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RANKING LACTATION CURVE FUNCTIONS OF DAIRY COWS IN SAUDI ARABIA

Ali A.K.A. ; A.M. AlSeaf; M.A.Alshaikh and M.S. Alkraidees
Dept. of Productive Animals
University of Saud King

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ABSTRACT : Ranking analysis was carried out on fourteen mathematical functions that have been used in the literature to describe the lactation curve.

A total of 20831 test day records of milk yield were obtained biweekly during the period 1996-1999 on two dairy farms of AL MARIE Company in the central region of Kingdom of Saudi Arabia. Ranking criteria included Adjusted R^2, Durbin Watson (DW) and Residual Standard Deviation (RSD).

Lactation curve function showed a diversity in ranking for each of five lactation, two season of calving, two milking levels and three classes of Days in milk (300, 405 and 450 days).

INTRODUCTION

Empirical algebraic functions of the lactation curve offer summaries of longitudinal milk yield patterns throughout lactation, from which cumulative curves can be estimated. These functions also allow milk yield prediction from incomplete data, and they can be used in functioning studies for analyzing systematic changes in milk yield caused by environmental and management factors.

Functions that described lactation curve have been classified into two major groups: linear and non-linear functions; In linear functions, parameters can be computed by simple regression, with log transformation of incomplete gamma function of Wood (1967, 1968, 1969, 1972, 1976 and 1980). Wood's function is the best known and most widely used linear function for describing the lactation curve. However, Cobby and La Du (1978) and Grossman and Koops (1988) found the Wood's functions overpredicted the actual data during early and late lactation and underpredicted data during mid lactation. Nelder (1966) developed the inverse polynomial function to function the lactation data. Kumar and Bahat (1979) found that Nelder function gave good fit for lactation that started at low yield and peaked earlier than usual. Non-Linear functions can not be expressed as a linear function of parameters, but can be solved iteratively. Grossman and Koops (1988) suggested the use of multiphasic function of two components with six parameters to describe the lactation curve and to remove bias early and later in lactation even though 305 day yield is fairly predicted.

Rook *et al* (1993) expressed daily milk yield as a function of a monotonically increasing function $\phi_2(t)$, which may be regarded as a growth curve, and monotonically decreasing function $\phi_2(t)$ which is referred to as a death curve. The function was $\phi_2(t)$ was described by Mitscherlich, Michaels-Menten generalized saturation Kinetic, Logistic, Goemperty and hyperbolic tangent. However, the function $\phi_2(t)$ was described by exponential and inverse straight line. Papajcsik and Bodero (1988) constructed six functions by pairing suitable increasing function such as X^b , 1-exp (x) and arctant (x) and arctan (x) and decreasing function such as exp (-x) and 1/ cosh (x).

Lactation records of dairy cows in Saudi Arabia are characterized by long lactation period due to the failure of conception at early stage of lactation, which resulted from heat stress as a limiting factor for conception Ali *et al.* (2000). Therefore, linear and non-linear functions were used to fit records of dairy cows raised under Saudi environmental conditions. In this study, 14 Mathematical functions were selected and each was fitted to biweekly milk yield for an entire lactation; the adequacy of these functions for fitting the data was the main objective of the study.

MATERIALS AND METHODS

The data used in this study consisted of 20831 milk records. Milk yield (Liters/days/cow) was collected biweekly during the period 1996 - 1999, on two dairy farms, two herds of AL MARAIE company in the central region of the Kingdom of Saudi Arabia. Years of calving (yc) were classified into four classes: yc1; included all records of cows calved in 1996;Yc2 included records of cows calved in 1997; yc3 included records of cows calved during 1998; and yc4 included records of cows calved during 1999. Cows were grouped to two groups according to calving season, S1 for cows calved from October to March and S2 for cows calved from April until September. Milk records were divided into tw milk production $\leq$ 9500 liters ; level two (ML2) cows with milk production > 9500 liters.

Statistical analysis included only records of calving age ranging from 24 to ≤ 75 (mo) . Due to the wide range of age at calving, the calving within lactations was classified follows : L1 : ≥ 24 to ≤ 38 mo; L2 : > 38 to ≤ 48 mo L3 < 48 to ≤ 58 to ≤ 68 mo ; and L5 : > 68 to ≤ mo; The data were classified into first lactation (Ln1) and lactation group (Ln 2-5 = pooled data of lactation 2, 3, 4 and 5), This was mainly due to the different shape of the first lactation compared to the 2^{nd} , 3^{rd} , 4^{th} and 5^{th} lactation for Holstein cows raised in Saudi Arabia (AL-Jumaah 1995, and Ali *et al.*, 2000).

According to the frequency distribution of the overall data, days open ranged from 50 to 190 days, was classified into seven intervals, twenty days each. The effect of lactation period (days in milk) into three categories : DIM 1 : for records with lactation period ≤ 300 days ; DIM 2 : for records with lactation period > 300 - 405 days ; DIM 3 : for ecords with lactation period > 405 days .

Marquardt's method of nonlinear regression was used to find the parameters and predicted values of the lactation curve using 14 mathematical function (Table 1-2). Marquardtís method is equivalent to performing a series of ridge regression, which correct for co-linearity or near singularity problems that arise from the correlation between the parameters. of the lactation curve as given by Bates and Watts (1988).

