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Modelling First Lactation of Holstein Cows on Herds in the Southeast Region of Turkey

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Abstract: Thirteen mathematical functions were compared to describe the lactation curve, using data taken daily, semimonthly, monthly and bimonthly intervals. The objectives of this study were to compare the most widely used functions for their ability to describe first lactation curves of Holstein cows in a herd located in the southeast region of Turkey and to examine their sensitivity to data reduction. Cows reared outside throughout all seasons and milked 3 times daily. The number of observations per lactation varied from 6-300. Criterias used to compare the models were squared multiple correlation coefficient (R^2), correlation coefficient (r) between the observed and estimated test day yields, Durbin-Watson (DW) statistic and mean squared prediction error (MSPE). The performance of models showed great differences in the comparison criteria across calving-seasons (S1-December to February; S2-March to May; S3-June to August; S4-September to November) and sampling groups (TD-0 included all daily records from 5-305th day after calving; TD-15 included records with 15 day interval from 5-305th day after calving; TD-30 included records with 30 day interval from 5-305th day after calving; and TD-60 included records with 60 day interval from 5-305th day after calving). The most appropriate model to describe lactation curve was Glasbey (GLAS) when all daily observations in lactation are used and regardless of that the observations are taken semimonthly, monthly, or bimonthly interval.

Key words: Holstein, lactation curve, nonlinear function, Turkey

INTRODUCTION

There are lots of advantage of evaluation of lactation curves such as prediction of total lactation milk yield and dairy herd managements. In addition, individual patterns are also of interest for genetic evaluation of dairy cows (Macciota *et al*., 2005). Several environmental conditions, e.g. calving year, calving age, calving season, service period, parity, calving interval and genetic factors causes a random variation of shapes among cows (Schmidt and Van Vleck, 1974; Tekerli *et al*., 2000). A large range of goodness of fit has been reported (Wood, 1969; Perochon *et al*., 1996).

Since, the first model to describe the lactation curve has been proposed by Brody *et al*. (1923), various models were developed and investigated. Numerous researches have investigated several mathematical functions to model the lactation curve of dairy cattle. Some of which were the parabolic exponential model (Sikka, 1950), the gamma function (Wood, 1967), Schaeffer model (Schaeffer *et al*., 1977), Glasbey (1983) model, the modified gamma function (Jenkins and Ferrel, 1984) and Ali and Schaeffer (1987) model. In general, gamma function has been the best for predicting lactation curves in dairy cows. Tekerli *et al*. (2000) reported that nonlinear models are computationally complex and requires large amount of data for parameter estimation. In addition, other dificulties arise when it comes to explain the biological meaning of estimates as the model used includes more than three parameters to be estimated. Therefore, it is important to use a mathemathical model with less parameters and producing the best prediction of lactation curve. The lactation models should also have the property of accounting the magnitude of yield or the shape of the lactation curve to make a proper decision of management in herds (Van Tassel *et al*., 1995). Moreover, model used should have the ability to estimate the real lactation curve when interval between test-days increases, that is, when fewer data points for lactation are available for analysis.

In general, researchers have used test-day records of lactation to investigate the suitability of mathematical models to describe the lactation curves. This means that the only ten to twenty observations per cow per lactation are included in the analyses. Currently big scaled farms are taking advantage of technological advances that the automatic measurament and recording of milk production

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in every milking of each cow in every day are possible. However, the investment for automatic recording of milk production currently require considirable amount of fundings. Thus, countries are paying more attention to reduce costs associated with milk recording (Liu *et al*., 2000; Silvestre *et al*., 2006). This cost associated problem is also main concern in Turkey. Therefore, the model used can be able to fit the data with increasing intervals between test days.

The objectives of this study are to examine the suitability of thirteen of the most widely used mathematical functions for describing lactation curve and to examine their sensitivity to data reduction, using first lactation of Holstein cows in a herd located in the southeast region of Turkey.

MATERIALS AND METHODS

Data: Daily test-day records were obtained from first lactations of Holstein cows from a private big scaled farm with electronic identification, automatic milking and recording systems. The farm was located in Sanlýurfa province, the southeast region of Turkey. On the farm, the cows were housed outdoors throughout the years, fed complete rations and milked three-times daily. The edits applied to the data are as follows: calving date was restricted to be in the period from November 1998 to February 2006 and age at first calving was from 20-30 mo. Records with unknown calving age were also discarded. Lactation period was limited to 5-305th day after calving due to the reason reported by Druet *et al*. (2003). The study was undertaken with 250,648 cow-days of 844 first lactations. The records were not adjusted for calving season, but cows in each calving season were analyzed seperately instead; season 1 (S1), December-February; season 2 (S2), March-May; season 3 (S3), June-Agust; and season 4 (S4), September-November. Each season inculuded 384, 182, 65, 213 daily lactation records, respectively. Overall means (±SD) for each season for total and daily milk yield in kilogram (kg) were 8339.33±71.85, 8189.17±116.69, 7362.32±217.97, 8096.92±8782 and 27.77±0.16, 27.67±0.16, 26.17±0.12 and 27.10±0.13 kg milk, respectively (Table 1).

Four data sets were sampled from each calving-season group; data set one included all daily record of cows (TD-0); data set two included records with 15 days interval starting from the 5th day after calving (TD-15); data set three included record with 30 days interval starting from 5th day after calving (TD-30) and the data set four included records with 60 day interval starting from 5th day after calving (TD-60). Each model were fitted to each data set within each calving-season group.

Lactation curve models: Thirteen mathematical functions were applied to fit the first lactation daily milk yield data of Holstein cows. For all models $Y_{(t)}$: is the milk yield in lactation at day t (DIM) and a, b, c, d, å, k, u and v are parameters to be estimated and e is base of natural logarithm.

