefficients of regression. The equation of the adjusted model is:

DMreal = 4.63(±0.72) + 0.78 (± 0.03) DM estimated R^2 0.77

It was noticed that both parameters were significant, though hypotheses H0 are rejected (table 3). This indicates that there are significant differences (P < 0.0001) between true and estimated values. Therefore the non-linear mixed regression model is considered not adequate for estimating DM yield.

The analysis of the residues demonstrated the lack of randomness and existence of atypical values. Figure 1 shows the relation between the real and estimated DM yield. The residues of the model are presented in the 1b.

According to Verbeke and Molenberghs (2000) the mixed statistical models allow modelling the response of an experimental or observational study, as function of factors or covariables whose effects can be considered as fixed constant or random variables. However, the models to be used in the simulation process must fulfill a group of conditions: high coefficients of determination, normal remainders, among others.

Lee and Nelder (1996) and Casanoves (2004) used non-linear mixed regression models in forest growth curves. These authors obtained good adjustments with the difference that instead of using two random variables, as created in this paper, they used three. The main difficulty of realizing inferences with this type of model is the computational aspect, since there are no explicit formulas for the calculation of the maximum realistic estimators. Furthermore, the optimization routines used must be combined with numeric integration routines, which are particularly difficult to use when employed more than three or four random effects in a model (SAS 2007). The situation above mentioned did not allow arriving to conclusive results on the applicability of the mixed model with predictive purpose; hence, the analysis was made through a CatReg model.

Analysis of categorical regression models. In table 4 are shown the estimated parameters for the models of seasonal categorical regression. In both seasons of the year, the coefficients of determination of the models were high and similar (P < 0.01). The independent variables accounted for more than 80 % of the yield variability. All parameters were significant (P < 0.001).

These values are in agreement with those reported

Table 3. Statistics of adjustment and estimation of the parameters of the model

Coefficient	Estimated value	SE (±)	F	p value	Significance
Constant	4.63	0.72	3597.51	732.39	P < 0.0001
Slope	0.78	0.03	1803.77	367.22	P < 0.0001

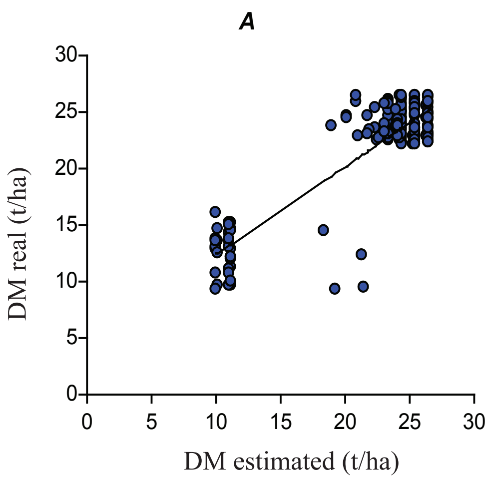


Figure 1a. Relationship between true and estimated DM yields by the model

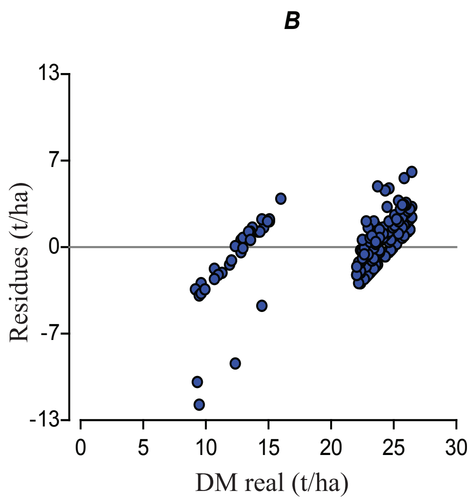


Figure 1b. Representation of the remainders of the model.

Table 4. Statistics of adjustment and estimation of the parameters of the model

Variable	Rainy period		Dry period	
Cutting	-0.026 ± 0.019***	R^2 = 83.30	-0.181 ± 0.010***	R^2 = 81.53
Cutting frequency	0.666 ± 0.014***	P < 0.01	0.515 ± 0.008***	P < 0.01
Nitrogen x cut	0.479 ± 0.008***		0.413 ± 0.010 ***	
Year	0.178 ± 0.011***		0.216 ± 0.010***	
Minimum temperature	0.099 ± 0.021***		0.103 ± 0.020***	
Maximum temperature	0.0 ± 0.015***		0.36 ± 0.020***	
Rainfall	0.029 ±0.010***		-0.039 ± 0.011***	
Global radiation	-0.017 ± 0.008***		0.093 ± 0.010***	

by Del Pozo and Herrera (1995), who applied a multiplicative model controlling the growth curve and the environmental effects in star grass. These authors obtained coefficients of determination of the models ranging between 65 and 83 %.

