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Effect of lameness on lactation curves of Vrindavani cattle

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Abstract
The present study was aimed to find the best lactation curve model that describes the milk production pattern of Vrindavani cattle suffered from lameness. In the present study, daily test day milk yield data of Vrindavani cattle suffered from lameness were collected from cattle and buffalo farm, LPM section, ICAR-IVRI over 5 years (2009-2014). Eight lactation curve models [Inverse quadratic polynomial model (ND), Incomplete Gamma function (WD), Linear decline model (CL), Wilmink model (WL) Mixed log model (ML), Mitscherlich x Exponential (ME), Morant and Gnanasakthy model (MG) and Ali & Schaeffer lactation curve model (AS)] were fitted and parameters were estimated by nonlinear regression using PROC NLIN procedure of statistical package SAS 9.4. The best model was selected based on different goodness of fit criteria and the result shows that the Mixed Log (ML) model was the best fitted to describe the lactation pattern of Vrindavani cattle suffered from lameness. The Durbin-Watson test was used to check the presence of autocorrelation present in the data set, whereas, Kolmogorov-Smirnova test and Shapiro-Wilk was used to check the normality of the residuals.

Keywords: Goodness of fit, lactation curve, lameness, mastitis, Vrindavani cattle

Introduction
India is home to some of the best crossbreds of cattle and the number of crossbred cattle in a household indicates the socioeconomic status of the farmers. According to the 20th livestock census, the cattle population of India was 192.49 million, out of which 50.42 million were exotic/crossbred and the exotic/crossbred cattle population has increased by 26.9% as compared to the previous census [1].

In the year 2018-19, the annual milk production of India was 187.7 MT, with record annual growth of 11.4 MT and in this period the per capita availability is about 394 gram/day, which is higher than the world average and the recommendation suggested by the nutritional advisory committee of ICMR [26].

Milk production is a complex biological phenomenon. The cattle immediately after calving to three days after parturition secrete colostrum. From the fourth day of parturition, milk secretion starts and in this period the milk production gradually increases with a very slow rate of up to two weeks. After the second week the milk production increase with a very increasing rate and reached the peak production level (First phase). The animal remains in peak production stage from two weeks to two or three months (Second Phase), then milk production decline gradually (Third Phase). The phase of milk production is diagrammatically represented by the lactation curve and many standard lactation curve models are developed to describe the milk production pattern of animals. However, a single model is not universally suitable for fitting especially when there was an incidence of disease on the farm.

Lactation curves are used for the prediction of daily/ monthly or total milk production of dairy animals. Brody *et al*. (1924) introduced the first lactation curve model (gamma function) to forecast milk yield over the lactation cycle of cows. One year later, Brody *et al*. (1924) modified his model with two exponential functions to describe the whole lactation pattern of Holstein-Friesian cows.[4] Lactation curve models have different forms including Inverse quadratic polynomial model [16], Parabolic exponential [21], Incomplete gamma function [25], Polynomial model [3], Exponential model [24], Cubic splines model [9] , Legendre polynomial [11], and log-quadratic model. [2]

After FMD mastitis and lameness are the real threat to dairy industries causing health and economic problems.

The lameness is very common with a high incidence rate and various factors are responsible for the lameness. However, better management strategies decrease the incidence of lameness. The effect of lameness increases the resting time of dairy animals and results in overall production loss. Lameness took third place in causing economic loss to dairy farmers but still among the most neglected and least studied dairy problems. The magnitude of loss resulting from lameness in dairy units is very similar in different countries, mostly varying between €40-50 per cow although some differences can be observed due to the different economic circumstances and exchange rates. [18]

Vrindavani cattle are recently developed synthetic crossbred cattle strain with an exotic inheritance of Holstein-Friesian, Brown Swiss, Jersey and indigenous inheritance of Hariana cattle. In the present situation, we cannot imagine lameness free dairy farms globally. Modelling the diseases effects and various environmental factors on milk production are of utmost importance for the prediction of milk production at any farm. Researchers tried to explore the effects of parity and other environmental factors on milk production in purebred cattle [14] and crossbred cattle [12] however, some researchers explore the effect of lameness on the lactation pattern of Murrah buffaloes [13]. Keeping in view the above mentioned facts the objective of this study was to find the best lactation curve model that describes the milk production of lame Vrindavani cattle (Vrindavani cattle suffered from lameness).