Goodness of fit of the functions was evaluated according to following criteria:

1. Adjusted $R^2 = 1 - \frac{(n-1)}{(n-p)} x (1-R^2)$

Where R^2 = multiple coefficient of determinate that was adjusted for the number of parameters (p) in the function since different functions have different numbers of parameters, n = Total number of observation.

2. Durbin-Watson coefficient (DW), which is a measure of first order positive auto correlation among residuals.

$$DW = \frac{\sum_{t=2}^{n} (et - et_{-1})^2}{\sum_{t=1}^{n^2} et}$$

e_t = residual at time t.

3. Residual standard deviation (RSD) while was obtained by

$$RSD = \sqrt{RS / (n - p)}$$

Rss = Residual Sums of Square.

Table 1-2 : Functions describe the

Table 1-2 : Functions describe Lactation curve used in this study .

N	Functions	Functions	Functions
1	Wood[3]	$y = atbe^{-ct}$	Wood 1976
2	Monophasic[3]	$y_t = a_1 b_1$ [1- $\tanh^2$ [$b_1 (t - c_1)$]	Grossman and Koops 1988
3	L COSH[3]	y = a In (bn)/ cosh (n)	Papajcsik and Bodero 1988
4	E ARC[3]	$y = a \arctan (bn)e^{-cn}$	Papajcsik and Bodero 1988
5	T COSH[3]	y = a arctan (bn) cosh (cn)	Papajcsik and Bodero 1988
6	Cobby[3]	$y = a - (bt) - ae^{-cn}$	Cobby and La Du 1978
7	Wilmink[3]	$y = a + (bt) + ce^{-0.05t}$	Wilmink 1987
8	Nelder[3]	$y = (l / a + (bt) + c^t)$	Nelder 1966
9	A COSH[3]	$y = an^b$ / cosh (cn)	Papajcsik and Bodero 1988
10	Ms[4]	$y = ae^{(-ct)} (b_1+t) (b_0 +(b_1-b_0 t)$	Rook et al 1993
11	Me[4]	$y = ae(-ct) (1-b_0 e - b_1 t)$	Rook et al 1993
12	Logistic[4]	$y = ae_{-ct} (1/ (1+b_0 e^{b_1 t}))$	Rook et al 1993
13	Morant[5]	$y = e^{a-bt-ct-d/t}$	Morant 1989
14	Diphasic[6]	$y_1=a_1 b_1[1-\tanh^2 (b_1 (t-c_1))]+a_2 b_2[1-\tanh^2(b_2(t-c_1))]$	Grossman and Koops 1988

yt= milk yield at time t. t= days in milk
a,b,c and d are parameter of the lactation curve 3,4,5 and 6 number of parameters
Ms= Michaelis - Menten exponential. Me = mitscherlich expeonential .

Lactation curve used in this study.

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RESULTS AND DISCUSSION

Goodness of fit measurements of different functions showed that adjusted values of R2 were high, and ranged from 0.919 to 0.998. High R2 value is desired statistic for testing goodness of fit, the large value could not clearly assign the best function. Non- genetic factors like lactation number, days in milk, milk level and season of calving had not showed sensible discrepancy of R2 values lactation, respectively. A value approximately 2.00 indicates an autocorrelation of zero (Theil, 1971). Therefore, better function for presenting lactation curves like the Diphasic, of Grossman and koops (1986) tend to have DW close to 2.00, very low value of DW (Close to zero) like Wilmink (1987) and equation (1) of Papajcsik and Bodero (1988) is an indication of poor fit.

Mean square error (MSE) is important criterion of testing the adequacy of fit of a certain function to the data, the smaller the RSD $=\sqrt{MSE}$ the more appropriate the function. (Table 2-2) shows the value of RSD and the rank that was assigned to each function where each additional 0.25 RSD mean an additional increment of + Sign.

Lactation with 300 DIM (Table 2-2) with long DIM (405d and 450) showed that neither Woodís equation nor Acosh is ranked at the top functions that described the lactation curve. With a DIM more than 300 days, EARC, Nelder and Michaelis Mentan exponential were the best functions for lactations 450 DIM. It is important to mention that, improper functions for describing the effects of DIM on milk production may fail to remove autocorrelation from the residual error; Scott *et al* (1996).

Perly curves for low producing cow. Differences of ranking functions were observed for lactation started at different calving season. Cows calved in summer showed that Wood, Lcosh, EARC, Tcosh, Nelder, Wilmink, Morant and Diphasic functions ranked similarly high. Winter season of calving had curves with no preference for specific functions although Monophasic, Cabby and Michaelis Menton exponential ranked low among other functions.

Ranking the 14 mathematical

Table 2 : Durbin Watson statistic (DW), R^2 (Coefficient of Determination and MSE (Mean Square Error after fitting the data by different mathematical function for 300 Days in milk .

