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Lactation curves for milk traits, live weight and body condition score for heavy and light Holstein-Friesian cows

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ABSTRACT

Two genetic lines of Holstein-Friesian cows divergently selected for heavy and light live weight but with similar genetic merit for farm profitability have been developed at Massey University since 1989. The objective of this experimental project was to evaluate differences in production, fertility and feed efficiency between the two lines when they are managed on grazed pasture and submitted to a seasonal system of reproduction. This paper describes the shapes of the lactation curves for yields of milk, fat and protein, live weight and body condition score of the two lines using the gamma function. Parameters of the gamma function for each of the traits were estimated for each of 84 cows using daily yields of milk, fat and protein and weekly measurements of live weight and body condition scores recorded during the production season 1998-99. Live weights and body condition scores of mature heavy and light cows at calving were 495 and 436 kg and 4.7 and 4.8 units, respectively. Respective values for first-calving cows were 397 and 352 kg live weight and 4.9 and 4.9 units of body condition score. Peak yields of milk, fat and protein for mature heavy (27.6 litres, 1.30 kg and 0.90 kg) were higher than for mature light (25.6 litres, 1.21 kg and 0.86 kg) cows but differences were not significant. Peaks of yield occurred between 27 and 31 days after calving with no significant differences between lines of cows. There were no significant differences between lines for changes in body condition score and persistency of milk, fat and protein production during lactation of mature cows. Compared to mature cows, first-calving cows had lower peak yields of milk, fat and protein. First-calving light cows were the most persistent and maintained the highest body condition score during lactation. Total predicted yields of milk, fat and protein for mature heavy (4,048 litres, 194 kg and 133 kg) were not significantly different from those for mature light (3,774 litres, 182 kg and 127 kg) cows. These results show that there are no significant differences in the shape of the lactation curve for heavy or light mature cows, but first-calving light cows maintained higher body condition score in late lactation.

Keywords: lactation curve; persistency; live weight; genetic line.

INTRODUCTION

Milk production in New Zealand is almost entirely derived from feeding high-quality fresh pasture throughout the year. The seasonal pattern of milk production is dictated by the pattern of pasture growth. Management practices are directed to synchronize the feed requirements of the herd with the rates of pasture growth. Cows are calved during spring, the period of rapid pasture growth, and dried off before winter, the period of slow pasture growth.

Feed requirements of the cow are related to her size and milk yield. The curve of milk and fat production of spring-calved cows in New Zealand follows the typical shape of the gamma function described by Wood (1967), (Henderson & Pringle, 1982). Production rises rapidly to a peak and then falls almost linearly until the cow is dried off.

Liveweight changes of British dairy cattle from several breeds were also described by the gamma function (Wood *et al.*, 1980). The liveweight curve for high-yielding cows is generally the inverse to the lactation curve; a rapid loss of live weight occurs after calving and then there is a slow daily gain of live weight until the start of the following calving.

Cattle in New Zealand are selected on the basis of an economic index known as Breeding Worth (BW), which is a measure of relative net farm profit per 4.5 tonne of pasture dry matter. The BW of an animal is calculated as the sum of the products of estimated breeding values and relative economic values for lactation yields of milk, fat and protein, cow mature live weight and longevity. Live weight has a negative relative economic value (Livestock Improvement, 2000) because the current costs of feed for maintenance

requirements are relatively higher than the returns from beef.

An experimental project was initiated in 1989 at Massey University, New Zealand to generate two lines of high genetic merit Holstein-Friesian cows that differ in mature live weight but with similar BW (García-Muñoz *et al.*, 1998). The objective of the experiment was to evaluate differences in production, fertility, grazing behaviour and feed efficiency between the two lines to document and justify the assumptions underlying the inclusion of live weight in the selection objective of New Zealand dairy cattle. García-Muñoz *et al.* (1998) and Laborde *et al.* (1998) reported results on the productivity and reproductive performance of the two lines.

The objective of this study was to compare the shape of lactation curves for milk, fat and protein yields, live weight and body condition score of two lines of cows. This information is required in order to optimise the recording of data for milk yield and live weight of cows in different line. It may also reveal interactions between genetic line and stage of lactation, which are important for practical management of the lines.

METHODS

Details of the mating strategy followed to develop the heavy and light cow lines are given by García-Muñoz *et al.* (1998). The data consisted of daily yields of milk, fat and protein and weekly measurements of body condition scores from 40 and 44 heavy and light cows recorded during the production season 1998-99. In total, there were nine first-parity cows from each line, 31 mature heavy cows and 36 mature light cows. Cows were stocked at 2.7 cows/ha, grazing predominantly rye grass-white clover for most of

the year using rotational grazing. The average annual pasture production was 12 tonne of dry matter per hectare and some silage was fed.