Material and Methods

The 6230 daily test day milk yield (DTDMY) data of 24 Vrindavani cattle suffered from lameness collected from individual history sheets/livestock production records maintained at Cattle and Buffalo farm of LPM Section IVRI, Izatnagar (Uttar Pradesh). Along with DTDMY data, data regarding disease condition, parity of animal and season of calving was also recorded from individual history sheets over 5 years (2009-2014).

Modeling the Shape of the Lactation Curve

In the present study 8 Lactation curve models (5 models with three parameters, 2 models with four parameters and 1 model with five parameters) were fitted on average test day milk yield data of Vrindavani cattle.

1. Lactation curve model based on 3 Parameter

A. Inverse quadratic polynomial model (Nelder, 1966) [16]

$$Y_t^{-1} = t / \left(a + bt + ct^2\right)$$

B. Incomplete Gamma function (Wood, 1967) [25]

$$Y_t = at^b e^{-ct}$$

C. Linear decline model (Cobby and Le Du., 1978) [6]

$$Y_t = \mathbf{a} - \mathbf{bt} - \mathbf{ae}^{-\mathbf{ct}}$$

D. Exponential model or Wilmink lactation curve model (Wilmink, 1987) [24]

$$Y_t = \mathbf{a} + \mathbf{be}^{-\mathbf{kt}} + \mathbf{ct}$$

E. Mixed log model (Guo *et al.*1995) [10]

$$Y_t = \mathbf{a} + \mathbf{bt}^{1/2} + c\ln(t)$$

where " Y_t " is the production at time t, "a" is the scale factor or milk yield at the beginning of lactation, "b" is the rate of change from initial production to peak yield and "c" is the rate of change from peak yield to the end of lactation. The factor "k" was related to the time of peak lactation and usually assumes a fixed value, but some researcher derived the value of "k" from the preliminary analysis based on average production and is equal to 0.065[22], 0.61[17] and 0.10 [5].

2. Lactation curve model based on 4 Parameter

Mitscherlich x Exponential (Rook *et al.*1993)

$$Y_t = \mathbf{a}\left(\mathbf{1} - \mathbf{be}^{-\mathbf{ct}}\right) - \mathbf{dt}$$

Where "a" is the scale factor or milk yield at the beginning of lactation, "b" is the rate of change from initial production to peak yield, "c" is the rate of change from peak yield to the end of lactation and "d" is parameter related to maximum milk yield.

F. Morant and Gnanasakthy model (Morant *et al.* 1989) [15]

$$Y_t = \exp\left(a - bt + ct^{1/2} + d/t\right)$$

Where "a" is the logarithm of expected yield at mid of lactation, "b" is the rate of change at mid of lactation, "c" is the rate of change of persistency and "d" is the rate of increase in yield at the beginning of lactation

3. Lactation curve model based on 5 Parameter

G. Ali & Schaeffer lactation curve model (Ali and Schaeffer, 1987) [3]

$$Y_t = \mathbf{a} + \mathbf{b}\delta + \mathbf{c}\delta^2 + \mathbf{d}\ \theta_i + \mathbf{e}\ \theta_i^2 + \mathbf{f}_t$$

where "a" is the scale factor or milk yield at the beginning of lactation, "b" is the rate of change from initial production to peak yield at a decreasing rate, "c" is the rate of change from initial production to peak yield at increasing rate, "d" is the rate of change from peak yield to the end of lactation at a decreasing rate and "e" is the rate of change from peak yield to the end of lactation at increasing rate

whereas δ ($\delta = t/305$) and θ_i ($\theta i = \ln(305/t)$) are a function of time

Statistical Analysis

In the present study for lactation curve fitting and estimation of parameter Levenberg–Marquardt algorithm Iteration procedure was used. The estimated value of parameters was finally used to predict milk yield. The models were fitted by using the PROC NLIN statement of the statistical package SAS 9.4 version.

The goodness of fit of the lactation models was tested by the following methods.

Coefficient of determination (R^2)

$$\mathbf{R}^2 = \mathbf{1} - \frac{\text{Residual Sum of Squares}}{\text{Total Sum of Squares}}$$

The value of coefficient of determination (R^2) ranges between 0-1. R^2 of 1 indicates that the regression line perfectly fits the data. Adjusted coefficient of determination (R^2_{adj}) is more comparable than R^2 for model that involves different numbers of parameters. A model with large R^2_{adj} is best fitted model.

