USING LINEAR AND NONLINEAR FUNCTIONS TO MODEL THE GROWTH OF SANTA GERTRUDIS CATTLE RAISED UNDER GRAZING

UTILIZAÇÃO DE FUNÇÕES LINEARES E NÃO LINEARES PARA AJUSTE DO CRESCIMENTO DE BOVINOS SANTA GERTRUDIS, CRIADOS A PASTO

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SUMMARY

This research aims to model the growth curve of Santa Gertrudis cattle using spline and nonlinear functions, derived from the Richards model, and to assess the quality of the fitted models, using weight records from Santa Gertrudis Brazilian Association (ABSG) data files. The best fit during certain growth phases was given by the five-segment linear model with nodes at 179, 264, 421 and 850 days old. The values of R^2, EMS and PEM ranged from 0.76 to 0.95; 6201.18 to 6840.5 and – 0.000507 to – 0.049348, the latter indicates a slightly overestimation of average observed weight. Spline functions provide a feasible alternative for the fitting of growth curves, and accurately predict the performance of the animals at early and late ages. Asymptotic weight and maturity rate given by nonlinear functions provide a practical estimate on final performance of animal growth and it is expected that larger animals will be less precocious. In addition, more frequent weight records should be provided in order to improve the fitting of mathematical models.

KEY-WORDS: Animal growth. Beef cattle. Segmented polynomial. Spline functions.

RESUMO

Objetivou-se com este trabalho ajustar a curva de crescimento de bovinos da raça Santa Gertrudis utilizando funções *spline* e não lineares derivadas do modelo Richards e verificar a qualidade do ajuste dos modelos testados, a partir de registros de pedigree provenientes do banco de dados da Associação Brasileira de Santa Gertrudis (ABSG). O melhor modelo para ajustes em fases determinadas foi obtido a partir do modelo linear com cinco segmentos, com pontos de junção aos 179, 264, 421 e 850 dias de idade. Os valores obtidos dos coeficientes de determinação (R^2), Quadrado Médio do Resíduo (QMRes) e Erro de predição Médio (EPM) foram de 0,76 a 0,95; 6201,18 a 6840,5 e - 0,0005 a - 0,0493, este último indicando uma pequena superestimação do peso médio observado. Os animais atingiram, em média, 542,8 kg de peso adulto e 9,7 meses no ponto de inflexão. O uso de funções *splines* é uma alternativa viável ao ajuste de curvas de crescimento e para a correta determinação do desempenho do animal em idades iniciais e tardias. Os valores de peso assintótico e taxa de maturidade obtidos pelas funções não lineares fornecem uma estimativa prática sobre o desempenho final no desenvolvimento dos animais e espera-se que animais maiores sejam menos precoces. Além disso, pesagens mais frequentes deverão proporcionar melhores qualidades de ajuste.

PALAVRAS-CHAVE: Bovinocultura de corte. Desenvolvimento ponderal. Funções splines. Polinômio segmentado.

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INTRODUCTION

The Santa Gertrudis, considered the first synthetic cattle breed developed in a ranch in Texas, USA, resulted from the mating of bulls and zebu cattle whose final composition about 3/8 Brahman and 5/8 Shorthorn aimed at producing meat economically. This genetic racial makeup sought both rusticity and weight gain, which are important selection criteria applied to genetic improvement of beef cattle (ALENCAR & BARBOSA, 2010).

The genes that influence animal weight at a given age, usually affect other ages also, and this can be verified by highly structured genetic correlations obtained over the life of the animal. This pleiotropic effect was described by Paz & Freitas (2004) for a crossbred between Canchim, Angus, Nelore and Simmental, as well as by Boligon et al. (2008) for Nellore cattle, among others.

The growth data when collected for the same animal from birth to maturity yield a growth curve, usually with sigmoid shape that can be fitted or described by linear functions (FITZHUGH, 1976).

Some researchers fitted the average growth curve of cattle using linear models by regressions of mainly fourth order (cubic), where the intercept as well as cubic, quadratic and linear regression coefficients are estimated. Hassen et al. (2004) tested cubic models to fit the growth curve of Angus cattle. However, the biological interpretation of the regression parameters is not clear, thus restricting the fitted growth curve to adjust the observed weights within the measured weight interval.

An alternative linear model which can be used to predict and adjust animal growth curve is the segmented polynomial, or the so-called spline functions that are governed by various segments of low degree polynomial joined together at certain points called nodes to form a continuous curve (HUISMAN et al., 2002).

