



Modeling of lactation curves of Red Sindhi dairy cows

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India ranks first in milk production followed by USA. Though it is highest in overall milk production but positioned second in cow milk production (61 million tonnes) where USA is the largest cow milk producer (91 million tonnes) (<http://dairy.ahdb.org.uk>) in the world. Milk production is not a continuous process. It is a phase wise process consisting three different phases, viz. ascending phase, persistence phase then declining phase. Lactation curve is relationship between milk yield and lactation length with respect to time. Proper prediction of milk production helps the dairy herd owners to make the management decision and selection. The lactation curve is important because its wide characterization of the animal production throughout the lactation allows estimating peak yield, peak period, lactation persistency and total milk yield. Maximum lactation performance is associated with a high initial rate of milk secretion and a high degree of persistence. Different types of mathematical models have been used in research to define the shape of lactation curve. The shape of lactation curve is not associated with the single factor but largely affected by various combinations of other biological factors. The objective of this study was to study milk production in Red Sindhi cows by fitting five different lactation curve models for weekly test day milk yield.

The data for the current study were compiled from Central Cattle Breeding Farm (CCBF), Chiplima, Odisha where purebred Red Sindhi cows are intensively maintained. The data set consisting of 885 lactation records were taken from history-cum-pedigree sheets and daily milk recording register over a period from 2009 to 2010. The data of animals having more than 150 days of lactation were taken for this study. All the milk records were arranged on weekly basis and weekly test day milk yield

(WTDMY) were recorded.

Following five lactation models were used to describe the lactation curve models of WTDMY of Red Sindhi cows.

Sikka model: $Y_t = a \exp(bt - ct^2)$

Wood model: $Y_t = at^b \exp^{-ct}$

Polynomial model: $Y_t = a + bt + ct^2$

Dijkstra model (DIJK): $Y_t = a \exp\{b(1 - \exp^{-ct})/c - dt\}$

Morant and Gnanasakthy model (MG): $Y_t = \exp(a - bt + ct^2/2 + d/t)$

where Y_t is the milk yield in lactation week 't' and a, b, c and d are the parameters.

Each model was fitted to weekly test day milk yield (WTDMY) of 305 days lactation by using PROC NLIN procedures of SAS 9.3 version (SAS Institute INC. 2011. Cary, NC, USA). The models were analyzed for the goodness of fit by using the adjusted coefficient of determination (Adj. R²), root mean square error (RMSE), Akaike's information criteria (AIC) and Schwartz Bayesian information criterion (SBC) (Dohare *et al.* 2015). The residuals obtained after analysis were tested by Shapiro-Wilk test to check the presence of normality. Durbin-Watson statistic was applied to test the presence of autocorrelation. The randomness of the residuals was tested by the run test.

Five different lactation curve models were fitted to the weekly test day milk yield (WTDMY) data compiled from Central Cattle Breeding Farm (CCBF), Chiplima, Odisha of Red Sindhi cows. The values of parameters of fitted models, viz. Sikka (SIK), Wood (WD), Polynomial (POL), Dijkstra (DIJK), Morant and Gnanasakthy (MG) is given in the Table 1. Various measures of goodness of fit of the models such as adjusted R², RMSE, AIC and SBC are also given in Table 1. From the various measures of goodness of fit statistics of various models, it is clear from the Table 1 that R²_{adj} was highest for the Polynomial model (Dave 1971) followed by Dijkstra model. But in every aspect of the goodness of fit test showing best results for POL model having lowest RMSE, AIC and SBC among five models followed by DIJK model. High range of RMSE value was obtained in case of WD model. Though DIJK model was second highest in comparison to POL model but its R²_{adj} value was 0.95. In our study, it was noticed that POL

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model gave best fit among all models.

