Lactation curves of Holstein-Friesian and Jersey cows in Zimbabwe

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Mean daily milk yield for 478 Holstein-Friesian cows from two herds, recorded between 1984–1985, and for 218 Jersey cows from two herds, recorded between 1984–1985, were used to estimate lactation curve parameters for Wood's gamma function: $Y_n = A\ n^b e^{-cn}$. Y_n is the predicted average daily milk yield in the n^{th} week; A is a scalar representing 'starting yield'; and e is the base of natural logarithm. The values of b and c (lactation curve constants describing the rates of rise to and decline from peak lactation, respectively), lactation persistency (s), goodness of fit (R^2) and projected 44 week milk yield were estimated. The analysis of variance indicated significant effects ($P<0,01$) of herd, parity and season on most of the lactation curve parameters in both breeds. The year effects were significant ($P<0,05$) in the Jersey but non-significant ($P>0,05$) in the Holstein-Friesian. The use of monthly or weekly milk yield totals to calculate mean daily yield had highly significant effects ($P<0,01$) on the lactation curve parameters of the Jersey.

Die gemiddelde daaglikse melkproduksie van 478 Holstein-Frieskoeie uit twee kuddes, vir die tydperk 1984–1985, en van 218 Jerseykoeie uit 2 kuddes, vir die tydperk 1984–1986, is gebruik om die laktasiekurwe parameters vir Wood se gammafunksie te bereken: $Y_n = A\ n^b e^{-cn}$. Y_n is die beraamde gemiddelde daaglikse melkproduksie in die n^{de} week, A verteenwoordig aanvangsproduksie en e is die grondtal van die natuurlike logaritme. Die waardes van b en c (laktasiekurwe konstantes wat, respektiewelik, die styging voor en daling na pieklaktasie aandui), laktasie volhouvermoë (s), akkuraatheid van passing (R^2) en voorspelde 44-week melkproduksie is bepaal. Die variansie-analise het betekenisvolle effekte ($P<0,01$) aangedui vir kudde, pariteit en seisoen vir meeste van die laktasiekurwe parameters by beide rasse. Jaareffekte was betekenisvol ($P<0,05$) by die Jersey, maar nie betekenisvol ($P>0,05$) by die Holstein-Fries nie. Die gebruik van maandelikse of weeklikse melkproduksie totale om gemiddelde daaglikse produksie te bereken, het hoogs betekenisvolle effekte ($P<0,01$) op die laktasiekurwe parameters van die Jersey gehad.

Keywords: Milk prodution, lactation curves, Holstein-Friesian, Jersey

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Introduction

In Zimbabwe the Holstein-Friesian (which will be referred to as 'Holstein' in this study) is the most common breed in the dairy industry, making up 85% of the national dairy herd. In the recent past the Holstein has replaced the European-type Friesian in most commercial herds and it can be said that the Holstein is well adapted to the commercial farming system in Zimbabwe. The Jersey breed makes up 13% of the national dairy herd and ranks second in popularity to the Holstein. Nearly all Jersey breeders are in the official milk-recording schemes and of late there has been a substantial use of top bulls from the USA for genetic improvement of the breed. The Jersey is well adapted to the commercial farming system in Zimbabwe and it has a high potential for use in cross breeding with the indigenous cattle breeds to improve milk production in the communal herds.

The feeding system practised on most dairy herds depends on the ability to produce home-grown feeds economically. Maize is grown for silage as a roughage source and for grain to make up the energy part of the concentrate nnix. Normally only high protein concentrate is purchased (Commercial farmers, 1987–88; pers. comm.)

In this paper the variation in milk yield during the course of lactation is described. Formulae for describing the lactation curve have been derived for dairy cattle breeds. One such function is the gamma function of Wood, 1969, namely:

$$Y_n = A\ n^b e^{-cn}, \qquad (1)$$

Y_n is the predicted average daily milk yield in the n^{th} week, b and c are constants, and e is the base of the natural logarithm. In this model, A is the 'starting yield' (when n = 0), b and c describe the rates of rise to and decline from the peak of lactation, respectively.

