Estimation of the mean lactation curve in crossbred female buffaloes (Buffalypso x Carabao)

Yenny García[1], L.M. Fraga[1], Gladys Guzmán[1], Marta Mora[1], D. García[1] and E. Padrón[2]

[1]*Instituto de Ciencia Animal, Apartado Postal 24, San José de las Lajas, Mayabeque*

[2]*Empresa Pecuaria Genética "El Cangre", Carretera "El Cangre" km 6½, Güines, Mayabeque*

Email: ygorta@ica.co.cu

The mean lactation curve of crossbred female buffaloes (Buffalypso x Carabao) was characterized in the Genetic Cattle Enterprise "El Cangre". A total of 18 412 productions of the control day (PCD) out of 1 377 female buffaloes were used. The minimum square constants of the PCD were obtained with the Mixed procedure of the SAS. The hyperbolic, square logarithmic, incomplete gamma, Wilmink, linear-square segmented polynomial, square-square segmented polynomial um linear function and polynomial with three square segments were used for adjusting the curve through the NLIN of SAS. When selecting the best model, the determination coefficient, adjusted determination coefficient, estimation standard error, model signification test, the test of Durbin Watson, the test of "Lack of Fit", distribution of the residues and deviation between the total observed and estimated milk productions were considered. The means of the PCD were between 2.15 ± 0.04 kg and 4.19 ± 0.03 kg. The lactation peak occurred in the second month with production of 4.03 kg. The goodness of fit and discrimination between the models demonstrated high fit in the square logarithmic model and polynomials, with two and three square segments. However, the polynomial with three square segments ($Y=3.5281+ 0.6903X -0.1791X^2+ 0.1818Z_1+0.0922Z_2$) had significant parameters with the highest fit values and estimated with precision all the phases of the curve. It is considered that this model represented the best the mean lactation curve of the female buffaloes under the conditions of the enterprise.

Key words: *curve, lactation, crossbred female buffaloes*.

Characterizing the lactation curve and its components allows increasing milk production and makes possible the correct selection of the animals for a genetic improvement. Tonhati *et al*. (2001) refer that the main applications of the lactation curves are related with the curve shape and its components. This knowledge would make easier designing improvement programs to consider, apart from the total production, the components determining a lactation curve with a more desirable shape from the biological and economical point of view.

With practical purposes, knowing the phenotypical curves allow taking proper decisions, in agreement with the environmental conditions, as for example, the performance predictions and feeding balance, depending on the nutritional needs. In this way, higher biological efficiency is achieved with the females interacting with the environment. The objective of this study was to characterize the shape of the mean lactation curve of the herd with different mathematical models, to provide the enterprise with a curve model to use the stated procedures.

Materials and Methods

For the study, 18 412 productions of the control day (PCD) of crossbred female buffaloes (variable gradations of Buffalypso x Carabao), belonging to the Genetic Cattle Enterprise "El Cangre" were used. The productions corresponded to 1 377 female buffaloes, 37 dairy units, with lactations from 1 to 9, and a total of 2 575 lactations of the calving years 2002- 2009.

The female buffaloes' feeding was mainly based on pastures. The calf stayed with the dam the first ten days. Later, the dams were incorporated to milking, conducted manually once a day supported by the calf, which was left an udder quarter for its feeding. The milk test recording was conducted monthly.

The minimum square constants of the PCD were used in each control, obtained through the following mixed model:

$Y_{ijkl} = \mu + \Gamma_i + \sigma_j + I_k (\alpha_i)+ e_{ijkl}$

where:

Y_{ijkl} = Production in the control day

μ = general mean

Γ_i= fixed effect of the group of contemporaneous (i = 1, 2….. 148)

σ_j = fixed effect of the control order (l = 1, 2,….9)

$I_k (\alpha_i)$ = random effect associated with each k-th animal (1, 2,. . ., 1377), nested in the i-the herd

e_{ijkl} = random error normally and independently distributed (0 σ_e^2).

