Using mixed models to describe growth in buffaloes

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Abstract

The objective of this study was to evaluate growth between 12 months and slaughter in 123 castrated male buffaloes. Body weight data, ultrasound, and bovimetric measurements were used. Linear mixed models of first and second order were used. The model included "lot" as a fixed effect. "Individual" and the three parameters of the model were included as random effects.

The second order model had the best fit. "Lot" had a highly significant effect (p <0.01) for most of the traits. The βo values, estimated for body weight (BW), Ribeye area (REA), and rump fat thickness (RFT), were 184, 20.3, and 0.65, respectively. Monthly increments (β1) corresponded to 28, 44, 3.72, 1.25; and deceleration (β2) was -0.61, -0.116, -0.011, respectively. Measurements of height at the sacrum (HS) and height at the withers (HC) agreed with literature reports for this species. Chest circumference measurements (CC), body length (BL), separation between the ilia (II), and distance between ilium-ischium (IIS) were lower than those reported in the literature. Buffalo growth was well described by the quadratic model. This model fits better the growth curve for buffaloes when random parameters are included. During the study, animals maintained the normal physiological behavior described for cattle growth.

Key words: Bovimetric, beef cattle, ultrasound

Modelos mixtos para describir el crecimiento de búfalos

Resumen

EL objetivo del presente trabajo fue evaluar el crecimiento desde los 12 meses hasta el sacrificio de un grupo de búfalos machos castrados. El trabajo se realizó con información de peso vivo, ultrasonido y mediciones bovinométricas en 123 animales. Se utilizaron modelos lineales mixtos de primero y segundo orden, en los cuales se incluyó el lote como un efecto fijo, y como efectos aleatorios el individuo y los tres parámetros del modelo.

El modelo de segundo orden tuvo el mejor ajuste; el lote tuvo un efecto altamente significativo (p<0,01) en la mayoría de las características. Los valores de β_0 estimados para peso vivo (PV), área del ojo del lomo (AOL) y espesor de grasa de la cadera (EGC) fueron 183,69, 20,3 y 0,65 con incrementos (β_1) mensuales de 28,4, 3,72, 1,25 y desaceleración (β_2) de -0,61, -0,116, -0,011, respectivamente. Las mediciones de altura al sacro (AS) y altura a la cruz (AC) coincidieron con los reportes de literatura para esta especie. Las mediciones de perímetro torácico (PT), largo del cuerpo (LC), distancia entre ilions (II) y distancia entre ilion-isquion (ISI) fueron inferiores a lo que reporta la literatura. El modelo cuadrático describió bien el crecimiento del ganado bufalino y su ajuste mejora al incluir parámetros aleatorios. Durante el estudio, los animales mantuvieron el comportamiento fisiológico habitual de crecimiento descrito para ganado vacuno.

Palabras claves: Bovinometría, ganadería de carne, ultrasonido

Introduction

Animal growth has economic relevance in beef production systems because it is closely related to key traits such as feed efficiency and meat quality. Farmers can be more efficient by slaughtering young animals with an appropriate meat: fat ratio, which leads to obtaining a better quality carcass (Berg and Butterfield 1976; Freitas 2005).

According to Lawrence and Fowler (1997), cattle growth is represented as a sigmoidal curve which can be modeled with mathematical functions. These functions can be used as a tool for genetic selection (Tedeschi et al 2000). According to García Berlanga et al (1995), a good fit is obtained for curve fragments when polynomial equations are used. Fit can be improved when random effects are included (Agudelo et al 2007).

Mixed models for growth analysis allow quantifying the variability between and within individuals, because their flexible covariance structure gives them the ability to handle unbalanced data (Aggrey 2009, Pinheiro and Bates 1995). These models can also adjust data with different intervals between measurements. Furthermore, they are more parsimonious than the classical models (James and Nekane 2004).

According to Wang and Zuidhof (2004), the fixed effects in a mixed model correspond to the population or mean value of the parameter. On the other hand, the random effects indicate the differences between the mean value of the parameter and the parameter value, adjusted for each individual. Littell et al (1998) defined fixed effects as the expected values of the observations, and random effects as the variance and covariances of the observations.

This study aimed to evaluate buffalo growth by bovimetric measurements, ultrasound, and body weight in a group of castrated male animals aged 12 months until slaughter, using mixed models.