In its logarithmic form,

$$\log_e (Y_n) = a + b \log_e (n) - cn, \qquad (2)$$

where 2 = $\log_e$ (A), the problem becomes one of linear multiple regression, and the new constants may be subjected to conventional statistical analysis. Hence the effect upon the constants — and therefore upon the curves they define — of whatever criteria may be interesting is easily determined. The values of a, b, and c are estimated for each lactation by fitting multiple regressions of $\log_e (Y_n)$ on $\log_e$ (n) and n.

The object in this study, using data from two typical Holstein and two typical Jersey herds near Harare, was to determine whether Wood's function could be used to describe the shape of the lactation curve in these breeds when kept in the sub-tropics. Studies on lactation curves are useful in enabling the farmer to predict the shape of the lactation curve and so estimate the required quantity of supplementary concentrate.

Materials and methods

The Holstein data consisted of lactations lasting 25–44 weeks obtained during the period 1984–85 from 478 cows in the two herds. The Jersey data consisted of lactations lasting 25–44 weeks obtained during the period 1984–86 from 218 cows in the two herds.

Zero grazing with *ad lib.* feeding was practised in both Holstein herds. The feed ingredients were maize silage and lucern-soya bean hay for roughage; maize grain for energy; and cotton meal and soya bean meal for protein. Intake of all the ingredients for mature Holstein cows averaged 22 kg dry matter(DM)/day/cow and for heifers 17 kg DM/day/cow. The maize silage made up 20% of the diet and its dry matter and crude protein content averaged 30% and 7–8%, respectively (Mutisi, 1988).

The Jersey cows were kept on natural pasture with supplementary feeding of maize silage, lucerne-soya bean hay and concentrate mixture of maize grain, cotton meal and soya meal.

In both breeds the mean daily milk yield of each cow during each week of lactation was computed from the weekly total yield. In herd 2 of the Jersey breed, the date consisted of either weekly or monthly total yield and therefore the mean daily yield of each cow during each week of lactation was computed from either the weekly or monthly total yields.

These data were fitted to the logarithm form of Wood's gamma function as given in equation (2). The parameters of $\log_e(A) = a$, b, and c were estimated for each lactation by fitting multiple regressions of $\log_e(Y_n)$ on $\log_e(n)$ and n.

The persistency of yield (s) was calculated according to Wood (1967) as:

$$S = -(b + 1)\log_e(c) \qquad (3)$$

Higher values of s indicate higher persistency.

The goodness of fit of equation (2) to each lactation curve was estimated by the proportion of variation (R^2) in log weekly yield accounted for by the gamma function, of which the root (R) is the multiple correlation coefficient. Estimated total yields of the gamma function were also computed.

The effects of herd, parity, year, and season on each of the components of the lactation curve (a, b, c, s, and R^2) were examined by within-breed analyses of variance (ANOVA) using the SPSS (1975) statistical package. Parity was classified into five classes of 1st, 2nd, 3rd, 4th, and ≥ 5th parity. Seasons considered were season 1: November to March (hot and wet) and season 2: April to October (cold and dry).

Data from herd 2 of the Jerseys were re-analysed separately to determine the effects of computing the mean daily yield of each cow from either monthly or weekly total yield on the components of the lactation curve.

The statistical model used for the ANOVA was as follows:

$$Y_{ijklm} = \mu + A_j + B_j + C_k + D_l + E_{ijklm}$$

where

Y_{ijklm} = the observation in the i^{th} herd on the m^{th} cow of j^{th} parity in the k^{th} year and in the l^{th} season.

μ = the overall mean

A_i = (i) the effect of the i^{th} herd
= (ii) The effect of using monthly or weekly totals for computing the mean daily yield for each cow (for within herd 2 analysis of variance)

B_j = the effect of the j^{th} parity of calving

C_k = the effect of the k^{th} year

D_i = the effect of the i^{th} season

E_{ijklm} = random error

Originally the interactions between all factors in the statistical model above were included in the ANOVA but it was found that the data involved were too few to make the three-way interactions meaningful and therefore these were removed from the final analyses of the Holstein data. For the same reason, all interactions were removed from the model for the Jersey data analyses.