The Brody Model (BRODY): It was proposed by Brody *et al.* (1923) using the exponential decline function:

$$Y_{(t)} = ae^{-ct} \quad (1)$$

Jenkins and Ferrell model (JF): This model obtained by means of modifield gamma function (Jenkins and Ferrell, 1984):

$$Y_{(t)} = ate^{-ct} \quad (2)$$

The Wood Model (WOOD): The gamma function described by Wood (1967) is one of the most popular models used to describe the lactation curve:

$$Y_{(t)} = at^{b}e^{-ct} \quad (3)$$

The Glasbey Model (GLAS): This model is based on auto-relations and used widespread to fit lactations (Glasbey, 1983):

$$Y_{(t)} = ay_{t-1} + (b - ba - ac) - ct(1 - a) \quad (4)$$

The Scheaffer Model (SCH): This model suitable work out gemerally herd which is milk yields nearly (Schaeffer *et al*., 1977) and a, b and c are parameters associated with beginning of lactation, inclining and declining slopes of the lactation curve, respectively:

Table 1: Summary of daily data from 844 lactations for DIM interval from 5 -305[1]

	S1	S2	S3	S4
Cows in Production (n)	384	182	65	213
Cow Days (n)	115223	53709	18174	63542
305-d milk (kg)	8339.33±71.85	8189.17±116.69	7362.32±217.97	8096.92±8782
Daily milk (kg d^{-1})	27.77±0.16	27.67±0.16	26.17±0.12	27.10±0.13

[1]S1: December-February, S2: Marc-May, S3: June-Agust S4: September-November

$$Y_{(t)} = \frac{ae^{-bt}\left(1-e^{-ct}\right)}{c} \qquad (5)$$

The Parabolic Exponential Model (PEM): Sikka (1950) proposed a parabolic exponential model that produced a turuncated bell curve for milk yield:

$$Y_{(t)} = ae^{\left(bt-ct^2\right)} \qquad (6)$$

The Quadratic Model (QUAD): This model was first fitted by Dave (1971) and a, b and c are parameters associated with beginning of lactation, inclining and declining slopes of the lactation curve, respectively:

$$Y_{(t)} = a + bt + ct^2 \qquad (7)$$

Cobby and Le Du Model (CLD): In this model suggested by Cobby and Le Du (1978) the exponential decline is replaced by a linear decline:

$$Y_{(t)} = a - bt - ae^{-ct} \qquad (8)$$

The Ýnverse Quadratic Polynomial Model (IQP): Polinomial model (IQP) of Nelder (1966) was applied to dairy cattle by Yadav *et al.* (1977):

$$Y_{(t)}^{-1} = b + at^{-1} + ct \qquad (9)$$

The Wilmink Model (WIL): The model was first proposed by Wilmink (1987) is the following:

$$Y_{(t)} = a + be^{-kt} + ct \qquad (10)$$

The parameters a, b and c are parameters associated with the level of production, the increase of production before the peak and with the subsequent decrease, respectively. Parameter k is related to the time of the peak of lactation and usually assumes a fixed value, derived from a preliminary analysis made on average production, thus the model has only 3 parameters to be estimated (Wilmink, 1987; Schaeffer *et al.*, 2000)

The Qubic Model (QUBIC): This model is called as 3rd order polynomial:

$$Y_{(t)} = a + bt + ct^2 + dt^3 \qquad (11)$$

ALI and Schaeffer Model (ASM): The ASM model was published by Ali and Schaeffer (1987) in a work where the authors studied 3 lactation curve models with the objective of computing relative efficiencies of selection to change the shape of the lactation curve. This model can be written as:

$$Y_{(t)} = a + b\delta_t + c\delta_t^2 + d\theta_t + \varepsilon\theta_t^2 \qquad (12)$$

Where,

$$\delta_t = t/305, \theta_t = \ln\left(305/t\right)$$

The Grosman Model (GROS): Grossman *et al.* (1986) modifield gamma function as:

$$Y_{(t)} = at^b e^{-ct}\left(1 + uSin(t) + vCos(t)\right) \qquad (13)$$

Comparison criterias for the lactation curve models: The analysis of residuals is a common technique in the comparison of models in which a residual for a given record of daily yield is the difference between the observed and predicted value by the model equation. All the calculations were carried out with SAS (1990) program. The following criteria were used to compare the models:

- Squared multiple correlation coefficient (R^2). It was calculated as:

$$R^2 = \frac{RSS}{TSS}$$

  RSS is the regression sums of squares and TSS is the total sums of squares.

- Correlation (r) between the real milk yield and the estimated milk yield, which is the degree of association between real and estimated values (Guo and Swalve, 1995; Silvestre *et al.*, 2006).
- Mean squared prediction error (MSPE), which determines the error in absolute terms (Guo and Swalve, 1995) without recognizing its variation through the lactation.
- The Durbin-Watson statistic (DW) was used to test for the presence of first-order autocorrelation in the errors. The test compares the error at DIM t with the error at DIM t – 1 and measures the significance of the correlation between these successive residuals (Silvestre *et al.*, 2006):

$$DW = \frac{\sum_{i=2}^{n}(e_i - e_{i-1})^2}{\sum_{i=2}^{n}(e_i)^2}$$

RESULTS

Thirteen mathematical functions were applied to fit the first lactation milk yield data of 844 Holstein dairy cows and in diverse circumstances of data availability. Four sampling groups from each calving-season were considered. Observed values are plotted against days in milk (DIM) for S1, S2, S3 and S4 in Fig. 1. Considering the season of calving, peak yield happened earlier and was lower in those cows calving in S3 and S4 compared with those calving in S1 and S2. Differences in curves for varying seasons were more clear during the peak yield and the increasing and the last part of the lactation curves, however, were similar for all calving-seasons. Cows calving in summer season (S3) produced lowest milk yield during the peak of lactation.

