Iranian Journal of Applied Animal Science

Evaluation of Various Approaches in Prediction of Daily and Lactation Yields of Milk and Fat Using Statistical Models in Iranian Primiparous Holstein Dairy Cows

Research Article

M. Elahi Torshizi[1*] and M. Hosseinpour Mashhadi[1]

[1] Department of Animal Science, Mashhad Branch, Islamic Azad University, Mashhad, Iran

Received on: 8 May 2014
Revised on: 8 Jul 2014
Accepted on: 15 Jul 2014
Online Published on: Mar 2015

*Correspondence E-mail: elahi222@mshdiau.ac.ir

ABSTRACT

In this research, 272977 test day records collected from 659 herds during years 2001 to 2011 by the Iranian animal breeding center were used. In the first section the ability of different models to predict daily milk yield from alternative milk recording was tested. The result showed that a complex model including noon milking time plus the effect of lactation curve of Ali and Schaeffer function is the best equation for prediction of daily milk yield. The highest correlation between true and estimated daily milk yield (0.892) and the lowest bias (2.391) were obtained using this method. Of the four models, the Ali and Schaeffer and the Wood models resulted in the best goodness of fit and gave a good description of the lactation curve (milk and fat yield) for dairy herds when test-day yield is used. Lastly, the most appropriate models for prediction of 305 d milk and fat yields were Ali and Schaeffer and Wood respectively. These models were able to predict milk and fat yields with the lowest residual mean square errors. Thus, the performance of models based on lactation curve functions were better than the test-interval method and the centering date method for prediction of 305-d milk and fat yield in Iranian primiparous Holstein cows.

KEY WORDS daily milk and fat yield, lactation curve, test interval method, wood function, 305 day milk and fat yield.

INTRODUCTION

Milk production has a great economic impact on dairy cattle industry and on the levels of income on small and large farms. In Iran milking frequency are three times per day and actual selection scheme for milk trait is based on the lactation animal model and this methodology relies on information of predicted 305 d lactation yield. But recently the random regression method is very popular in estimation breeding value of animals for milk production trait in dairy cattle. The milk recording is carried out approximately every 30 days. Three milk samples (morning, noon and night) are taken by a supervisor on a test-day on a controlled farm for every cow. There are some statistical methods for estimating accurate daily yield at a lower cost from single milking such as single and quadratic regression on each milking time, separate regression for milking interval class, single regression plus milking interval as a covariate and Delorenzo and Wigans model and modified Delorenzo and Wigans model (Liu *et al.* 2000). Schaeffer *et al.* (2000) proposed a multiple regression model for prediction of daily milk yield from different milking schemes. Prediction of daily milk yield using a.m.-p.m. test day records showed that separate regressions for every combination of parity, milking interval class and lactation stage were more accurate for estimation of daily milk yield than the Delorenzo and Wiggans model (Liu *et al.* 2000 and Gantner *et al.* 2006). These authors also reported that daily yield estimated from evening milking time was less accurate than from morning milking times. The stage of lactation is included in any test-day model because of the curvilinear relationship with milk production (Swalve, 2000). Several mathematical functions such asthe Wood gamma function, Wilmink function and Ali and Schaeffer model have been widely proposed for modeling the shape of lactation curves and prediction of milk and fat yield (Wood, 1967; Grossman and Koops, 1988; Dijkstra *et al.* 1997). Among these models the Wood, Wilmink and Ali and Schaeffer functions are the most popular for fitting of milk and fat yield during lactation. Moreover, applicability of different orders of legendre polynomials (LP) as a lactation curve models for daily milk yield and 305 d were used in many studies (Ptak *et al.* 2004; Silvestre *et al.* 2006; Macciotta *et al.* 2007). In many situations and countries the cumulativemilk yields for 305-d or the lactation model is used for the estimating breeding value of cattle (Grzesiak *et al.* 2003), decision about cow culling and limitation of processing large amount of test day (TD) data (Vasconcelos *et al.* 2004) because the advantage of lactation model is in low computational demands. The 305 d yields are calculated from the individual test-day records collected during lactation according to the methods approved by ICAR (2003). Iran and many other countries use the test interval method (TIM) which is a method to estimate cumulative milk yield per lactation. Several studies pointed out that TIM is less accurate than other methods for prediction of cumulative 305-d milk yields while Pool and Meuwissen (1999) reported that using 5th order of Legendre polynomials produced more accurate 305 d milk yields than TIM. Dongre *et al.* (2011) founded that the inverse polynomial function is most suitable for prediction of TD data and first lactation 305 d milk yield in Sahiwal cattle in India. Ptak *et al.* (2004) reported that methods of cumulative 305 d milk yields based on lactation curve have some advantages over the routine models but Schaeffer and Jamrozik (1996) found that there is no significant difference between standard lactation curve and TIM in prediction of total milk yield of 305 d. The objectives of this study were; a) to compare statistical models for estimation of daily milk yield from alternative milk recording (morning, noon or night milking records) b) evaluation of different mathematical functions for prediction of daily milk and fat yield and finally c) to compare various approaches of prediction of cumulative 305 d milk yield based on lactation curve function (s) with (TIM) and centering date method (CDM) in Iranian primiparous Holstein.

