Modeling lactation curve for genetic evaluation of Murrah buffaloes

Saroj Kumar Sahoo¹, Avtar Singh², Shakti Kant Dash¹ and G.S. Ambhore³

ICAR-National Dairy Research Institute,
Pithoragarh-262 401, Uttar Pradesh, India.
Received: 05-05-2017 Accepted: 08-06-2017 DOI: 10.18805/ijar.B-3432

ABSTRACT
In this study, four lactation curve models viz. Gamma-type function (GF), Mixed log function (MLF), Exponential function (EF) and Polynomial regression function (PRF) were fitted to predict the weekly test-day milk yields pertaining to 961 Murrah buffaloes progeny of 101 sires spread over a period of 36 years (1977-2012) maintained at ICAR-NDRI, Karnal. The PRF was the best fit with highest R²(99.3%) and lowest RMSE (0.3%) which was used subsequently to estimate the first lactation 305-day or less milk yield (FL305DMY) from weekly test-day milk yields. The sires were evaluated using four linear models viz. Least Squares(LSQ), Simple Regressed Least Squares (SRLS), Sire (BLUP-SM) and animal (BLUP-AM) models from actual as well as PRF predicted FL305DMYs. BLUP-AM was the most efficient, among the sire evaluation models, in predicting the breeding values. Sire evaluation on the basis of predicted data (using PRF) was similar to that on the basis of actual data indicating that the best fitted lactation curve function can be used as an alternative for early animal evaluation and reduction of generation interval.

Key words: Lactation curve, Murrah buffalo, Sire evaluation, Test-day milk yields.

INTRODUCTION
The different methods of sire evaluation viz., least squares (LSQ), simple regressed least squares (SRLS), best linear unbiased prediction (BLUP) and restricted maximum likelihood method (REML) have been used by different workers (Dongre and Gandhi, 2014; Kumar et al. 2015). Sire evaluation using a test-day models have higher accuracy due to having a large number of measurements per daughter. In addition, there are possibilities for adjusting more and detailed fixed effects. For sire evaluation, a test-day milk yield model reduces residual variance by providing more information per sire by using all available test day records of sire’s daughters and by detecting or adjusting for more environmental effects in the genetic evaluation model. The investigation on fitting of lactation curve models using weekly test-day records is scanty in Murrah buffaloes. Accordingly, the objectives of the study was to fit and compare the four reported lactation curve models to find out the best fitted lactation curve function and to compare different sire evaluation methods using actual and predicted 305-days or less first lactation milk yield from the best fitted lactation curve model.

MATERIALS AND METHODS
Data on 39059 weekly test-day milk yields and first lactation 305-days or less milk yield records of 961 Murrah buffaloes sired by 101 bulls spread over a period of 36 years (1977-2012) maintained at ICAR-National Dairy Research Institute (NDRI), Karnal were used in the present study. The statistical analysis was carried out with the help of various statistical packages such as LSML computer programme of Harvey (1990); WOMBAT software (Meyer, 2007) and SAS enterprise guide 9.3. The following models were used to study the effects of genetic and non-genetic factors on 305-days yield and test day milk yield records of first lactation Murrah buffalo data, respectively.

Yijklm = μ+S+P+A+Beijklm
TDYijklm = μ+S+P+A+B+eijklm

where, Yijklm is the 305-day milk yield of the m⁻th individual of i⁻th sire in k⁻th age group of j⁻th period and s⁻th season, TDYijklm is the test-day milk yield of the m⁻th individual of i⁻th sire in k⁻th age, group of j⁻th period and s⁻th season, μ is the population mean, S is the fixed effect of i⁻th season (i=1to4), P is the fixed effect of j⁻th period (j=1to12), A is fixed effect of k⁻th age group (k=1to5), B is random effect of i⁻th sire, NID (0, σ²), eijklm is random error, assumed to be normally and independently distributed with mean zero and constant variance i.e. NID (0, σ²).