Individual cow milk yields were recorded using an automatic milk recording system (Westfalia Separator). Percentages of fat and protein were measured for individual cows on 6 to 8 occasions during lactation by monthly herd testing. Daily yields of fat and protein were calculated from the daily yields of milk and monthly fat and protein percentages for each cow. Individual live weights were recorded each week up to the end of the lactation period.

The shapes of the lactation curves for milk, fat and protein for each cow were analysed using a gamma function represented as:

$$y_t = at^b e^{-ct} + \epsilon$$

where y_t = yield on day t ($t=1, 2, \dots$, last day that the cow was milked), a = a scaling factor to represent the yield at the beginning of the lactation, b and c are factors associated with the inclining and declining slopes of the curve, e is the base of the natural logarithms and ϵ is a residual error. Typical lactation curves for milk, fat and protein yields have positive b and c , and curves with negative b or c are considered to be atypical lactations. The persistency of lactation for milk, fat and protein is defined by $s = -(b+1)\ln(c)$ (Wood, 1970). Higher values of s represent higher values of persistency. The day at peak production was defined as $t_{\max} = b/c$, with production at that day $y_{\max} = a(b/c)^b e^{-b}$. Total yields (y_{total}) of milk, fat and protein

were calculated as the integral of the curve from day 1 to the last day (t_{total}) that the cow was milked.

The gamma function was also used to describe the changes of live weights and condition scores during the lactation as suggested by Wood *et al.* (1980). Estimates of the parameters a , b and c describing lactation curves for yields of milk, fat and protein, live weight and body condition score for each cow were calculated using a non-linear regression approach (PROC NLIN) of SAS (2000). Goodness of fit was measured by the coefficient of determination.

Various aspects of the lactation curve for yields of milk, fat and protein (a , b , c , s , y_{\max} , t_{\max} , y_{total} , and t_{total}) and for live weight and body condition score (a , b and c) were analysed using least-squares analysis of variance (PROC GLM) of SAS (2000). The linear model included the effects of line (heavy and light), parity (first and later), interaction between line and parity, month of calving (August and September) and proportion of USA Holstein genes present in the cow (as a covariate).

RESULTS

Estimates of parameters of the lactation curve for milk, fat and protein are shown in Table 1. Figure 1 shows the shapes of the lactation curves for milk yields of different line-parity groups. In general, the coefficients of determination were higher than 0.93 for all milk traits.

Line had no significant effect on any of parameters of

TABLE 1: Number of cows and means¹ of estimates of parameters of the lactation curve for milk, fat and protein for heavy and light cows.