The group of contemporaneous was defined as herd-year and calving season. The criterion calving year was defined "in season" (July-October) and "out of season" (November-June). The MIXED procedure of the SAS (Statistical Analysis System), version 9.1.3 (2007) was used in for this analysis.

Linear (linear hyperbolic and square logarithmic), no linear (incomplete gamma and Wilmink) and multiphasic functions such as the segmented polynomials (SP) were used for adjusting the mean lactation curve of the herd:

Square logarithmic function (SLF):

$Y_x = a_0+a_1X+a_2X^2+a_3\ln(X)$;

Incomplete gamma function (IGF): $Y_X=a_0X^{a_1}e^{-a_2X}$;

Hyperbolic linear function (HLF): $Y_x = a_0+a_1X+a_2X^{-1}$;

Wilmink function: $Y_x = a_0+a_1X+a_2 \exp(-0.005X)$;

Square-linear segmented polynomial (SLSP): $Y = a_0+ a_1X+ a_2X^2-a_2Z$;

where: $Z=0$, if $X \leq K$, $Z=(X-K)^2$, if $X > K$.

Square-square segmented polynomial (SSSP): $Y= a_0 + a_1X + a_2X^2 + (b_2 - a_2) Z$;

where: $Z=0$, if $X \leq K$, $Z=(X-K)^2$, if $X>K$.

square polynomial with three segments (SPSSS): $Y= a_0 + a_1X + a_2X^2 + b_2Z_1 + c_2Z_2$;

where: $Z_1=(X-K_1)^2$, if $X > K_1$, $Z_2 =(X-K_2)^2$, if $X > K_2$.

In the described models,

y = daily milk production

X = lactation days

a_0, a_1, a_2, a_3, b_2 and c_2 = parameters of each function

K, K1, K2 = Joining points between the segments of each segmented polynomial.

The estimation of the parameters was conducted through the non-linear regression. The modified method of Gauss-Newton, available in the NLIN of SAS, version 9.1 (2007) was applied.

The estimation of the peak production (PP) and peak time (PT) was carried out according to each adjusted model. The coefficient of determination (R^2), coefficient of determination adjusted to the freedom degrees (R^2A), standard error of estimation, signification test of the model and the statistical parameters of Durbin Watson were considered for selecting the best model. The test "Lack of fit", the distribution of the residues (Guerra *et al*. 2003) and the deviations between the total observed and estimated milk productions (El Faro 1996) were also considered.

Results and Discussion

The square minimum constants in each control may be observed in table 1. They ranged between 4.19 ± 0.03 kg, and between 2.15 ± 0.04 kg for the last weighing. Other authors (Macciotta *et al*. 2005, Tonhati *et al*. 2008 and Aspilcueta-Borquis *et al*. 2010) obtained superior values with the Mediterranean and Murrah breeds and their crossings. This could be due to the differences in the managing systems, feeding and selection intensity these breeds have been submitted to. However, the highest production was found in the second dairy control in all studies.

The mean lactation curve of the population under study is presented in figure 1. The mean production was initiated with 4.04 ± 0.03 kg. The production peak was reached in the second control, with 4.19 ± 0.03 kg, and the minimum value (2.15 ± 0.04 kg) in the ninth, coinciding with the lactation end. The total milk production estimated throughout the lactation curve was of 864.30 kg. In general, this performance is similar to that observed by Fraga *et al*. (2003), Mitat (2008) and García *et al*. (2010), who stated production increase up to the peak, with later slow and continous diminishing, up to the end of lactation.

One interesting characteristic of the curve is that, after the second month, there was a tendency to a continuous declination of production up to the seventh month of lactation. From that moment on, there was a change in the curve. A lower difference on the declination presented in previous stages is described. This propitiated that the declination rate of the month production was not constant.

The occurrence of a critical area could be explained because it is expected that during lactation, the suckling need is less. The female buffaloes producing the most were those surpassing the 240 d of lactation, being more persistent and with a higher genetic quality.