Materials and methods

Body weight data (BW, n = 526) from 123 castrated male buffaloes (*Bubalus bubalis sp.*) were collected. The initial age of the animals ranged from 12.8 to 19.8 months. The study was conducted at El Teatro farm (Figure 1), located in Buenavista (Colombia, 7.8 degrees, -75.4 minutes of longitude from Greenwich), area classified as tropical moist forest (altitude 80 m. over sea level, and 28 ºC temperature). At least three measurements were taken from each animal. Animals were grazing on *Brachiaria humidicola* and native pastures.

The bovimetric measurements taken were: height at the withers (HC, n = 423 of 115 animals), height at sacrum (HS, n = 411 of 114 animals), chest circumference (CC, n = 413 of 117 animals), body length (BL, n = 517 of 118 animals), ilium-ischium distance (IIS, n = 514 of 118 animals), and distance between ilia (II, n = 520 of 118 animals) (Figure 2).

Ribeye area (REA, n = 520 of 118 animals) was measured with ultrasound images taken transverse to the loin muscle, between the 12th and 13th ribs. To measure rump fat thickness (RFT, n = 534 of 119 animals) ultrasound images were taken from the tip of the hip towards the caudal region, between the iliac and ischial tuberosities. Ultrasound images were taken with an Akila-Pro scanner, equipped with a 3.5 MHz (18 cm) transducer. Subsequently, images were measured using Eview software (Pie Medical 1996).

Figure 1. Pictured here is a group of castrated male buffaloes at El Teatro farm

Statistical analysis

Linear mixed models of first and second order were used. "Lot" was included as a fixed effect in the model, whereas "individual" and the three model parameters (, ,) were considered as random effects. In order to select the number of random parameters to include in the model, we took into account the contribution of the parameter in the improvement of the model, and selected the model with the best fit and the least number of parameters by a $\chi 2$ test. The R statistical software (version 2.11.1) was used for the analysis.
The model used was:

$$y_{ijk\gamma} = (\beta_0 + b_{0\gamma:k}) + (\beta_1 + b_{1\gamma:k})(X_j) + (\beta_2 + b_{2\gamma:k})(X_j^2) + L_k + e_{ijk\gamma}$$

$y_{ijk\gamma}$ = Dependent variable value for animal γ, in group k, at age j (BW, REA, RFT, HC, HS, CC, BL, II, IIS);

β_0= intercept;
b_0= random effect associated with $\beta_0 \sim$ N (0, σ^2_{b0});
β_1= regression coefficient related to growth;
b_1= random effect associated with $\beta_1 \sim$ N (0, σ^2_{b1}σ);
β_2= regression coefficient related to growth;
b_2= random effect associated with $\beta_2 \sim$ N (0, σ^2_{b2}σ);
X_j= time (age);
L_k= effect of lot;
$e_{ijk\gamma}$= experimental error ~ N (0, σ^2_eσ).

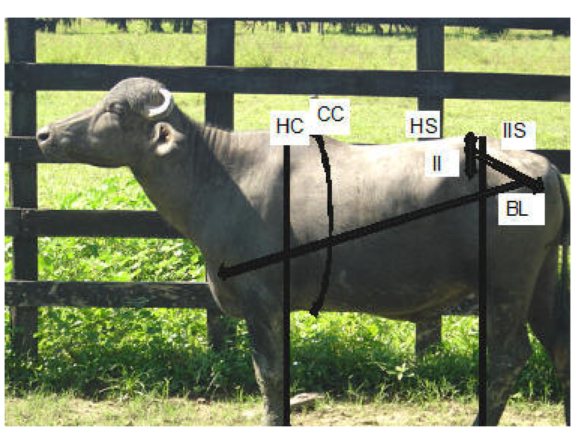


Figure 2. This image illustrates the bovimetric measurements taken in a group of castrated buffalo in northern Colombia.

Results and Discussion

According to our results, the quadratic model had the best fit for all the traits, and the estimated parameters were highly significant (p <0.01). The quadratic model has been used by De Las Heras et al (2008) and by Chong et al (2006) to assess growth in cattle and fish, respectively, due to its good fit and computational ease. "Lot" had no significant effect (p> 0.05) on REA, but it was highly significant (p <0.01) for other traits.

Figure 3 shows the interquartile range plots and the standardized residuals plotted against predicted values. In the residuals versus predicted values plots, errors are randomly distributed, confirming the model's fit without any tendency to underestimate or overestimate. The RFT and REA had the largest errors, whereas IIS, BW and CC had the smaller errors. The interquartile range plots suggest normality of the data for all the traits, with some outliers at the beginning and end. The outliers could be caused by the heterogeneity among individuals or by external causes not included in the study. In general, the model had a good fit.