MATERIALS AND METHODS

The 272977 test day records of 32491 primiparous Holstein cows in 659 herds from 2001 to 2011 were used in this study. There were three milk weights for all dairy cows and Days in milk (DIM) were between 200 and 305 days because fitting lactation curve and 305 d milk yields can be predicted with appropriate accuracy when cows have at least 200 days milk production (Ptak *et al.* 2004). Table 2 shows structure and some descriptive statistics of the data used in this study.

Based on literature review, there are some statistical functions to estimate daily milk yield (Y_d) from partial yield (morning (y_{mo}), noon (y_{no}) or night (y_{ni}) milking records). These models were:

Tripling method:

$$Y_D = 3y_{mo}, 3y_{no} \text{ or } 3y_{ni}$$

In this model, estimation of test day milk yield obtained by tripling the average of morning, noon and evening milking.

Single linear regression models:

$$Y_D = b_0 + b_1 y_{mo}, y_{no} \text{ or } y_{ni}$$

Daily milk yield is regressed on morning, noon and night partial milk yield and a single regression equation was fitted for whole data set.

Modified Delorenzo and Wiggans model:

$$Y_D = b_0 + b_1 y_{mo}, y_{no} \text{ or } y_{ni} + b_2(\text{dim-158})$$

The reference DIM is 158 which represent the days in milk at the middle stage of lactation (Liu *et al.* 2000). This model is combination of daily milk yield regressed on different milking times plus the effect of lactation curve of Ali and Schaeffer:

$$YD = b_0 + b_1 y_{mo,}\ y_{no \text{ or }} y_{ni} + b_2(\text{dim}/305) + b_3(\text{dim}/305)^3 + b_4 \ln(305/\text{dim}) + b_5 \ln^2(305/\text{dim})$$

In each model, morning (y_{mo}), noon (y_{no}) or night (y_{ni}) milking record was used separately and consequently total numbers of models are twelve. Different approaches of daily milk yield prediction from alternative milk recording scheme were compared on the basis of correlation between actual and prediction daily milk yield (r), standard deviation of the difference between estimated and actual milk yields (SD estimation error; SDEE) and absolute value of mean difference between estimated and actual daily milk yield (bias) (Gantner *et al.* 2006). For the second parts of this study, four different models were selected from the literature and analysed in order to predict daily milk and fat yield (Table 1).