The table 2 summarizes the estimated mean equations and the estimated components per each function. The equations estimated the components of the curve, closed to those observed, except for the model of Wilmink, which described the peak before the beginning of lactation and did not estimate its production. The deviations were small between the estimated milk production and that proved in all the models. They were lightly inferior in the polynomial with three square segments (0.20 %). This showed similar values to those recorded for the different components of the curve, having effect on the estimated

Table 1. Days in lactation, square minimum constants, standard error and significance in each control

Control	Days in lactation	Estimator (kg)	SE±	Sig.
1	0-30	4.04	0.03	***
2	31-60	4.19	0.03	***
3	61-90	3.98	0.03	***
4	91-120	3.63	0.03	***
5	121-150	3.22	0.03	***
6	151-180	2.85	0.03	***
7	181-210	2.50	0.03	***
8	211-240	2.23	0.03	***
9	241-270	2.15	0.04	***

*** P < 0.001

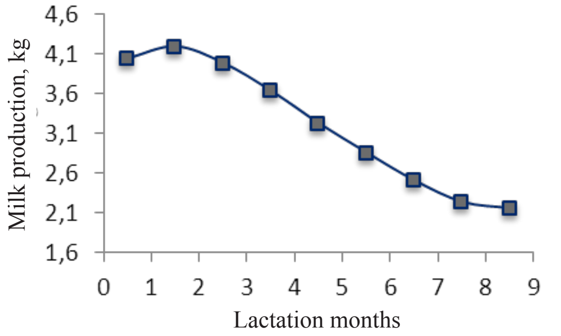

Figure 1. Mean lactation curve observed for the crossbred female buffaloes of Buffalypso.

The incomplete gamma and linear hyperbolic functions (figure 2) estimated the maximum production point in the second month. In the case of the first, it overestimated the milk production between the fifth and eight month of lactation, respectively. Besides, it showed values below that observed in the last two controls. The second function underestimated the milk production up to the fourth month and estimated superior values later. The model of Wilmink overestimated the initial production, it practically described a straight. The function estimated the lactation peak before calving (-6.15 d), and did not estimate the production during it. Later, it underestimated the production from the second to the fourth month. From the fifth month on, it overestimated up to the eighth month, so it did not describe the curve properly. A different result was found by Mitat (2008) in this same genotype.

Table 2. Mean equation, initial production (IP), peak time (PT), peak production (PP), estimated total production (ETP) and deviations for the crossbred female buffaloes of Buffalypso, according to the different assessed functions.

Function	Resulting equation	IP (kg)	PT (Días)	PP (kg)	ETP (kg)	Deviations (%)
SL	$Y = 5.2939 - 1.3216X + 0.0542X^2 + 1.9654\log X$	4.02	1.73	4.24	861.9	0.27
IG	$Y = 4.7827X^{0.2609}e^{0.1608}$	4.07	1.62	4.18	861.9	0.27
LH	$Y = 5.1975 - 0.3518X - \frac{0.7620}{X}$	4.08	1.47	6.23	861.9	0.27
W	$Y = 14.3494 - 0.6740X - 9.9075\exp(0.05X)$	4.25	-6.15	-	862.2	0.24
SLSP	$Y = 3.4495 + 0.8209X - 0.2289X^2$ $Z = 0$ if $X \leq 2.5$ or $Z = (X-2.5)^2$ if $X > 2.5$	4.04	1.79	4.18	862.2	0.24
SSSP	$Y = 3.4006 + 0.8454X - 0.2157X^2 - 0.4531Z$ $Z = 0$ if $X \leq 3.0$ or $Z = (X-3.0)^2$ if $X > 3.0$	4.03	1.95	4.22	861.9	0.27
SPSSS	$Y = 3.5281 + 0.6903X - 0.1791X^2 + 0.1818Z_1 + 0.0922Z_2$ $Z_1 = (X-3.0)^2$ if $X > 3.0$; $Z_2 = (X-7.0)^2$ if $X > 7.0$	4.03	1.92	4.19	862.5	0.20

SL: Square logarithmic; IG: Incomplete Gamma; LH: Linear hyperbolic; Wil: Wilmink; SLSP: square linear segmented polynomial; SSSP: square-square segmented polynomial; SPSSS: square polynomial with three segments.

total milk production for this model.