Adjusted coefficient of determination (R^2_{adj})

$$\mathbf{R^2}_{adj} = \mathbf{1} - \frac{\text{MSPE}}{\text{MS(Corrected Total)}}$$

$$R^2_{adj} = 1 - \frac{(1-R^2)(P-1)}{n-1}$$

Root Mean Square Error (RMSE)

$$\text{RMSE} = \sqrt{\frac{\sum (Y_i - \overline{Y}_i)^2}{n-p}}$$

Mean Absolute Error (MAE)

$$\text{MAE} = \frac{\sum \left| Y_i - \overline{Y}_i \right|}{n}$$

where, Y_i is the milk yield, i =1, 2, 3, 4…, “n” is the number of experimental observations, “p” is the number of parameters, predicted value. The small value of RMSE and MAE indicates a better-fitted model.

Akaike’s Information Criteria (AIC)

$$\mathbf{AIC} = \mathbf{2P - 2ln(L)}$$

$$\text{AIC} = n \log_e \text{MSE} + 2p$$

If the number of parameters is more than corrected Akaike’s Information Criteria (AIC_c) is used instead of Akaike’s Information Criteria (AIC)

Corrected Akaike’s Information Criteria (AIC_c)

$$\mathbf{AIC_c} = \mathbf{AIC} + \frac{2p(p+1)}{n-p-1}$$

where, “p” is the number of parameters in the model and “L” is the maximized value of the likelihood function for the model. The preferred model is the one which has minimum AIC value

Bayesian information criterion (BIC)

$$\text{BIC} = n \log_e \text{MSE} + P \log_e (n)$$

The preferred model is the one which has minimum BIC value

Examination of Residuals (Errors)

Residuals or errors are defined as the difference between the observed and predicted value of the response. For modeling purposes, there are two assumptions (a) The errors are independently and identically distributed i.e.$\varepsilon \sim N(0, 1)$ (b) The errors have constant variance. In the present study, the assumption may be tested by using the Durbin-Watson Test (to test the presence of autocorrelation) and Shapiro-Wilk Test (to test the normality of the residuals)

Results and Discussion

The eight models [Inverse quadratic polynomial model (ND), Incomplete Gamma function (WD), Linear decline model (CL), Wilmink model (WL) Mixed log model (ML), Mitscherlich x Exponential (ME), Morant and Gnanasakthy model (MG) and Ali & Schaeffer lactation curve model (AS)] were fitted on DTDMY data. The summary of recorded milk production is mentioned below (Table 1).

Table 1: Total milk production (305 days), lactation length and peak production of Vrindavani Cattle in healthy and disease condition

Vrindavani cattle	305-day milk production (kg)		Lactation length (days)		Peak production (kg)	
	Mean	SE	Mean	SE	Mean	SE
Healthy Cattle	3257.57	0.13	299.58	0.76	17.98	0.21
Lame Cattle	2452.81	0.15	259.71	11.29	11.98	1.06

Lactation curve of Vrindavani cattle suffered from lameness

The ML model was best fitted model to describe the DTDMY (Daily test day milk yield) data of lame Vrindavani cattle ($R^2_{(adj)}$ = 0.9789, MAE = 0.2914, RMSE = 0.0344, AICc = -2050.1 and BIC = -2039.0). AS was 2nd best fitted model ($R^2_{(adj)}$ = 0.9777, MAE = 0.2955, RMSE = 0.0617, AICc = -1688.8 and BIC = -1670.3) followed by CL model ($R^2_{(adj)}$ = 0.9708, MAE = 0.3057, RMSE = 0.1031, AICc = -1380.0 and BIC = -1368.9) and ME model was least fitted to describe the DTDMY (Daily test day milk yield) data of lame Vrindavani cattle ($R^2_{(adj)}$ = 0.8596, MAE = 0.4821, RMSE = 0.4608, AICc = -464.5 and BIC = -449.7). Except ME model, all models are fitted well to DTDMY data of lame Vrindavani cattle with adjusted coefficient of determination range from 0.9305 to 0.9789. The value of parameters of different lactation curves are mentioned below (Table 2). The pattern of fortnight test day milk record of lame Vrindavani cattle and predicted milk production (by fitted model) are graphically represented. (Figure 1).

Table 2: Estimated value of parameters of different lactation curve models of Vrindavani cattle suffering from lameness along with different measures of goodness of fit.