In this part, Proc NLIN and REG in SAS (2005) were employed to fit the nonlinear and linear regression functions. The goodness of fit the models was evaluated using R^2, RMSE, Akaka's information criterion (AIC) and sum of daily deviation (SDD). AIC is a measure of the goodness of fit of an estimated statistical model (Akaike, 1974). It can describe the trade of between bias and variance in model construction. AIC is not a test on the model in the sense of hypothesis testing; rather it is a tool for model selection. Given a data set, several competing models could be ranked according to their AIC, with the one having the lowest AIC being the best but SDD is the sum of differences between average and predicted milk or fat yield by each model which was calculated in different stages of the lactation (5-100 days, 101-200 days and 201-305 days). A positive or negative amount of SDD shows that the model overestimated and underestimated milk yield in a specific period respectively.

The important assumption in this study was that if a function could predicted daily milk yield accurately, then it would be able to predict cumulative 305 d milk yield with minimum error.

Cumulative 305 d milk and fat yield with the best function (s) of the previous part was compared with TIM and CDM. TIM and CDM for milk yield (MY) and fat yield (FY) as follow (ICAR, 2011):

Test interval method:

$$MY= I_0M_1 + I_1((M1+M2)/2) + I_2((M2+M3)/2) + I_{n-1}((M_{n-1}+M_n)/2) + I_nM_n$$

$$FY= I_0F_1 + I_1((F1+F2)/2) + I_2((F2+F3)/2) + I_{n-1}((F_{n-1}+F_n)/2) + I_nF_n$$

and evening with daily milk yield in a.m-p.m data were 0.979 and 0.975 respectively.

Where:
M_1, M_2 and M_n: milk weights in kilogram.
F_1, F_2 and F_3: fat yield in kilogram.
I_1, I_2 and I_{n-1}: intervals in days between recording dates.

Centring date method:

$$MY or FY = \sum_{i=1}^{n} Y_i * h_i$$

Where:
MY or FY: milk or fat yield estimation.
Y_i: i^{th} milk or fat production recording.
h_i: day interval between two recording.
i: number of recording.

Different methods of cumulative 305 d milk and fat yield for individual cows were computed with SAS programming. Evaluation of different methods was analyzed by correlation coefficient (r), coefficient of variation (CV), standard deviation of the results (SD) and root mean square error (RMSE) of the cumulative milk yield by the various methods.

RESULTS AND DISCUSSION

The average, standard deviation and coefficient of variation for milk yield different times and daily fat yield was shown in Table 2. The average milk yield in the morning, noon and night was similar and the CV at noon was higher than at other milking times.

Table 1 Equations used to describe the lactation curves of dairy Holstein cows

Function	Statistical form
Wood	$Y= at^b e^{-ct}$
Wilmink	$Y= a + bt + c\ exp^{(-0.05t)}$
Ali and Schaeffer	$Y_t= a + b(t/305) + c(t/305)^2 + d\ ln(305/t) + f\ ln^2(305/t)$
Legendre polynomial (k=4)	$Y_t = \sum_{i=1}^{n} \alpha_i p_j$

Where:
Y:milk or fat yield.
t: time of lactation.
a, b, c, d and f: parameters that define the scale and shape of the curve in the model.
α_i, p_j and n: coefficients, function of time and degree of polynomials respectively.

Higher variance was observed for milk yield in the morning and noon than night milking. This Table also showed that the coefficient of variation in daily fat yield is twice of the daily milk yield. The pairwise phenotypic correlations between morning, noon and night daily milk yields were 0.881, 0.889 and 0.888 respectively (almost similar). Liu *et al.* (2000) reported that the correlation between morning

But Kompan *et al.* (2006) showed that evening milking have lower correlation with daily yields than morning milking in dairy sheep with evening and morning measured yields. In this study the correlation coefficients between am-pm milking was 0.908 but in our study the correlations for morning-noon, morning-night and noon-night milk yields were lower (0.665, 0.672 and 0.696 respectively).