Model	DW	R^2	RSD	RANK*
1	1.00	0.994	0.24	+
2	0.31	0.992	0.58	+++
3	1.86	0.991	0.31	++
4	0.80	0.993	0.40	++
5	0.99	0.996	0.25	+
6	0.61	0.992	0.31	++
7	0.25	0.996	0.66	+++
8	0.61	0.998	0.32	++
9	0.18	0.994	0.74	+++
10	0.48	0.992	0.36	++
11	1.82	0.997	0.21	+
12	0.42	0.993	0.50	++
13	1.86	0.994	0.18	+
14	3.03	0.993	0.16	+

* an increment of 0.25 SD an + increment in rank.

functions according to lactation number exhibited a diversity of ranking function from first to second lactation to other lactations. In first lactation the functions of Wood, LCOSH, ERAC, TCOSH, Cobby, Nelder, Morant and the Diphasic showed the same higher ranking. While Wilmink function showed the least. Ranking function for first lactation was similar to their ranking in summer season of calving, which means that similar sets of data have the same pattern of the lactation curve. Second lactation showed that the functions of Wilmink, ACOSH, and Diphasic have the best rank. Finally third, forth and fifth lactations had to a great extent a similar trend of ranking, Morant equation ranking the best in the last three lactation.

Comparing different function of the lactation, Ali (1996) found

Table 3 : Durbin Watson statistic (DW), R^2 (Coefficient of Determination and MSE (Mean Square Error after fitting the data by different mathematical function for 405 Days in milk .

Model	DW	R^2	RSD	RANK*
1	1.55	0.991	0.31	++
2	0.33	0.993	0.52	+++
3	0.99	0.997	0.62	+++
4	1.90	0.995	0.44	++
5	0.47	0.996	0.31	++
6	0.53	0.993	0.25	++
7	0.32	0.994	0.51	+++
8	0.73	0.996	0.24	+
9	0.21	0.992	0.62	+++
10	0.56	0.991	0.32	++
11	0.54	0.992	0.42	++
12	0.51	0.996	0.44	++
13	1.02	0.997	0.12	+
14	2.24	0.993	0.14	+

* an increment of 0.25 SD an + increment in rank.

that Triphasic function with nine parameters was the most accurate function for representing the lactation curve. Whereas Mitscherlich exponential, logistic and Monophasic function displayed the poorest fit for the data. Vargas et al (2000) examined nine mathematical functions and found that the diphasic function and lactation persistency function resulted in the best goodness of fit as measured by adjusted

Table 4 : Durbin Watson statistic (DW), R^2 (Coefficient of Determination and MSE (Mean Square Error after fitting the data by different mathematical function for 450 Days in milk .

Model	DW	R^2	RSD	RANK*
1	1.55	0.992	0.31	++
2	0.94	0.995	0.48	++
3	1.08	0.996	0.46	++
4	1.95	0.992	0.22	+
5	0.91	0.994	0.46	++
6	0.18	0.993	0.22	+
7	0.58	0.996	0.61	+++
8	2.25	0.995	0.22	+
9	0.81	0.998	0.50	++
10	1.97	0.992	0.23	+
11	2.00	0.993	0.27	++
12	0.94	0.991	0.49	++
13	2.23	0.992	0.61	++
14	0.03	0.994	0.29	++

* an increment of 0.25 SD an + increment in rank.

Table 5 : Durbin Watson statistic (DW), R^2 (Coefficient of Determination and MSE (Mean Square Error after fitting the data by different mathematical function for milk level (ML2) .

Model	DW	R^2	RSD	RANK*
1	0.54	0.998	0.38	++
2	0.19	0.995	0.87	+++
3	1.18	0.996	0.25	+
4	0.49	0.994	0.41	++
5	0.57	0.992	0.35	++
6	0.40	0.993	0.47	++
7	0.23	0.995	0.70	+++
8	0.39	0.992	0.48	++
9	0.16	0.991	0.91	+++
10	0.33	0.992	0.50	++
11	1.78	0.997	0.20	+
12	0.33	0.995	0.61	+++
13	1.60	0.994	0.22	+
14	1.40	0.996	0.24	+

* an increment of 0.25 SD an + increment in rank.

coefficient of determination, residuals standard deviation and Durbin Watson coefficient. All other functions showed less accuracy and positively correlated residuals.

Residuals for different functions of 3, 4, 5 and 6 parameters were plotted against testñdays. (Fig 1) shows the residuals plotting for Wood Acosh and Tcosh (functions with 3

Table 6 : Durbin Watson statistic (DW), R^2 (Coefficient of Determination and MSE (Mean Square Error after fitting the data by different mathematical function for milk level (ML1) .

Model	DW	R^2	RSD	RANK*
1	0.79	0.994	0.50	++
2	0.55	0.992	0.64	+++
3	0.83	0.991	0.63	++
4	0.64	0.992	0.49	++
5	0.26	0.996	0.46	++
6	0.74	0.994	0.46	++
7	0.43	0.995	0.73	+++
8	0.79	0.994	0.46	++
9	0.62	0.996	0.55	+++
10	0.73	0.993	0.52	+++
11	0.83	0.994	0.52	++
12	0.83	0.993	0.53	+++
13	1.86	0.998	0.37	++
14	0.23	0.992	0.27	++

* an increment of 0.25 SD an + increment in rank.

parameters) Wood's function tended to underpredict actual test yield in the first 100 days and underpredict from 350 d to 450 d. Arctan, Cosh, and Tcosh equation had more underprediction at the first 200 d and more overproduction at the last 50 d. However, Acosh plotting lied between Wood and Tcosh function. (Fig 2) Shows that Lcosh underpredicted heavily at the first 120 d Cobby and Lcosh equation exhibited overproduction of at actual test-day yield at the first 100 d. (Fig 3 and Fig 4) Monophasic function underpredicted actual test day along the entire lactation ploHing of logistic function (4 Parameter) vibrated with underprediction for most of the lactation (Fig 5). Comparison of the residuals plotting for function with 3,4,5 and 6 Parameters are given in (Fig 6). Diphsic with 6 parameters exhibited

Table 7 : Durbin Watson statistic (DW), R^2 (Coefficient of Determination and MSE (Mean Square Error after fitting the data by different mathematical function for Season (S2).

