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MODELING LACTATION CURVE STANDARDS FOR TEST-DAY MILK YIELD IN HOLSTEIN, BROWN SWISS AND SIMMENTAL COWS

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ABSTRACT

Standard lactations (305 days [d]) of Brown Swiss (BS, n = 54,985), Simmental (SM, n = 114,189) and Holstein (HO, n = 137,703) breeds of cow were analyzed, and their lactation curves were calculated. For the prediction of the milk yield of cows at 305 d and the prediction of lactation – curve standards (LCS), a regression equation system was developed separately for each breed and parities (1, 2, ≥ 3). The regression equation system was used for the estimation of Wood curve parameters for arbitrary milk yield on the basis of the first daily milk recording. An analysis, using the least power norm method (L_p), of the conformity between the calculated Wood's curves and those estimated using the regression equations on the verification data set (n = 34,374) indicated that the equations can provide a good prediction of LCS. Our results indicate that the expected milk yield in a standard lactation and the lactation curve trajectory of an individual cow in a herd may be predicted using a simple algorithm on the basis of the proposed regression equations and known daily milk yield in the initial period of lactation.

Key words: dairy cow, wood model, lactation curve, least power norm.

INTRODUCTION

The monitoring of milk records at the farm level and prediction of the expected milk yield help to control the breeding of dairy cows more efficiently. Knowledge of the lactation curves allows prediction of total milk yield from a single or several test days early in lactation and it is valuable tools in farm management (Nasri *et al.*, 2008; Dijkstra *et al.* 2010). The quantity of milk produced depends on the lactation curve trajectory, which is influenced by genetic and environmental factors. The environmental factors alter the genetic potential efficiency of milk-producing animals andshape of their lactation curves. The factors are related to animal diet, the health condition of cows, events linked with fertility and the type of management, as well as with specific climate conditions (Gajster, 1991; Fleischer *et al*., 2001; Rekik and Gara, 2004; Macciotta *et al*., 2006). The shape and height of the curve are influenced by consecutive lactations, age at calving, calving season (Macciotta *et al*., 2006), pregnancy period (Tekerli *et al*., 2000; Rekik and Gara, 2004; Cole *et al*., 2009), and the length of the drying-off period before calving (Capuco *et al*., 2003). Furthermore, different management and feeding regimes in different geographic location, regions and countries notably influence milk yield (Leclerc *et al*., 2008; Bebbington *et al*., 2009; Andersen *et al.*, 2011).

A number of various mathematical methods and modelshave been described and estimated the lactation curve and expected milk yield. Some methods are oriented more on better fitting of mathematical functionswith little consideration of the lactation biology (Wood, 1967) andothersare focused to improve understanding the biological processes in mammals (Dijkstra *et al*., 1997; Pollott, 2000). The mechanistic model provides an understanding of factors controlling the variations in milk production and they have more biological interpretation. They can be too complex for routine use outside the research in practice (Nasri *et al*., 2008; Ehrlich, 2011). The problems those occur most frequently at all models and lead to the atypical shape of lactation curves are in a few numbers of measurements for the estimation of model parameters, inadequate distribution of measurements with regard to time of sampling, missing measurements for lactation curve phases, and unexplained oscillations of milk yield. Owing to missing measurements in the early period after calving, the attainment of the peak time (PT) and peak yield (PY) cannot be estimated reliably enough. This may lead to an atypical shape of the lactation curve (Dijkstra *et al*., 1997; Pollott, 2000; Rekik and Gara, 2004; Macciotta *et al*., 2005; Silvestre *et al*., 2009). With a limited number of measurements for each cow, complex models with several parameters cannot be used. Given that the prediction of milk yield is a common problem in practice, the ability to predict the milk yield using lactation – curve standards (LCS) for individual milk yields has been verified. To our knowledge, several methods for the prediction of milk yield have been developed (de Vries, 2005; Cole *et al*., 2011), but no suitable LCS has been applied widespread in practice.

The objective of this study was to develop a system of regression curves to predict the shapes of the curves and milk yield in standard lactations (of 305 days) of Holstein, Brown Swiss and Simmental cows.Specific curve parameters were estimated using regression models to predict milk yield and milk peak with lactation curve standards.