Comparative study of the models for TD-0: Statistical measures used to compare performance of the models are summarized in Table 2a and b. Each of thirteen models was evaluated separately for sampling group TD-0 for each calving-seasons, S1, S2, S3 and S4. For the R^2-values (Table 2a), more similarity was observed among seasons within the models than among the models within seasons. The model GLAS produced the highest values for all seasons than all the other models while IQP produced the lowest values for all seasons. No significant difference among the other 11 models was observed within seasons. In terms of correlations (r) between the observed and the estimated lactation curves, the highest values were

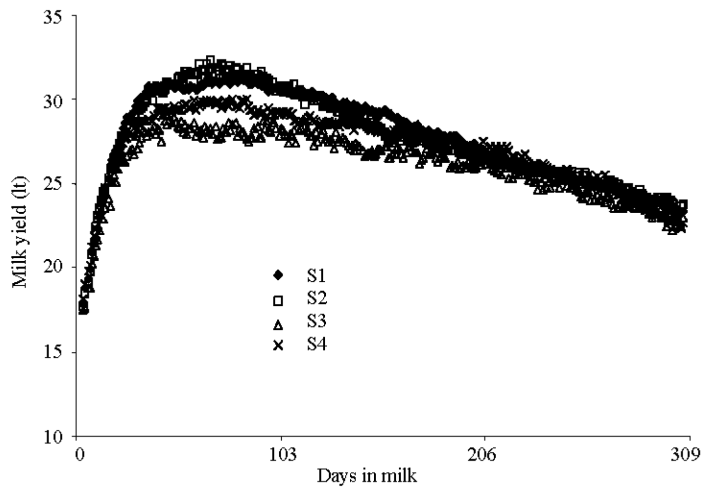

Fig. 1: Daily milk yield of first lactation by calving-seasons (S1 = calving-season 1-December to February; S2 = calving-season 2-March to May; S3 = calving-season 3-June to August; S4 = calving-season 4-September to November)

Table 2a: Comparasion criterias of the models by calving-seasons for TD-0[1]

	R^2				r			
M	S1	S2	S3	S4	S1	S2	S3	S4
[1]	0.9521	0.9448	0.9443	0.9564	0.55	0.56	0.45	0.52
[2]	0.9236	0.9154	0.9099	0.9239	0.80	0.78	0.79	0.78
[3]	0.9583	0.9508	0.9484	0.9609	0.98	0.96	0.96	0.98
[4]	0.9903	0.9879	0.9889	0.9890	1.00	1.00	0.98	0.99
[5]	0.9521	0.9448	0.9481	0.9564	0.55	0.56	0.93	0.52
[6]	0.9556	0.9476	0.9466	0.9592	0.82	0.77	0.78	0.84
[7]	0.9554	0.9474	0.9466	0.9592	0.81	0.76	0.78	0.84
[8]	0.9578	0.9506	0.9481	0.9602	0.96	0.96	0.93	0.93
[9]	0.6979	0.7172	0.7668	0.7878	0.98	0.97	0.97	0.97
[10]	0.9585	0.9513	0.9487	0.9609	1.00	0.99	0.98	0.98
[11]	0.9573	0.9500	0.9475	0.9599	0.93	0.92	0.87	0.90
[12]	0.9585	0.9514	0.9486	0.9610	1.00	0.99	0.98	0.99
[13]	0.9583	0.9508	0.9484	0.9609	0.98	0.96	0.96	0.98

[1]TD-0: Daily test per lactation, M: Model, S: Season, R^2: Squared multiple correlation coefficient, r: Correletion between observations and predict vales

Table 2b: Comparasion criterias of the models by calving-seasons for TD-0[1]

	DW				MSPE			
M	S1	S2	S3	S4	S1	S2	S3	S4
[1]	0.01	0.01	0.06	0.02	5.32	5.44	3.32	3.77
[2]	0.00	0.00	0.01	0.00	26.86	27.78	25.78	27.20
[3]	0.10	0.09	0.56	0.23	0.28	0.64	0.34	0.22
[4]	1.43	1.84	2.88	1.60	0.04	0.07	0.17	0.07
[5]	0.01	0.01	0.34	0.02	5.32	5.44	0.62	3.77
[6]	0.02	0.02	0.13	0.04	2.47	3.25	1.60	1.50
[7]	0.02	0.02	0.12	0.04	2.62	3.40	1.63	1.53
[8]	0.07	0.10	0.36	0.09	0.68	0.77	0.58	0.77
[9]	0.01	0.01	0.04	0.02	0.26	0.46	0.31	0.31
[10]	0.39	0.35	1.02	0.29	0.07	0.15	0.19	0.17
[11]	0.03	0.05	0.20	0.06	1.06	1.28	1.01	0.96
[12]	0.40	0.53	1.13	0.49	0.07	0.10	0.18	0.11
[13]	0.10	0.09	0.56	0.23	0.28	0.63	0.34	0.22

[1]TD-0: Daily test per lactation, M: Model, S: Season, MSPE: Mean squared prediction error, DW: Durbin-Watson statistic