Model	DW	R^2	RSD	RANK*
1	1.89	0.991	0.19	+
2	0.44	0.997	0.48	++
3	1.75	0.993	0.20	+
4	1.59	0.996	0.20	+
5	1.85	0.994	0.20	+
6	1.59	0.997	0.20	+
7	0.27	0.992	0.62	+++
8	1.57	0.995	0.22	+
9	0.16	0.996	0.78	+++
10	0.47	0.991	0.50	+++
11	1.35	0.994	0.27	++
12	0.71	0.996	0.39	++
13	1.96	0.991	0.20	+
14	1.87	0.995	0.22	+

* an increment of 0.25 SD an + increment in rank.

Table 8 : Durbin Watson statistic (DW), R^2 (Coefficient of Determination and MSE (Mean Square Error after fitting the data by different mathematical function for season (S1) .

Model	DW	R^2	RSD	RANK*
1	0.67	0.994	0.47	++
2	0.40	0.995	0.74	+++
3	0.82	0.997	0.41	++
4	0.47	0.991	0.55	+++
5	0.63	0.996	0.46	++
6	0.48	0.991	0.55	+++
7	0.35	0.993	0.78	+++
8	0.49	0.995	0.57	+++
9	0.30	0.997	0.85	+++
10	0.48	0.998	0.56	+++
11	2.20	0.994	0.28	++
12	0.45	0.992	0.72	+++
13	1.81	0.993	0.31	++
14	3.03	0.998	0.15	+

* an increment of 0.25 SD an + increment in rank.

Table 9 : Durbin Watson statistic (DW), R^2 (Coefficient of Determination and MSE (Mean Square Error after fitting the data by different mathematical function for Lactation 1.

Model	DW	R^2	RSD	RANK*
1	1.94	0.982	0.18	+
2	0.38	0.985	0.56	++
3	2.04	0.982	0.19	+
4	1.09	0.986	0.19	+
5	2.11	0.983	0.16	+
6	1.35	0.982	0.19	+
7	0.04	0.987	2.41	+++
8	1.38	0.985	0.20	+
9	0.12	0.982	0.91	+++
10	0.01	0.981	0.26	++
11	1.74	0.986	0.25	++
12	0.75	0.984	0.41	++
13	2.25	0.998	0.005	+
14	2.39	0.982	0.18	+

* an increment of 0.25 SD an + increment in rank.

Table 10 : Durbin Watson statistic (DW), R^2 (Coefficient of Determination and MSE (Mean Square Error after fitting the data by different mathematical function for Lactation 2.

Model	DW	R^2	RSD	RANK*
1	0.63	0.984	0.41	++
2	0.39	0.986	0.64	+++
3	0.86	0.983	0.36	++
4	0.45	0.982	0.45	++
5	0.63	0.983	0.39	++
6	0.47	0.982	0.45	++
7	0.24	0.987	0.82	++++
8	0.50	0.981	0.46	++
9	0.03	0.988	2.31	++++
10	0.47	0.982	0.46	++
11	1.39	0.988	0.32	++
12	0.52	0.986	0.36	+++
13	1.53	0.984	0.72	+++
14	0.01	0.983	4.22	+++

* an increment of 0.25 SD an + increment in rank.

Table 11 : Durbin Watson statistic (DW), R^2 (Coefficient of Determination and MSE (Mean Square Error after fitting the data by different mathematical function for Lactation 3.

Model	DW	R^2	RSD	RANK*
1	0.53	0.982	0.38	++
2	0.38	0.983	1.07	++++
3	1.79	0.986	0.43	++
4	0.90	0.984	0.71	+++
5	1.24	0.987	0.57	+++
6	0.92	0.988	0.71	+++
7	0.27	0.985	1.29	++++
8	0.89	0.982	0.71	+++
9	0.10	0.981	2.73	++++
10	0.59	0.986	0.85	++++
11	2.38	0.987	0.36	++
12	0.49	0.988	0.96	++++
13	1.53	0.994	0.22	+
14	1.64	0.984	0.47	++

* an increment of 0.25 SD an + increment in rank.

Table 12 : Durbin Watson statistic (DW), R^2 (Coefficient of Determination and MSE (Mean Square Error after fitting the data by different mathematical function for Lactation 4.

Model	DW	R^2	RSD	RANK*
1	0.23	0.982	1.10	++++
2	0.44	0.983	0.88	++++
3	1.97	0.985	0.39	++
4	1.51	0.982	0.44	++
5	1.86	0.984	0.39	++
6	1.50	0.987	0.44	++
7	0.42	0.987	0.87	++++
8	1.52	0.986	0.44	++
9	0.06	0.982	2.65	++++
10	1.48	0.983	0.45	++
11	1.73	0.987	0.45	++
12	1	0.982	0.59	+++
13	1.53	0.986	0.22	+
14	2.58	0.984	0.37	++

* an increment of 0.25 SD an + increment in rank.