MATERIALS AND METHODS

Data sources: Data consisting of 6,770,267 records (599,817 lactations) for milk yield were obtained from 6,946 small-scale dairy herds. A dataset was constructed using 220,421 cows of different breeds (Brown Swiss (BS; n = 44,254), Simmental (SM; n = 81,342) and Holstein (HO; n = 94,825)). The cows were dried-off between 305 and 380 days and they calved between January 1, 2000 and May 1, 2011. Among them there were 165,732 cows of first, 134,994 of second, and 299,090 of third and later parity. On average the cows had 2.7 calving's. All data were collected within the regular control of milk recording and are located in the Central Cattle Database at the Agricultural Institute of Slovenia. The data set was edited to exclude records with first postpartum recorded milk yield ≤ 4 days, lactation length < 305 or > 380 days and lactations which were not followed according to ICAR rules (ICAR, 2010).

Model to describe the lactation curve and milk yield estimate: The incomplete gamma function was used to fit lactation curves and observed daily milk yield was presented using following equation (Wood, 1967):

$$Y_t = a\, t^b e^{-ct} \quad [1]$$

where Y_t is dependent variable (test-day milk yield), a is parameter connected with average test-day milk yield, b is parameter determining the slope of the increasing part of the function, c is parameter determining the slope of the decreasing part of the function and t is number of days after calving.

The estimation of the parameters of the curve, which follows a set of measured daily milk yields of a cow, is obtained according to the method of Marquardt (R Development Core Team, 2011) using nonlinear regression. The shape of the curve can be recognized on the basis of the signs of the estimated parameters. The relative maximum of a function was expressed by:

$$PT = \frac{b}{c} \quad [2]$$

where PT represents the number of days after calving at which the lactation peak is reached. In this case the maximum daily peak yield (PY) is estimated by insertion of the value obtained into equation [1]. The estimated milk yield in an arbitrary period (M) is expressed with a determined integral [equation 3].

$$M = a\int_0^{305} e^{ct} t^b dt \quad [3]$$

At the same time we may estimate the quantity of milk produced in the period until the last recording and/or drying off, or we may predict the expected milk yield for an arbitrary period.

Lactation – curve standards (LCS): When predicting milk yield for cows for which the volume of data is less than or equal to the number of the estimable parameters of the model to be able to estimate the lactation curve trajectory reliably, LCS was used. The LCS was developed only from data of completed 305-d normally shaped lactations (n = 420,990).

The shape of the lactation curve is determined by the parameters b and c obtained after the estimation of the parameters of milk yield according to Wood (1967). The calculations for the lactations were classified into 100 kg milk yield classes. In present study, a lactation curve was considered atypical if either b or c parameter was negative. The atypical lactation curves were further divided into continuously increasing, reversed standard and continuously decreasing curves. With regard to the fact that regular recordings are not performed on precisely determined days after calving, and that there are few measurements carried out on certain days, the standard lactation from the fifth day on was divided into ten-day intervals (ICAR, 2011).

From the daily milk yields at each interval, the average daily milk yield within individual milk yield classes was calculated. These values were used to estimate the parameters of a curve and to calculate the milk quantity produced over 305 days. Thus, the LCS for average milk yields in individual classes were obtained, in which the dependence of the peak of the standard lactation (time and quantity of milk) on milk yield class and the parameter c were studied. The lactation peak was expressed with a linear regression equation [equation 6] using regression analysis. The characteristic "time after calving" was obtained when the highest milk yield [equation 5] and value of parameter c [equation 4] were expressed using quadratic regression. Regression analysis was performed within individual breeds for the 1^{st}, 2^{nd}, ≥ 3^{rd} lactation and for all breeds at the 1^{st} and ≥ 2^{nd} lactations. The remaining parameters of Wood's (1967) function were expressed with reparametrization [equations 7 and 8].

Based on linear regression equations [4 to 6] and equations [7 to 8] we defined Wood's (1967) parameters for the lactation curve and used them in equation [1] to plot the curve.

$$c = \beta_0 + \beta_1 i + \beta_2 i^2 \quad [4]$$

$$PT = \beta_0 + \beta_1 i + \beta_2 i^2 \quad [5]$$

$$PY = \beta_0 + \beta_1 i \quad [6]$$

$$b = cPT \quad [7]$$

$$a = \frac{PY}{(PT^b e^{-b})} \quad [8]$$

The denotations β_0, β_1, β_2 in equations [4 to 6] represent regression coefficients, and "i" gives the quantity of milk in a standard lactation.