Results and discussion

The lactations contributing to the analysis are classified by herd, parity, year and season in Table 1.

Lactation curve parameters were estimated from equation (2) for each herd-year-season and parity. This gave 4O sets of herd-year-season and parity constants for milk yield in the Holstein breed and 18 sets of herd-season and parity constants for milk yield in the Jersey breed. The parameter means for herd-season and parity are shown in Tables 2a and 2b for the Holstein and Jersey breed, respectively.

The means of lactation persistency (s), goodness of fit (R^2) as percentage and the total projected 44-week milk production (Y), indicated in Tables 2a and 2b, were estimated from the corresponding lactation curve parameters a, b, and c in the same tables.

The analyses of variance in Table 3 show the extent to which herd, parity, year, and season were related to the lactation curve parameters a, b, and c, persistency (s) and goodness of fit (R^2). In addition, the within-Jersey-herd-2 analysis of variance [Table 3(iii)] indicates the effect of using monthly or weekly total milk yield for computing the mean daily yield for each cow.

Though not consistent, herd, parity, and season had a significant ($P < 0{,}05$) effect on the lactation curve constants (a, b, and c) as well as on persistency (s) and goodness of fit (R^2) in at least one of the Holstein or Jersey herds. This would mean that herd management, parity, and season could affect the lactation curve and consequently the milk yield at all stages of lactation.

It is indicated in Tables 2a and 2b that, as parity increased, a, b, and R^2 values increased, but the c and s values decreased. The effect of parity on the shape of the curve, particularly on persistency, is probably due to the combination of a standard service interval with increasing

Table 1 Total number of lactations, used in the analysis, distributed by herd, parity, year and season

	Parity					Year			Season	
Herd	1	2	3	4	≥5	84	85	86	1	2
					Holstein					
1	79	58	29	29	47	110	132	—	105	137
2	78	46	43	37	32	123	113	—	119	117
					Jersey					
1	19	15	14	14	25	28	55	4	38	49
2	56	38	28	9	0	46	45	40	72	59

Table 2a Holstein means of the functions of lactation curve: a, b and c; persistency (s) goodness of fit (R^2) and projected 44 week milk yield (Y) kg

Parity	Parameter	Herd – Season 1 – 1	1 – 2	2 – 1	2 – 2
	a	4,94	4,90	4,58	4,52
	b	0,15	0,27	0,22	0,29
1st	c	–0,02	–0,03	–0,03	–0,03
	s	5,08	4,63	4,51	4,58
	R^2	62,33	82,31	51,24	62,22
	Y	6762	6593	4124	4779
	a	5,19	5,24	4,96	4,78
	b	0,25	0,31	0,34	0,43
	c	–0,05	–0,05	–0,06	–0,06
2nd	s	4,08	4,00	4,04	4,14
	R^2	79,83	84,92	83,19	77,97
	Y	6194	7036	5255	5043
	a	5,31	5,30	4,83	4,91
	b	0,27	0,23	0,34	0,35
	c	–0,05	–0,04	–0,05	–0,05
3rd	s	4,01	4,05	4,20	4,08
	R^2	92,48	86,21	76,58	73,79
	Y	7409	7149	5576	5550
	a	5,24	5,26	5,16	4,98
	b	0,29	0,30	0,20	0,37
	c	–0,04	–0,05	–0,03	–0,05
4th	s	4,20	4,12	4,08	4,16
	R^2	76,69	91,07	80,47	76,07
	Y	6691	7688	6122	6156
	a	5,24	5,26	5,16	4,98
	b	0,29	0,30	0,20	0,37
	c	–0,04	–0,05	–0,03	–0,05
5th	s	4,30	4,10	4,23	4,14
	R^2	82,40	81,92	78,55	75,91
	Y	8001	6901	7083	6271

Table 2b Jersey means of the functions of lactation curve: a, b and c; persistency (s) goodness of fit (R^2) and projected 44 week milk yield (Y) kg