Table 13 : Durbin Watson statistic (DW), R^2 (Coefficient of Determination and MSE (Mean Square Error after fitting the data by different mathematical function for Lactation 5.

Model	DW	R^2	RSD	RANK*
1	1.84	0.981	0.61	+++
2	0.75	0.986	0.97	++++
3	2.20	0.987	0.55	+++
4	1.54	0.982	0.69	+++
5	1.93	0.983	0.60	+++
6	1.55	0.984	0.69	+++
7	0.55	0.986	1.12	++++
8	1.50	0.982	0.69	+++
9	0.14	0.988	2.43	++++
10	1.06	0.984	0.83	++++
11	2.57	0.986	0.53	+++
12	0.98	0.982	0.85	++++
13	1.53	0.981	0.22	+
14	3.16	0.988	0.50	++

* an increment of 0.25 SD an + increment in rank.

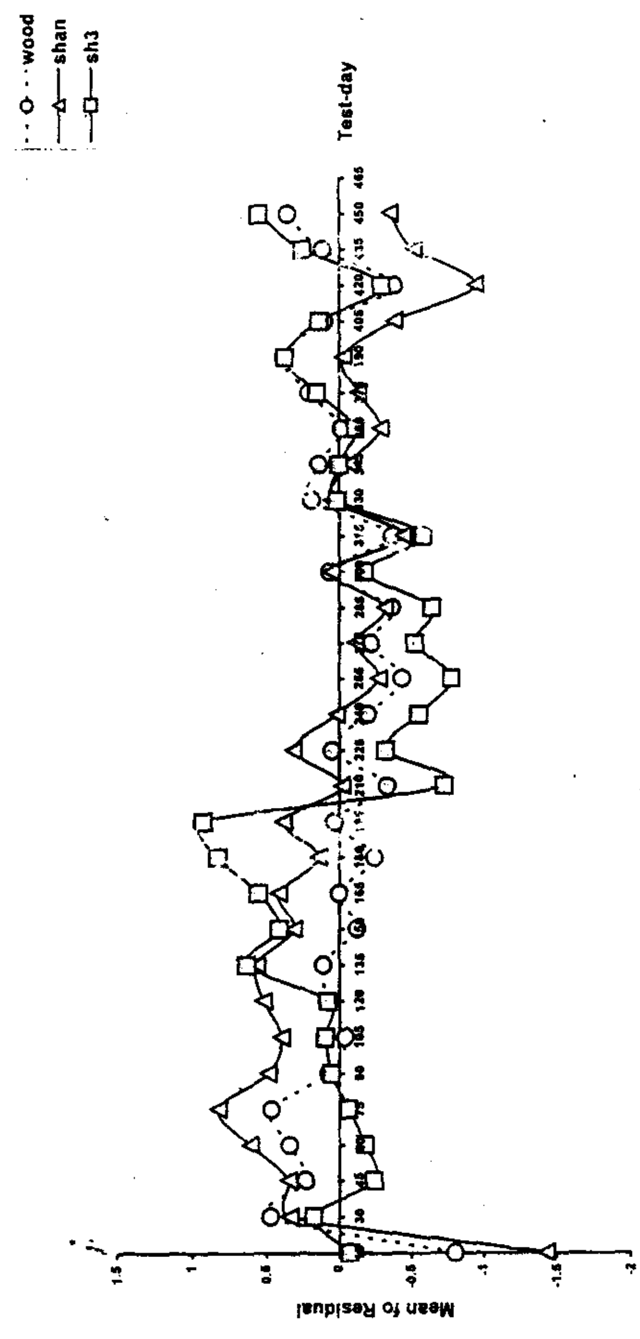

Fig. 1 : Residual for wood . Acosh and Tcosh pbheal against test- day (DM 450).