The coefficients of determination, accuracy and bias for the 12 models used to estimate daily milk yield from single milking weights are presented in Table 3. The model with the highest correlation and lowest bias and standard deviation of different between estimated and actual milk yield fit the best to the data set. In model 1, correlation between real milk and estimated daily milk yield of each times are similar (0.88). Simple tripling of the morning, noon and night milking (model 1) gives the highest bias and accuracy compared to the other models.

This means that tripling method of single yields overestimate daily milk yield base on the morning, noon and night milking. Javanovac *et al.* (2005) also mentioned that the doubling method of milk yield in two time milking cows resulted in bias estimation of daily milk yield. The performance of model 2 (single linear regression model) was better than model 1 especially for the bias item. In this model single linear regression using noon milking times produced the best fit of prediction daily milk yield. The result shows that based on simple linear regression (model 2), noon milking time was appropriate for prediction of daily milk yield but the models 3 and 4 produce more accurate result (i.e., lower SDEE and lower biases).

decreased; Table 3). Evaluation of the remaining models showed that the most complex model (model 4) gave the best fit to the data for prediction of daily milk yield.

In this model the effect of lactation curve by Ali and Schaeffer function included into the function. Using noon milking time with Ali and Schaeffer function is the best model for prediction of daily milk yield in Iranian primiparous Holstein cows. In other words, in three milking time dairy cows, daily yield estimated form noon milking is more accurate than those of morning or night milking. Estimated goodness of fit statistics of various models is presented in Table 4.

In these models R^2 ranged from 0.93 to 0.97 and 0.42 to 0.95 for milk and fat yield respectively. The range of RMSE was between 0.568 and 0.696 for the milk yield. Amongst the models, the Wood and Ali and Schaeffer functions were better than other models. They have the higher R^2, smaller RMSE and AIC. As shown Table 4, the coefficient of determination of the Wood model was slightly better than that of the Ali and Schaeffer model and the RMSE was lower. Positive or negative amounts of SDD show that the model overestimated and underestimated milk yield in a specific period.

Table 2 Descriptive statistics of milk and fat yield

Trait	Milk yield (kg)			Fat yield (kg)		
	Mean	SD	CV	Mean	SD	CV
Morning	9.936	2.715	27.326	-	-	-
Noon	9.491	2.705	28.502	-	-	-
Night	9.435	2.612	27.693	-	-	-
Daily	28.863	7.118	24.664	0.835	0.409	48.937

CV: coefficient of variation.
SD: standard deviation.

Table 3 Correlation, accuracy and bias between true and estimated daily milk yield and coefficients of different models

Model	Partial yield	r[1]	SDEE	Bias[2]	Coefficients					
					b_0	b_1	b_2	b_3	b_4	b_5
1	$3y_{mo}$	0.881	3.853	2.839	-	-	-	-	-	-
	$3y_{no}$	0.889	3.510	2.704	-	-	-	-	-	-
	$3y_{ni}$	0.888	3.608	2.613	-	-	-	-	-	-
2	y_{mo}	0.881	3.367	2.525	5.90	2.31	-	-	-	-
	y_{no}	0.889	3.253	2.522	6.64	2.34	-	-	-	-
	y_{ni}	0.888	3.27	2.524	6.03	2.41	-	-	-	-
3	y_{mo}	0.882	3.366	2.515	5.98	2.39	0.04	-	-	-
	y_{no}	0.890	3.245	2.413	6.70	2.32	0.02	-	-	-
	y_{ni}	0.885	3.273	2.407	6.09	2.40	0	-	-	-
4	y_{mo}	0.884	3.326	2.501	12.49	2.25	9.84	2.56	-2.49	0.17
	y_{no}	0.892	3.216	2.391	12.30	2.28	7.76	1.37	-2.17	0.13
	y_{ni}	0.890	3.240	2.391	9.88	2.36	4.60	0.05	-1.25	0.02

[1] Correlation between real and estimated daily milk yield.
[2] Absolute value of mean difference between estimated and real daily milk yield.
SDEE: standard deviation of the difference between estimated and actual daily milk yields.