Line-Parity ³	n	Lactation curve traits ²								
		a	b	c	y_{\max}	t_{\max}	s	t_{total}	y_{total}	R ²
Milk										
Heavy-1	9	12.8 ^{ab}	0.178 ^a	0.0062 ^b	19.4 ^b	28.5 ^a	6.03 ^{ab}	164 ^b	2,623 ^b	0.95
Heavy-2+	31	15.1 ^{ab}	0.260 ^a	0.0083 ^a	27.6 ^a	30.9 ^a	6.04 ^{ab}	204 ^a	4,048 ^a	0.99
Light-1	9	12.3 ^b	0.226 ^a	0.0066 ^{ab}	19.3 ^b	28.5 ^a	6.29 ^a	165 ^b	2,652 ^b	0.93
Light-2+	35	16.3 ^a	0.199 ^a	0.0073 ^{ab}	25.6 ^a	26.6 ^a	5.91 ^b	201 ^a	3,774 ^a	0.99
Difference										
H-L		-0.9 ^{ns}	0.037 ^{ns}	0.0006 ^{ns}	1.5 ^{ns}	3.1 ^{ns}	0.05 ^{ns}	1.0 ^{ns}	188 ^{ns}	
(2+)-1		3.2 ^{**}	0.026 ^{ns}	0.0015 ^{ns}	7.3 ^{**}	-0.5 ^{ns}	-0.19 [*]	39 ^{**}	1,267 ^{**}	
Fat										
Heavy-1	9	0.63 ^{ab}	0.201 ^a	0.0071 ^a	0.97 ^b	26.9 ^a	5.97 ^a	164 ^b	125.8 ^b	0.97
Heavy-2+	31	0.74 ^a	0.244 ^a	0.0078 ^a	1.30 ^a	30.8 ^a	6.05 ^a	204 ^a	193.6 ^a	0.97
Light-1	9	0.54 ^b	0.256 ^a	0.0075 ^a	0.91 ^b	30.4 ^a	6.27 ^a	165 ^b	122.6 ^b	0.97
Light-2+	35	0.77 ^a	0.197 ^a	0.0070 ^a	1.21 ^a	27.7 ^a	5.97 ^a	201 ^a	181.9 ^a	0.97
Difference										
H-L		-0.01 ^{ns}	0.025 ^{ns}	0.0006 ^{ns}	0.08 [*]	1.6 ^{ns}	-0.01 ^{ns}	1.0 ^{ns}	7.6 ^{ns}	
(2+)-1		0.17 ^{**}	0.008 ^{ns}	0.0001 ^{ns}	0.31 ^{**}	0.6 ^{ns}	-0.10 ^{ns}	39 ^{**}	63.2 ^{**}	
Protein										
Heavy-1	9	0.44 ^b	0.174 ^a	0.0063 ^a	0.65 ^b	27.0 ^a	5.97 ^b	164 ^b	87.3 ^b	0.98
Heavy-2+	31	0.52 ^{ab}	0.246 ^a	0.0079 ^a	0.90 ^a	30.5 ^a	6.04 ^{ab}	204 ^a	132.8 ^a	0.97
Light-1	9	0.39 ^b	0.235 ^a	0.0068 ^a	0.63 ^b	31.2 ^a	6.31 ^a	165 ^b	87.5 ^b	0.97
Light-2+	35	0.59 ^a	0.174 ^a	0.0069 ^a	0.86 ^a	24.3 ^a	5.87 ^b	201 ^a	127.0 ^a	0.97
Difference										
H-L		-0.05 ^{ns}	0.044 ^{ns}	0.0007 ^{ns}	0.03 ^{ns}	4.0 [*]	0.06 ^{ns}	1.0 ^{ns}	3.8 ^{ns}	
(2+)-1		0.14 ^{**}	0.004 ^{ns}	0.0001 ^{ns}	0.23 ^{**}	-1.8 ^{ns}	-0.19 [*]	39 ^{**}	42.4 ^{**}	

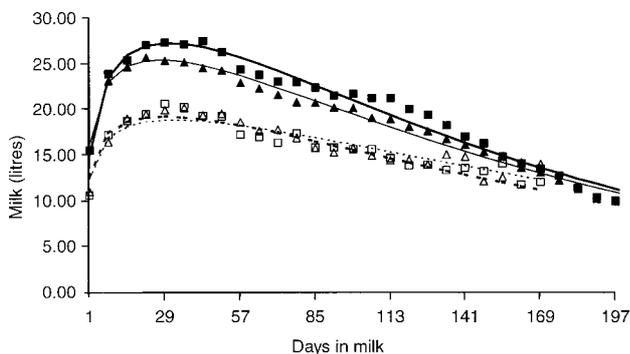
¹ Means with different superscripts within variable and line-parity group differ significantly ($P < 0.05$).

² Modeled as $y_t = at^b e^{-ct}$ where y_t = yield on day t , a = scaling factor to represent the yield at the beginning of the lactation, b and c are factors associated with the inclining and declining slopes of the curve, y_{\max} = peak yield calculated as $a(b/c)^b e^{-b}$, t_{\max} = days in milk at peak yield calculated as b/c , s = a measure of persistency calculated as $-(b+1)\ln(c)$, t_{total} = total days in milk, y_{total} = total yield of milk, fat or protein calculated as the integral under the curve from 1 to the last day in that cow was milked.

³ H = heavy line, L = light line, 1 = First parity, and 2+ = Second and later parities.

^{ns} no significant effect.

FIGURE 1: Lactation curves for milk yield of first-calving and mature cows from two lines selected for live weight; actual yields from mature heavy cows (■), first-calving heavy cows (□), mature light cows (▲), first-calving light cows (△), and predicted yields for mature heavy cows (—), first-calving heavy cows (---), mature light cows (—), and first-calving light cows (---).



the lactation curve for milk, fat and protein, except for peak yield of protein ($P < 0.05$). Heavy cows produced 188 litres milk, 7.6 kg fat and 3.8 kg protein and had 1 day in milk more than the light cows but the differences were not statistically significant. Total predicted yields of milk, fat and protein for mature heavy (4,048 litres, 194 kg and 133 kg) did not differ significantly from those for mature light (3,774 litres, 182 kg and 127 kg) cows.

Peak yields of milk, fat and protein for mature heavy (27.6 litres, 1.30 kg and 0.90 kg) were higher than for mature light (25.6 litres, 1.21 kg and 0.86 kg) cows but differences were not significant ($P > 0.05$). Peaks of yield occurred between 27 and 31 days after calving with no significant differences between lines of cows.