The spline functions use several segments to model the average curve and provide multicollinearity reduction, a common problem in regressions with strongly related traits, which is easily verified by the high values obtained for the correlation and determination (R^2) coefficients, close to 1 and to 100%, in which case the regression coefficients have no significance, according to the conventional t test (JOHNSON & WICHERN, 1984).

The spline function enables the fitting of low degree polynomials for short segments of the growth curve, and therefore, allows more flexibility when fitting fluctuating seasonal cattle growth (MEYER, 2000). According to Meyer (1999), the problems encountered while estimating the parameters at each end of the studied period may have been caused by the use of polynomial orders that fit the data inadequately. Thus, it is expected that the use of these models permits fine fitting of the average population curve, reducing seasonal growth interference.

The use of Logistic, Brody, Von Bertalanfy and Gompertz functions enables the study of animal growth in adulthood and the use of nonlinear models in order to verify the correlation between weights at different ages and the resulting adult with lower body weight (parameter *A*), faster weight gain (parameter *k*), associated with decreasing sexual maturity and lower percentage of carcass fat (THOLON & QUEIROZ, 2007)

The objective of this work was to model the growth rate curve of Santa Gertrudis cattle using spline and nonlinear functions, derived from the Richards model, and to verify the most critical regions for the fitting of the average growth curve of animals.

MATERIAL AND METHODS

The data used in the study were supplied by the Brazilian Association of Santa Gertrudis (ABSG). A consistency data study was performed to discard the odd data, that is, the data with three standard deviations above or lower than the mean for each age bracket. We also excluded the data from animals that had less than three weighing data. After consistency, the data file had 87264 weights of cattle aged up to 5 years old (1825 days).

To estimate the nodes or junction points of the spline functions, we first visually inspected the plot of the mean weights. This analysis is important as it helps to visualize how many segments will make up the curve and the probable inflection points of the curves. Thus, these inflection points seem most likely to indicate the nodes (MEYER, 2005).

Models with two, three and four nodes (K) and, therefore curves with three, four and five segments were tested using the statistical software SAS® (SAS 9.3, SAS Institute, Cary, North Carolina, USA). The general polynomial model is the following:

$$y = a_0 + a_1 X + a_2 X^2 + b_1 Z_1 + b_2 Z_2 + b_3 Z_3 + b_4 Z_4$$

where:
$Z_1 = (X - K_1)^2$, if $X>K_1$;
$Z_2 = (X - K_2)^2$, if $X>K_2$;
$Z_3 = (X - K_3)^2$, if $X>K_3$;
$Z_4 = (X - K_4)^2$, if $X>K_4$.

In the above model, y is the weight, X is age, a_0 is the intercept, a_1, a_2, are the linear and quadratic parameters, b_1, b_2, b_3 and b_4 are the polynomial regression coefficients and K_1, K_2, K_3 and K_4 are the nodes at 179, 264, 421 and 850 days old, respectively.

The quality of the fitting was given by the point where the residual mean square (RMS) was the lowest and the adjusted determination coefficient (R^2_a) the highest, as follows:

$$R_a^2 = \frac{(n-1)R^2 - p}{n - p - 1}$$

Where: p = number of function parameters; n = number of observations; R^2 = determination coefficient; R_a^2 = adjusted determination coefficient (MAZZINI et al., 2003).

In order to help the accuracy analysis, an average prediction error (MPE) was estimated. It corresponds to the mean of all prediction errors (PE), considering each observation as a deviation between observed and estimated weights, divided by the weight observed and multiplied by 100, when expressed as percentage. This value takes a plus (+) or minus (-) sign, depending whether the function underestimated or overestimated the observed weight, respectively (GOONEWARDENE et al., 1981).

The nonlinear models of Brody, von Bertalanffy, Logistic and Gompertz were also tested by the NLIN procedure of the SAS software, using the modified Gauss-Newton method summarized by Silveira Jr. et al. (1992).

The convergence criterion used was 10 exp-9, and the nonlinear model equations for the growth curves are presented below.

Logistic Model $Y= A*(1+b*exp(-k*x))^{-1}$
Brody Model $Y= A*(1-b*exp(-k*x))$
von Bertalanffy Model $Y= A*(1-b*exp(-k*x))^3$
Gompertz Model $Y=A*exp(-b*exp(-k*x))$

where:
Y = estimated weight;
A = asymptotic weight;
b = scale parameter;
k = maturity rate;
x = age.

To determine the best quality fitting of the nonlinear functions in addition to RMS and R^2, the mean prediction errors (MPE), and the verification of critical points by plotting the prediction errors (PE) were also used. The estimate of the MPE was given by the average of all deviations obtained between the observed and predicted values (PE) for each observation.