The modified De Lorenzo and Wiggans model was the best for noon milking time but is less accurate than model 1 and 2. As the complexity of the model increased (models 1 to 4), the accuracy increased (i.e., the SDEE and the bias

The results indicate that total SDD of Ali and Schaeffer model was lower than that of the other models for milk yield trait. Scott *et al.* (1996) reported that the Wood model has the tendency to overestimate milk yield prior to peak and at the final stage of lactation. So based on goodness of fit statistics in the Table 4 it conclude that Ali and Schaeffer and the Wood models are functions for prediction of daily milk yield. Although Results from these equations were similar, the performance of Ali and Schaeffer function for cumulative milk yield production is better. But in fat yield trait the Wood model was the best for describing fat yield during 305 d of lactation.

Actual average and estimated average milk yield of the different functions for milk and fat yield are presented in Figure 1 and 2. These Figures show that the average variation of fat production is higher than of milk yield during days in milk. Also the Wood function was the best for fitting both fat and milk yield but the 4th order of Legendre polynomial is not fitted the fat yield during 305 d.

With respect to results of previous section, the prediction of total 305 d milk and fat yield with superior functions would be more accurate than other methods. For testing this hypothesis the average, standard deviation (SD), coefficient of variation (CV) and standard error (SE) of different models of prediction 305 d milk and fat yield are presented in Table 5. The results show that the average of milk and fat yield from TIM and CDM lower relative to that of the other models (Table 5). This means that the TIM and CDM underestimated total 305 d milk and fat yield in primiparous dairy cows. This is in agreement with the results of Otwinowska-mindut *et al.* (2010). Mcdaniel (1969) reported that TIM produces more accurate estimates than does the CDM when milk weights and component samples are available each month. Vasconcelos *et al.* (2004) estimated average milk and fat yield of the cows with two methods of TIM and autoregressive multiple lactation test day model.

function was less than of the Wood function. For this trait, the mean of 305 d milk yield in Ali and Schaeffer and the Wood model are close together and for the other two models is the same.

The average of 305 d fat yield for the Wood model is higher than the other models and the variability of this model is higher than the other models too.

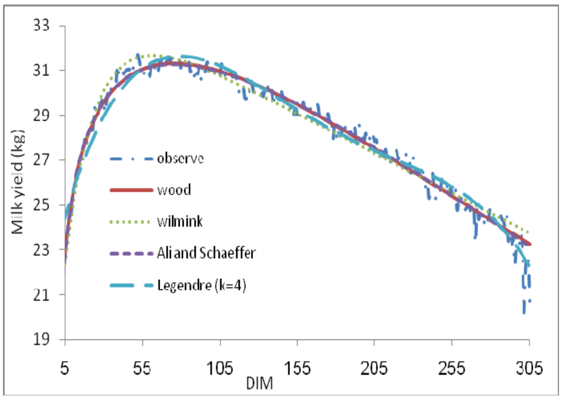

Figure 1 Actual and estimated milk yield using different models

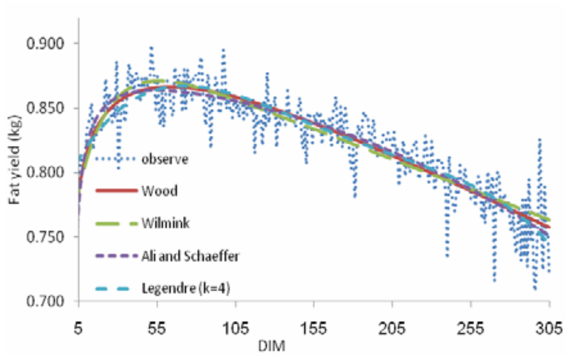

Figure 2 Actual and estimated fat yield using different models

Table 4 Coefficient of determination (R^2), root mean square error (RMSE), Akaike information criterion (AIC) in different models plus sum of daily deviation (SDD) for stages of lactation