The models were statistically significant, with probability values of 0.001. So were the parameters of the curves, except that of Wilmink that did not show significance for any of its parameters.

Figure 2 shows the mean curves observed and estimated by the different uni-phasic functions. In general, all the models used made good approaches to the mean curve of the herd, except for the function of Wilmink. It overestimated the initial production and did not estimate the maximum point. The square logarithmic model described properly the initial stage of lactation up to the seventh month of lactation.

The function of Wilmink presented an additional parameter in respect to the other uni-phasic functions (a^3). As the value was positive, it contributed to the slow diminish of milk production. However, this model did not describe the curve change, occurring from the seventh month of lactation on. This result did not coincide with that observed by Fraga *et al*. (2003) and Méndez (2008), who stated that this model did not overestimate either underestimate the phases of the curve, so it described the milk production values with higher precision.

All the functions previously described had problems for accompanying the change of curve between the seventh and ninth control, precisely when there was change on the milk production declination rate. Muñoz Berrocal *et al*. (2008) had referred a similar result with the Murrah breeds and its crossings. A similar tendency was recorded for the models incomplete gamma, linear hyperbolic and model of Wilmink in a study conducted in Cuba by Mitat (2008). According to this author, the cited models underestimated the milk production in the decreasing phase, after the production peak.

Figure 3 presents the curves observed and adjusted by the assessed segmented polynomials. In the case of the linear square segmented polynomial, the critical point was estimated through the square segment. It was considered that there was a tendency to the linear decrease of the month production after

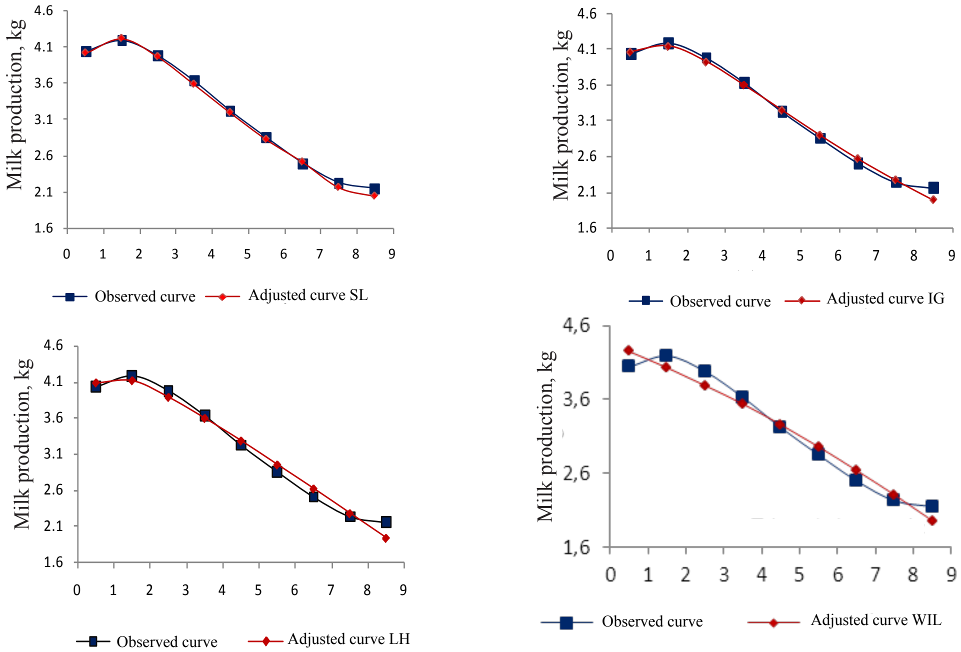

Figure 2. Mean lactation curves observed and estimated for the square logarithmic function (LS), incomplete gamma (IG), linear hyperbolic (LH) and Wilmink (WIL) for crossbred female buffaloes of Buffalypso.

