Genetic and Economic Evaluation of Persistency in Dairy Cattle

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Abstract

Test day models with random genetic regressions on functions of days in milk were used to estimate genetic parameters for shape of the lactation curve and to develop genetic evaluations for persistency of lactation. A measure that quantifies differential yield between day 60 and 280 of lactation was less correlated to 305-day yield than other measures of persistency and is recommended for genetic evaluation. The impact of persistency on feed costs and milk returns was evaluated and found to be highly dependent on lactation length and calving interval. The economic value of persistency was derived under an optimized insemination and culling strategy, which resulted in an average calving interval of 12.4 months, and was approximately 5% relative to the economic value of production. The economic value of persistency was almost tripled when reproductive performance was lowered to a level which resulted in an average calving interval of 13 months. Consideration of health and reproductive costs will increase the economic value of persistency.

Introduction

Shape of the lactation curve of dairy cows is determined by genetic and environmental factors. A lactation curve parameter that is of particular interest is persistency (Wood, 1967), which can be described as the ability of the cow to maintain production following peak yield. Differences in persistency reduce accuracy of genetic evaluations, especially when incomplete records are used (Van Arendonk *et al.* 1995). However, persistency is also of direct economic importance (Sölkner and Fuchs, 1987). This paper presents results from research into genetic and economic aspects of persistency that is underway at the University of Guelph.

Genetic Aspects

Schaeffer and Dekkers (1994) proposed the use of random regression test day models for genetic analysis of production traits, which allow for genetic variation in shape of the lactation curve in analysis of test day yields. The random regression model used in the present study for analysis of test day records in first lactation was (Jamrozik and Schaeffer, 1995; Jamrozik *et al.*, 1995):

$$\begin{aligned} y_{ijkl} = {} & HTD_i + \beta_{0k} + \beta_{1k}X_{1jl} + \beta_{2k}X_{2jl} + \beta_{3k}X_{3jl} + \beta_{4k}X_{4jl} \\ & + \gamma_{0j} + \gamma_{1j}X_{1jl} + \gamma_{2j}X_{2jl} + \gamma_{3j}X_{3jl} + \gamma_{4j}X_{4jl} + p_j + e_{ijkl} \end{aligned}$$

where y_{ijkl} is daily yield on test day l for cow j in herd-test-day group i and calving in region-age-season subclass k, HTD_i is the fixed effect of herd-test-day group i, X_{mk} are functions of days in milk (DIM) (X_{1k}=DIM/305, X_{2k}=(DIM/305)^2, X_{3k}=ln(305/DIM), and X_{4k}=ln(305/DIM)^2), β_{mk} are fixed regression coefficients within region-age-season subclass k, γ_{0j} is a random genetic intercept for cow j, γ_{mj} (m=1,2,3,4) are random genetic regression coefficients specific to cow j, p_j is a random environment effect common to all test-days of cow j, and e_{ijkl} is a random environment effect specific to y_{ijkl}.

In matrix form: $Y = X_{HTD}b_{HTD} + X\beta + W\gamma + Zp + e$, with: $\mathrm{Var}\begin{bmatrix}\gamma\\p\\e\end{bmatrix} = \begin{bmatrix}G\otimes A & 0 & 0\\0 & I\sigma_p^2 & 0\\0 & 0 & R\sigma_e^2\end{bmatrix}$,

where γ is a vector of 5 genetic effects per animal (γ_{0j}, γ_{1j}, γ_{2j}, γ_{3j}, and γ_{4j}), G is a matrix of genetic (co-)variances among genetic effects, A is the numerator relationship matrix, R is a diagonal matrix with elements determined by DIM to account for differences in residual variance by stage of lactation (29 classes), and σ_p^2 and σ_e^2 are the variance of permanent environment and residual effects.

(Co-)variance components for the above model were obtained by Gibbs sampling from 50,41[illegible] lactation test day records on 6,516 Holstein cows (Jamrozik and Schaeffer, 1995). Parameter estim[illegible] were used to derive estimates of genetic parameters for several part lactation yields (Y_i, for i=1,2[illegible] yield during the i^{th} 100 days of lactation, and Y_T is 305-day lactation yield) are in Table 1.