The following four models were selected for lactation curve analysis:
1. Gamma-type function: (Wood, 1967) : Y=at^be^-ct
\[
In(Y)= In (a) + bln(t) - ct
\]
The milk yield up to week t is given by
\[
Y= \int_0^t a t^b e^{-ct} dt
\]
Thus we can get total 305 days milk yield (43 weeks) as the integral of the average weekly milk yields.

¹Corresponding author’s e-mail : sarojvet6804@gmail.com
²Department of AGB, CoVS, GADVASU, Ludhiana. ³Department of AGB, ICAR-NDRI, Karnal-132 001, Haryana, India.
⁴CBF, Igatpuri, MAFSU, Nagpur, Maharashtra.
2. Mixed log function (Guo and Swalve, 1995):
\[ Y_t = a + b \sqrt{t} + c \log t \]

3. Exponential function (Catillo et al., 2002):
\[ Y_t = a + b e^{0.70t} + ct \]

Where, \( Y_t \) = Average milk yield in \( t \)th week of lactation, \( a \) = Initial milk yield after calving, \( b \) = Inclining slope parameter up to peak yield, \( c \) = Declining slope parameter, \( t \) = Length of time since calving.

4. Polynomial regression function (Ali and Schaeffer, 1987):
\[ Y_t = a + b x + c x^2 + d \log(1/x) + e \log(1/x)^2 \]

Where, \( Y_t \) = Average milk yield in \( t \)th week of lactation, \( a \) = Associated with peak yield, \( b \& c \) = Associated with the decreasing slope, \( d \) and \( e \) = Associated with the increasing slope, \( x = t/lactation \) length.

The four standard lactation curve models were fitted to predict the weekly test day milk yields. The most suitable model was identified on the basis of the highest adjusted \( R^2 \) value and lowest root mean square error (RMSE) value which was subsequently used for genetic evaluation of Murrah buffaloes using the predicted 305-day first lactation milk yields. The first lactation 305-day or less milk yield (FL305DMY) was estimated by addition of the predicted weekly test day (per day average \( x \) 7) estimates (of the best lactation curve model) up to 43 weeks.

**Sire evaluation:** Genetic evaluation of sires based on actual and predicted 305-day first lactation milk yields was carried out using the following linear models:

**Least squares method (LSQ):** The least squares method (Harvey, 1979) was used to estimate the breeding value of bulls.

**Simple regressed least squares (SRLS):** The simple regressed least squares technique (SRLS) was applied as given by Harvey (1979) using least squares analysis.

**Sire model:** The sire model (Henderson, 1975) was used for sire evaluation.

**Animal model:** Single trait animal model was considered for estimation of breeding values using WOMBAT software (Meyer, 2007).

**Effectiveness of sire evaluation methods:** The effectiveness of different sire evaluation methods was judged by error variance and relative efficiency, coefficient of determination \( (R^2) \) value, coefficient of variation and spearman’s rank correlation estimates.

**RESULTS AND DISCUSSION**

Fitting of different lactation curve models on weekly test day milk yields: Among all the models fitted to the data highest \( R^2 \) value (99.3%) with lowest RMSE (0.3%) was estimated for polynomial regression model. Whereas, the exponential function had lowest \( R^2 \) value (88.5%) with highest (1.26%) RMSE value (Table 1).

**Aziz et al.** (2006) and Katneni (2007) reported appreciable \( R^2 \) values (96.0% and 96.2%) using gamma type function in Egyptian buffaloes and Murrah buffaloes, respectively. Dimauro et al. (2005) and Kumar (2007) reported \( R^2 \) values (94.4% and 99.6% respectively) using exponential function in Italian water buffaloes and Murrah buffaloes, respectively. In the present study since the polynomial regression function had the best fit with maximum adjusted \( R^2 \) (99.3%) and minimum RMSE (0.3%) values, the first lactation 305 day milk yield (F305DMY) was estimated by addition of the predicted weekly test days (per day average \( x \) 7) up to 43 weeks of this function.