RESULTS AND DISCUSSION

Figure 1 shows mean weights and standard deviations for different ages. Santa Gertrudis calves are born with a mean weight adjusted by the quadratic, quadratic, quadratic, quadratic, quadratic, segmented polynomial (QQQQQSP) of 37.454 kg and are weaned at seven months when weight reaches 210.649 kg. At the year end, they weigh 299.149 kg, 388.960 kg at yearling, and reach the minimum slaughter weight of 450 kg when they are 24.4 months old, considering 50.00% carcass yield, since Henrique et al. (2004) reported carcass yields between 53.17 and 54.34% for Santa Gertrudis cattle reared in confinement, while ABSG (2011) reported yield of 56.00 and 52.70% for male and female, respectively.

During the initial growth phase, the standard deviation shows that animal weights vary less; however, as the animals grow older the variances become larger, and the fitting more difficult. This difference in variation is, generally, attributed to fewer data and to the cumulative effect that promotes this variation during animal development, as well as the dependence of standard deviation values relative to data magnitude. Thus, higher weights have also higher standard deviations.

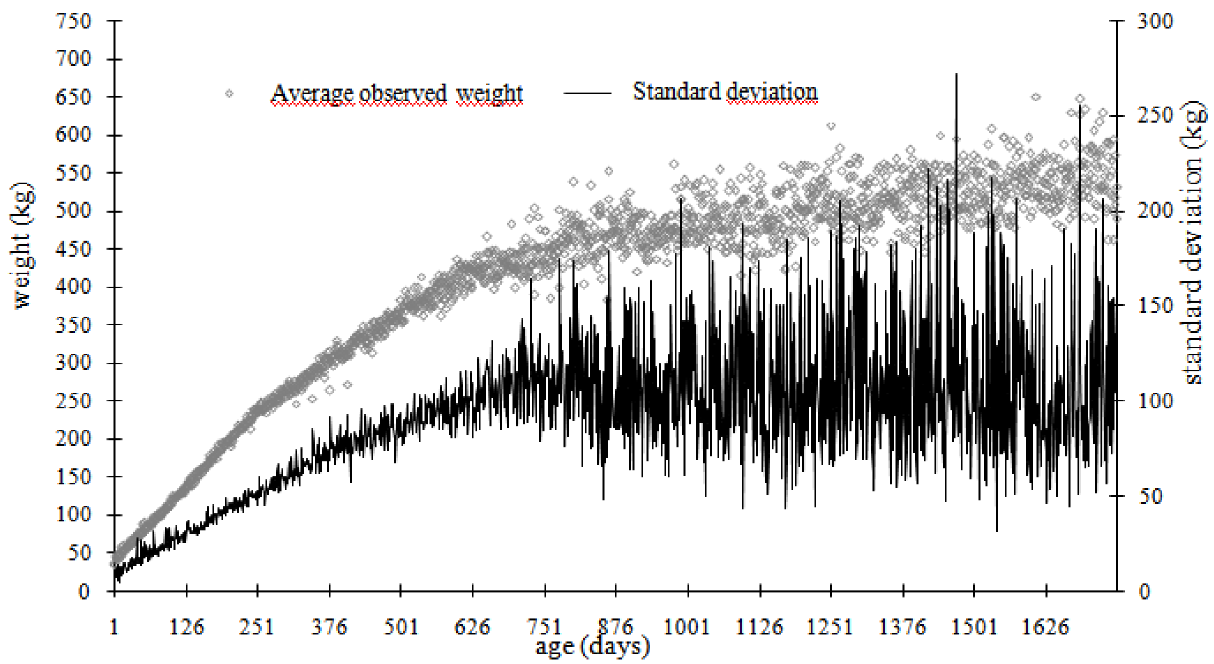

Figure 1 – Mean weight values and their standard deviation versus age of Santa Gertrudis cattle.

The best fit for average growth curve was given by the Brody model (Table 1). However, among the spline functions, the lowest RMS value was given by the quadratic polynomials segmented at 179, 264, 421 and 850 days old, while the values for the intercept (a_0) and regression coefficients (a_1, a_2, b_1, b_2, b_3 e b_4), were 37.45397; 0.76481; 0.0003389; -0.00242; 0.00208; -0.00048392 and 0.00046703, respectively.