Conformity of lactation curves with LCS using L_p norms: For further analysis, only lactations between 305 and 380 days were included (n = 341,251) in data set. From this data set were randomly selected and excluded 34,374 lactations for further verification of LCS standards. Altogether 306,877 lactations (BS, n = 54,985; SM, n = 114,189; HO, n = 137,703) were encompassed in the estimation of the parameters of the regression equations. The purpose was to determine the average absolute daily differences and the conformity of the lactation curves with the LCS for these milk yields. On the basis of regression equations, the corresponding LCS weredetermined for these milk yields. The two curves were compared over the entire range of a standard lactation divided into three periods; 0–100 days, 101–200 days and 201–305 days of lactation. For determination of the deviation of the estimated milk yield (y_w) from the LCS (y_r), the sum of the absolute differences (D) in the estimated daily milk yields for the observed interval were used, divided into the period Δ for which the estimation was made.

$$D = \frac{1}{\Delta}\sum_{i=s}^{e} | y_{wi} - y_{ri} | \quad (s = 0, 101, 201; e = 100, 200, 305) \quad [9]$$

Least power norm (L_p): To determine how well the curves overlapped spatially the least power norm (L_p) (Callegaro *et al*., 2009) [equation 10] was used. Choosing different p values can alter the ranking strategy. If interest is focused on the overall difference between curves, it is appropriate to take small p values. Otherwise, higher p values are more appropriate for study of outliers or small sections of the curve. In present study we were interested in the compliance of curves for the whole lactation, therefore we took the value of p = 1.

Small L_p values indicate a good spatial overlap for the whole standard lactation period. The L_p norms were calculated from normalized absolute differences [equation 10]. L_p values close to zero indicate good spatial overlap, and higher values mean that the curves differ from each other. Despite the fact that there is no real upper limit of L_p value, the expected values are in the interval $0 \le L_p \le 1$.

$$L_p = \left(\frac{1}{305} \cdot \int_1^{305} | y_{wi} - y_{ri} |^p dx\right)^{\frac{1}{p}}; \ p = 1 \quad [10]$$

Therefore, to present the precision in a more representative fashion, the L_p norm is denoted by the letter H in equation [11], as proposed by Callegaro *et al*. (2009):

$$H = 100\,(1 - L_p) \quad [11]$$

The H value has an upper limit that approaches H = 100, which indicates that the curves coincide throughout their length. The H value does not have a lower limit and the lower its value the lesser the curves coincide.

The calculation of the basic lactation curves and other parameters was performed using the R program (R Development Core Team, 2011).

RESULTS AND DISCUSSION

One of the most common models in fitting the observed daily milk yields is Wood`s lactation curve (1967). The disadvantages of the Wood`s function arise from the use of power function t^b, to describe the growth phase of lactation (Friggens *et al.*, 1999). At calving time when t = 0, milk production is 0 and the function predicts 0 yield. This major criticism of the Wood`s function was dismissed by Tozer and Huffaker (1999) by following explanation: when a cow calves the colostrum produced has no economic value and the cow does not enter in the milk-producing herd immediately after calving. Therefore, fixing production at zero at calving is not a significant problem when determining an appropriate function to use in management research. This model provides good flexibility in fitting the estimated curve to the measured values and does not require a large number of measurements, which cannot be obtained in regular milk recording. It has been concluded that the incomplete gamma function and its variants proved powerful in terms of fitting observed daily milk yields (Grossman and Koops, 2003; Val-Arreola *et al*., 2004; Silvestre *et al*., 2006).

Table 1. Means and standard deviations (SD) of parameters for individual curves classified according to the 4 shapes detected by the Wood (1967) model and means with standard deviations (SD) of days to the first milk recording

Shape[2]	n	a		b		c		First lactation record[1]		
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	%
1	457	14.1	5.8	0.049	0.062	-0.00037	0.00038	21.6	21.0	0.1
2	420,990	15.9	7.8	0.205	0.221	0.00410	0.00223	20.8	15.0	70.2
3	37,064	82.2	105.5	-0.308	0.180	-0.00114	0.00118	27.5	16.2	6.2
4	141,306	36.6	28.5	-0.094	0.082	0.00153	0.00101	22.0	12.7	23.6

[1] Days between calving and first milk recording
[2] 1 = continuously increasing, 2 = standard curve, 3 = reversed standard, 4 = continuously decreasing curve.