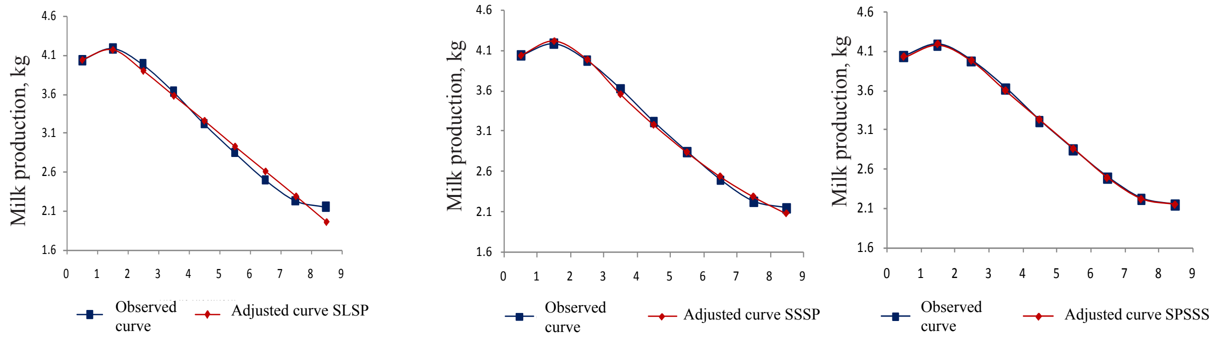

Figura 3. Mean lactation curves observed and estimated for the square linear segmented polynomial (SLSP), square segmented polynomial (SSSP) and square polynomial with three segments (SPSSS) for crossbred female buffaloes of Buffalypso.

the peak.

This polynomial underestimated the month production up to the fourth control, and showed superior values in the declination phase of the lactation curve up to the eighth control. The three polynomials made proper estimations of the production peak. The first two polynomials did not describe the change of the curve at the end of the lactation. However, the polynomial with the three square segments estimated with precision all the phases of the curve, such that presented in the final phase. This coincided with that reported by Muñoz- Berrocal *et al*. (2001), El Faro (2006) and Aspilcueta *et al*. (2008). Besides, this polynomial showed proper approaches for the different curve components (table 2).

The analysis of the figures 4 and 5 demonstrated that the residues are small in all models. Besides, it reaffirmed the proper adjustment in the logarithmic model and the polynomials with two and three square segments, respectively. These lasts corroborated the fulfillment of the incorrelation assumption of the errors, shown randomly disperse in relation with the classifying variable. Besides, they did not describe tendencies.

This assumption was not fulfilled for the model of Wilmink, linear hyperbolic and the linear square segmented polynomial. In them, the residues distribution, although small, was less random. Positive and negative values alterning were observed, indicating positive residual correlation (Draper and Smith 1987).

As table 3 shows, for the mean curve, all the assessed models had proper adjustments, according to the majority of the criteria assessed for the mean curve of the herd, with coefficients of determination lightly adjusted, and higher in the polynomial with three square segments. Identical result was achieved with the square logarithmic model (99.96 % and 99.76 %), together with the lowest standard error of the estimation (0.01 and 0.03, respectively) and the sum of the square of error (0.0008 and 0.007, respectively). The highest value for

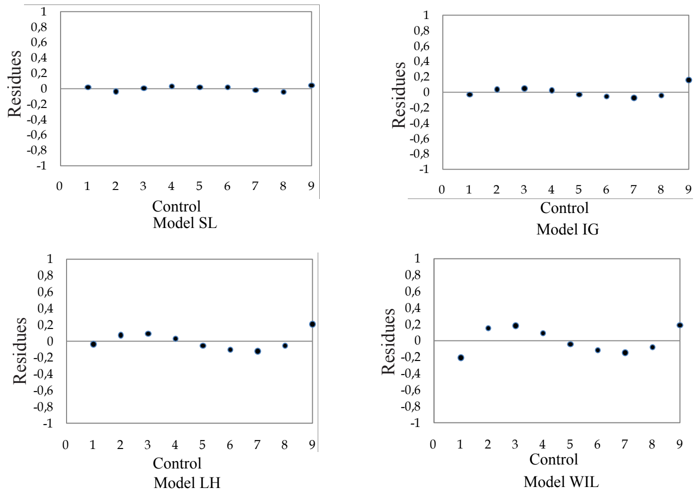

Figure 4. Dispersion of the estimated residues for the mean curves of crossbred female buffaloes of Buffalypso, adjusted for the model incomplete gamma (IG), square-logarithmic (SL), linear hyperbolic (LH) and of Wilmink (Wil).

