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A comparison of nonlinear models for describing growth in Muzaffarnagri lambs under field conditions

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Muzaffarnagri sheep is one of the most important sheep breeds of India. The native breeding tract of this breed is Muzaffarnagar district of Uttar Pradesh, India. The breed is well integrated in agricultural system and is thriving well owing to its characteristics of faster growth rate of lambs (Singh 1995) and feed conversion efficiency (ICAR 1990). The breed is primarily maintained for mutton purpose, however, it also produces fleece of course quality.

Researchers in the field of behavioural and life sciences often come across with the growth studies. The type of model needed in a specific area and in a specific problem depends on the type of growth that occurs. In general growth models are mechanistic rather than empirical ones (Draper and Smith 1981). Bhadula and Bhat (1980) fitted 3 functions, viz. linear, exponential and quadratic in Muzaffarnagri sheep and its half bred with corriedale. Based on R^2 values quadratic function showed a best fit. Brody (1945) defined growth as relatively irreversible in magnitude of measured dimension or function. Statistical analysis of data on growth of animals involves choosing a suitable growth curve/model and proper method of pooling the results over the group of experiments. Brown *et al.* (1976) compared 5 non-linear models, viz. Von Bertalanffy, Logistic, Gompertz, Brody and Richards to fit weight-age data of beef and dairy cows.

Lambe *et al.* (2006) compared the use of various models to describe growth in lambs of 2 contrasting breeds from birth to slaughter. Biologically relevant variables were estimated for each lamb from modified versions of the logistic, Gompertz, Richards, exponential models and linear regression. The Richards and Gompertz models provided the best fit (average $R^2 = 0.986$ to 0.989) in both breeds. Singh Okendro *et al.* (2007) studied use of non-linear models to describe growth pattern of *Tor putitora* (Hamilton) and found Von Bertalanffy model as best suitable model to describe growth pattern. Singh *et al.* (2008a, 2008b) studied the growth pattern of different breeds of cattle under homoscedastic and heteroscedastic error conditions. Singh Okendro *et al.* (2009a, 2009b) also fitted different growth models in different breeds of fish at different situations. The present study was undertaken to compare the use of various growth models to describe the growth of Muzaffarnagri breed of sheep under field conditions.

A survey was conducted in the breeding tract in 3 districts, viz. Muzaffarnagar, Meerut and Saharanpur of Utter Pradesh, India. Thirty-six flocks were surveyed and body weights of 151 male and 166 female lambs were recorded. The age of the lambs was recorded by interviewing the owners. Most of the farmers disposed off the male lambs by the age of 6–7 months, lesser data points were observed in male lambs between the age of 7–12 months. Four non-linear models, viz. Logistic model: $X_t=\beta/(1+\beta_2-\beta_3 t)+\varepsilon$, Gompertz model: $X_t=\beta_1 \exp(-\beta_2 e-\beta_3 t)+\varepsilon$, Von Bertalanffy model: $X_t=\beta_1/(1-\beta_2 e-\beta_3 t)^3+\varepsilon$, and Brody's model: $X_t=\beta_1/(1-\beta_2 e-\beta_3 t)+\varepsilon$; where X_t, dependent variable, i.e. weight of lamb at the age of t month; β_1, asymptotic weight; β_2, scaling parameter; β_3, rate of maturity; were fitted to the lamb data using SAS (Statistical Analysis System) software.

The empirical comparison of models was done based on the measures, viz. the coefficient of determination (R^2) as suggested by Kvalseth (1985) for non-linear models:
R^2 = 1–(residual sum of squares/total sum of squares),

where, residual sum of squares= $\sum_{i=1}^{n}(Y_i-\hat{Y}_i)^2$ and total sum of squares= $\sum_{i=1}^{n}(Y_i-\bar{Y})^2$

Y_i, dependent variables (weights); $\hat{Y}_i$, predicted values or estimated value; and $\bar{Y}$, mean of dependent variables. Also, it was suggested that the nonlinear model should not be judged as the best model only on the basis of R^2, and one

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should go for the measures like RMSE (root mean squared error) and MSE (mean square error) for judging the goodness of fit of the model.

$$\text{Root mean square error (RMSE)} = \left[\sum_{i=1}^{n} \frac{\left(Y_i - \hat{Y}_i\right)^2}{n-p}\right]^{1/2},$$

$$\text{Mean square error (MSE)} \quad \frac{\sum_{i=1}^{n}(Y_i - \hat{Y}_i)^2}{n-p},$$

n, number of observations and p, number of parameters in the model.