Model	Parameter	Mean	±	S.E.	R^2(adj)	MAE	RMSE	AICc	BIC
AS	a	14.109	±	1.053	0.9777	0.2955	0.0617	-1688.8	-1670.3
	b	-13.548	±	1.868					
	c	3.093	±	0.887					
	d	0.507	±	0.543					
	e	-0.424	±	0.070					
CL	a	12.927	±	0.054	0.9708	0.3057	0.1031	-1380.0	-1368.9
	b	0.031	±	0.000					
	c	0.206	±	0.006					
ME	a	7.896	±	1.318	0.8596	0.4821	0.4608	-464.5	-449.7
	b	-0.549	±	0.514					
	c	0.000	±	0.102					
	d	0.027	±	0.614					
MG	a	2.127	±	0.004	0.9758	0.3016	0.1286	-1242.9	-1228.1
	b	0.417	±	0.004					
	c	0.076	±	0.005					
	d	1.925	±	0.092					
ML	a	5.099	±	0.173	0.9789	0.2914	0.0344	-2050.1	-2039.0
	b	-1.532	±	0.018					
	c	4.399	±	0.076					
ND	a	0.387	±	0.022	0.9305	0.5544	0.1350	-1215.4	-1204.3
	b	0.053	±	0.001					
	c	0.000	±	0.000					
WD	a	6.025	±	0.139	0.9708	0.3444	0.1059	-1363.5	-1352.4
	b	0.245	±	0.007					
	c	0.006	±	0.000					
WL	a	13.444	±	0.070	0.9638	0.3486	0.1698	-1075.4	-1064.3
	b	-6.711	±	0.227					
	c	-0.033	±	0.000					

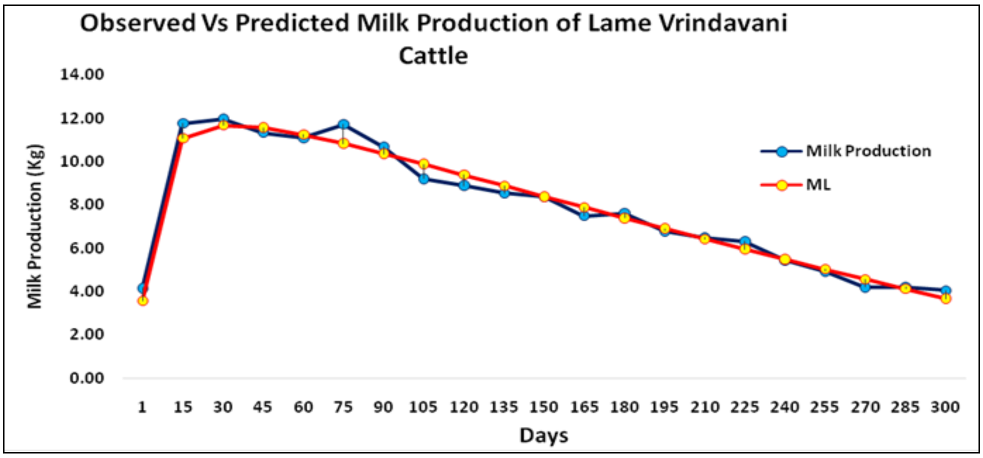

Fig 1: Observed Vs predicted (by best-fitted model) milk production of lame Vrindavani cattle.

The milk production, day in milk and peak production of lame Vrindavani cattle is significantly lower than the healthy Vrindavani cattle. Except ND model, all models exactly predicted the total milk production. The ND model overpredicted the peak production and total milk production. The peak production, total production and value of parameters of different lactation curves are mentioned below (Table 3).

Table 3: Descriptive Statistics of Predicted Milk Production by different Model of lame Vrindavani Cattle

Model	Predicted Milk Production	
	Peak Production (kg)	Total Production (kg)
AS	11.71	2452.74
CL	12.11	2450.55
ME	12.20	2452.81
MG	11.69	2451.78
ML	11.68	2452.89
ND	12.45	2462.57
WD	11.68	2453.25
WL	11.62	2452.79
Observed Milk Production	11.98	2452.81

The residual obtained from different functions was plotted graphically (Figure 2) and test statistics are mentioned (Table 4). Kolmogorov-Smirnova test shows that the test statistics obtained from residual of AS and WD function are significant, but the Shapiro-Wilk test statistics obtained from residual of different functions were non-significant i.e. residuals are normally distributed. In this study, the Durbin-Watson test (DW test) was used to check the presence of autocorrelation in residuals. The DW statistic always has a value range between 0.0 to 4.0. A value of 2.0 means there is no autocorrelation. DW statistics values from 0.0 to 2.0 indicate positive autocorrelation and values from 2.0 to 4.0 indicate negative autocorrelation. The DW statistics of residual obtained from different models range from0.1282 to 0.7490 i.e. the residuals were positively autocorrelated.