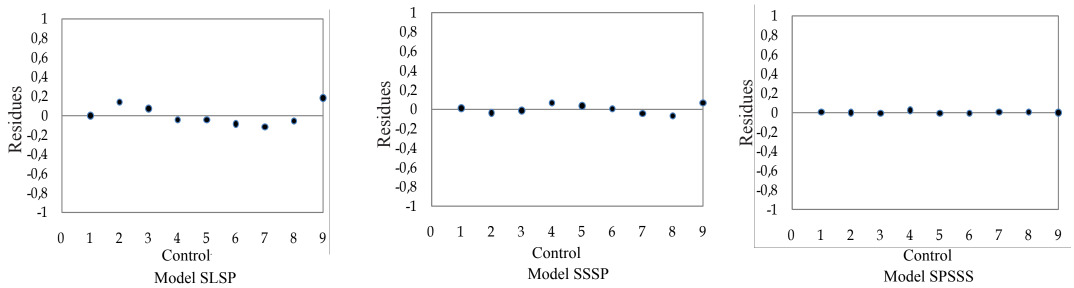

Figure 5. Dispersion of the estimated residues for the mean curves of crossbred female buffaloes of Buffalypso, adjusted for square linear segmented polynomial (SLSP), square-square segmented polynomial (SSSP) and square polynomial with three segments (SPSSS).

the model of Wilmink was found for each of them (0.18).

The Durbin-Watson statigraph was significant for the functions incomplete gamma, Wilmink, linear hyperbolic and for the linear segmented square polynomial. This is explained becasue the values are below the critical point (1.29), and corroborate that observed in the analysis of residues (figures 4 and 5). This could be consequence of the ordering in function of time in the lactation curves. That is why the errors may not be independent ones from the others. In that case, there would be a correlation between the successive pair of residues. Besides, it is important to consider that these residues have the genetic effects, as they are deviations of a same female buffalo. They also include the permanent environmental effects. In the rest of the models, this statigraph was not significant, indicating a proper adjustment of the model.

Table 3. Coefficient of determination (R^2), adjusted coefficient of determination (R^2 A), standard error of the estimation (SEE), sum of square of error (SSE), statistics Durbin-Watson (DW) and test Lack of Fit (LF) for the different functions assessed.

Models	R^2 (%)	R^2 A (%)	SEE	SSE ±	DW	LF
SL	99.85	99.76	0.03	0.007	2.02	1.81
IG	99.19	98.92	0.08	0.04	1.19*	0.43
LH	98.16	97.06	0.12	0.09	1.09*	0.6
Wil	96.35	95.14	0.17	0.18	1.28*	6.38*
SLSP	98.69	98.26	0.10	0.06	1.14*	0.36
SSSP	99.65	99.54	0.05	0.01	1.72	0.24
SPSSS	99.98	99.96	0.01	0.0008	2.79	0.18

DW: * Significant ($P<0.05$) when higher than Ft (2.29); LF: * Significant ($P<0.05$) when higher than Ft (2.10). SL: square logarithmic; IG: Incomplete Gamma; LH: Linear hyperbolic; Wil: Wilmink; SLSP: square linear segmented polynomial; SSSP: square-square segmented polynomial; SPSSS: polynomial with three square segments.

However, when analyzing the test "lack of fit", it was found that the statigraph was only significant (P < 0.05) for the model of Wilmink, reaffirming that the model had lack of adjustment and is improper.