Parity	Parameter	Herd – Season 1 – 1	1 – 2	2 – 1	2 – 2
	a	5,13	5,13	5,66	5,68
	b	0,15	0,18	0,98	1,13
	c	0,02	–0,02	–0,24	–0,28
1st	s	4,72	4,74	2,84	2,66
	R^2	65,86	71,89	71,51	75,75
	Y	7344	7982	4779	4664
	a	5,49	5,30	6,01	5,81
	b	0,17	0,33	1,04	1,90
	c	–0,04	–0,05	–0,27	–0,48
2nd	s	3,95	4,03	2,66	1,99
	R^2	82,42	73,32	73,36	78,17
	Y	7527	7867	5962	5120
	a	5,54	5,52	6,14	5,51
	b	0,18	0,12	0,72	1,49
	c	–0,04	–0,02	–0,20	–0,35
3rd	s	3,84	4,30	3,00	2,74
	R^2	90,69	83,63	72,54	83,34
	Y	8120	9988	6677	4448
	a	5,48	5,38	6,07	5,90
	b	0,22	0,30	1,28	1,60
	c	–0,04	–0,04	–0,36	–0,39
4th	s	4,07	4,17	2,29	2,27
	R^2	79,99	82,99	77,20	79,46
	Y	8488	9496	5103	6029
	a	5,49	5,45	—	—
	b	0,15	0,27	—	—
	c	–0,03	–0,04	—	—
	s	4,19	4,33	—	—
	R^2	88,00	82,06	—	—
	Y	8611	940		

potential yield (Wood, 1968) The author stated further that as the animal grows older she starts her lactation at a higher level, but because the inhibiting effect of pregnancy occurs at about the some stage of lactation, whatever the level of production, the rate of decline is more rapid in older cows. It will be necessary to have several lactations of the same cow to isolate the effect of the service interval on persistency.

Another explanation for the effect of parity on the shape of the lactation curve could be the difference in the rate of depletion of body reserves, i.e. the mature cows use their body reserve much faster in the early stages of lactation which lead to higher values of b and lower c values than in the heifer.

The year effects were non-significant ($P < 0,05$) in all parameters in the Holstein data but highly significant ($P < 0,01$) in all parameters in the Jersey data. This may be explained by the fact that in 1985 the Jersey herd 2 changed its recording system from weekly to monthly totals. Another explanation could be due to the differences in the herd management of the two breeds, i.e the Holstein-Friesian (Zero grazing) and the Jersey herds (supplemented natural grazing). It can therefore be expected that the nutrition of the Jersey herds would change from year to year according to the prevailing climatic conditions, compared to the more constant nutritional level in the case of the Holstein herds.

From the Jersey herd 2 data ANOVA — see Table 3(iii) — the year effects were not significant ($P > 0,05$) in all lactation curve parameters and it is further suggested that using monthly or weekly totals for calculating the mean daily yield will significantly ($P < 0,01$) affect the a, b, c, and s parameters of the lactation curve. The mean values of a, b, and c parameters were higher when computed from monthly than from the weekly total yields; these were 5,91, 1,29, and –0,33 *vs* 4,67, 0,25, and –0,03, respectively. Persistency (s) and goodness of fit (R^2) values were lower when computed from the monthly than from the weekly total yields; these were 2,46 and 74,82 as compared to 4,29 and 79,18, respectively. The mean 44-week projected yields were significantly different ($P < 0,01$) when calculated using lactation curve parameters derived from monthly or weekly records; these were 5 400 and 5 000 kg/lactation,

Table 3 Analysis of variance of parameters: a, b, and c of the function $\log_e(y) = a + b \log_e(n) - cn$, persistency (s) and goodness of fit (R^2)

