Modelling extended lactation curves for milk production traits in Italian Holsteins

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ABSTRACT - Test day records of milk production traits (milk yield, fat and protein percentage, and somatic cell score) of 45,132 Italian Holstein cows were analyzed with seven mathematical models in order to assess the main features of lactations of different length. Lactations curves were grouped according to parity (1, 2, and 3) and lactation length (1<350d; 2=from 351 to 450d; 3=from 451 to 650d; 4=651 to 1000d). Models with a larger number of parameters showed better fitting performances for all classes of length for milk yield, whereas poor fitting was observed for fat and protein percentages and SCS in the 651-1000d class. In lactation with length>650d, peak yield was about 31, 37, and 39 kg for first, second, and third parity respectively; peak was predicted at around 60 and 40 days for younger and older animals respectively. The asymptotic level of production was below 10 kg.

Key words: Dairy cattle, Extended lactations, Mathematical models.

Introduction - In several countries, the average lactation length of dairy cattle has increased markedly in recent years, essentially due to reproductive failures but also to management strategies. The search for suitable mathematical models for extended lactations is of great importance both for genetic evaluations via random regression models, and for management decisions, especially for assessing an economically convenient asymptotic level of production. Some authors argue that models conceived for lactations of standard length may not be suitable for extended lactations and that specific functions should be developed. Such a consideration is surely correct for models characterised by a poor flexibility and a small number of parameters but may be questionable with flexible models. Aim of this work is to study main features of lactations of different length and compare classical and specifically conceived functions for modelling extended lactations.

Material and methods - Data used were 726,739 test day records of milk yield belonging to 68,899 lactations of 45,132 Italian Holstein cows. The analysed data were recorded in the period from 2002 to 2006 by the Italian Breeders Association in Northern Italy. Lactations were grouped according to parity (first, second, and third) and to lactation length (1<350d; 2=from 351 to 450d; 3=from 451 to 650d; 4=651 to 1000d). Lactation records were discarded if the first test date occurred after 70 d from parturition or if the last test date occurred after 1000 d of lactation. The analysis was carried out in two steps: at first, individual lactation curves were modelled with six common lactation curve functions: Wood (WD), Wilmink (WIL), Ali and Schaeffer (AS) multiple regression, fourth-order Legendre polynomials (LEG), quadratic (QSLP), and cubic splines (CSPL) with three knots. Then a comparison between AS and a modified version of the Dijkstra function (DJ)

$$y = b_0 + b_1 \exp\left[\frac{b_2\left(1-\exp\left(b_3 - t\right)\right)}{b_3} - b_4 t\right]$$

recently proposed to model extended lactations (Van Raden *et al.*, 2006), was performed on average lactation curves for milk yield (MY), fat (FP) and protein (PP) percentage, and somatic cell score (SCS) for each parity within length class. Goodness of fit was assessed by using the adjusted R-squared (ADJRSQ), and the Durbin-Watson statistic (DW). Time at which peak yield occurs (Tp), peak production

(Yp), cumulative 305d (P_{305}) or at dry off (P_{tot}) production, time at inflection point (T_f) were calculated for each of the different models.

Results and conclusions – Table 1 shows the comparison of adjusted R-squared obtained by the different models for individual milk yield lactation curves. As expected, functions with a larger number of parameters show better fitting performances, with about 75% of curves showing an ADJRSQ higher than 0.70 for AS, LEG, QSLP and CSPL (Table 1).

AS and DJ models gave similar performances when modelling average lactation curves with R^2 ranging between 0.99 and 0.71 for MY. The two functions were able to adequately fit milk composition in lactations shorter than 650 days (about 0.88, 0.97, and 0.87 for FP, PP, and SCS, respectively, for both models), whereas they gave poor results in the highest length class (>650d) with R^2 from 0.38 to 0.14 for FP and SCS, better for PP, around 0.66. Considering that residuals substantially did not show autocorrelation (DW ~ 2.00), these figures may be ascribed to the large variability of data in the longest lactations. As an example Figures 1 a, b, c, and d show the predicted values for MY, FP, PP, and SCS estimated by AS for 651-1000d class. As expected, milk yield lactation curves of first parity cows had a lower peak yield and higher persistency, especially after 300 days, compared to higher parities (Figure 1 a). This result is in agreement with previous report for US (Dematawewa *et al.*, 2007) and Australian (Haile-Mariam *et al.*, 2008) Holstein. Milk components showed an opposite trend with respect to MY (Figures 1 b, c, and d). In particular, FP and PP did not show substantial variation among parities, whereas differences have been detected for SCS, with a higher level for the older cows. Moreover, FP and PP tended to reach a plateau around 500-600 days in milking (DIM), whereas SCS shows a continuously increasing trend.

