Proceedings, 10th World Congress of Genetics Applied to Livestock Production

Lactation Curve Modeling for Murrah and Surti Buffalo Breeds in Sri Lanka

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ABSTRACT: Lactation curves are useful in obtaining complete lactation records for genetic selection from incomplete records which is a common problem in dairy buffaloes in Sri Lanka. A data set of 12,518 monthly lactation records of purebred Murrah and Surti cows from seven government farms in Sri Lanka were used to model lactation curves. The models proposed by Gaines, Wood, Rook and Dijkstra were fitted using nonlinear regression procedures. With only two parameters, the Gaines's model failed to provide a satisfactory fit. Rook's model provided the best fit for both breeds, while the Dijkstra's model was the second best. Thus, a four parameter mechanistic model such as Rook's model can be recommended for lactation curve modeling of buffaloes in Sri Lanka. The overall performance levels of both breeds showed the need for improvement in management standards in addition to genetic improvement.
Keywords: Buffalo; modeling; Lactation curve

Introduction

The dairy buffalo population (0.4 million heads) makes a significant contribution (20 percent) to the national milk production in Sri Lanka, being second only to dairy cattle (www.statistics.gov.lk, 2012). Buffalo cows have a competitive advantage over dairy cows, as buffalo milk is richer in total solids and particularly butter fat (hence the higher price per litre of milk) and the males are a useful source of draught power. The present buffalo population consists of pure Murrah, Surti and Nili-Ravi breeds imported from India and Pakistan, pure local animals and their crosses. However, low genetic potential of the present buffalo population has been a major barrier for wider usage in commercial production (Dematawewa and Silva, 2000). Lack of consistent milk recording (with many missing data) has made it difficult to construct the complete lactation curve for individual animals and to estimate their total (e.g. 305-day) milk yields, which is a major hindrance to genetic evaluation and selection of candidate animals in the field. However, the lactation curve of an individual or a group can be expressed as a mathematical model that describes the relevant general pattern of milk production throughout the lactation (Aziz et al., 2006; Dematawewa et al., 2007). Once the parameters of the model are estimated using the available yield information, it can be used to predict the missing values and thereby construct the complete (i.e. 305-day) lactation yield. Lactation models have evolved over time from simple linear regression models and inverse polynomials (Gaines, 1926; Nelder, 1966) to complex non linear multiphasic models (Grossman and Koops, 2003). Metry et al. (1994) attempted to fit polynomial functions for first lactations of Egyptian buffaloes. Although polynomials have the flexibility to handle the typical shape of initial phases of lactation curves, any extrapolations could yield negative yield estimates or increasing trends that are inappropriate. Using crossbred buffaloes in Brazil, Barbosa et al. (2007) also showed that polynomials or linear hyperbolic functions do not fit well for most lactation curves. The incomplete gamma function (Table 1) proposed by Wood (1967) has been one of the most popular non linear models due to its simplicity (3 parameters only) and better fit, as used by Ibrahim (1995) for buffaloes, though it has been criticized for estimating the initial yield at calving time to be zero (Scott et al., 1996). Aziz et al. (2006) found that Wood's model and a model used to describe vibration of materials in Physics (Hayashi et al., 1986) fitted equally well for lactation curves of buffaloes, though both were empirical models. Some mechanistic models have been criticized for having an excessive number (>4) of parameters (Pollot, 2000; Grossman and Koops, 2003). Alternatively, Rook et al. (1993) and Dijkstra et al. (1997) also developed four parameter mechanistic models, both of which were found to fit satisfactorily for extended lactations of US Holsteins (Dematawewa et al., 2007). Therefore, the objective of this study was to compare four popular two, three and four parameter models (Table 1) on their suitability for modeling lactation curves of purebred Murrah and Surti buffaloes in Sri Lanka.

Materials and Methods

Data. The lactation records used in this study included 12,518 monthly total milk yields from purebred Murrah (n=5561 records) and Surti (n=6957 records) buffalo cows managed in six large scale government farms in Sri Lanka. Those farms are distributed across the island, covering all major scale herds and climatic regions of the country. Management practices included predominantly free grazing and limited in house feeding of pasture and concentrates at night. The cows were in their first to thirteenth lactation while 28.1, 23.6, and 48.3 % cows were in first, second and other parities, respectively. Lactation length varied up to 28 months, however, the maximum lactation length was limited to 16 months as there were only 0.61 % records beyond the truncation point. Monthly total yields were converted to daily average yields of the respective months and expressed as the mid month daily yield of the respective month. Mid monthly dates were converted to days in milk (DIM) relative to respective dates of calving.

Models. Table 1 shows the four mathematical functions used to model the lactations of Murrah and Surti cows separately. Gaines' model (Gaines, 1926) was tested as a much simpler (two parameters) model. Wood's model (Wood, 1967) was used as one of the best fitting three parameter models. In addition, the two four-parameter mechanistic models of Rook et al. (1993) and Dijkstra et al. (1997) were selected, as they were proven to provide satisfactory fits to long lactations (Dematawewa et al., 2007).