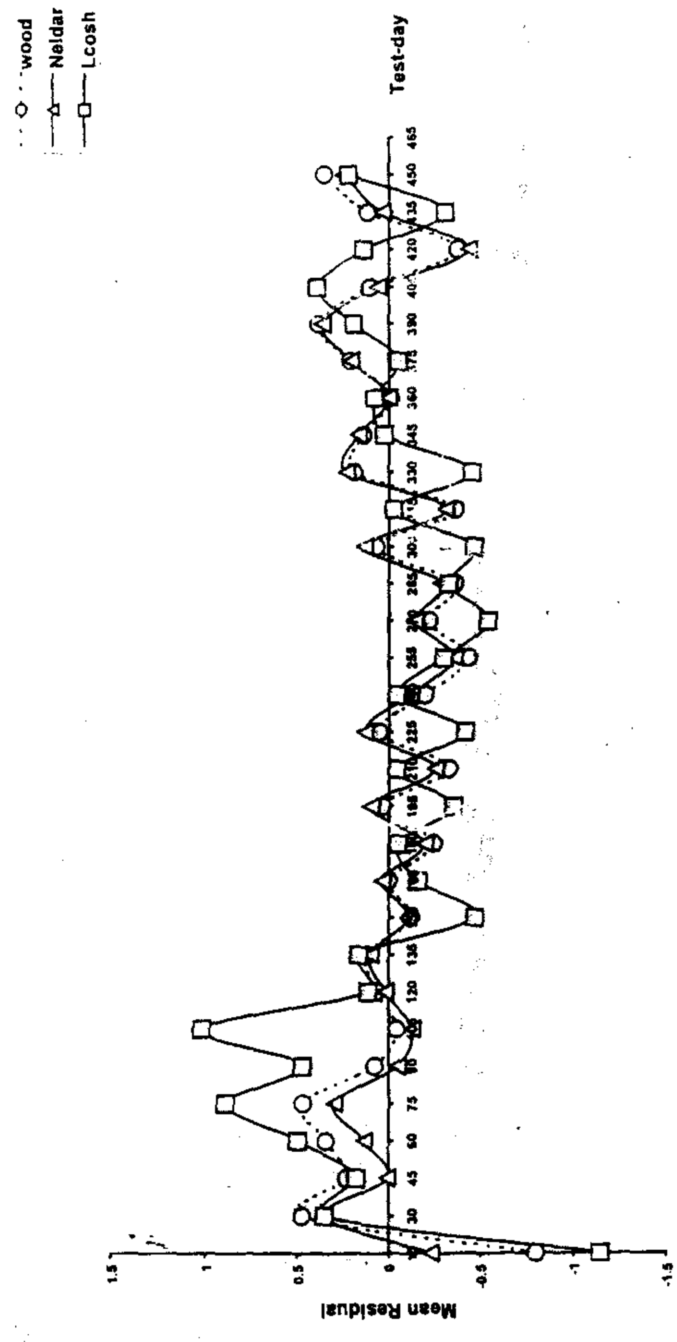

Fig. 2 : Residual for wood . Neldar and lcosh pbhea aginst test- day (DM 450).

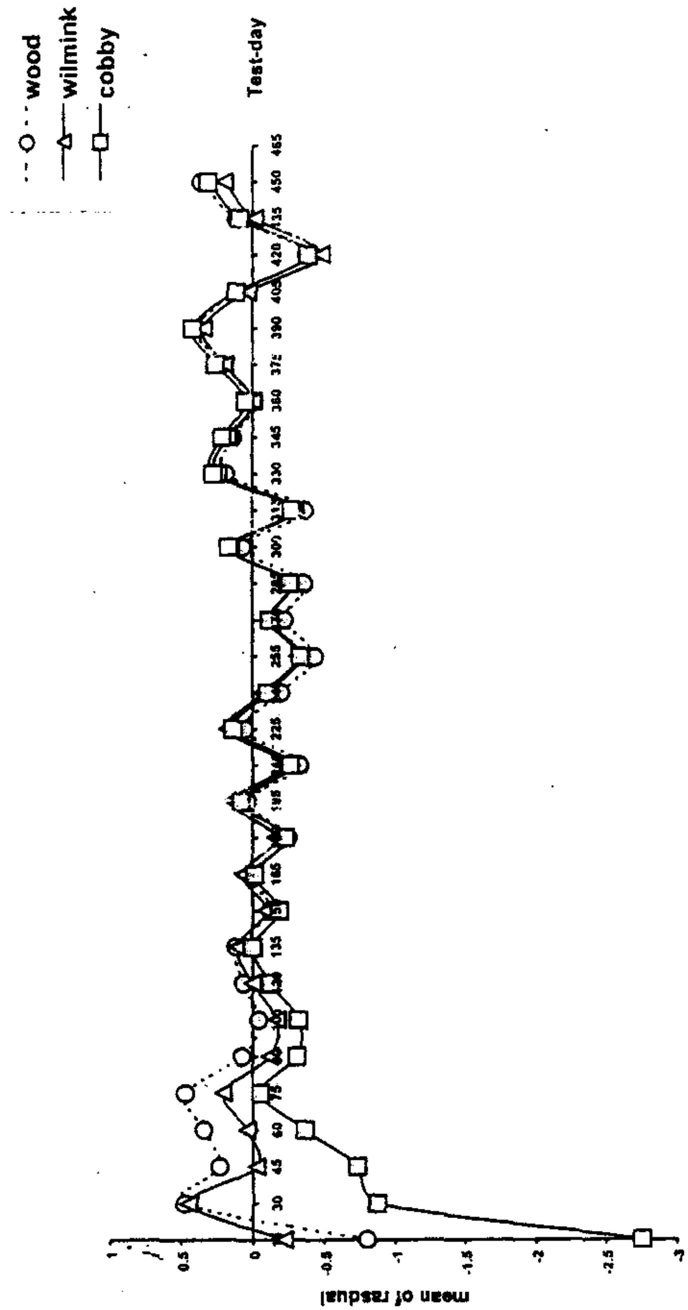

Fig. 3 : Residual for wood . Wilk and cobby pbheal test - day (DM 450).