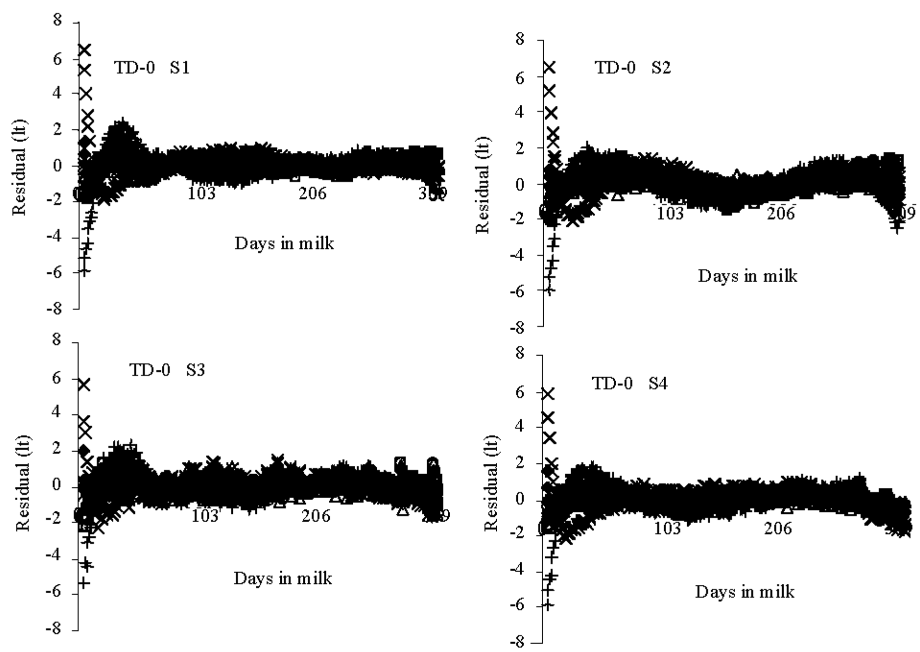

Fig. 2: Residual plots of selected models for sampling groups of TD-0 by calving seasons (S1 = calving-season 1-December to February; S2 = calving-season 2-March to May; S3 = calving-season 3-June to August; S4 = calving-season 4-September to November) (▲ ASM, □ WOOD, △ GLAS, × CLD, ∗ WIL, o GROS, + QUBIC), TD-0 Si-all daily records by ith calving-seasons

obtained from WOOD, GLAS, CLD, IQP, WIL, QUBIC, ASM and GROS (Table 2a). No difference among the models GLAS, WIL and ASM was observed and they produced larger correlation than those estimated by WOOD, CLD, IQP, QUBIC and GROS, which produced very similar values for all seasons. Smaller values were obtained from all the other models. Except for SCH in S3, the smallest and identical correlation coefficients were obtained by BRODY and SCH in all seasons. For the comparison criteria MSPE, the models GLAS, WIL and ASM ranked the best by giving the smallest values (Table 2b). In contrast to this, the largest value was observed from the model JF in all seasons. With regard to DW statistic, GLAS was the best for all seasons except for S3 where the value was a little larger than 2.5 indicating a slightly negative autocorrelation among successive residuals (Table 2b). For all the other 12 models, however, very severe and positive autocorrelation among errors was observed in all seasons. Residuals from the models WOOD, GLAS, CLD, WIL, QUBIC, ASM and GROS were plotted against days in milk in Fig. 2 for S1, S2, S3 and S4. Residuals from the other models were not plotted due to the reason that they produced large residuals in magnitude. As seen in Fig. 2, the models CLD and QUBIC could not handle the variation in data properly at the very beginning of the lactation in all seasons. The model CLD severely underestimated the real milk yield while QUBIC models severely overestimated the real milk yield at the beginning of the lactation. Although, the models WOOD, GLAS, WIL, ASM and GROS showed better performance than CLD, QUBIC and the other models, the models WOOD, WIL, ASM and GROS were not good at describing the lactation curves in the increasing part right before the peak yield.

In general, in sampling group TD-0, considering the comparison criteria R^2, r and MSPE together, the models WOOD, GLAS, CLD, WIL, QUBIC, ASM and GROS have ability to account for the variation in the data. However, when the additional comparison criterion of DW statistic is considered, in all models, excluding GLAS, the autocorrelations among the successive residuals were severely positive. Thus, the results showed that GLAS is the only model with the ability of explaining the variation in the data when all daily observations in lactations are used in analysis.

Comparative study of the models for sampling groups TD-15, TD-30 and TD-60: Table 3-6 summarize the performance of the various models for R^2, r, DW statistic and MSPE, respectively, in situations in which data were sampled 15 days, monthly and bimonthly intervals (TD-15, TD-30 and TD-60) within each calving-season groups when the first sample date occurred at the fifth day of lactation.

Comparison criteria R^2: In TD-15, the model GLAS produced the highest and consistent scores than those obtained from the other models for all seasons (Table 3). The models JF (0.0211) and WOOD (0.0584) in S3, SCH in S1 (0.0189) and S2 (0.0187) produced the lowest values. Larger but inadequate values were obtained from IQP (0.5009-0.7821) in all seasons. In TD-30, the highest scores were obtained from GLAS (0.9594-0.9763) in all seasons, but the smallest scores were obtained from JF (0.0372) in S1 and (0.8862) in S3, from PEM (0.0370-0.0416) and from IQP (0.3818- 0.8907) in all seasons. In TD-60, the best model was GLAS (R^2>0.9600) in all seasons, the models SCH, PEM and GROS, however, showed the worst performances (R^2<0.1500) in all seasons.

In general from Table 3, the efficiency of GLAS is the highest and consistent regardless of sampling groups and calving seasons. Although, the values estimated by BRODY, QUAD, CLD, WIL, QUBIC and ASM were lower than those obtained from GLAS, they were also performed adequately and consistently across sampling groups and calving-seasons.