A total of 1,778,211 first lactation test day records on 228,330 Holstein cows were used for ge[illegible] evaluation based on the above model (Jamrozik *et al.* 1995). Sire solutions for lactation curve parame[illegible] were used to derive estimated breeding values for 305-day and part lactation yields and for th[illegible] persistency measures ($P_{31}=Y_3/Y_1$, $P_{3T}=Y_3/Y_T$, and $P_D=110\{(\mu_{60}-\mu_{280})-(y_{60}-y_{280})\}$, where μ_i and y_i [illegible] population average and individual yield at i DIM). P_D defines the area of a triangle that represe[illegible] differential yield between day 60 and day 280 of lactation due to persistency, compared to a lactat[illegible] curve with an average shape. Standard deviations and correlations between estimated breeding values [illegible] sires are in Table 1. P_D was less correlated to 305-day yield than other persistency measures (Table 1[illegible]

Economic Aspects

Current breeding goals and genetic evaluation systems are based on standardized 305-day lactatio[illegible] production. Random regression test day models can increase accuracy of genetic evaluations for 305-d[illegible] lactation yield but also provide genetic evaluations for persistency. Because of its economic importance[illegible] persistency must be included as a trait in the breeding goal. When 305-day lactation yield is included i[illegible] the breeding goal, the economic value of persistency must be derived as the effect of persistency on profi[illegible] at constant 305-day production. The economic value of persistency then consists of four main components: the effect of persistency on a) health costs; b) reproductive performance; c) feed costs; and d) returns from milk for given 305-day production.

Effects of persistency on health costs and reproductive performance (a and b) result from lower metabolic stress during early lactation for persistent lactations, which have lower peak yields. Direct estimates of their economic impact are not available, but are expected to be moderate (Ten Hag, 1995). Effects of persistency on feed costs (c) result from the fact that yield is spread out more evenly for persistent lactations, which increases the fraction of feed energy that can be provided by roughage compared to more expensive concentrates (Sölkner and Fuchs, 1987). The impact on feed costs depends on production parameters and on the price difference between roughage and concentrate. For a given 305-day yield, persistent cows produce higher yields past 305 days in milk than less persistent cows, but they give less milk per day for short lactations. The economic impact of this (d) depends on lactation length, which in turn depends on reproductive performance and insemination strategy.

The contribution of factors c) and d) to the economic value of persistency was quantified for production circumstances in Canada based on the bio-economic model developed by Van Arendonk (1985) and adapted by Rogers *et al.* (1988) and Dekkers (1991). Basic production and economic parameters are in Table 2. The Wood function (Wood, 1967) was used to describe lactation curves because of availability of parameters: $y_t=at^be^{-ct}$. Lactation curve parameters were obtained from test day data on Canadian Holsteins (Table 3). Effects of previous calving interval on production were accounted for based on Sadek and Freeman (1992). Effects of days open in the current lactation were ignored to avoid confounding with shape of the lactation curve. A 2-month dry period was used.

Rations were formulated to meet energy requirements while maximizing dry matter intake based on a roughage and concentrate component. Energy requirements were based on National Research Council (1980). Maximum average daily dry matter intake was determined by month of lactation based on age-dependent weight (W), average daily milk yield (Y), and fat% (F%) (OMAFRA):

$$DMI = 0.2404 + 0.0107\ W + .04685\ W^{.75} + 0.132\ Y + .0495\ Y\ F\%$$

Two feeding regimes were considered: I) a separate ration was formulated for each cow which maximized roughage intake; II) only 3 rations were available, with energy densities of 1.44, 1.56, and 1.68 Mcal NE_l/kg dry matter, and each cow was fed the ration that allowed it to meet energy requirements within its dry matter intake capacity. Cows consumed no more dry matter than to meet energy needs.

Feed costs and returns from milk production were computed for 15 production classes, which were defined as a percentage of the mean based on a normal distribution of milk production in the herd (Van Arendonk and Dijkhuizen, 1985), and for varying calving intervals (11 to 16 months). Differences in lactation production were modelled by changing parameter a of the Wood function.

The impact of a genetic change in persistency on feed costs and returns from milk production per lactation was evaluated by running the model for five sets of lactation curve parameters. Alternative lactation curves were derived by finding parameters b and c which resulted in a ± 0.5 or ± 1.0 phenotypic standard deviation change in persistency parameter P_{31} from the base, while keeping initial yield (parameter a) and total 305-day yield constant. The phenotypic standard deviation of P_{31} was set equal to .142 and was assumed to be constant across lactations, which is supported by empirical results on Canadian Holsteins and by Sölkner and Fuchs (1987). Parameters for varying levels of persistency and corresponding changes in persistency measures P_{3T} and P_D are in Table 3.