Parity number had a significant effect on several parameters of the lactation curve. In general, mature cows had higher values for a , y_{max} , t_{total} and y_{total} than first-parity cows for milk, fat and protein yields. However, mature cows had lower persistency for milk and protein yields ($P < 0.05$).

Month of calving affected significantly the shape of the lactation curve. Compared to cows calving during September, cows calving during August had significantly ($P < 0.05$) higher total yields of milk (3,753 vs 3,310 litres), fat (178.3 vs 159.5 kg) and protein (124.8 vs 109.5 kg) and more days in milk (203 vs 173). The summer in 1999 was very dry and cows in both lines were dried off relatively early because of slow pasture growth, with the cows in first parity dried off before the mature cow. Cows calving during September had higher ($P < 0.05$) yields at peak for fat (1.24 vs 1.15 kg) and protein (0.85 vs 0.81 kg), peaked earlier (21 vs 31 days) and were less persistent than cows calving during August.

Estimates of parameters for the lactation curve for live weight and body condition score are shown in Table 2. The value of a shows that heavy cows were 54 kg heavier than light cows at the start of the lactation ($P < 0.01$) but the curves followed the same shape during the lactation (Figure 2a). Effects of line and parity were significant on the values for a and b of the lactation curve for live weight and body condition score. These values for a and b were very small indicating that live weight did not decline dramatically after calving as reported in other studies (e.g. Wood *et al.*, 1980; Korver *et al.*, 1985).

TABLE 2: Number of cows and means¹ of estimates of parameters of the lactation curve for live weight and body condition score for heavy and light cows.

Line-Parity ³	n	Parameter of the curve ²			R ²
		a	b (x10 ³)	c (x10 ⁴)	
Live weight					
Heavy-1	9	396.7 ^{bc}	-6.432 ^a	-4.957 ^a	0.67
Heavy-2+	28	495.1 ^a	-5.711 ^a	-5.600 ^a	0.56
Light-1	9	351.7 ^c	5.237 ^a	-4.035 ^a	0.62
Light-2+	28	436.1 ^b	-0.901 ^a	-3.553 ^a	0.53
Difference					
H-L		54.0 ^{**}	-6.4043 ^{ns}	-1.775 ^{ns}	
(2+)-1		90.3 ^{**}	-2.406 ^{ns}	-0.057 ^{ns}	
Condition score					
Heavy-1	9	4.87 ^a	-21.216 ^a	3.829 ^a	0.59
Heavy-2+	25	4.65 ^a	-25.035 ^a	-0.936 ^b	0.35
Light-1	7	4.91 ^a	-27.523 ^a	-1.896 ^b	0.58
Light-2+	26	4.75 ^a	-24.982 ^a	0.612 ^{ab}	0.40
Difference					
H-L		0.06 ^{ns}	1.497 ^{ns}	0.245 ^{ns}	
(2+)-1		-0.20 [*]	-1.033 ^{ns}	-1.471 ^{ns}	

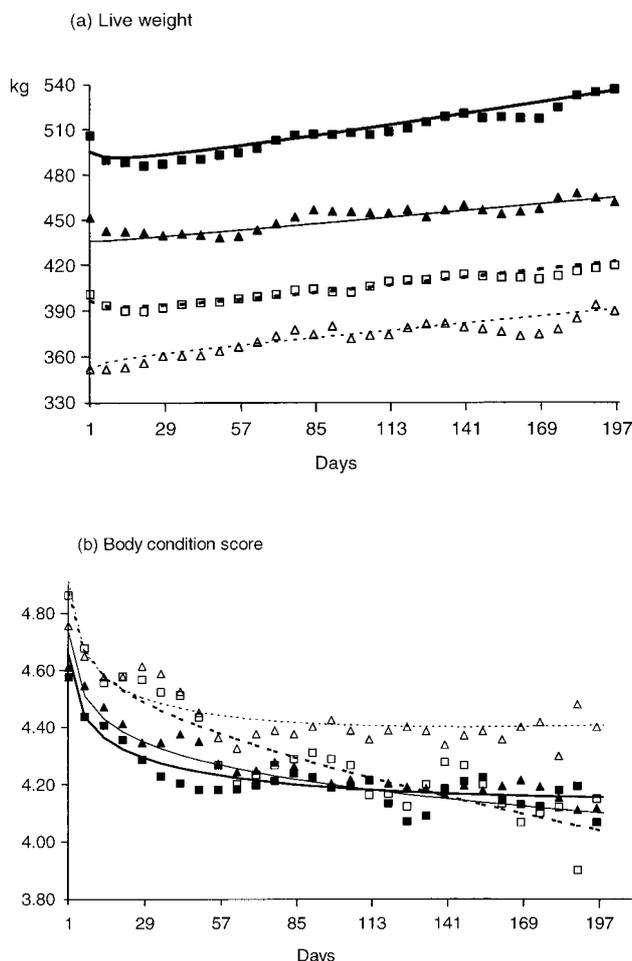
¹ Means with different superscripts within variable and line-parity group differ significantly ($P < 0.05$).