Comparison criteria r: In TD-15, high and similar correlations (ranged from 0.96-1.00) between the observed and the estimated lactation curves were obtained from WOOD, IQP, WIL, ASM and GROS in all calving-seasons (Table 4). Although, GLAS produced lower score (0.91) in S3, it produced higher value (0.97) in the other seasons. Negative scores were obtained from JF in S3 and from SCH in S1 and S2. In TD-30, the models WOOD, CLD, IQP, WIL, ASM and GROS performed well (ranged from 0.97 to 1.00) in all seasons. In TD-60, the models WOOD, CLD, WIL and ASM showed better fit the data. The models, SCH, PEM and GROS, however, performed worst in all seasons, producing highly negative correlation between the observed and estimated yield.

In general, regarding the comparison criteria r, the models WOOD, CLD, WIL and ASM behaved the same across all calving-seasons in all sampling groups, which

Table 3: Squared multiple correlation coefficient (R^2) of the models acording to sampling groups by seasons[1]

	TD-15				TD-30				TD-60			
M	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
[1]	0.9458	0.9394	0.9332	0.9509	0.9387	0.9316	0.9248	0.9451	0.9288	0.9223	0.9252	0.9357
[2]	0.9163	0.9094	0.0211	0.9174	0.0372	0.9027	0.8862	0.9100	0.8938	0.8859	0.8769	0.8902
[3]	0.9572	0.9507	0.0584	0.9602	0.9567	0.9496	0.9382	0.9596	0.9557	0.9495	0.9458	0.9581
[4]	0.9814	0.9812	0.9705	0.9809	0.9763	0.9753	0.9594	0.9756	0.9726	0.9678	0.9669	0.9716
[5]	0.0189	0.0187	0.9332	0.9509	0.9387	0.9316	0.9248	0.9451	0.0738	0.0733	0.0839	0.0803
[6]	0.9518	0.9446	0.9376	0.9562	0.0372	0.0370	0.0416	0.0406	0.0738	0.0733	0.0839	0.0803
[7]	0.9517	0.9444	0.9376	0.9562	0.9486	0.9404	0.9324	0.9541	0.9473	0.9389	0.9415	0.9521
[8]	0.9559	0.9497	0.9410	0.9589	0.9565	0.9496	0.9383	0.9592	0.9557	0.9505	0.9452	0.9580
[9]	0.5009	0.7482	0.7821	0.7575	0.3818	0.6929	0.7205	0.8907	0.8135	0.7487	0.3581	0.8682
[10]	0.9575	0.9514	0.9420	0.9603	0.9571	0.9503	0.9385	0.9598	0.9557	0.9505	0.9452	0.9580
[11]	0.9552	0.9488	0.9396	0.9582	0.9541	0.9471	0.9357	0.9570	0.9545	0.9478	0.9451	0.9564
[12]	0.9576	0.9514	0.9420	0.9604	0.9571	0.9504	0.9387	0.9600	0.9559	0.9505	0.9459	0.9583
[13]	0.9572	0.9507	0.9417	0.9602	0.9568	0.9496	0.9382	0.9597	0.1341	0.1363	0.1471	0.1426

1TD-i: Test day intervals per lactation, M: Model, Si: Season i

Table 4: Correlation coefficients between the observed and the estimated lactation records (r) of the models acording to sampling groups by seasons[1]

	TD-15				TD-30				TD-60			
M	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
[1]	0.34	0.35	0.25	0.29	0.16	0.16	-0.04	0.13	0.09	0.09	0.19	0.08
[2]	0.84	0.83	-0.73	0.84	-0.75	0.88	0.88	0.88	0.95	0.93	0.97	0.94
[3]	0.99	0.97	0.96	0.98	0.99	0.98	0.97	0.99	1.00	0.98	1.00	0.99
[4]	0.97	0.97	0.91	0.97	0.91	0.91	0.81	0.91	0.89	0.84	0.92	0.89
[5]	-0.66	-0.65	0.25	0.29	0.16	0.16	-0.04	0.13	-0.81	-0.81	-0.86	-0.81
[6]	0.75	0.70	0.72	0.77	-0.75	-0.75	-0.83	-0.77	-0.81	-0.81	-0.86	-0.81
[7]	0.74	0.69	0.72	0.77	0.74	0.69	0.74	0.78	0.83	0.77	0.89	0.85
[8]	0.94	0.93	0.93	0.92	0.98	0.98	0.98	0.97	1.00	1.00	0.98	0.99
[9]	0.97	0.97	0.97	0.97	0.98	0.98	0.97	0.98	0.99	1.00	0.92	0.99
[10]	1.00	0.99	0.98	0.99	1.00	1.00	0.98	0.99	1.00	1.00	0.98	0.99
[11]	0.91	0.89	0.85	0.88	0.92	0.91	0.87	0.89	0.97	0.95	0.98	0.96
[12]	1.00	1.00	0.98	0.99	1.00	1.00	0.99	1.00	1.00	1.00	1.00	1.00
[13]	0.99	0.97	0.97	0.98	0.99	0.98	0.97	0.99	-0.72	-0.70	-0.79	-0.71

[1]TD-i: Test day intervals per lactation, M: Model, Si: Season i.