Quinn *et al.* (2005) also used quadratic or polynomial lactation curve model to find empirical algebraic model for Irish cattle. Whereas Dongre (2013) studied FTDMY of Sahiwal cow (first lactation) located at NDRI, Karnal and showed that Inverse polynomial function described the best fit with the highest coefficient of determination ($R^2_{adj} = 0.999$) with the lowest value of RMSE (0.107). Dohare *et al.* (2014) observed that MG model gave higher R^2_{adj} value of 0.988. Though SIK and MG model were best fit in comparison other model but the values of coefficient of determination were very high for all models. The average pattern of estimated milk yield by all five models with respect to observed milk yield is shown in Fig. 1.

Among all five models, first two best fitted models with respect to observed value of WTDMY are presented in Fig. 2. On the other hand, Wood model gave the least fit with R^2_{adj} value less than 0.80 except for this model all other models had R^2_{adj} value more than 0.90. In contrary to this, Cankaya *et al.* (2011) concluded that the Wood model was the best-fitted model for explaining properties of milk yield of Jersey cows with $R^2_{adj} = 0.916$.

Testing of residuals: The outcomes of testing of residuals done by various tests are given in Table 2. Shapiro-Wilk's

test indicated that residuals were not normally distributed for Wood and DIJK model ($P < 0.05$). The residuals of other models such as SIK, POL and MG were normally distributed ($P > 0.05$). Durbin Watson statistics showed residuals of all the models were positively auto-correlated as a range of 0 to 2 indicates a positive autocorrelation in residuals of all models. For SIK, WD, DIJK models same interpretation was done by Hossein-Zadeh and Ghavi (2016). In contrary to this, Quinn *et al.* (2005) reported no autocorrelation in case of Wood model. The two best-fitted models POL and DIJK showed the highest number of runs 13 and 15 respectively. Only Wood model had small runs suggesting residuals were less randomly distributed. The same conclusion was drawn about the WD model by Nasri *et al.* (2008). A small number of runs of the sign is obtained when the residuals are not randomly distributed, hence residuals of the same sign tend to cluster together on some parts of the curve (Motulsky and Ransnas 1987). In all the cases the residuals were not independent of each other ($P < 0.05$).

Summary measures: Various summary measures were obtained from the fitted lactations curves of Weekly Test Day Milk Yield (WTDMY) data (Table 3). The Observed peak yield was 71.47 kg on sixth week which was more

Table 1. Estimated parameters along with goodness of fit of different lactation curve models

Parameter	SIK	WD	POL	DIJK	MG
	(Mean±SE)	(Mean±SE)	(Mean±SE)	(Mean±SE)	(Mean±SE)
a	7.383±0.288	6.075±0.645	7.630±0.188	9.431±0.127	1.999±0.070
b	0.043±0.004	0.430±0.067	0.309±0.020	0.000±0.000	-0.043±0.006
c	0.001±0.00	0.045±0.005	-0.010±0.00	-0.226±0.016	-0.003±0.00
d	-	-	-	-0.058±0.004	-0.001±0.124
Adj R ²	0.919	0.774	0.971	0.950	0.917
RMSE	0.654	1.095	0.392	0.510	0.662
AIC	-33.675	10.734	-77.555	-54.032	-31.682
SBC	-28.392	16.017	-72.271	-46.987	-24.638

Table 2. Tests for the presence of autocorrelation, normality and randomness in residuals of Red Sindhi cows

Model	Shapiro-Wilk Test		DW Statistics	Run Test		
	Statistics	P value		Runs	Z value	P value
SIK	0.963	0.178	0.381	9	-4.012	0.000
WD	0.903	0.002	0.136	4	-5.556	0.000
POL	0.986	0.865	0.887	13	-2.776	0.005
DIJK	0.749	0.000	0.617	15	-2.158	0.031
MG	0.963	0.178	0.381	9	-4.012	0.000

Table 3. Summary measures of estimated lactation curve models

Summary measure	Observed value	Estimated by models				
		SIK	WD	POL	DIJK	MG
First weekly yield (kg)	49	53.872	40.663	55.503	66.045	53.851
Peak period (wk)	6	15	6	6	6	15
Peak yield (kg)	71.47	71.043	75.964	70.14	70.875	71.043
Last weekly yield (kg)	8.185	22.505	31.227	13.398	9.583	22.505
Total milk yield (kg)	2369.747	2376.969	2377.907	2369.710	2369.262	2376.927