Among 599,817 lactation curves, 70.2% had a typical lactation shape and 29.8% had atypical shapes for lactation curves (Table 1). Our results are in a good agreement with the results of previous studies. Tekerli *et al*. (2000) reported 26.3% of atypical curves on a total 1278 completed lactation. Rekik and Gara (2004) found out that the percentage of individual atypical curves ranged from 15 to 42%. These curves were more frequent in the state and cooperative herds than in herds of farmers and herds of groups of investors. Moreover, percentage of atypical curves has been related to the subsequent parity and calving season. Second and subsequent parities and July-August calving season increase the percentage of atypical curves from 37 to 49%, respectively.

One of the reasons for the atypical shapes of lactation curves obtained using the estimation of parameters according to Wood (1967) is too low a number of measurements, and their distribution according to milk recordings scheme (Dijkstra *et al*., 1997; Pollott, 2000; Macciotta *et al*., 2005; Silvestre *et al*., 2009). The atypical shapes of lactation curves in present study were excluded from further processing. Of course, in practice also for these atypical shapes, lactation curves would be estimated on first milk recordings. One of the important factors that affect the shape of the curve is the time of performance of the first recording after calving (Macciotta *et al*., 2005). Given that the lactation curve for the majority of cows reaches a peak between the fourth and the eighth week (Olori, 1999), measurements taken in its increasing part, before the fourth week, should be available in order to obtain a more reliable estimate of the lactation curve. Results from the present study are in a good agreement with the previous observation. The average number of days from calving to the first recording for curves of typical shape was 20.8 days (Table 1).

In Table 2, the results of the average milk yields in standard lactations within the BS, SM and HO breeds at the 1st, 2nd and ≥3rd lactations are presented, with parameters of Wood's curve and standard errors.

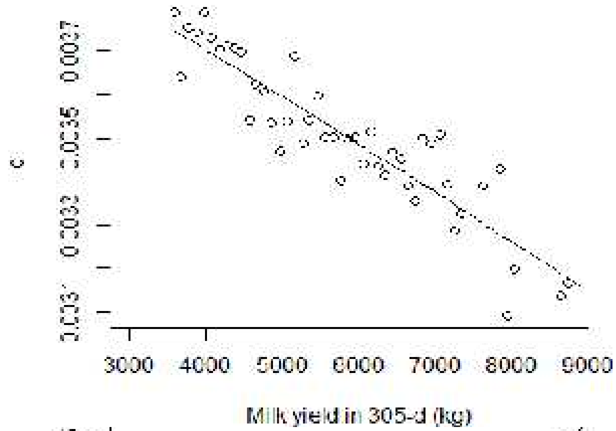
Table 2. Mean milk yields with estimated Wood curve parameters (a, b, c), day of peak yield (PT) and peak yield (PY) for Brown (BS), Simmental (SM) and Holstein (HO) breed of 1th, 2nd and ≥ 3rd parity cows with standard deviations (SD)

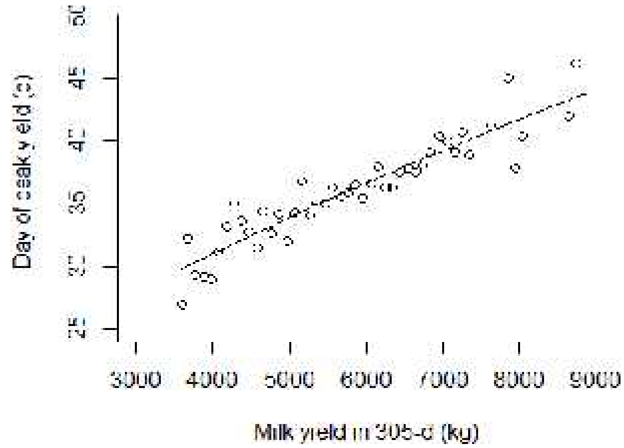
B[1]	P[2]	n	305-d	a		b		c		PT		PY	
			Mean	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
BS	1	14,967	5,094	13.7	5.6	0.156	0.144	0.00298	0.00151	54.3	23.5	20.6	4.2
	2	11,841	5,622	16.3	7.0	0.166	0.160	0.00375	0.00169	46.5	20.8	24.5	5.3
	≥ 3	34,290	5,797	16.4	7.2	0.180	0.162	0.00400	0.00174	47.3	19.3	25.7	5.5
SM	1	34,001	4,847	12.9	5.3	0.162	0.149	0.00308	0.00153	54.8	23.3	19.7	4.3
	2	26,342	5,285	15.4	6.7	0.166	0.158	0.00380	0.00172	46.2	20.5	23.2	5.5
	≥ 3	66,587	5,426	15.6	6.9	0.180	0.170	0.00406	0.00178	46.6	19.4	24.4	5.7
HO	1	50,162	6,671	15.7	6.7	0.184	0.149	0.00290	0.00144	64.7	25.4	26.1	5.1
	2	37,822	7,400	19.3	8.6	0.193	0.162	0.00385	0.00172	52.2	20.2	31.4	6.8
	≥ 3	65,239	7,617	19.4	9.0	0.212	0.179	0.00417	0.00183	52.7	20.1	33.1	7.0