Table 4 shows the impact of persistency on average feed costs and milk returns per lactation for cows with a calving interval of 11, 12, 13, or 14 months. Results shown are a weighted average of costs and returns for each of the 15 production levels and apply to feeding strategy I. For a calving interval of 12 months, benefits from increasing persistency were entirely due to reduced feed costs (constant 305-day yield). Feed costs were little affected by persistency in lactation 1 because of a high base persistency in first lactation. For other calving intervals, persistency affected milk returns to a greater degree than feed costs (Table 4). Persistency had a negative effect on milk returns for short lactations and a positive effect for long lactations (Table 4).

Limiting rations to availability of only 3 rations (feeding strategy II) increased feed costs, but reduced the impact of persistency on feed costs compared to strategy I (results not shown) because of less flexibility in formulating rations. With strategy I, several rations fed to individual cows consisted entirely of roughage. Reducing dry matter intake capacity by 5% reduced, rather than increased, the impact of persistency on feed costs (results not shown). This is explained by the fact that, although reducing dry matter intake increased energy density of the ration throughout the lactation, increasing persistency reduced energy density of the ration in early lactation but had an opposite effect in later lactation.

Results in Table 4 show that the economic benefit of increasing persistency depended highly on lactation length, which is, in turn, determined by reproductive performance and by the insemination and culling strategy. To derive the economic value of persistency under an optimized insemination and culling strategy, results from the bio-economic model were used in the dynamic programming model of Van Arendonk and Dijkhuizen (1985). The economic value was determined as the effect of a change in persistency on annualized profit expected from an average replacement heifer. An interest rate of 5% and a planning horizon of 15 years was used. Results are in Table 5 which, besides results for the base situation, also shows results for a 50% increase or decrease in reproductive performance to illustrate the impact of average calving interval.

Increasing persistency by 0.5 phenotypic standard deviations, which is equal to one genetic standard deviation, assuming a heritability of 0.25, increased annualized profit by C$7.6 (Table 5). In comparison, increasing production by one genetic standard deviation (800 kg ME milk with constant fat and protein

%) increased annualized profit by $140. The effect of persistency on profit was nonlinear and incre[ased] with level of persistency (Table 5). The economic value of persistency was reduced by 12% when [o]nly 3 rations were fed (strategy II).

The relatively low economic value of persistency in the base situation is due to an average calv[ing] interval of less than 12.4 months under the optimized culling and insemination strategy, which is lo[wer] than the average calving interval of around 13 months observed in practise. The economic value [of] persistency was almost tripled when reproductive performance was reduced by 50% (Table 5), wh[ich] resulted in an optimized average calving interval of 13.0 months. With high reproductive performa[nce] (+50%), both an increase and decrease in persistency improved net returns (Table 5). The avera[ge] calving interval was less than 12 months in that situation.

Increasing persistency generally had a small effect on calving intervals, which is illustrated in Tab[le] 5, except for first lactations with high persistency, in which case a delay of the first insemination wa[s] profitable for high producing cows. Persistency also affected average herd life and timing of voluntar[y] culling (Table 5); with higher persistency, voluntary culling was postponed.

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TABLE 1. Estimates of genetic correlations (below diagonal), heritabilities (on diagonal), correlations between estimated breeding values for sires with at least 10 daughters (above diagonal), and standard deviations of true (SD BV) and estimate breeding values (SD EBV) for milk yield and persistency.

	Y_1	Y_2	Y_3	Y_T	P_D	P_{31}	P_{3T}	SD BV
Y_1	*.42*	.87	.68	.89	-.39	.08	.05	250
Y_2	.70	*.42*	.90	.99	-.02	.49	.41	257
Y_3	.16	.67	*.39*	.93	.39	.79	.75	255
Y_T	.75	.96	.74	*.32*	.02	.51	.46	625
P_D	-.74	-.24	.51	-.19	*n/a*	.85	.89	419
SD EBV	163	192	204	524	183	.07	.02	

TABLE 2. Summary of production and economic parameters.

Energy content of roughage/concentrate (Mcal NE/kg dry matter)	1.41 / 1.93
Price of roughage/concentrate (C$/kg dry matter)	.075 / .225
Average mature equivalent 305-day milk production (kg)	8000
Mature equivalent fat/protein content (%)	3.70 / 3.20
Price of milk/fat/protein (C$/kg)	.0549 / 3.00 / 7.49
Price of 24 month replacement heifer (C$)	1300
Average probability of conception after insemination (%)	60
Cost per insemination (C$)	35

TABLE 3. Lactation curve parameters and persistency measures for the base level of persistency (italic) and deviations from base parameter values for alternative levels of persistency.