Martínez *et al*. (2010), Rodríguez *et al*. (2011) and Rodríguez *et al*. (2013) on modelling accumulated DM yield of king grass or of its clones, concluded that the Gompertz and logistical models were those of best adjustment. These studies were subordinated to functions allowing the estimation of biomass production in function of time.

Márquez *et al*. (2007) and Bautes and Zarza (2009) evaluated the effect of the cutting frequency and N fertilizer on the productive performance in elephant grass and crossed Bermuda grass by means of linear and quadratic regressions. These authors obtained coefficients of determination ranging between 85 and 99 %. However, in this study with the use of the categorical regression DM yield could be estimated from the main factors included in the productive performance of king grass.

In table 5 is shown the importance of each variable in the accumulated DM yield, where the cutting frequency was the one of greatest incidence for both seasonal periods, followed by nitrogen per cut and the year. Different authors of the tropical area, as Vega *et al*. (2006), Ramírez *et al*. (2009) and Santana *et al*. (2010) pointed out that the cutting frequency is one of the factors of greatest influence on yield and pasture quality, due to the fact that age provokes changes in their morphology and chemical constituents. As age is prolonged, without reaching the point in which pasture quality is affected, higher yields are attained.

Pasture response to increase biomass production with age coincides with the results reported by Verdecia *et al*. (2008), García *et al*. (2009) and Ramírez *et al*. (2010), who evaluated different pastures varieties of Brachiaria and Panicum genera under the edaphic and climatic conditions of Granma province.

These results suggest that for further studies, the variables that must be included in the models are cutting frequency, nitrogen per cut and the year. In the SPSS (2010) it is considered that from the model must be eliminated those variables whose contribution to the explanation of the variation of the dependent variable is small.

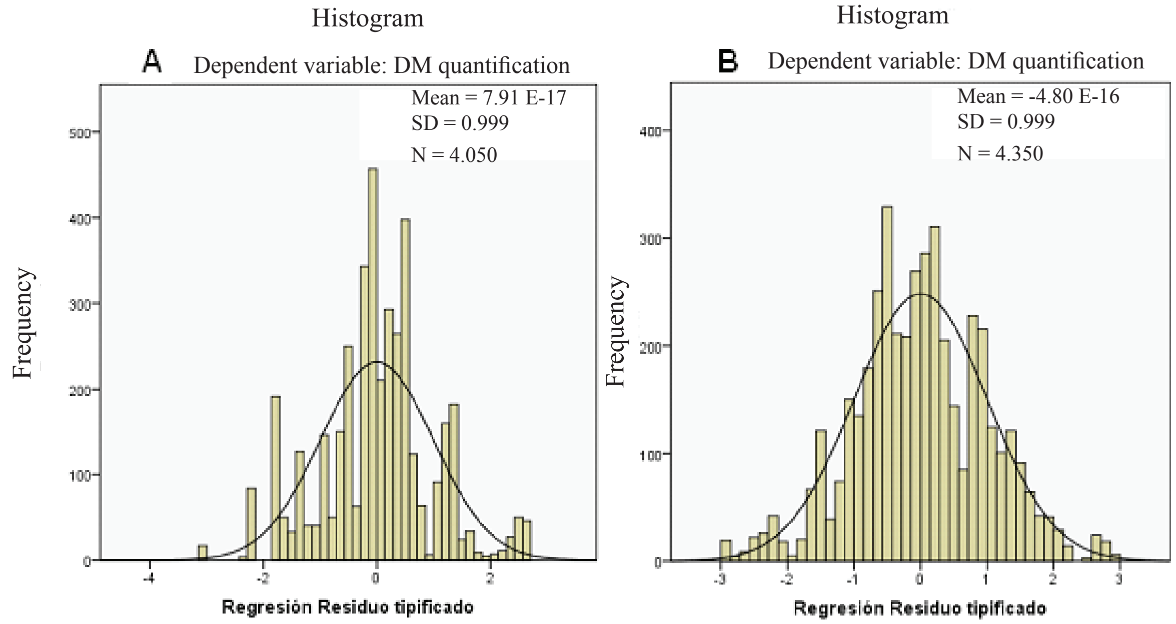
Figures 2a and b evidence that in both seasonal periods the remainders follow a distribution approximately normal. This is closely related to the treatment of the database through the Bootstrap method.