Models	R^2	RMSE	AIC	SDD (kg) 1-100	SDD (kg) 101-200	SDD (kg) 201-305
Milk yield						
Wood	0.97	0.569	-142.36	2.486	-6.139	3.592
Wilmink	0.94	0.630	-112.02	-19.042	28.312	-9.269
Ali and Schaeffer	0.95	0.568	-139.85	0.121	-0.125	-0.003
Legendre polynomial (k=4)	0.93	0.696	-86.79	-0.666	5.070	-4.403
Fat yield						
Wood	0.95	0.032	-852.74	0.067	-0.010	0-.026
Wilmink	0.43	0.040	-850.63	-0.152	0.245	-0.092
Ali and Schaeffer	0.44	0.037	-849.96	0.121	-0.125	0.003
Legendre polynomial (k=4)	0.42	0.038	-845.15	0.091	-0.146	-0.244

R^2: coefficient of determination; RMSE: root mean square error; AIC: Akaike information criterion and SSD: sum of daily deviation.

The average of milk and fat yield for TIM were reported 7071 and 252.6 kg respectively in primiparous Holstein cows. The highest SD, CV and SE in 305 d milk yield are related to the Wood model and SD of Ali and Schaeffer

But Pool and Meuwissen (1999) found that the 5th order Legendre polynomial random regression test day model, produce the best fit and is more accurate TIM for prediction 305-d milk yield. Moreover, Schaeffer and Jamrozik (1996) reported that there is no significant different between standard lactation curve and TIM in prediction of 305-d milk yield.

The correlation between TIM with and the Wood and Ali and Schaefferis higher than that of CDM.

Table 5 Means, standard deviation (SD), coefficient of variation (CV) and standard error (SE) of different methods of prediction cumulative 305 d milk and fat yield

Models	305 d milk yield				305 d fat yield			
	Mean	SD	CV	SE	Mean	SD	CV	SE
TIM	7283.64	1653.90	22.70	9.17	218.57	64.76	29.62	0.36
CDM	7247.91	1665.26	22.97	9.23	217.53	64.71	29.74	0.36
Wood	8512.60	2838.41	33.34	15.74	221.48	68.42	30.89	0.38
Ali and Schaeffer	8664.10	1695.08	19.56	9.40	-	-	-	-

TIM: test interval method and CDM: centering date method.

Ptak *et al.* (2004) showed that method based on lactation curve models were better than other models to predict total milk yield. In their study, they reported that higher order of Legendre polynomial (order 4 compared to 3 and 2) were the best for fitting lactation curves and to predict 305 d milk yields. Koonawootrittriron *et al.* (2001) showed that the second degree polynomial was the best out of seven models to predict daily and 305-d milk yields. Wilmink (1987) reported that single and multiple regressions achieved similar accuracies of prediction for 305 d milk yields. In our study the incomplete Gamma function and Ali and Schaeffer model was more accurate than the TIM and CDM methods and the latter methods are not accurate for prediction of cumulative 305 d milk yield. This not in agreement with the result of Sajjad Khan *et al.* (1999) which reported that the Wood function is comparable test interval method and centering date method for prediction 305 d milk yield. Correlation among yields from different methods of 305 d milk and fat yield in first parity are given in Table 6. In cumulative 305 d milk yield trait, the range of correlations is from 0.70 to 0.99 but in cumulative fat yield is between 0.89 and 0.99 respectively.

The two optimum functions in previous section were the Wood and Schaeffer functions and the highest correlation of cumulative milk yield is between these models (0.88). The highest correlation was obtained between TIM and CDM (0.99).