Table 5: Durbin-Watson statistics (DW) of the models acording to sampling groups by seasons[1]

	TD-15				TD-30				TD-60			
M	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
[1]	0.50	0.49	0.63	0.50	1.04	1.00	1.16	1.01	1.57	1.75	1.43	1.61
[2]	0.11	0.10	0.05	0.11	0.12	0.32	0.35	0.33	0.80	0.79	0.83	0.81
[3]	0.88	0.37	1.58	1.00	1.76	0.80	2.44	1.52	1.88	2.00	2.99	2.83
[4]	0.78	0.68	1.60	1.09	1.41	0.87	1.95	1.29	1.64	1.83	1.90	2.18
[5]	0.05	0.05	0.63	0.50	1.04	1.00	1.16	1.01	0.25	0.27	0.23	0.25
[6]	0.76	0.65	0.97	0.81	0.12	0.11	0.11	0.11	0.25	0.27	0.23	0.25
[7]	0.73	0.63	0.96	0.79	1.48	1.26	1.69	1.55	2.22	2.32	2.23	2.41
[8]	1.42	1.37	1.57	1.22	1.22	1.99	1.48	1.23	2.85	2.21	1.99	1.98
[9]	0.15	0.07	0.12	0.17	0.17	0.08	0.16	0.23	0.38	0.15	0.29	0.34
[10]	1.78	0.58	1.96	1.12	2.11	1.10	2.33	1.00	2.85	2.21	1.99	1.98
[11]	1.05	0.87	1.22	0.98	2.01	1.61	2.19	1.76	2.95	2.98	2.96	2.98
[12]	2.87	0.63	2.57	1.66	2.06	1.54	2.52	2.18	3.56	3.57	3.55	3.57
[13]	0.85	0.38	1.28	0.97	1.56	0.81	2.24	1.82	0.25	0.27	0.23	0.24

[1]TD-i: Test day intervals per lactation, M: Model, Si: Season i

Table 6: Mean squared prediction error (MSPE) of the models acording to sampling groups by seasons[1]

	TD-15				TD-30				TD-60			
M	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
[1]	768.00	785.70	366.80	449.30	851.60	867.70	374.20	487.80	426.80	522.20	158.90	264.80
[2]	3E+3	2E+3	3E+3	3E+3	7E+4	3E+3	4E+3	4E+3	7E+3	6E+3	7E+3	8E+3
[3]	0.18	0.26	0.35	0.05	0.32	0.20	0.67	0.09	0.04	0.40	0.00	0.03
[4]	3.88	7.24	4.35	1.78	16.28	15.63	12.50	5.42	2.97	9.81	1.10	4.79
[5]	4E+4	4E+4	366.80	449.30	851.50	867.70	374.21	487.89	1E+5	1E+5	8E+4	1E+5
[6]	145.50	173.90	75.90	75.80	7E+4	7E+4	5E+4	6E+4	1E+5	1E+5	8E+4	1E+5
[7]	133.40	161.00	67.60	101.50	86.24	96.98	42.60	42.25	42.90	99.68	8.77	32.12
[8]	11.86	12.23	4.03	9.37	0.67	1.66	0.47	0.94	0.07	0.01	0.20	0.10
[9]	4.39	18.28	10.69	3.31	9.85	18.79	17.45	3.55	3.22	16.38	74.49	3.89
[10]	0.01	0.01	0.20	0.11	0.01	0.01	0.23	0.15	0.07	0.01	0.20	0.10
[11]	13.81	12.15	11.31	9.58	14.64	7.04	12.37	8.14	0.59	2.64	0.21	1.34
[12]	0.00	0.01	0.08	0.02	0.00	0.00	0.05	0.01	0.00	0.00	0.00	0.00
[13]	0.17	0.24	0.47	0.05	0.16	0.22	0.49	0.08	9E+4	9E+4	7E+4	8E+4

[1]TD-i: Test day intervals per lactation, M: Model, Si: Season i

imply that these models were not affected by the data reduction. On the other hand, the models GLAS, SCH and PEM fitted worse as the data points in the analyses were reduced.

Comparison criteria DW: In addition to the above examinations, the models were also tested with Durbin-Watson statistic (DW). The serial correlation of residuals was examined in order to understand whether or not the models were successful in describing the lactation curves and the results are represented in Table 5. Residuals from the models which produced the smallest values were plotted against days in milk in Fig. 3-5 for the sampling groups TD-15, TD-30 and TD-60, respectively. It is expected that the value of DW should stay between 1.5 and 2.5. When the DW value is less than 1.5, there is a positive serial correlation of residuals. In contrast, a DW greater than 2.5 means that there is a negative serial

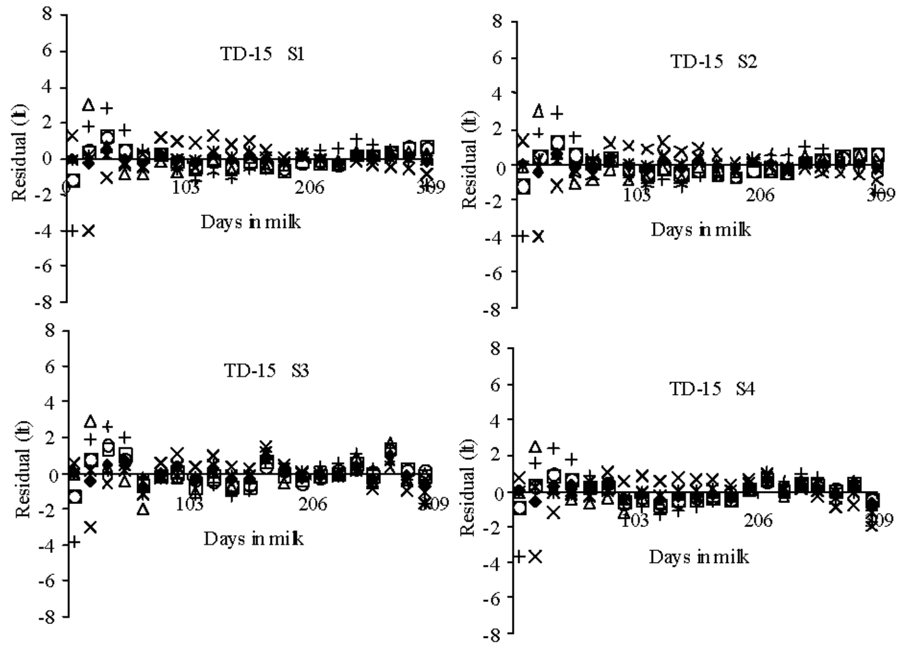

Fig. 3: Residual plots of selected models for sampling groups of TD-15 by calving seasons (S1 = calving-season 1-December to February; S2 = calving-season 2-March to May; S3 = calving-season 3-June to August; S4 = calving-season 4-September to November) (▲ ASM, □ WOOD, △ GLAS, × CLD, ∗ WIL, ○ GROS, + QUBIC), TD-15 Si-data sampled as 15 days interval by ith calving seasons