The Gompertz model RMSE (2.0995) was minimum and R^2 (0.9410) was maximum among all the models for male lambs (Table 1). Hence, Gompertz model was the best fit for male lambs. Growth rate was highest (0.2336) by logistic model and asymptotic weight (45.5736) was maximum in Gompertz model. It is concluded from Table 2 that for Gompertz model RMSE (1.8064) was minimum and R^2 (0.9576) was maximum for female lambs also. So Gompertz model was best fitted among all the models for female lamb growth. In both sexes, all nonlinear models fitted the data well but the Gompertz models provided the best fit. Asymptotic weight was also maximum (44.9517) by this model and growth rate was maximum (0.2347) by Logistic as well as Brody models. Between male and female lambs RMSE was less for female lambs than male. So, we can conclude that Gompertz model was better fitted for female lamb than male. Asymptotic weight was more for male lambs and growth was better for female lambs. It is found that growth for male lambs was [illegible] predicted at beginning and gave under prediction at later [illegible] whereas prediction for female lambs was good at later [illegible] and over prediction at early age. Hence, from the above results, it is concluded that Gompertz model is best fitted model for male and female lambs. Similar findings were reported by Lambe *et al.* (2006).

Table 1. Parameter estimates of different nonlinear models for male lambs

Parameter	Logistic	Gompertz	Brody	Von Bertalanffy
ß1	41.1675	45.5736	41.1674	43.5757
	(10.4346)	(14.8715)	(10.4345)	(12.7154)
ß2	3.4735	1.7104	-3.4735	-0.7171
	(0.7645)	(0.2167)	(0.7845)	(0.1123)
ß3	0.2336	0.1467	0.2336	0.1761
	(0.0819)	(0.0704)	(0.0819)	(0.0742)
R^2	0.9341	0.9410	0.9341	0.9385
MSE	4.9245	4.4076	4.9246	4.5909
RMSE	2.2192	2.0995	2.2192	2.1425

Figures in bracket indicate asymptotic standard errors.

Table 2. Parameter estimates of different nonlinear models for female lambs

Parameter	Logistic	Gompertz	Brody	Von Bertalanffy
$ß_1$	40.1580	44.9517	40.1579	42.8585
	(6.6567)	(10.3078)	(6.6567)	(8.6206)
$ß_2$	3.5140	1.7242	−3.5140	−0.7243
	(0.5563)	(0.1559)	(0.5563)	(0.0808)
$ß_3$	0.2347	0.1447	0.2347	0.1746
	(0.0606)	(0.0515)	(0.0606)	(0.0545)
R^2	0.9528	0.9576	0.9528	0.9559
MSE	3.6388	3.2630	3.6388	3.3991
RMSE	1.9075	1.8064	1.9075	1.8436

Figures in bracket indicate asymptotic standard errors.

SUMMARY

This study compared the use of various models to describe growth in lambs of Muzaffarnagri breed from birth to [illegible] months of age (most of the cases it is maturity age for lambs). It is found from the results that for male lambs Gompertz model is the best fitted model followed by Von-Bertalanffy Model. Growth rate is maximum, by Logistic model [illegible] weight at 12 month of age is maximum given by Gompertz model. In case of female lambs results of Gompertz model is the best and growth rate is maximum for Logistic [illegible] followed by Von Bertalanffy model. Maturity weight [illegible] maximum by Gompertz model. It is concluded that Gompertz model is the best model to describe growth of male [illegible] female lambs up to the age of 12 months.

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