Table 6 Correlation coefficients among different methods of cumulative 305 d milk yield (above diagonal) and fat yield (below diagonal) prediction

Models	TIM	CDM	Wood	Ali and Schaeffer
TIM	1	0.99	0.82	0.86
CDM	0.99	1	0.73	0.70
Wood	0.91	0.90	1	0.88
Ali and Schaeffer	-	-	-	1

TIM: test interval method and CDM: centering date method.

These results and the previous section (Table 5) indicate that TIM and CDM give relatively similar accuracy in cumulative 305 d milk yield estimation but the performance of these methods is completely lower than of methods of milk yield prediction based on lactation curve functions.

This showed that these methods (TIM and CDM) are not as equivalently accurate for 305 d milk yield. Fracz and Ptak (2003) reported a high correlation between the 305-d milk and fat yield using TIM and Ali and Schaeffer function as well. The correlations between the Wood model and TIM and CDM for cumulative fat yield were similar (0.91 and 0.90 respectively).

So the result of Table 4 and 5, show that Ali and Schaeffer and the Wood functions gave the best goodness of fit for prediction of total milk and fat yield in 305 d standard lactation period respectively and the performance of the models for these traits are optimum.

CONCLUSION

In this study several statistical models for estimation of daily milk yield from alternative milk recording were used. The result showed that model 4 which included effect of lactation curve by Ali and Schaeffer function gives the best fit to the data for prediction of daily milk yield. In this model, the best time of milking for prediction of daily milk yield was noon milking time. With the complexity of the models, the accuracy increased and the bias between true and estimated daily milk yield decreased. Evaluation of daily milk and fat yields (based on R^2, RMSE, AIC and SDD) using individual fitting of proposed functions showed that Ali and Schaeffer and the wood equations made the best description of daily milk yield and the Wood function predicted fat yield of the milk better than the other models. Based on the results of prediction of daily milk and fat yields, we can conclude that the most appropriate models for prediction of cumulative milk and fat yields in standard lactation periods are Ali and Schaeffer and the Wood functions respectively. So 305 d cumulative milk and fat yields by these functions are more accurate than of standard methods of TIM or CDM.

ACKNOWLEDGEMENT

The center of animal breeding of Iran is greatly acknowledged for supplying the data used in this study.

REFERENCES

Akaike H. (1974). A new look at the statistical model identification. *IEEE Trans. Auto. Control*. **19,** 716-723.

Dijkstra J.J., France M.S., Dhanoa J.A., Maas M., Hanigan D., Rook A.J. and Beever D.E. (1997). A model to describe growth patterns of the mammary gland during pregnancy and lactation. *J. Dairy Sci*. **80,** 2340-2354.

Dongre V.B., Gandhi R.S., Singh A. and Malhotra R. (2011). Prediction of first lactation 305-d fortnightly test day milk yields using lactation curves models in Sahiwal cattle. *Int. J. Agric. Res. Rev*. **1(2),** 87-90.

Fracz A. and Ptak E. (2003). Prediction of 305 d milk yield of black and white cows using Ali and Schaeffer lactation curve model (in polish). *Rocz. Nauk. Zoot. Supl*. **17,** 349-352.

Gantner V., Jovanovac S., Kovac M., Malovrh S. and Kompan D. (2006). VaFrious approaches to study daily milk yield prediction from alternative milk recording scheme. *Acta Agraria Kaposvariensis*. **10(2),** 105-112.

Grzesiak W., Wojcik J. and Binerowska B. (2003). Prediction of 305-d first lactation milk yield in cows with selected regression models. *Arch. Tierz. Dumm.* **46(3),** 215-226.

Grossman M. and Koops W.J. (1988). Multiphasic analysis of lactation curves in dairy cattle. *J. Dairy Sci*. **71,** 1598-1608.

ICAR. (2003). International Committee for Animal Recording. ICAR Guidelines Approved by the General Assembly Held in Interlaken.

ICAR. (2011). International Committee for Animal Recording. Guidelines Approved by the General Assembly Held in Riga.