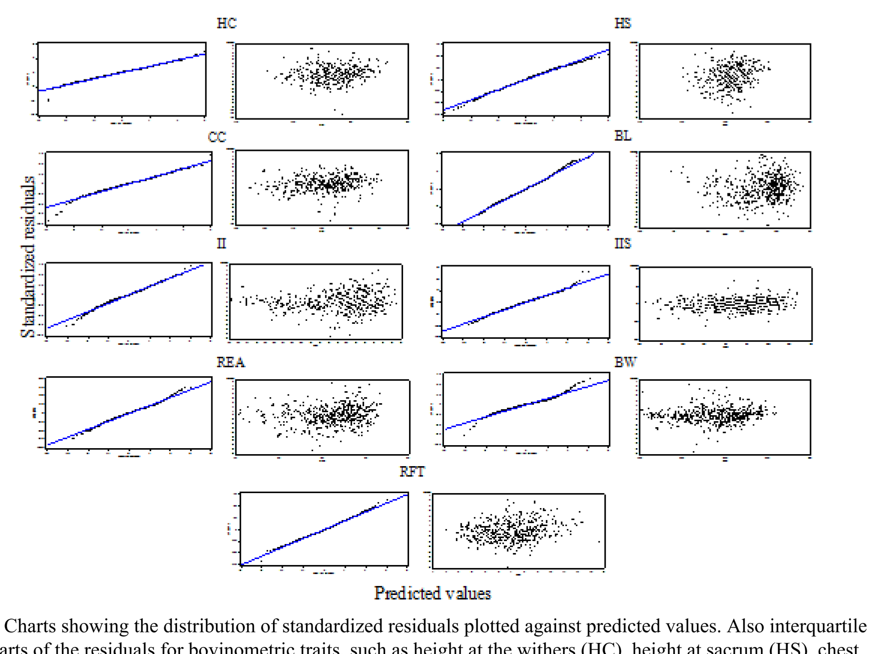


Figure 3. Charts showing the distribution of standardized residuals plotted against predicted values. Also interquartile range charts of the residuals for bovinometric traits, such as height at the withers (HC), height at sacrum (HS), chest circumference (CC), body length (BL), distance between ilia (II), distance between ilium and ischium (IIS), body weight (BW), Ribey area (REA), and rump fat thickness (RFT) for a group of castrated male buffaloes in northern Colombia.

The values of -2 log of maximum likelihood and the differences observed between models are presented in Table 1.

No significant difference (p> 0.05) was found for the model with one β_0, two ($\beta_0 \beta_1$) or three ($\beta_0 \beta_1 \beta_2$) random parameters for HC, HS, CC, BL, IIS, and REA, thus these traits were evaluated with one random parameter in the model. A model with two random parameters was selected for II, BW, and RFT, because a significant difference (p <0.05) was found between the single and the two random parameters model. The model with three random parameters converged only in HC, CC and REA. Figure 4 shows the curves and the estimated parameters for each trait.

Table 1. Maximum likelihood estimates and χ^2 test for the mixed models evaluated to describe growth of castrated male buffalo in northern Colombia.

#PA	HC	HS	CC	BL	II	IIS	BW	REA	RFT
1	**2305.5^a**	**2185.3**	**2726.2^a**	**3541.5^a**	2650.1^a	**2222.2^a**	5059.6^a	**3279.1^a**	2201.8^a
2	-	-	2724.6^a	3538.1^a	**2625.4^b**	2221.9^a	**4992.6^b**	3266.2^b	**2161.6^b**
3	2291^a	-	2714.9^a	-	-	-	-	3265.4^{ba}	-