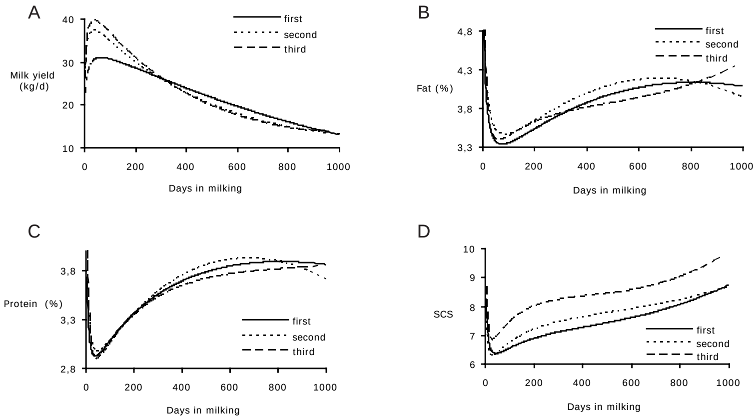
Table 1. Distribution of individual lactation curve fits in different classes of adjusted r-squared.

		Length class							
		<350		351-450		451-650		651-1000	
		ADJRSQ Class							
Models*		0.7-0.9	>0.9	0.7-0.9	>0.9	0.7-0.9	>0.9	0.7-0.9	>0.9
AS	$Y_t = a_0 + a_1x + a_2x^2 + a_3 \log(1/x) + a_4 (\log(1/x))^2$	35.2	38.2	39.2	39.5	43.2	37.2	47.9	27.8
LEG	$Y_t = a_0{*} P_0 + a_1{*} P_1 + a_2{*} P_2 + a_3{*} P_3 + a_4{*} P_4$	32.1	42.6	37.0	42.4	42.1	39.9	49.5	30.3
QSLP	$Y_t = a + b_1t + b_2t^2 + c(t-N_j)^2$	35.4	37.5	39.7	38.7	43.6	36.0	47.6	30.0
CSLP	$Y_t = a + b_1t + b_2t^2 + b_3t^3 + c(t-N_j)^3$	35.5	37.7	37.6	41.7	42.0	40.6	47.1	33.2
WD	$Y_t = at^be^{-ct}$	36.1	10.7	39.6	11.8	43.1	11.8	43.9	11.3
WIL	$Y_t = a + be^{-kt} + ct$	39.3	22.8	41.9	24.6	45.5	22.5	49.3	14.1

**Y=test day data (milk yield, fat percentage, protein percentage or scs); a_i, b_i, c_i and k=function parameters; P_i=function of the time; N_j=knot point; t=time from parturition in days; x=t/lactation length.*

Table 2 reports main features for milk yield lactation curves calculated with AS and DJ parameters. No differences among length classes were observed for peak occurrence and peak yield. In general, P_{305} tends to increase with lactation length. P_{tot} also shows this trend, but it is interesting to notice that, in 651-1000d class, this trait is greater in first than in later parities. The asymptotic level of production estimated by

Figure 1. Estimates for milk yield (A), fat percentage (B), protein percentage (C), and SCS (D) for different parities by AS model for the 651-1000d lactation length class.



DJ model is below 10 kg for 651-1000d class, whereas the yield at the final test available estimated by the AS model is around 13 kg. The two models detect and inflection point of the curve between 100 and 150 DIM, except from AS for first parity. The two models resulted suitable for modelling extended lactations for milk yield and protein percentage. Moreover, they allowed for the calculation of technical parameters that can be very useful for management and breeding decisions.

Table 2. Time to the peak (Tp), production to the peak (Yp), production to the final test day or asymptotic production (Pa), cumulative production until 305 day (P_{305d}), cumulative production until the dry off (P_{tot}), time at inflection point (T_f) for parity within lactation length classes.

		Model											
		AS						DJ					
Length	Parity	Tp	Yp	Pa*	P_{305}	P_{tot}	T_f	Tp	Yp	Pa*	P_{305}	P_{tot}	T_f
<350d	1	61	30.8	19.4	8,307	9,213	no	66	31.2	-955.6	8,293	9,213	no
	2	38	37.5	16.6	9,125	9,931	no	41	37.8	-1111.9	9,116	9,931	no
	3	40	39.0	16.6	9,377	10,181	no	42	39.3	-1035.5	9,374	10,181	no
351-450d	1	53	31.0	16.4	8,516	11,437	no	69	31.4	-1233.4	8,501	11,437	no
	2	38	38.0	14.4	9,472	12,152	no	39	38.2	-379.2	9,471	12,152	no
	3	40	39.5	13.9	9,751	12,389	no	41	39.8	-175.7	9,749	12,389	no
451-650d	1	61	31.3	14.2	8,670	15,379	no	60	31.8	-924.5	8,665	15,379	no
	2	42	38.3	14.1	9,744	16,021	150	45	38.9	2.8	9,719	16,021	105
	3	47	39.2	14.7	9,991	16,174	150	52	39.8	5.4	9,956	16,174	105
651-1000d	1	65	31.0	13.1	8,740	20,659	258	65	31.4	-14.5	8,736	20,659	160
	2	38	37.3	13.1	9,599	19,834	106	46	37.3	9.5	9,609	19,834	105
	3	39	39.6	13.8	9,668	18,460	105	40	39.6	10.9	9,679	18,460	105

Pa= sum of coefficients a_0, a_1 and a_2 for AS model; b_0 for DJ model.

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