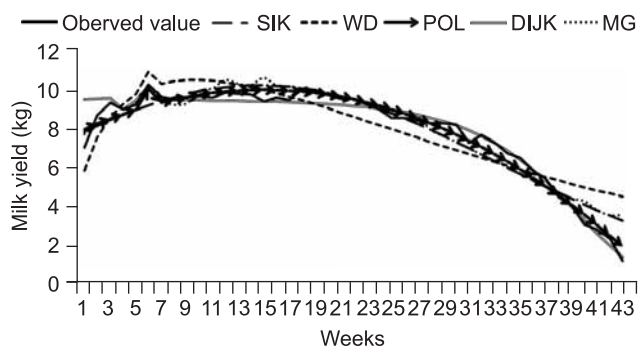


Fig. 1. Observed and predicted WTDMY of five different lactation curve models.

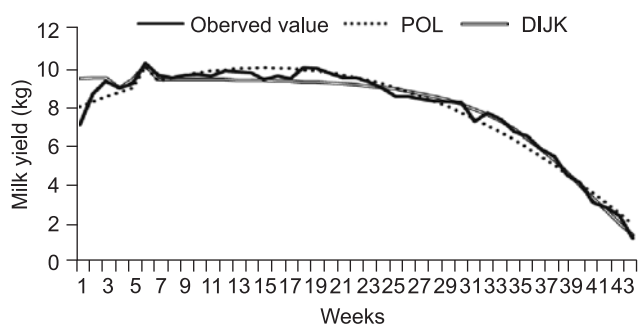


Fig. 2. Observed and predicted WTDMY of first two best fitted lactation curve models.

close to the peak yield obtained by SIK and MG models. But peak period of rest three models, viz. WD, POL and DIJK showed same peak period with observed value (Table 3). Similar type of conclusion was drawn by Ferreira *et al.* (2015) that peak production and time of peak yield of WD and DIJK models were similar. In our study though peak yield was not same but peak period was same for these two models. Wood model was one of the fitted models which gave lowest milk production in early lactation; same conclusions were also drawn by Nasri *et al.* (2008). However, both POL and DIJK model estimated very close total milk yield with respect to total milk yield.

Finally, it was concluded that on the basis of average weekly test day milk yield (WTDMY), Dave's polynomial model was best-fitted model for prediction of Red Sindhi cows in Indian conditions followed by Dijkstra model and Wood model was least predicted with over prediction of peak yield with respect to observed value.

SUMMARY

The Lactation curve is the relationship between milk yield and lactation length with respect to time. The present study is based on the data on the lactation records of Red Sindhi cows compiled from Central Cattle Breeding Farm (CCBF), Chiplima, Odisha. Five different lactation curve model, viz. Sikka (SIK), Wood (WD), Polynomial (POL), Dijkstra (DIJK), Morant and Gnanasakthy (MG) models were fitted to the weekly test day milk yield (WTDMY) of Red Sindhi dairy cows. The goodness of fit of the models were judged by adjusted coefficient of determination ($Adj. R^2$), root mean square error (RMSE), Akaike's

information criteria (AIC) and Schwartz Bayesian information criterion (SBC). The normality of the residuals was tested by Shapiro–Wilk's test and autocorrelation was tested by Durbin Watson test. From the analysis of data it is evident that all the models fitted very well the lactation data of Red Sindhi cows with high degree of accuracy ($Adj. R^2 > 91\%$) except for the Wood (WD) model. However among all the models, Polynomial model (Dave 1971) was the best fitted model followed by Dijkstra model. Wood model was the least fitted model among all the lactation models. Highest observed peak yield was at sixth week, the same peak period was given by Wood, Polynomial and Dijkstra models. All the estimated peak yields were ranged between 70.14 kg to 75.96 kg.

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