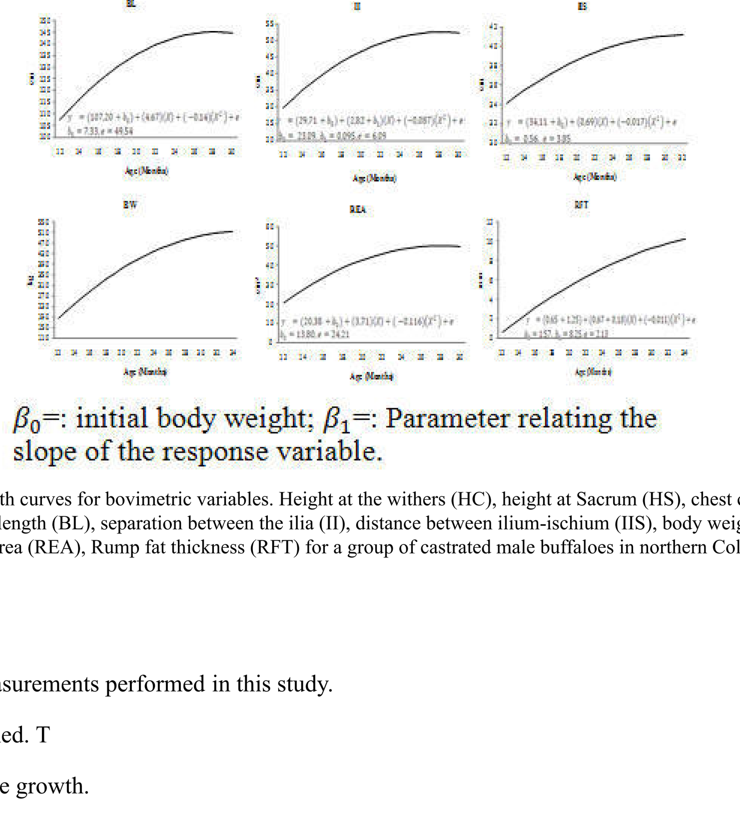
 # PA = number of random parameters; HC = height to the withers; HS = height at sacrum; CC = chest circumference; BL = length of the body; II = distance between ilia; IIS = distance between ilium and ischium; REA = Ribeye area; RFT = Rump fat thickness. Different letters indicate significant difference (p <0.05) for the χ^2 test.

The estimated BW at 12 months (183 kg) was below that reported for grazing buffaloes in Brazil, which fluctuate between 301 kg and 351 kg (Malhado et al 2008; Jorge et al 2005). These low BW values demonstrate a flaw in Colombian production systems, which can be improved by selecting individuals with high growth potential, and by improving post-weaning animal handling. These strategies should increase performance and profitability (Montes et al 2008). The BW gain $\beta 1$ was 28.4 kg, which is higher than that reported by Oliveira (2005), who found 20.4 kg monthly gain for male buffaloes in Brazil. The figure is similar to that reported by Laurence et al (2010) who found 27.7 kg gain in pure Murrah buffaloes in a silvopastoral system. Growth deceleration (β_2) was -0.61, indicating weight gain tends to decrease as the animal gets older.

The estimated RFT values agreed with the normal growth physiology. Early in life, fat deposition was low (β_0 = 0.65 mm), with 1.25 mm monthly increases (β_1), which continued after having fully developed bone and muscle tissues. The estimated β_2 was -0.01. This close-to-zero value indicates that slowdown of this trait was minimal for the evaluation period. The trend was to increase, representing an acceleration of fat tissue deposition at older ages - compared with bone and muscle tissues (Berg and Butterfield 1976). Rodriguez et al (2001) reported higher REA values (between 33.4 and 40.8) for crossed buffaloes raised in feedlots in Brazil. Those results, compared to this study, could be explained by feeding differences in both studies. Hamlin et al (1995) reported better fit with the quadratic model to describe growth of REA and RFT in cattle.

The estimated values for HS, HC and CC were $\beta 0$ (119.35, 114.68, 149.37), $\beta 1$ (2.3, 2.1, 4.72), and $\beta 2$ (-0.06, -0.06, -0.1), respectively. Lourenço et al (2010) and Crudeli et al (2007) reported similar results to those found in this study for HS (117 cm-134 cm) and HC (115 cm-130 cm). These same authors reported 161 cm and 183 cm for CC, and 132 cm for BL, which are higher than those found in this study. Our results suggest that animals were in the final phase of the second wave of growth, where the animal grows in height, and the third wave was starting -in which the animal grows in amplitude. This would explain why animals had not reached the adult perimeter, despite their height was similar to that reported in other studies (Hammond 1960).

Measurements at the hindquarters (II, IIS) were lower than those reported by Laurence et al (2010), who obtained 50 cm for II, and 48 cm for IIS in Brazilian buffaloes. Our results were 29.7 cm for II, and 34.11 cm for IIS. These differences confirm the smaller size of our animals compared to the mentioned study, which could be explained by a difference in development stages of the animals used in both studies.



β_0=: initial body weight; β_1=: Parameter relating the slope of the response variable.

Figure 4. Growth curves for bovimetric variables. Height at the withers (HC), height at Sacrum (HS), chest circumference (CC), body length (BL), separation between the ilia (II), distance between ilium-ischium (IIS), body weight (BW), Ribeye area (REA), Rump fat thickness (RFT) for a group of castrated male buffaloes in northern Colombia.

Conclusions

- Buffalo growth was well described by the quadratic model with the measurements performed in this study.
- When random parameters are included in the model, a better fit is obtained. T
- he animals maintained normal physiological behavior described for cattle growth.

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Go to top