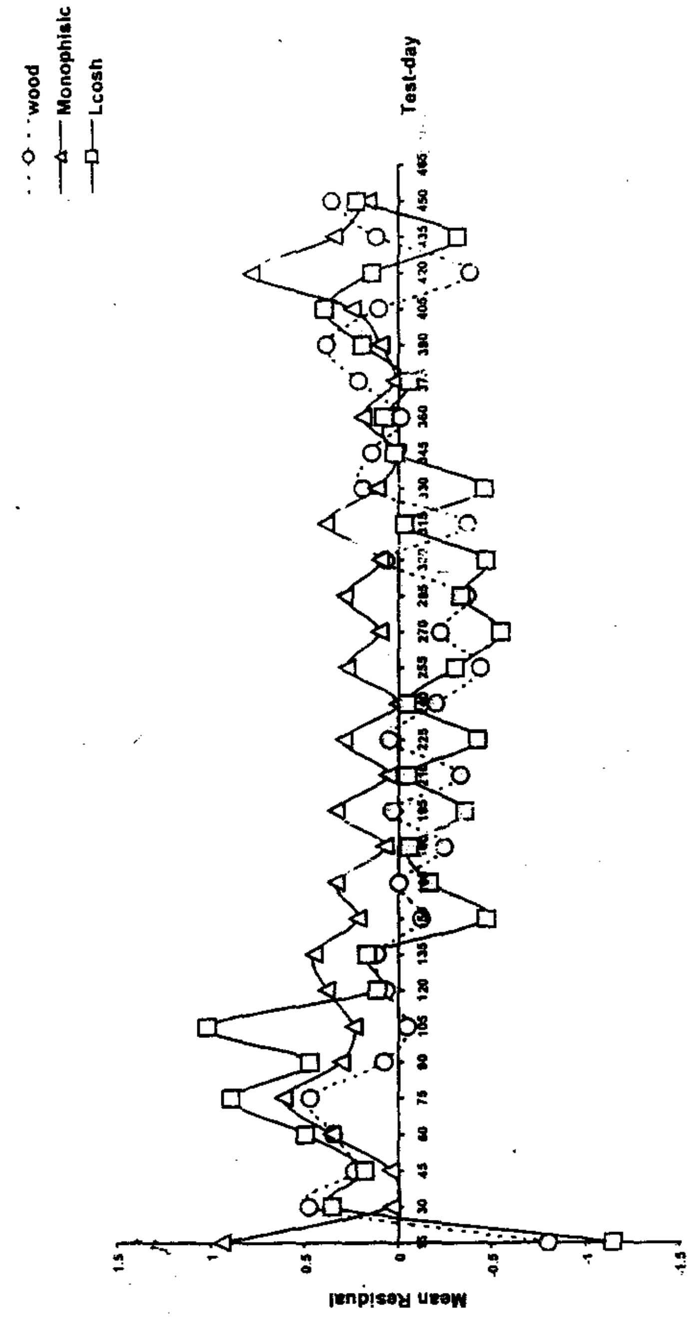

Fig. 4 : Residual for wood . Monophisic and lecsh pbheal test- day (DM 450).

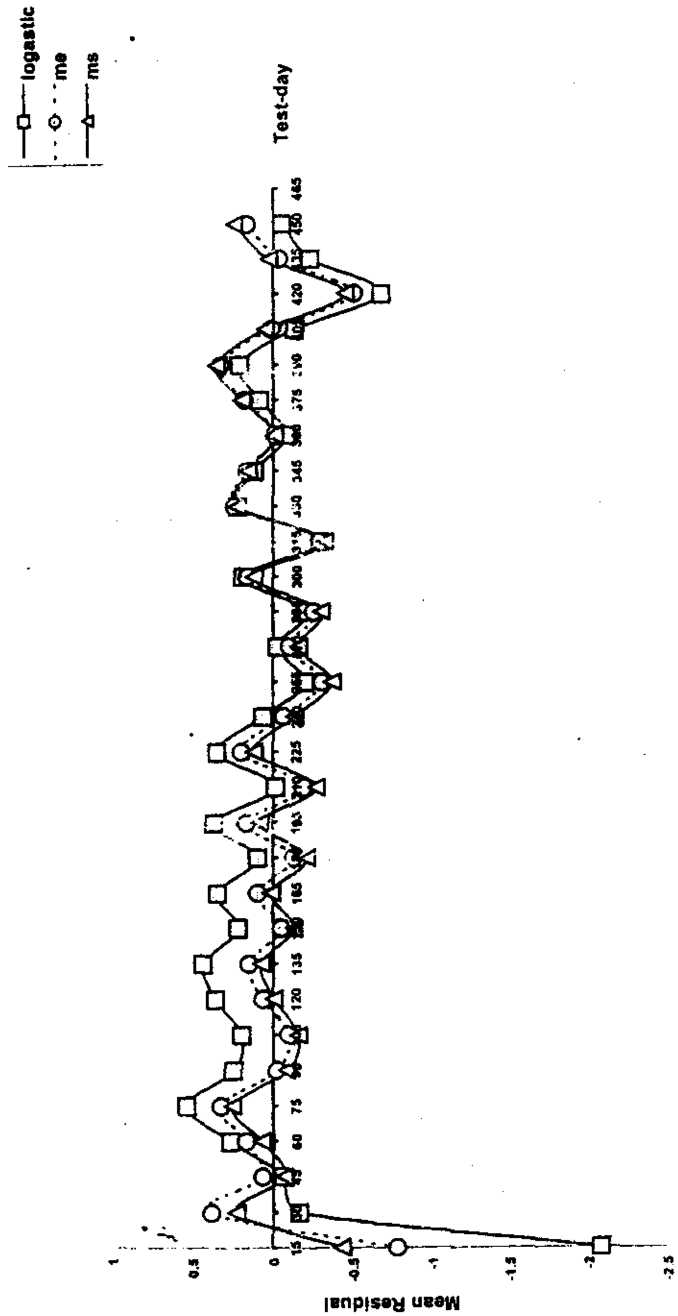

Fig. 5 : Residual for wood . Ms and Mo pbheal anainst test (DIM 450).