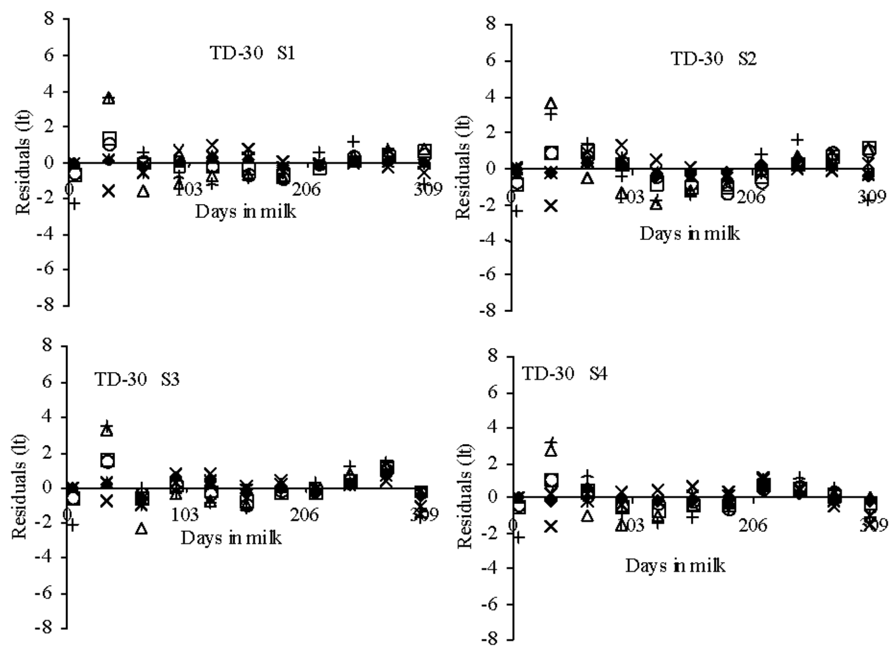

Fig. 4: Residual plots of selected models for sampling groups of TD-30 by calving seasons (S1 = calving-season 1-December to February; S2 = calving-season 2-March to May; S3 = calving-season 3-June to August; S4 = calving-season 4-September to November) (▲ ASM, □ WOOD, △ GLAS, × CLD, ∗ WIL, ○ GROS, + QUBIC), TD-30 Si-data sampled as 30 days interval by ith calving-seasons

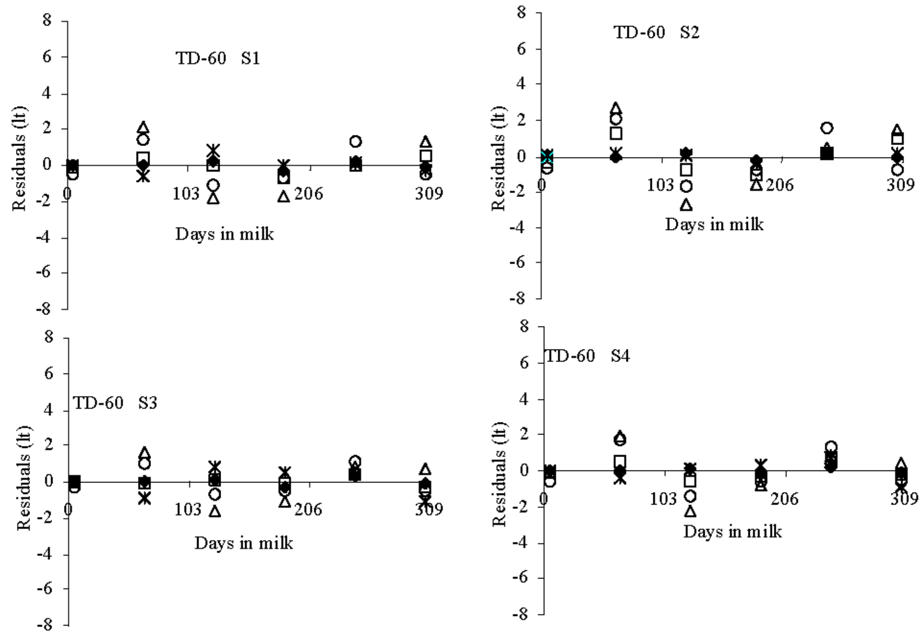

Fig. 5: Residual plots of selected models for sampling groups of TD-60 by calving seasons (S1 = calving-season 1-December to February; S2 = calving-season 2-March to May; S3 = calving-season 3-June to August; S4 = calving-season 4-September to November) (▲ ASM, □ WOOD, ▵ GLAS, × CLD, ∗ WIL, o QUBIC), TD-60 Si-data sampled as 60 days interval by ith calving seasons

correlation of residuals (Ott, 1992). Both of the above cases indicate that the model used in the analysis could not describe the variation in the data adequately. Therefore, it is clear from the analyses that the only models, in TD-15, stayed in acceptable range were WOOD and GLAS in S3, CLD in S1 and S3 and ASM in S4. In TD-30, no aotocorrelation among the successive residuals were obtained by the model QUBIC in all seasons. The only models, other than QUBIC, stayed in acceptable range were WOOD and GROS in S1, S3 and S4, GLAS in S3, QUAD in S3 and S4, CLD in S2, WIL in S1 and S3 and ASM in S1, S2 and S4. In TD-60, the models GLAS and QUAD across all calving-seasons described the data best. The models CLD and WIL were good only in S1, S2 and S3, BRODY was good in S1, S2 and S4 and WOOD was good in S1 and S2. Serial correlation of residuals for the models QUBIC and ASM in TD-60 tended to be highly negative.