Parity	Persistency	Curve parameters			305-day yield (kg)	Persistency measure		
		a	b ($x10^3$)	c ($x10^5$)		P_{31}	P_{3T}	P_D
1	Low	0	+40.68	+1.33	0	-.141	-.030	-541
	Medium low	0	+19.47	+.63	0	-.070	-.014	-259
	Base	*14.051*	*144.97*	*2.32*	*6000*	*.824*	*.292*	*0*
	Medium high	0	-18.47	-.59	0	+.071	+.014	+246
	High	0	-35.64	-1.13	0	+.142	+.026	+474
2	Low	0	+54.98	+1.94	0	-.143	-.039	-789
	Medium low	0	+26.11	+.91	0	-.072	-.019	-378
	Base	*19.331*	*159.64*	*4.19*	*6800*	*.586*	*.241*	*0*
	Medium high	0	-23.73	-.80	0	+.071	+.017	+343
	High	0	-45.43	-1.52	0	+.141	+.033	+659
3	Low	0	+60.17	+2.17	0	-.143	-.042	-910
	Medium low	0	+28.16	+1.00	0	-.072	-.020	-430
	Base	*20.217*	*191.70*	*5.00*	*7400*	*.530*	*.226*	*0*
	Medium high	0	-25.55	-.88	0	+.071	+.018	+393
	High	0	-48.68	-1.66	0	+.142	+.035	+752

TABLE 4. Feed costs (C$) and milk returns (C$) per lactation for the base level of persistency (italic) deviations from base values for alternative levels of persistency for different calving intervals.

Parity	Persistency level	11 Feed	11 Milk	12 Feed	12 Milk	13 Feed	13 Milk	14 Feed	14 Milk
		Calving interval (months)							
1	Low	+10	+31	+1	0	-5	-36	-9	[illegible]
	Medium low	+4	+15	+0	0	-4	-18	-6	[illegible]
	Base	*505*	*2241*	*550*	*2461*	*591*	*2670*	*628*	[illegible]
	Medium high	-3	-15	+1	0	+6	+18	+11	[illegible]
	High	-5	-29	+2	0	+11	+35	+21	[illegible]
2	Low	+25	+42	+20	0	+16	-45	+12	[illegible]
	Medium low	+11	+21	+10	0	+8	-22	+5	-46
	Base	*515*	*2609*	*550*	*2802*	*584*	*2975*	*616*	[illegible]
	Medium high	-9	-19	-7	0	-5	+22	-3	+45
	High	-16	-38	-12	0	-8	+43	-4	+90
3	Low	+33	+47	+27	0	+23	-49	+18	-98
	Medium Low	+15	+23	+13	0	+11	-24	+8	-49
	Base	*503*	*2841*	*537*	*3032*	*569*	*3200*	*599*	*3347*
	Medium high	-13	-22	-11	0	-9	+24	-7	+49
	High	-22	-43	-19	0	-14	+47	-10	+97

TABLE 5. Average profit per replacement heifer and management parameters for the base level of persistency (italic) and deviations from base values for alternative levels of persistency.

	Reproductive performance	Low	Med. low	*Base*	Med. high	High
		Level of persistency				
Profit per year (annuity)	-50%	-22.4	-13.4	*1347.2*	+19.1	+46.4
	Base	-7.9	-5.0	*1490.2*	+7.6	+19.8
	+50%	+7.0	+2.5	*1542.4*	+1.2	+10.6
Calving interval lact. 1 (mo.)	-50%	-.05	-.05	*13.03*	+.00	+.03
	Base	-.07	-.03	*12.38*	+.04	+.33
	+50%	-.15	-.12	*11.98*	+.54	+1.48
Calving interval lact. 2 (mo.)	-50%	-.06	-.02	*13.02*	+.01	+.02
	Base	-.05	-.02	*12.36*	+.01	+.02
	+50%	-.02	-.01	*11.84*	+.06	+.39
Days in milk at voluntary culling	-50%	-45	-24	*309*	+21	+43
	Base	-32	-14	*249*	+17	+40
	+50%	-24	-17	*225*	+20	+24
Herd life (yr)	-50%	-.18	-.10	*2.56*	+.08	+.08
	Base	-.27	-.15	*3.66*	+.10	+.16
	+50%	-.26	-.10	*3.87*	+.10	+.18