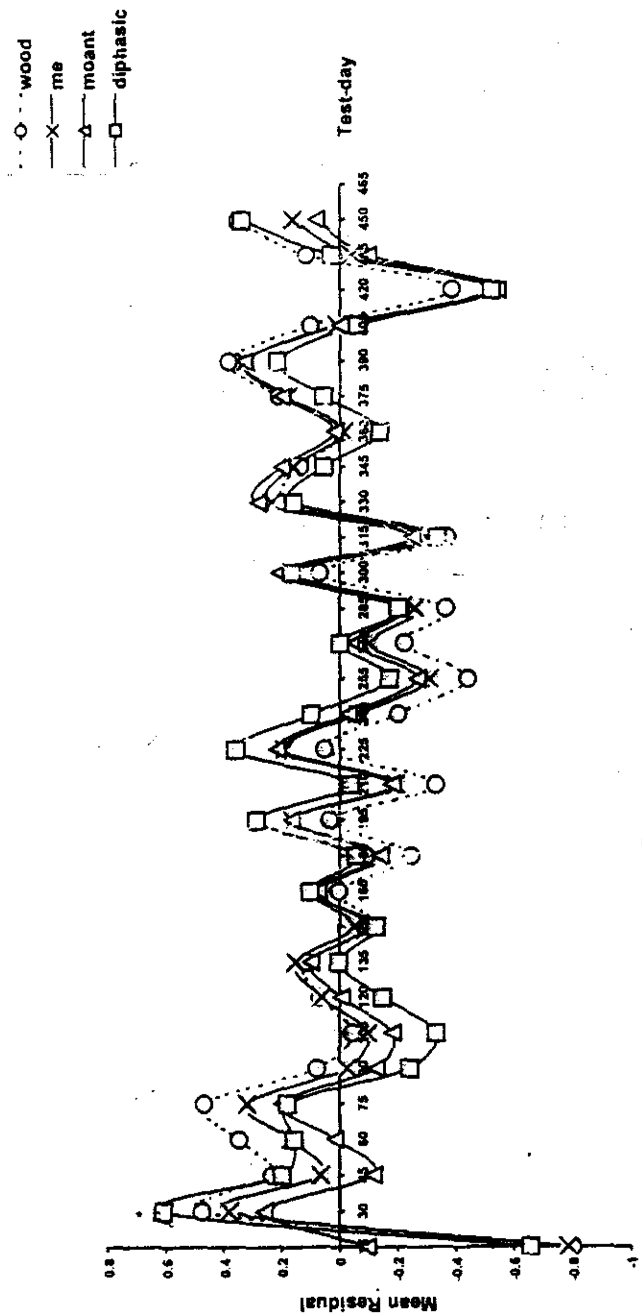

Fig. 6 : Residual for wood . Morant and Diphasic pbheal against test - day (DIM 450).

underprediction early and late lactation, which was supported by Grossman and Koops (1988) and Vargas et al (2000).

In conclusion lactation curve functions rank differently with different data sets from different origins and different genetic structures. They also ranks differently with data sets from different non genetic factors such as days in milk (DIM), season of calving, milk level and lactation number.

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ترتيب معادلات منحنى الحليب لأبقار الحليب في المملكة العربية السعودية

أحمد كمال أحمد على ، على ال سيف
محمد عبدالرحمن ال شيخ ، منصور الكرديس
قسم الانتاج الحيوانى - كلية الزراعة - جامعة الملك سعود

أجرى التحليل الأحصائى لترتيب أربعة عشرة معادلة والتى نشرت فى الدراسات السابقة لوصف منحنى الحليب ، إستخدم فى هذه الدراسة ٢٠٨٣١ سجل حليب حيث كان هناك يوم أختبار كل أسبوعين فى الفترة من عام ١٩٦٩ إلى ١٩٩٩ لمزرعتين لشركة المراعى فى المملكة العربية السعودية .

استخدمت ثلاثة مقاييس احصائية لترتيب معادلات منحنى الحليب وهى قيمة E^2 المعدلة قيمة داربن واتسون Darbin Watson وقيمة الانحراف المعيارى المتبقى Residual Standard Deviation (RSD) وقد أظهرت النتائج تنوعاً فى ترتيب معادلات الحليب طبقاً لأقسام البيانات المستخدمة فى التحليل وهى خمسة مواسم حليب ، موسمى ولادة ومستويين لإنتاج الحليب وثلاثة أقسام لطول مدة الحليب وكان ترتيب معادلة Wood (1967) $y = atbe^{-ct}$ ومعادلة Morant (1989) $y=e^{a-bt-cr-d/t}$ ومعادلة ذات الوجهيين Grossman and Koops (1988) $y_2 = a_1 , b_1[(1-c1)] + a_2b_2[(1-tanh_2 (b(t-c_2))]$ وهو الأعلى فى المعادلات الأربعة عشر لأقسام البيانات المستخدمه فى الدراسة .