² Modeled as $y_t = a + b e^{-ct}$ where y_t = live weight or body condition score on day t , a = scaling factor representing the live weight or body condition score at the beginning of the lactation, b and c are factors associated with the inclining and declining slopes of the curve.

³ H = heavy line, L = light line, 1 = First parity, and 2+ = Second and later parities.

^{ns} no significant effect.

FIGURE 2: Live weights and body condition scores during lactation of first-calving and mature cows from two lines selected for live weight; actual scores and live weights from heavy cows (■), first-calving heavy cows (□), mature light cows (▲), first-calving light cows (△), and predicted scores and live weights for mature heavy cows (—), first-calving heavy cows (---), mature light cows (—), and first-calving light cows (---).



Live weights and body condition scores of mature heavy and light cows at calving were 495 and 436 kg and 4.7 and 4.8 units, respectively. Respective values for first-calving cows were 397 and 352 kg live weight and 4.9 and 4.9 units of body condition score. Figure 2b shows the curves of changes in body condition score during the lactation for the different breed-parity groups. There were some significant effects ($P < 0.05$) of the interaction line \times parity on the parameter c . First-parity heavy cows lost more body condition during the lactation than first-parity light cows.

There were no significant differences between lines for changes in body condition score and persistency of milk, fat and protein production during lactation of mature cows. The coefficients of determination of the gamma function fitting weekly measurements of live weight and body condition score ranged between 0.35 and 0.67.

The percentage of USA Holstein genes had no significant effects on the parameters of the lactation curve for all traits studied.

DISCUSSION

Heavy cows produced slightly more milk and milk solids than light cows but the differences were not statistically significant. These results are similar to those reported by García-Muñiz *et al.* (1998) for the years 1992 through 1997, except that in the earlier study the differences were larger (385 litres milk and 16 kg milk solids) and significant. If the estimate of parameter a of the lactational curve for live weight is considered to represent the live weight at calving, heavy cows were 54 kg heavier than light cows (Table 2) ($P < 0.01$).

Researchers in other countries (Tekerli *et al.*, 2000; Collins-Lusweti, 1991) have reported that mature cows had lower persistency for milk production than first-calving cows, possibly because the mature cows use their body reserves much faster in the early stages of lactation in association with higher peaks of milk yield than the first-calving cows. Dechow *et al.* (1992) found that mature cows lost more body condition after calving than first-calving cows, which was also observed in the present study for the light cows. Mature cows from the light line tended to have lower persistency for milk and protein production than mature heavy cows ($P < 0.05$) and tended to lose more body condition (Figure 2b). First-calving light cows tended to maintain higher condition score than the other line-parity groups, whereas first-parity heavy cows lost significantly more body condition score.

The shape of the lactation curve was affected by the month of calving in this study, in agreement with the experimental evidence provided by (Wood, 1972) and reviewed by Garcia & Holmes (1999). The effect of calving month is directly related to the availability of pasture to supply the increased requirements at the start of the lactation. For pasture-based dairy systems in which cows calve in spring, earlier calving cows generally show lower peak yields, higher persistency and more days in milk than later calving cows, because the later cows are generally fed more generously at the beginning of the lactation than the earlier calving cows.

Average percentages of USA Holstein genes present in the heavy and light cows in this sample were 40 and 16%,

respectively. This fact limits any conclusion from this study regarding the effects of USA Holstein genes on the parameters of the lactation curve for the different traits investigated because cows having 100% of USA Holstein genes were not present in the study.

The values of coefficients of determination obtained in fitting the data of the traits studied indicate that the gamma function is adequate to model the lactation curve for milk, fat and protein yields ($R^2 > 0.93$) but not for live weight and body condition score ($0.35 > R^2 > 0.67$).

CONCLUSIONS

These results show that shape of the lactation curve of grazing cows is affected by several factors. Selection for high or low live weight has not altered significantly the shape of the lactation curve for mature cows but some differences are apparent for first-calving light cows, mainly in persistency of protein production and changes in body condition score during lactation.

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