It is considered that the square, logarithmic models and polynomials with two and three square segments demonstrated high adjustment with R^2A over 99 %. The Durbin-Watson test was not significant. Nevertheless, the polynomial with three square segments had significant parameters, and the highest adjustment values according to all the tests conducted. It also showed proper approaches for the different components of the curve and described precisely all the phases of the curve. It is considered that this model described the best the form of the mean lactation curve of the female buffaloes under the conditions of the enterprise. However, deepening in the study of individual curves is necessary.

References

Aspilcueta, R., Bignardi, A. B., Seno, L., Camargo, G., Muñoz-Berrocal, M., Albuquerque, L., Di Palo R. & Tonhati, H. 2010. Genetic parameters for milk yield analyzed by test-day models in Murrah buffaloes in Brazil. Italian J. Animal Sci. 9:179

Aspilcueta, R., Muñoz-Berrocal, M., Tonhati, H., Sesana, R. & Hurtado-Lugo, N. 2008. Modelación para ajuste de la curva de lactación usando función lineal, no lineal y polinomios segmentados en ganados con alto grado de sangre Brown Swiss. Livestock Res. Rural 18:59

Draper, N. M. & Smith, H. 1981. Appl. Regresion Anal. Segunda Ed. New Yor, Wiley.

El Faro, L. 1996. Estudo da curva de lactação de um rebanho da raça caracu. Tese da Doutorado. Jaboticabal. UNESP FCAVJ, SP. p. 179

Fraga, L.M., Gutiérrez, M., Fernández, L., Fundora, O. & González, M. E. 2003. Preliminary study of lactation curves in graded Murrah buffaloes. Cuban J. Agric. Sci. 37:149

García, Y., Fraga, L. M., Padrón, E., Rodríguez, N., Alcides, A., Guzmán, G. & Mora, M. 2010. Genetic Studies on Water Buffalo Species (*Bubalus bubalis*) in Cuba. 9th World Buffalo Congress. Argentina

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

Macciotta, N. P., Vicario D. & Cappio-Borlino, A. 2005. Detection of Different Shapes of Lactation Curve for Milk Yield in Dairy Cattle by Empirical Mathematical Models. J. Dairy Sci. 88:1178

Méndez, M. 2008. Caracterización productiva y reproductiva del búfalo (*Bubalus bubalis*) en algunos hatos en la provincia Granma. Cuba. Master Thesis. Instituto de Ciencia Animal. Universidad de Granma, Cuba

Mitat, A. 2008. La producción de leche en el día de control para la selección de búfalas en Cuba. PhD Thesis. IIPP y CIMA, C. de la Habana.

Muñoz Berrocal, M., Tonhati, H., Aspilcueta Borquis, R. & Hurtado-Lugo, N. 2008. Uso de modelos lineales y no lineales para el estudio de la curva de lactancia en búfalos Murrah y sus cruces en sistemas de cría extensiva en el estado de São Paulo.

Muñoz-Berrocal, M. F., Tholon, P., Pelicioni, L. C. & Tonhati, H. 2001. Uso de polinomios ordinarios y segmentados en el ajuste de curvas de lactación de búfalas Murrah y sus mestizos en Brazil. Proc. VI World Buffalo Congress. Maracaibo. Venezuela. p. 354-359

SAS 2007. SAS User's guide: Statistics. Version 9.1.3. SAS. Institute. INC, Cary, N.C., USA.

Tonhati, H., Cerón-Muñoz, M. F., El Faro L., Muñoz-Berrocal, M., Albuquerque, L. G. & Duarte, J. M. C. 2001. Estimación de parámetros genéticos y fenotípicos para producción de leche de búfalas, usando modelos de regresión aleatoria. 1. (Co) varianzas. Proc. VI World Buffalo Congress. Maracaibo, Venezuela. Pp. 342-347

Tonhati, H., Cerón-Muñoz, M., de Oliveira, A. J., El Faro, L., Ferreira, A. L. & Albuquerque, L. 2008. Test-day milk yield as a selection criterion for dairy buffaloes (*Bubalus bubalis* Artiodactyla, Bovidae). Genetics and Molecular Biology, Sociedade Brasileira de Genética 31:674

Received: March 23, 2013