Considering all sampling groups and seasons, the points indicating positive autocorrelations among errors (as DW<1.5) were much more than those representing negative autocorrelations (Table 5).

Comparison criteria MSPE: The small MSPEs were obtained by the models ASM, WIL and WOOD, respectively, in all seasons for all sampling groups (Table 6). The model CLD performed well in TD-30 and TD-60 while the model GROS performed well in TD-15 and TD-30. The efficiency of the model GROS strongly depended on the length of test-day interval. These results seem to indicate that the models ASM, WIL and WOOD were not affected by the interval between test-days. MSPEs for the other models were larger across all calving-seasons in all sampling groups.

DISCUSSION

Total peak yields were the lowest for cows calving in summer season, S3 (Fig. 1), due to limited resources of feeding and heat stress in the southeast region of Turkey. This observation supports the findings reported in earlier research (Keown *et al.*, 1986; Tekerli *et al.*, 2000; Rekik *et al.*, 2003). The highest peak (Fig. 1) and lactation milk yields (Table 1) were reached by cows that calved during the winter (S1) and spring (S2) seasons. This result is in agreement with the findings reported by Ray *et al.* (1992), but conradicts in parts to findings in earlier researches (Keown *et al.*, 1986; Tekerli *et al.*, 2000) that cows calving in fall and winter had the highest peak and lactation milk yields. All the cows used in this research were in their first lactation, this indicates that days to reach peak yield depend not only on parity in which the cows are lactating (Rao and Sundaresan, 1979) but depend also on season of calving.

Considering all four comparison criteria together, GLAS was the only model with the ability of describing the variation in the data best in the sampling group TD-0 although, the models WOOD, CLD, WIL, QUBIC, ASM and GROS can also be used if the autocorrelation among the successive residuals are ignored. The models WOOD, WIL and ASM fitted the data good enough in TD-15, in TD-30 and in TD-60 and seemed not affected by data reduction, while the model GROS performed good in sampling groups TD-15 and TD-30 and the model CLD performed good in TD-30 and TD-60. The other models showed worse performance for all sampling groups and calving-seasons.

The results represented in this study are directly comparable to findings reported by Silvestre *et al.* (2006) for the models WOOD, WIL and ASM when all daily data were used. They reported lower correlation between observed and estimated lactation but reported less severe positive autocorrelation among errors. They did not examine GLAS that described the data best in our study in TD-0. When monthly test-day data (TD-30) were used, WOOD, WIL and ASM functions described the lactation curve with similar accuracy (R^2) in our study. However, accuracy of models WOOD, WIL and ASM was not affected by increasing the interval between tests, contradicting to findings reported by Silvestre *et al.* (2006).

Variation in fit of the models was observed among calving-seasons, among models and among sampling groups. The variation in fit among calving-seasons within the same sampling group, based on the DW statistic and MSPE values, suggests that the suitability of the models depends not only on the mathematical form of the function, but also on trends in lactation, which vary among calving-seasons (Fig. 1). This variation in lactation has been observed in previous studies but was attributed to the effects of several other environmental and genetic factors, such as calving age, calving year, parity and pregnancy status (Tekerli *et al.*, 2000).

Based on the four comparison criteria in this research, model ranking are different within the sampling groups and within the calving-seasons. Researcher has to decide to which criteria more emphasis should be given and also flexibility, robustness and computational easiness of the model should be considered (Druet *et al.*, 2003). We gave more weight to correlation (r) between real and estimated test-day yield so that models with smallest Mean Squared Prediction Error (MSPE) were guarantied. Afterwards, the emphasis was given to the squared multiple correlation coefficients (R^2) followed by the Durbin Watson (DW) statistic. Thus, the models ASM, WIL and WOOD were identified as the best three functions to describe the lactation curves regardless of the sampling groups and calving-seasons.

Countries are paying more attention to reduce costs associated with milk recording (Liu *et al.*, 2000; Silvestre *et al.*, 2006). This cost associated problem is also main concern in Turkey. Therefore, the models considered should have the ability to fit the data with increasing intervals between test days. For this purpose, Silvestre *et al.* (2006) suggested that the functions such as Qubic Spline (SPL) and Legendre polynomials should be investigated in details. Based on the results reported in our study that, WOOD, WIL and ASM had the advantage of describing the lactation curve adequately with fewer observations (i.e., as in TD-60 with 6 observation in a lactation) than required for the other models, we can conveniently recommend that these three models are appropriate for data with increasing intervals between test days.

CONCLUSION

Considering daily data, GLAS function showed superior fit to the data, although , the performance of all models, except IQP, was acceptable when DW statistic was not considered in comparison criteria. Differences among models became more visible as the test day interval increased, that is, less data point for lactation was used. The performance of all the models, except ASM, WIL and WOOD, were strongly affected by the decrease in the amount of the data. Therefore, we concluded that the most appropriate model to describe lactations was GLAS when all daily observations in lactations are used, or were ASM, WIL and WOOD when the observations are taken semimonthly, monthly, or bimonthly. Sensitivity of models to variation in interval from calving to first test day and genetic relationship of lactation curve parameters for the recommended functions require further investigation.

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