Table 1. Lactation models fitted for daily yields of buffalo cows.

Model	Functional form*	Reference
Gaines	$Y_t = a \exp(-bt)$	Gaines (1926)
Wood	$Y_t = a\, t^b \exp(-ct)$	Wood (1967)
Rook	$Y_t = a\{1/[1+ b/(t-c)]\}e^{(-dt)}$	Rook et al. (1993)
Dijkstra	$Y_t= a \exp[(b(1-e^{-ct})/c) - dt]$	Dijkstra et al. (1997)

*Y_t is the milk yield of the t^{th} day in milk since calving; a, b, c, and d are the parameters to be estimated.

Table 2. Parameter estimates and model selection criteria* for various lactation models fitted to daily yields of Murrah buffaloes (for all herds and parities combined).

	Lactation Model			
	Gaines	Wood	Rook	Dijkstra
a	3.6680	0.5725	6.4810	0.9035
b	0.0005	0.5280	22.3531	0.0737
c		0.0047	4.7303	0.0421
d			0.0025	0.0020
R^2	0.7845	0.8131	0.8148	0.8146
MSE	3.1069	2.6949	2.6716	2.6753
BIC	22113	21330	21289	21297

*a, b, c, and d are parameter estimates; R^2=coefficient of determination; MSE= mean square error; and BIC= Bayesian information criterion.

Model Selection Criteria Nonlinear regression analysis was carried out using the PROC NLIN procedure in SAS (SAS, 2000) for the two breeds separately including records of all herds and parities. The above procedure does not permit fitting any fixed effects such as herd, parity or birth month. Therefore the analysis was repeated for each contemporary group (herd-parity-birth month) separately. The standard errors of the resulting parameter estimates were used to compare different contemporary groups. Coefficient of determination (R^2) and mean square error (MSE) were used to select the model with the lowest error variance. Generally, models with more parameters tend to give better fits while increasing the complexity of the model. Bayesian information criterion (BIC) given below penalizes a model for having more parameters while giving credit for the better fit. Therefore, BIC was also added as an additional model selection criterion.

$$BIC = -2 \log (L) + K \log (N)$$

where L, K and N are the maximum likelihood, the number of independent parameters and sample size, respectively. Here, models with lower BIC values were preferred. The nonlinear mixed procedure (PROC NLMIXED) in SAS was used to obtain BIC estimates for each model and breed. The estimates obtained by the NLIN procedure were used as priors to perform the NLMIXED procedure as the Rook and Dijkstra models had problems of convergence.

Results and Discussion

The lactation curves produced by the four models for Murrah and Surti breeds (for all contemporary groups combined) are in figures 1 and 2. Gaines' model provided an unsatisfactory fit for both Murrah and Surti breeds. Although it had a nonlinear (exponential) component, the model with two parameters did not have the ability to generate the two bends (right and left) that are required by the typical lactation curves. The other three models fitted well for the pre-peak yields. However, Wood's model underpredicted yields in the latter part of the lactation substantially in both breeds. The Rook and Dijkstra models fitted considerably well for yields of Murrah cows but both under predicted yields in the later part of the lactation of Surti cows. Those results show the inability of the fitted curves to bend upwards in the later stage of lactation. However, the yields in the latter part of the lactation used in this study might be influenced by selection bias. Most the cows that show much lower yields during the later stages of lactation are usually dried off or culled voluntarily or involuntarily, allowing the cows which are showing some reasonable yields to continue to be in milk. Thus averaging

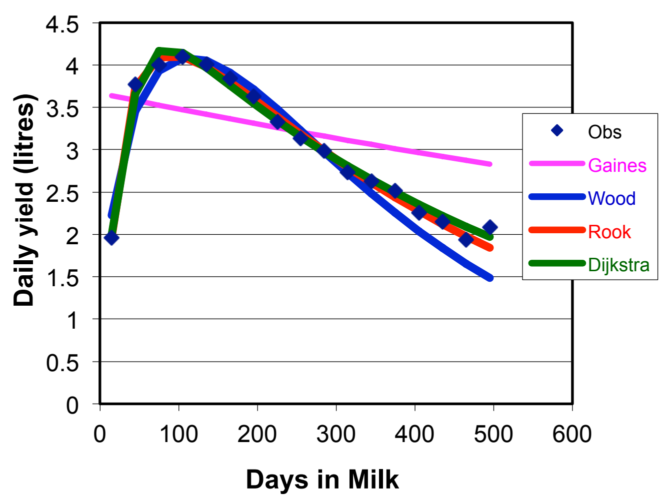

Figure 1: Lactation curves of the Gaines, Wood, Rook and Dijkstra models fitted to daily milk yields of Murrah buffaloes (all contemporary groups combined). Observations (☐) are means of respective daily yields of all Murrah cows.