The linear and nonlinear models tested represented adequately the weights, displayed low mean prediction errors, with a small overestimation of the mean observed weights (Table 1 and Figures 2 and 3). The residual estimates were very close (Table 1), thus suggesting that the chosen models were appropriate to describe the data (GLASBEY, 1988). Nevertheless, at older ages the fitting of the weight data was more difficult (Figures 2 and 3), a fact that has also been reported by Meyer (1999).

According to the polynomial model with 5 segments, the differences observed in the growth patterns of the phases described between ages delimited by nodes, corresponding to the stages of weaning, onset of puberty, maturity and termination of the animals can be clearly seen (Figure 2). In traditional cattle raising, these phases are defined in classes, pre-adjusted for birth weight, weaning (205 days), one year, at 452 and 550 days old (BIF, 2010); however, growth is continuous and the fitting for ages not included in the classes is important for the correct estimation of performance and enables predicting the average age of the animals, allowing the adequacy of cattle management.

Table 1 – Values for asymptotic weight (A), integration constant (B), maturity rate (K), determination coefficient (R^2), residual mean square (RMS), mean prediction error (MEP) of the models: segmented polynomial with five quadratic segments (QQQQQ SP), Logistic, Brody, Gompertz and von Bertalanffy, for the fitting of the growth curve of Santa Gertrudis.

MODEL	A	B	K	R^2	RMS	MEP
QQQQQ SP	-	-	-	0.76	6201.2	-0.012320
Logistic	527.5	4.3148	0.00452	0.95	6840.5	- 0.049348
Brody	561.8	0.9614	0.00198	0.95	6638.4	- 0.000507
Gompertz	538.2	1.9574	0.00322	0.95	6706.8	- 0.032533
von Bertalanffy	543.7	0.5105	0.00280	0.95	6669.9	- 0.023571

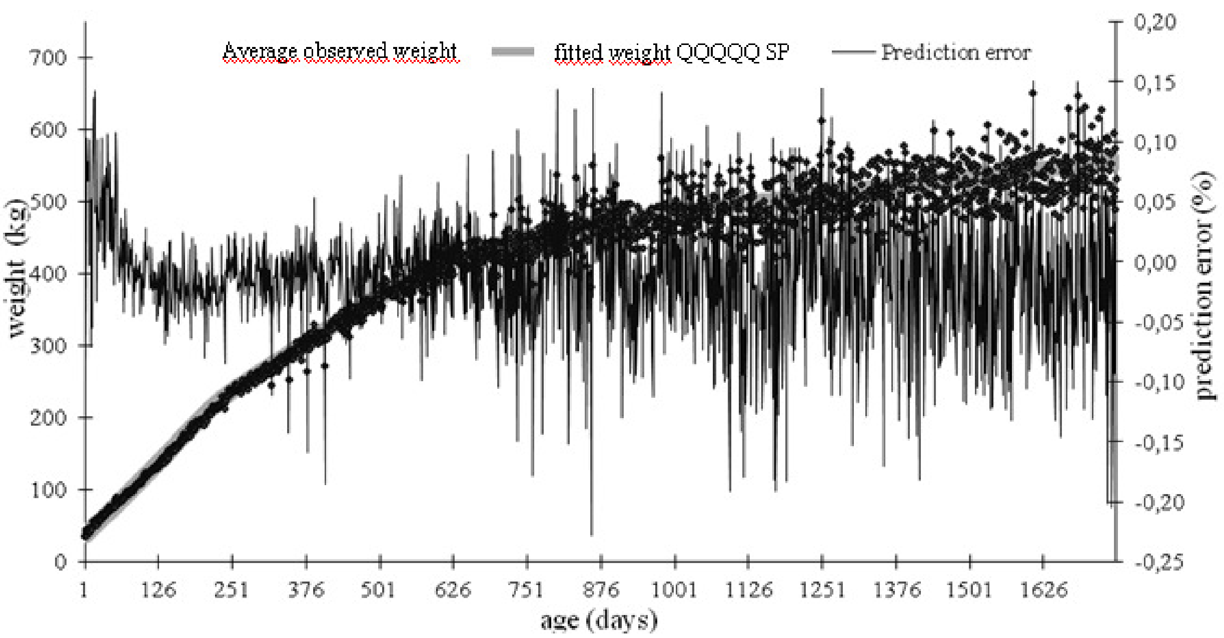

Figure 2 – Adjusted weights and prediction errors (PE) versus age for Santa Gertrudis cattle, given by the segmented polynomial model with five segments (QQQQQ SP) with nodes at 179, 264, 421 and 850 days old.