Source of variation	DF	Mean squares a	b	c	s	R^2
			(i) Holstein			
Herd	1	11,256**	0,210**	0,003*	0,631	10217**
Parity	4	3,524**	0,172**	0,010**	8,255**	6107**
Year	1	0,001	0,044	0,001	0,131	864
Season	1	0,0104	0,554**	0,005**	0,846*	2900**
Herd × Parity	4	0,302**	0,063	0,001	0,828**	796
Herd × Year	1	0,028	0,090	0,004**	1,876**	110
Herd × Season	1	0,200	0,033	0,000	1,265*	1414*
Parity × Year	4	0,039	0,027	0,001	0,160	134
Parity × Season	4	0,040	0,038	0,000	0,225	2002**
Year × Season	1	0,008	0,000	0,000	0,151	449
Error	455	0,066	0,027	0,000	0,214	348
Total	477	0,121	0,031	0,001	0,299	447
			(ii) Jersey			
Herd	1	9,65**	48,10**	3,38**	114,79**	489
Parity	4	1,02*	0,87*	0,07**	0,07**	833*
Year	2	0,96**	2,79**	0,14**	3,39**	1701**
Season	1	1,82*	3,76**	0,16**	0,10	184
Error	209	0,31	0,51	0,02	0,41	253
Total	217	0,37	0,79	0,04	1,12	278
			(iii) Jersey – Herd 2			
Records used (m/w)	1	15,23**	5,36**	0,54**	25,07**	169
Parity	3	0,58	0,74	0,06	0,70	424
Year	2	0,13	0,58	0,01	0,11	1464
Season	1	1,21	5,68**	0,30**	2,67	1083
Error	124	0,38	0,78	0,03	0,39	264
Total	131	0,51	0,92	0,04	0,69	288

* $P < 0,05$; ** $P < 0,01$

respectively. Considering the R^2 values, it would appear that the lactation curve functions estimated from monthly total yields significantly ($P < 0,01$) overestimate the 44-week yields. One would therefore recommend the use of the weekly totals for lactation studies.

In the Holstein analysis: the herd × parity interactions were highly significant ($P < 0,01$) for a and s parameters; the herd × year interactions were highly significant ($P <$ 0.01) for c and s; herd × season interactions were significant ($P < 0,05$) for s and R^2; and parity × season interactions were highly significant ($P < 0,01$) for R^2. These interactions could significantly affect the course of lactation, i.e. could change values of the lactation parameters ; a, b, c, s, and R^2.

Important features of the lactation curve are the weeks of maximum yield, peak yield, and persistency. The week of maximum yield is given by:

$$n_{max} = b / c$$

(Wood, 1980).

The calculated n_{max} for herd, season, and parity are given in Table 4. Pooled across herd seasons, predicted maximum yield was later in the first lactation than in later lactations for both breeds; the averages were in the 9th and 7th weeks, respectively. This can also be attributed to differences in the rates of depletion of body reserves between mature cows

Table 4 The week of maximum yield (n_{max})

Herd–Season	Parity 1	2	3	4	>5
			Holstein		
1 – 1	11	5	6	7	7
1 – 2	9	6	6	7	6
2 – 1	7	6	8	7	7
2 – 2	10	7	7	7	7
			Jersey		
1 – 1	8	4	5	6	5
1 – 2	9	7	6	8	7
2 – 1	7	4	4	4	–
2 – 2	4	4	4	4	4

and heifers. Higher rates of depletion at early stages of lactation in the mature cows would lead to early peak (Wood, 1968).

Wood (1967) argues that for lactations starting at the same level, total yield is a function of $c^{-(b+1)}$ and consequently defines $-(b + 1) \log_{e(c)}$ as a measure of persistency. This is a dimensionless quantity that can only be used for comparisons of lactations. Based on Wood's definition, persistency was comparatively high for heifers in both breeds, on average 4,7, but declined at the second and following lactations to 4,1 on average, which agrees with the findings of Ababuker & Buvanendran (1981). The lactation curve estimates of the parameters b and c in this study are close to those found by Wood (1980) using British data. The parameters are similar enough to encourage confidence in using Wood's equation to fit lactation curves in the Holstein and Jersey herds in Zimbabwe for the purpose of planning. However, it is clear from the results in this study that lactation data should be corrected for herd, parity, season, and year (for different feeding programmes). The use of Wood's equation as a planning tool will therefore depend on the repeatability of the various factors which have been discussed above. The latter should consequently be used with due caution or evaluated in the context in which they are to be employed.

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