Data from this study will allow, in subsequent studies, to carry out the simulation and validation of the biomass production of king grass under different conditions.

It is concluded that the non-linear mixed regression model used accounted for less than 80 % of the total variance of DM yield. This limited its utilization with predictive character, although the possibility of its use in

Table 5. Weight of each variable in the DM yield

Variable	Importance	
	Rainy season	Dry season
Cutting	0.014	0.063
Cutting frequency	0.608	0.489
Nitrogen x cut	0.357	0.298
Year	0.221	0.108
Minimum temperature	-0.012	0.025
Maximum temperature	-0.031	0.007
Rainfall	0.012	-0.001
Global radiation	0.034	0.011



A) rainy season
B) dry season
Figure 2. Histogram of the remainders of the categorical regression

similar experiments must not be rejected. However, the categorical regression model attained, in general, better performance in the estimation of DM yield with high precision in the adjustment, according to the established statistical criteria. Furthermore, it allowed identifying the variables and effects of greater importance in the rainy and dry periods. Cutting frequency was that of highest incidence in both periods.

References

Agudelo, D.A., Cerón, M.F. & Restrepo, L.F. 2008. Modelación de funciones de crecimiento aplicadas a la producción animal. Rev. Col. Cienc. Pec. 21:39

Balzarini, M., Di Rienzo, J.A., Casanoves, F., González, L., Tablada, M., Guzmán, W & Robledo, C.W. 2008. Software estadístico InfoStat. Estadística y Biometría. Facultad de Ciencias Agropecuarias. Universidad Nacional de Córdoba. 329 pp.

Bautes, C.D. & Zarza, A. 2009. Efecto de la fertilizacion nitrogenada y la frecuencia de cuts sobre el comportamiento productivo de dos pasturas de *Cynodon dactylon* (l) pers en la estanzuela. Available: http://www.inia.org.uy/estaciones/la_estanzuela/actividades/documentos/cbautes.pdf. [Consulted: 19/12/12]

Casanoves, F. 2004. Análisis de ensayos comparativos de rendimiento en mejoramiento vegetal en el marco de los modelos lineales mixtos. PhD Thesis. Escuela para Graduados. Facultad de Ciencias Agropecuarias. Univ. Nacional de Córdoba.

De Leeuw, J. 2005. Multivariate analysis with optimal scaling. Department of Statistics UCLA. Available: http://repositories.cdlib.org/uclastat/papers/2005103002/pdf [Consulted: 12/02/13]

Del Pozo, P. P. & Herrera, R. S. 1995. Modelado del crecimiento del pasto estrella (*Cynodon nlemfuensis*). 1. Modelo multiplicativo con control de la curva de crecimiento y los efectos ambientales. Pastos y Forrajes 18:171

Draper, N. R. & Smith, H. 2002. Applied regression analysis. Third edition. John Wiley and Sons. New York. 588 pp.

Efron, B. 1979. Bootstrap Methods. Another look at the Jacknife. Annals of Statistics 7:1

Efron, B. & Tibshirani, R. J. 1993. An Introduction to the Bootstrap. New York: Chapman & Hall. 436 pp.

El Halimi, R. 2005. Non linear mixed-effects models and non parametric inference. PhD Thesis Departamento de Estadística. Universidad de Barcelona. Barcelona. 246 pp.

García-Cardoso, C.R., Martínez, R.O., Tuero, R., Cruz, A.M., Romero, A. Estanquero, L., Noda, A. & Torres, V. 2009. Evaluation of *Panicum maximum* vc. Mombaza and modelling of agronomic indicators for three years on typical red ferrallitic soil in Havana province. Cuban J. Agric. Sci. 43: 287

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. 1990. Evaluación agronómica. In: R.S. Herrera (Ed). King grass. Plantación, establecimiento y manejo en Cuba. 1ra Ed. Instituto de Ciencia Animal. La Habana. Cuba. Pp. 111-170

Hinkley, D. E., & Winstead, W. H. 1988. Bootstrap Methods: A Very Leisurely Look. Paper presented at the Annual Meeting of AERA. Boston.

Kiviste, A., Álvarez, J.G., Rojo, A. & Ruíz, A.D. 2002. Funciones de crecimiento de aplicación en el ámbito forestal. Ministerio de Ciencia y Tecnología. Instituto de Investigaciones y Tecnología Agraria y Alimentaria. Madrid. España. 190 pp.