Javanovac S., Gantner V., Kuterovac K. and Klopcic M. (2005). Comparison of statistical models to estimate daily milk yield in single milking testing schemes. *Italian J. Anim. Sci*. **4,** 27-29.

Kompan D., Gantner V., Kovac M., Klopcic M. and Jovanovac S. (2006). Estimation of daily milk yield from alternative milk recording schemes in dairy sheep. *Acta Agraria Kaposvariensis*. **10,** 169-176.

Koonawootrittriron S., Elzo M., Tumwason M. and Sintala W. (2001). Prediction of 100-d and 305-d milk yield in multibreed dairy herd in Thailand using monthly test-day records. Availabl in:
www.animal.ifas.ufl.edu.

Liu Z., Reents R., Reinhardt F. and Kuwan K. (2000). Approaches to estimating daily yield from single milking testing schemes and use of a.m-p.m. records in test-day model genetic evaluation in dairy cattle. *J. Dairy Sci*. **83,** 2672-2682.

Macciotta N.P.P., Miglior F., Cappio-Borlino A. and Schaeffer L.R. (2007). Fitting different functions to the individual deviations in the random regression test day models for milk yield in dairy cattle. *Italian J. Anim. Sci*. **6,** 153-155.

McDaniel B.T. (1969). Accuracy of sampling procedures for estimating lactation yields: a review. *J. Dairy Sci*. **52,** 1742-1761.

Otwinowska-mindut A., Ptak E., Jagusiak W. and Satola A. (2014). Modeling lactation curves of polish Holstein-Friesian cows. Part II. Prediction of 305 d lactation milk, fat and protein yields. *J. Anim. Feed Sci.* **23,** 29-36.

Pool M.H. and Meuwissen T. (1999). Prediction of daily milk yields from a limited number of test days using test day model. *J. Dairy Sci*. **82,** 1555-1564.

Ptak E., Satola A. and Czaja H. (2004). Prediction of 305-day lactation milk, fat and protein yields using Legendre polynomials and test day yields from different parts of lactation. *Anim. Sci. Pap. Reprod.* **2,** 173-183.

Sajjad Khan M. and Iqbal J. (1999). Lactation length adjustment. *Int. J. Agric. Sci. Biol*. **1,** 179-183.

SAS Institute. (2005). The SAS System for Windows, Version 8.2. Cary, NC.

Scott T.A., Yandell B., Zepeda L., Shaver R.D. and Smith T.R. (1996). Use of lactation curves for analysis of milk production data. *J. Dairy Sci*. **79,** 1885-1894.

Schaeffer L.R. and Jamrozik J. (1996). Multiple-trait prediction of lactation yields for dairy cows. *J. Dairy Sci*. **38,** 2044-2055.

Schaeffer L.R., Jamrozik J., Van Drop R., Kelton D.F. and Lazenby D.W. (2000). Estimating daily yields of cows from different milking schemes. *Livest. Prod. Sci.* **65,** 219-227.

Silvestre A.M., Petim-Batista F. and Colaco J. (2006). The accuracy of seven mathematical functions in modeling dairy cattle lactation curves based on test-day records from varying sample schemes. *J. Dairy Sci*. **89,** 1813-1821.

Swalve H.H. (2000). Theoretical basis and computational methods for different test-day genetic evaluation methods. *J. Dairy Sci.* **83,** 1115-1124.

Vasconcelos J., Martins A., Petim-Batista M.F., Colaco J., Blake R.W. and Carvalheira J. (2004). Prediction of daily and lactation yields of milk, fat and protein using an autoregressive repeatability test day model. *J. Dairy Sci*. **87,** 2591-2598.

Wilmink J.B.M. (1987). Adjustment of test-day milk, fat and protein yield for age, season and stage of lactation. *Livest. Prod. Sci.* **16,** 335-348.

Wood P.D.P. (1967). Algebraic model of the lactation curve in cattle. *Nature*. **216,** 164-165.