**Sire evaluation:** Hence, in the present investigation, 101 Murrah sires with five or more daughters per sire were evaluated and ranked on the basis of actual and predicted first lactation 305-day milk yields. The average estimated breeding values (EBVs) for 101 Murrah sires based on actual and predicted FL305DMY of their daughters by different sire evaluation methods are presented in Table 2.

**Actual milk yield:** The average breeding values of Murrah sires evaluated on the basis of actual first lactation 305 day milk yield by least squares method was lowest (1815 kg) and highest in case of BLUP-SM (1863 kg). Analysis revealed that the sires with estimated breeding values above the average breeding value were lowest in case of LSQ and SRLS (43.56%). Sire model had highest number of sires (49.50%) followed by animal model (46.53%) above the average breeding value. Range of breeding values was highest for LSQ method (1367 kg) and lowest for BLUP-SM (278 kg).

**Predicted milk yield:** In comparison to the actual similar analysis of the predicted performance data indicated results in agreement with actual performance. Average breeding values of Murrah sires on the basis of predicted first lactation 305 day milk yield by least squares method was lowest (1829 kg) and highest in case of BLUP-SM (1872 kg). Analysis revealed that the sires with estimated breeding values above the average breeding value were lowest in case of LSQ and

<table>
<thead>
<tr>
<th>Functions</th>
<th>Parameters of function</th>
<th>Adjusted ( R^2 ) (%)</th>
<th>RMSE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GF</td>
<td>( Y_t = 3.98e^{0.54x}e^{0.05x} )</td>
<td>92.78</td>
<td>0.94</td>
</tr>
<tr>
<td>EF</td>
<td>( Y_t = 9.13-11.74e^{-0.03x} )</td>
<td>88.50</td>
<td>1.26</td>
</tr>
<tr>
<td>PRF</td>
<td>( Y_t = 3.4-0.25(x_j)-0.01(x_j^2)-3.44<em>log(x_j)-1.07</em>log(x_j)^2 )</td>
<td>99.30</td>
<td>0.30</td>
</tr>
<tr>
<td>MLF</td>
<td>( Y_t = 6.97-3.724x+5.544log(t) )</td>
<td>95.60</td>
<td>0.78</td>
</tr>
</tbody>
</table>
Table 2: Average expected breeding values (EBVs) of Murrah sires using actual and predicted first lactation 305-day milk yield by different sire evaluation methods.

<table>
<thead>
<tr>
<th>Sire evaluation methods</th>
<th>Average EBV (kg)</th>
<th>Number of sires above average EBV</th>
<th>Number of sires below average EBV</th>
<th>Maximum EBV (kg)</th>
<th>Minimum EBV (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual first lactation 305-day milk yield</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LSQ</td>
<td>1815</td>
<td>44 (43.56%)</td>
<td>57 (56.44 %)</td>
<td>2685</td>
<td>1318</td>
</tr>
<tr>
<td>SRLS</td>
<td>1839</td>
<td>44 (43.56%)</td>
<td>57 (56.44 %)</td>
<td>2400</td>
<td>1353</td>
</tr>
<tr>
<td>BLUP-SM</td>
<td>1863</td>
<td>50 (49.50%)</td>
<td>51 (50.50%)</td>
<td>2017</td>
<td>1739</td>
</tr>
<tr>
<td>BLUP-AM</td>
<td>1847</td>
<td>47 (46.53%)</td>
<td>54 (53.47%)</td>
<td>2180</td>
<td>1577</td>
</tr>
</tbody>
</table>

| Predicted first lactation 305-day milk yield (Polynomial Regression Function) | | | | | |
| LSQ | 1829 | 47 (46.53%) | 54 (53.47%) | 2618 | 1835 |
| SRLS | 1854 | 47 (46.53%) | 54 (53.47%) | 2397 | 1391 |
| BLUP-SM | 1872 | 49 (48.51%) | 52 (51.49%) | 2025 | 1874 |
| BLUP-AM | 1861 | 50 (49.50%) | 51 (50.50%) | 2215 | 1624 |

Sires. The rank correlations between EBVs for actual 305-day or less milk yield by BLUP-SM and BLUP-AM were the highest (0.96) and medium in case of LSQ with either BLUP-SM or BLUP-AM. Lower estimates of correlations were obtained in case of SRLS with BLUP-AM.