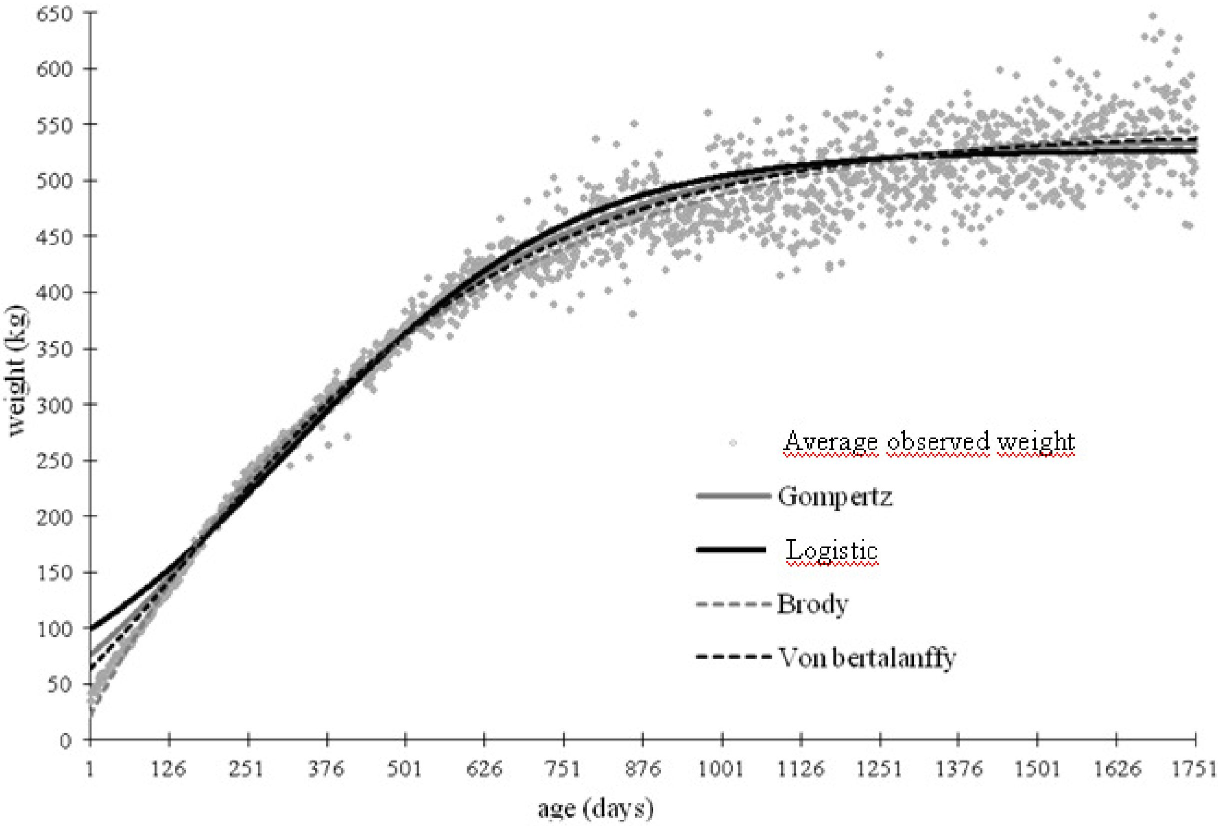

Figure 3 – Adjusted weights versus age of Santa Gertrudis cattle, using the models of Gompertz, Logistic, von Bertalanffy, and Brody.

Teixeira & Albuquerque (2003) found significant age regression effects on the weaning average weight of cattle in the pre-weaning. Laureano et al. (2011) reported the same effect in Nellore cattle at weaning and yearling.

The use of nonlinear models allowed us to infer about animal performance on a broad perspective, thus, the animals of the present study had average weight 542.8 kg when they reached maturity and, at 9.7 months old, they reached an inflection point given by the inverse of *k*. The correlation between *A* and *k* varied according to the models from -0.67 to -0.83, it is, therefore, expected that bigger animals are less precocious.

The possibility of biological interpretation of the nonlinear model parameters is an important factor to be considered during the decision process of choosing a model. The estimated *A* and *k* values allow to predict adult animal weight, rate of weight gain and to establish a growth rate pattern that allows to adjust nutritional management. However, the spline functions seem to be more precise to model age effect on animal weight, especially in the pre- and post-weaning period when great changes of growth rate pattern happen (Figure 2).

CONCLUSION

The use of spline functions proved to be a viable alternative to fit the growth rate curve of Santa Gertrudis cattle; while the nonlinear models allow predicting the rate of growth and maturity weight of the animals, providing practical estimates of animal performance.

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