Lee, Y. & Nelder, J.A. 1996. Hierarchical Generalized Linear Models. J. R. Statist Soc. B. 58 (3)

Legates, D. R. & McCabe, G. J. 1998. Evaluating the use of "goodness-of-fit" measures in hydrologic and hydroclimatic model validation. Water Resources Res. 35: 233

Márquez, F., Sánchez, J., Urbano, D. & Dávila, C. 2007. Evaluación de la frecuencia de cut y tipos de fertilización sobre tres genotipos de pasto elefante *Pennisetum purpureum*. 1. Rendimiento y contenido de proteína. Zoot. Trop. 25:253

Martínez, R. O. 2007. Un modelo de manejo del pasto en el período seco para la producción de leche. XI Seminario Manejo y Utilización de Pastos y Forrajes en Sistemas de Producción de leche. Instituto de Ciencia Animal. La Habana. Cuba. p. 31

Martínez, R.O., Tuero, R., Torres, V. & Herrera, R.S. 2010. Models of biomass acumulation and quality in varieties of elephant grass, Cuba CT-169, OM – 22 and king grass during the rainy season in the western part of Cuba. Cuban J. Agric. Sci. 44:187

Ramírez, J. L., Verdecia, D., Leonard, I. & Álvarez, Y. 2010. Rendimiento de materia seca y calidad nutritiva del pasto *Panicum maximum* vc. Likoni en un suelo fluvisol de la región oriental de Cuba. REDVET, 11 (7). Available: http://www.veterinaria.org/revistas/redvet/pdf. [Consulted: 25/01/2013].

Ramírez, O., Hernández, A., Carneiro, Sila., Pérez, J., Enríquez, J. F., Quero, A., Guadalupe, J., Herrera, H. & Cervantes, A. 2009. Acumulación de forraje, crecimiento y características del pasto Mombasa (*Panicum maximum* Jacq.). Rev. Técnica Pec. 47:203

Rodríguez, L., Larduet, R., Martínez, R. D., Torres, V., Herrera, M., Medina, Y. & Noda, A. 2013. Modeling of the biomass accumulation dynamics in *Pennisetum purpureum* cv. king grass in the Western region of Cuba. Cuban J. Agric. Sci. 47: 119

Rodríguez, L., Torres, V., Martínez, R.O., Jay, O., Noda, A.C. & Herrera, M. 2011. Models to estimate the growth dynamics of *Pennisetum purpureum* vc. Cuba CT-169. Cuban J. Agric. Sci. 45: 349

Romera, A. J., McCall, D. G., Lee, J. M. & Agnusdei, M.G. 2009. Improving the McCall herbage growth model. New Zealand J. Agric. Res. 52: 477

Romera, A. J., P. Beukes, Clark, C., Clark, D., Levy, H. & Tait, A. 2010. Use of a pasture growth model to estimate herbage mass at a paddock scale and assist management on dairy farDM. Computers and Electronics in Agriculture 74: 66

Santana, A.A., Pérez, A. & Figueredo, M.E. 2010. Efectos del estado de madurez en el valor nutritivo y momento óptimo de cut del forraje napier (*Pennisetum purpureum* Schum.) en época lluviosa. Rev. Mex. Cienc. Pec. 1: 277

SAS. 2007. Statistical Analisys System. User's guide statistics. SAS Institute Inc. Cary, NC, USA

SPSS. 2010. SPSS version 19.0 for Windows. Statistical Package for the Social Sciences. IBM.

Torres, V. & Ortíz, J. 2005. Application of modelling and simulation to the production and feeding of farm animals. Cuban J. Agric. Sci. 39:385

Thornley, J.H.M. & France, J. 2007. Mathematical Models in Agriculture. Quantitative Methods for the Plant, Animal and Ecological sciences. 2nd Ed. Cromwell Press, Trowbridge. 906 pp.

Vega, E., Ramírez, J. L., Leonard, I. & Igarza, A. 2006. Rendimiento, caracterización química y digestibilidad del pasto *Brachiaria decumbens* en las actuales condiciones edafoclimáticas del Valle del Cauto. REDVET, 7 (5). Available : http://www.veterinaria.org/revistas/redvet/n050506/html. [Consulted: 25/01/2013]

Verbeke, G. & Molenberghs, G. 2000. Linear Mixed Models for Longitudinal Data. Springer, New York. 350 pp.

Verdecia, D., Ramírez, J. L., Leonard, I., Pascual, Y. & López, Y. 2008. Rendimiento y componentes del valor nutritivo del *Panicum maximum* cv. Tanzania. REDVET, 9 (5). Available en: http://www.veterinaria.org/revistas/redvet/pdf. [Consulted: 25/01/2013]

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