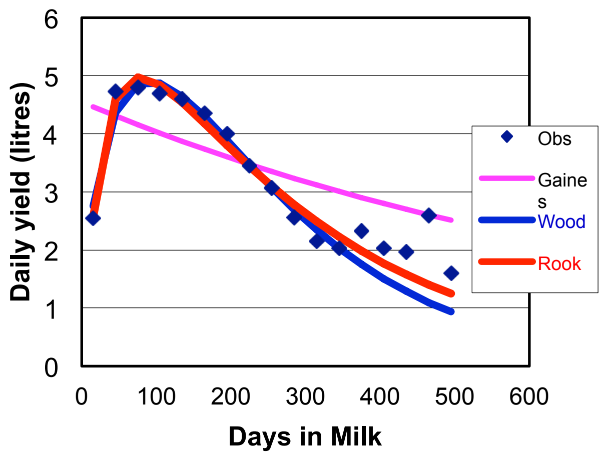

Figure 2: Lactation curves of the Gaines, Wood, Rook and Dijkstra models fitted to daily milk yields of Surti buffaloes (all contemporary groups combined). Observations (□) are means of respective daily yields of all Surti cows.

The R^2 values were the lowest for Gaines' model (while MSE and BIC were the highest) for both breeds, which agrees with the lack of satisfactory fit shown in Figures 1 and 2. Similarly Wood's model provided the lowest R^2 values and the highest MSE values among the other three models, justifying the poor fit depicted in the two figures. Among the four parameter models, the Rook function provided marginally better fits than Dijkstra's model in both cases. Interestingly, although Dijkstra's model provided a slightly better fit than Wood's model for the Surti breed, Wood's model was superior in terms of BIC, showing how BIC penalizes a model for having more parameters.

Fitting the models separately for individual parities within a breed showed that Rook's model was the most superior for all parities and breeds. Therefore, Rook's model was used for further analysis. Standard errors of the parameters estimates of Rook's model showed that significant differences ($p<0.05$) exist among the contemporary groups within a breed with respect to the parameters. The estimates of a, b, c and d parameters for heifers of Murrah breed were 5.6746, 21.6233, 5.4313, and 0.0018, respectively. For older cows of Murrah breed (2nd and later parities), the respective estimates were 6.9768, 24.9622, 3.9563, and 0.0028. Surti heifers reported slightly higher estimates (9.8402, 43.4796, 2.3368, and 0.0038) while older Surti cows reporting 10.6010, 37.5493, 1.0823, and 0.0044, respectively.

Based on Rook's model, the 305 day total yields of Murrah and Surti breeds (across all herds and parities) were 1048 and 1168 litres, respectively. Their respective peak yields were 4.1 and 4.9, litres. These results show the comparative performance of the two breeds under the given management conditions.

Conclusions

The three and four parameter models considered in this study can be used satisfactorily for modeling lactation curves of Murrah and Surti breeds under present management conditions in Sri Lanka. Rook's model can be considered as the most preferred choice among the four models. Contrary to popular belief, the Surti breed was a slightly better milk producer than the Murrah, which could be due to an interaction effect between genotype and environment under poor management conditions. These results indicate the need for better feeding and management conditions along with genetic improvement.

Literature Cited

Aziz, M. A., Shalaby, N. A., El-Shafie, O. M. et al. (2006). Livest. Res. Rural Devt., 18(5):1-12. http://www.lrrd.org/lrrd18/5/aziz18059.htm

Barbosa, S. B.P., Pereira, R. G. A., Santoro, K. R. et al. (2007). Ital. J. Anim. Sci. 6(Suppl.2):1075-1078.

Dematawewa, C. M. B., Pearson, R. E., and VanRaden, P. M. (2007). J. Dairy Sci., 90:3924-3936.

Dematawewa, C. M. B. and Silva, G. L. L. P. (2000). Proc. 3rd Asian Buffalo Congr., Kandy, Sri Lanka, NSF Publ., Colombo, pp. 129-142.

Dijkstra, J., France, J., Dhanoa, M. S. et al. (1997). J. Dairy Sci. 80:2340-2354.

Gaines, W. L. (1926). J. Gen. Phy., Urbana, pp. 27-31.

Grossman, M. and Koops, W. J. (2003). J. Dairy Sci., 86:988-998.

Hayashi, T., Nagamine, Y., and Nishida, A. (1986). Jap. J. Zootech. Sci., 57:471-478.

Ibrahim, M. A. M. (1995). Egyptian J. Anim. Prod., 32:113-123.

Metry, G.H., Mourad, K.A., Wilk, J. C. et al. (1994). J. Dairy Sci., 77:1306-1314.

Nelder, J. A. (1966). Biometrics, 22:128-141.

Pollott, G. E. (2000). J. Dairy Sci. 83:2448-2458.

Rook, A. J., France, F., and Dhanoa, M. S. (1993). J. Agric. Sci., Cambridge, 121:97-102.

SAS. (2000). SAS Institute Inc., Cary, NC.

Scott, T. A., Yandell, B., Zepeda, L. et al. (1996). J. Dairy Sci., 79:1885-1894.

Wood, P. D. P. (1967). Nature, 216:164-165.