Error variance: The accuracy, efficiency and stability of different sire evaluation methods were compared on the basis of coefficient of determination ($R^2$), error variance and coefficient of variation, respectively (Table 4). The results showed that the error variance of BLUP-AM for actual first lactation 305-day or less milk yield was lowest as compared to the other methods. On the basis of error variance, the BLUP-AM was considered most efficient followed by LSQ method. The relative efficiency (RE) of LSQ, SRLS and BLUP-SM methods in comparison to BLUP-AM (most efficient method) were 88.16, 84.12 and 86.98%, respectively.

Table 4: Effectiveness of different sire evaluation methods for actual and predicted first lactation 305-day milk yield in Murrah buffalo.

<table>
<thead>
<tr>
<th>Methods</th>
<th>Error Variance ($R^2$)</th>
<th>Relative Efficiency</th>
<th>Coefficient of determination (%)</th>
<th>Coefficient of variation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LSQ</td>
<td>177546.78</td>
<td>88.16</td>
<td>20.38</td>
<td>23.22</td>
</tr>
<tr>
<td>SRLS</td>
<td>186085.94</td>
<td>84.12</td>
<td>31.21</td>
<td>23.47</td>
</tr>
<tr>
<td>BLUP-SM</td>
<td>179962.28</td>
<td>86.98</td>
<td>27.12</td>
<td>22.89</td>
</tr>
<tr>
<td>BLUP-AM</td>
<td>156530.60</td>
<td>100</td>
<td>25.61</td>
<td>21.57</td>
</tr>
</tbody>
</table>

| Predicted First Lactation 305-day milk yield (Polynomial Regression Function) | | | | |
| LSQ | 160609.33 | 86.95 | 19.36 | 21.91 |
| SRLS | 167161.78 | 83.54 | 25.41 | 20.04 |
| BLUP-SM | 161871.83 | 86.27 | 25.61 | 21.57 |
| BLUP-AM | 139649.90 | 100 | 45.55 | 20.04 |

**SRLS (46.53%).** Animal model had highest number of sires (49.50%) followed by sire model (48.51%) above the average breeding value. Range of breeding values was highest for LSQ method (1263 kg) and lowest for BLUP-SM (271 kg).

The results indicated the BLUP-SM and BLUP-AM had the highest stability and were superior with respect to other models on the basis of actual as well as predicted first lactation 305 day milk yield which were in agreement with the findings of Singh et al. (2014).

Effectiveness of sire evaluation methods based on actual and predicted variables

Spearman’s rank correlation: The rank correlations of EBVs estimated by actual 305-day milk yield and predicted 305-day milk yield are presented in Table 3. These rank correlations were measured using the ranks of 101 Murrah sires. The rank correlations between EBVs for actual 305-day or less milk yield by BLUP-SM and BLUP-AM were the highest (0.96) and medium in case of LSQ with either BLUP-SM or BLUP-AM. Lower estimates of correlations were obtained in case of SRLS with BLUP-AM.

Error variance: The accuracy, efficiency and stability of different sire evaluation methods were compared on the basis of coefficient of determination ($R^2$), error variance and coefficient of variation, respectively (Table 4). The results showed that the error variance of BLUP-AM for actual first lactation 305-day or less milk yield was lowest as compared to the other methods. On the basis of error variance, the BLUP-AM was considered most efficient followed by LSQ method. The relative efficiency (RE) of LSQ, SRLS and BLUP-SM methods in comparison to BLUP-AM (most efficient method) were 88.16, 84.12 and 86.98%, respectively.

Table 3: Rank correlations among breeding values of sires estimated by different methods on the basis of actual and predicted first lactation 305-day milk yield.