Table 4: Test for the presence of autocorrelation and normality of residuals in lame Vrindavani cattle by different lactation curve models

Model	Durbin-Watson	Kolmogorov-Smirnov[a]		Shapiro-Wilk	
	Statistics	Statistics	Sig.	Statistics	Sig.
AS	0.7490	0.046	.200	.986	.004
CL	0.6079	0.087	<0.001	.953	<0.001
ML	0.7326	0.049	.075	.988	.010
ME	0.1282	0.219	<0.001	.610	<0.001
MG	0.7171	0.054	.032	.963	<0.001
ND	0.2206	0.076	<0.001	.982	.001
WD	0.5261	0.030	.200*	.980	<0.001
WL	0.4506	0.070	.001	.934	<0.001

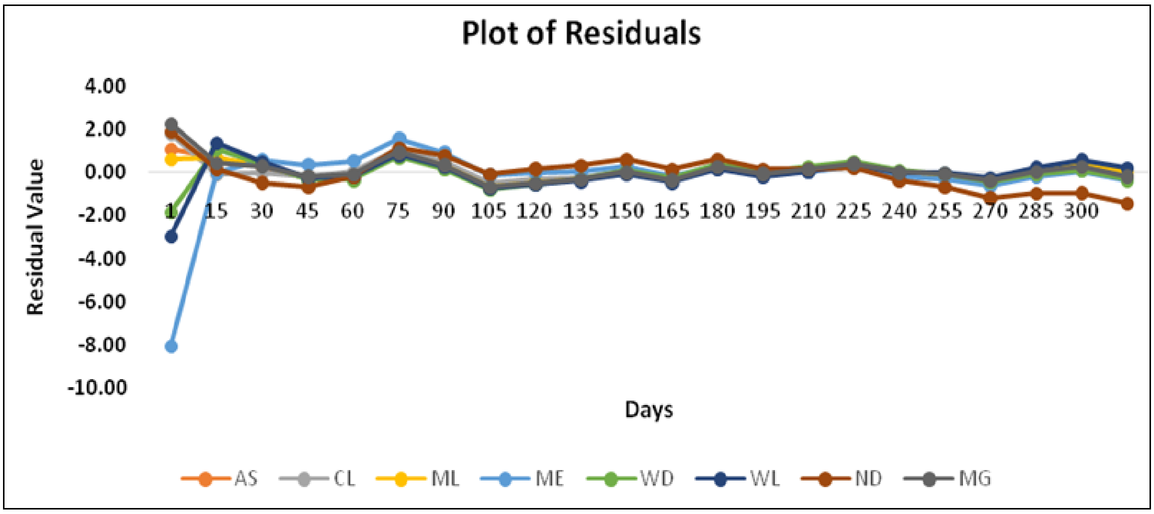

Fig 2: Plot of residuals for lame Vrindavani cattle by different lactation curve models

However, the effect of lameness was significant and the milk production decreases by 24.7% when Vrindavani cattle suffered from lameness. Similar to the present finding, Rowlands *et al*. (1986) also observed that milk production of cattle significantly decreases due to lameness [20]. Coulon *et al*. (1996) concluded that the average loss due to lameness range 270-420 kg/animals and summer foot lesions were more severe than winter lesions, regardless of the stage of lactation [7]. Whereas, other researchers in different environmental conditions studied the effects of lameness and concluded that the milk loss of cows varied between 0.3-3.3 kg/day [8], 1.5-2.8 kg/day [19] and 1.5 kg/day [23].

Conclusions
Lameness is one of the major threats to dairy industries, restricted movement of farm animals, floor quality of farm, nutritional and other management practices adopted in the farms are associated with this disease. The total milk production, peak production and lactation length of lame Vrindavani cattle are lower with comparison to healthy Vrindavani cattle. Out of eight models, the Mix log model is the best fitted to the DTDMY data of lame Vrindavani cattle and the Inverse polynomials is the least fitted lactation curve model. However, all models except the Inverse polynomials lactation curve model exactly predict the peak production and total production, however Inverse polynomials lactation curve model over predict the peak production and total production.

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