<table>
<thead>
<tr>
<th>Methods</th>
<th>LSQ with SRLS</th>
<th>LSQ with BLUP-SM</th>
<th>LSQ with BLUP-AM</th>
<th>SRLS with BLUP-SM</th>
<th>SRLS with BLUP-AM</th>
<th>SRLS with BLUP-AM</th>
<th>BLUP-SM with BLUP-AM</th>
<th>BLUP-SM with BLUP-AM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual 305-day milk yield</td>
<td>0.834**</td>
<td>0.786**</td>
<td>0.770**</td>
<td>0.709**</td>
<td>0.628**</td>
<td>0.957**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predicted 305-day milk yield (based on polynomial regression function)</td>
<td>0.850**</td>
<td>0.793**</td>
<td>0.783**</td>
<td>0.702**</td>
<td>0.637**</td>
<td>0.944**</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

LSQ: Least squares method; SRLS: Simple regressed least squares method; BLUP-SM: Best linear unbiased prediction sire model method; BLUP-AM: Best linear unbiased prediction animal model method; ** significant at 1 % level.
Further, the results for predicted 305-day milk yield based on polynomial regression function showed that the error variance of BLUP-AM was lowest in comparison to other methods. The relative efficiency (RE) of LSQ, SRLS and BLUP-SM methods in comparison to BLUP-AM (most efficient method) for EBVs was lesser. Thus, on the basis of error variance the BLUP-AM was most efficient in predicted yields.

Error variance estimates were in conformity with Singh et al. (2014) who reported BLUP-AM method to be more efficient than LSQ. However Rana (2008) reported that LSQ was more efficient than BLUP method. Relative efficiency estimates were in agreement with the findings of Singh et al. (2014) in Murrah buffalo. However, Banik and Gandhi (2006) in Sahiwal cattle reported the relative efficiency of BLUP in comparison to LSQ for 300-day milk yield to be 97%.

**Coefficient of determination:** The coefficient of determination (R² value) of fitting LSQ, SRLS, BLUP-SM and BLUP-AM were estimated and higher the R² value indicated the better fit model. It was observed that for actual and predicted 305-day milk yields based on polynomial regression function, the R² estimate of BLUP-AM was relatively higher than other methods of sire evaluation followed by SRLS method. Similar findings were also reported by Singh et al. (2014) in Murrah buffaloes. Therefore, BLUP-AM was considered more accurate than other methods of sire evaluation for actual as well as predicted 305-day milk yields.

**Coefficient of variation:** Estimates of coefficient of variation were used as the criterion to compare the stability of different sire evaluation methods. The method which had CV very near to the unadjusted data was considered as more stable. CV (%) of unadjusted data for first lactation 305-day milk yield was 26.56%. In case of actual 305-day milk yield, the CV (%) was most near to unadjusted data in SRLS (23.47%) and LSQ (23.22%) methods. CV was almost similar for BLUP-SM (22.89%) and BLUP-AM (21.35%) indicating that all these methods were almost equally stable. Banik and Gandhi (2006) however reported that the deviation of CV with respect to unadjusted data was lower in BLUP compared to LSQ indicating that BLUP method was more stable than LSQ.

The coefficient of variation of different sire evaluation models for predicted 305-day milk yields were marginally lower in comparison to sire evaluation models used on actual data. Singh et al. (2014) in Murrah buffaloes also reported nearly equal stability of all the methods.

**CONCLUSION**

Polynomial regression model fitted best among all the lactation curve models considered in the study. BLUP-AM was the most efficient, among the sire evaluation models, in predicting the breeding values. Sire evaluation on the basis of predicted data was similar to that of evaluation on the basis of actual data indicating that the predicted data can be used as an alternative for early animal evaluation and reduction of generation interval.

**ACKNOWLEDGEMENT**

The authors are immensely grateful to Director, ICAR-NDRI, Karnal for providing necessary facilities for conducting this research work.

**REFERENCES**