[1] B = breed, [2] P = parity

Values of the parameters of Wood's curve obtained in present study are comparable with those reported by other authors (Rekik and Gara, 2004; Val-Arreola *et al*., 2004; Dematawewa *et al*., 2007; Cole *et al*., 2011). Equations [4–8] were used to express the parameters of the lactation curve based on the milk yield in a standard lactation. The regression coefficients calculated for the parameters c, PY, and PT are presented in Table 3. In addition to these values, determination coefficients (R^2) are indicated. Based on the milk yield in a standard lactation for all breeds, the PY was estimated using a linear regression equation with a maximum R^2 (0.99). The R^2 value estimated of the present study was higher than reported by other authors. The adjusted coefficient of determination changed in the range 0.958 to 0.982 in relation to lactation season for Simmental cows (Korkmaz *et al*., 2011). The lower R^2 value was found for Holstein cows of Costa Rica (0.957) using Wood model (Vargas *et al*., 2000). Even lower R^2 values ranged from 0.902 to 0.938 estimated with the same model for Holstein (Sahinler, 2009) and 0.916 for Jersey cows in Turkey (Cankaya *et al*., 2011).

The parameter c, which affects the decreasing part of Wood's curve, shows lower correlation with the milk yield in a standard lactation. Its value alters the shape of the decreasing portion and the curve peak at the same time. The variability in the shape of lactation curves may be influenced both by genetic and by several environmental factors (Albarrán-Portillo and Pollott, 2008; Gradiz *et al*., 2009; Leclerc *et al*., 2008). However, the genetic factors have low influence and may not change the shape of the lactation curve effectively (Farhangfar and Rowlinson, 2007).





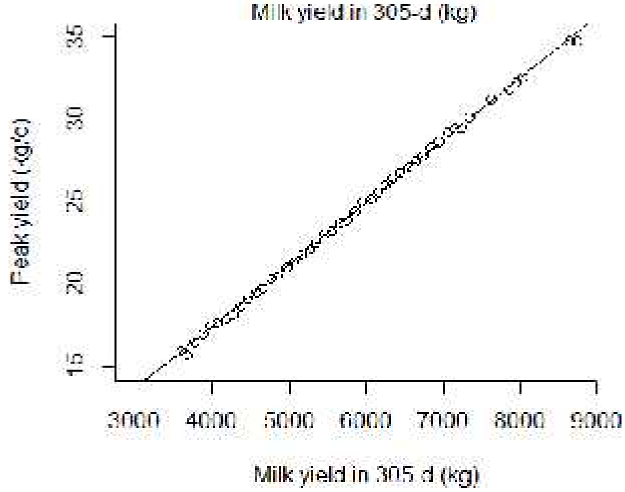


Figure 1. Regression lines between milk yield in 305-d and Wood parameter c, peak time and milk yield at peak time for Brown Swiss cows at 3rd parity

For small-scale dairy enterprises, the prediction of lactation curves frequently is required for a group of animals composed of various breeds. For this purpose we repeated the regression analysis for the parameters c, PT and PY for all breeds together, and separately within the 1st and ≥ 2nd lactations. The parameters of the Wood's curve were expressed with two sets of regression equations, with a high determination coefficient for parameter c (R^2 = 0.89 at 1st lactation and R^2 = 0.74 at ≥ 2nd lactations) and also for PT and PY (Table 3).

Table 3. Regression coefficients for the estimation of Wood parameter c, day of peak yield (PT) and peak yield (PY) in accordance with milk yield in 305-d lactation, breed and parity

Breed[2]	Parity	n	c[1]				Peak time (PT)[1]				Peak yield (PY)[1]		
			β_0	β_1	β_2	R^2	β_0	β_1	β_2	R^2	β_0	β_1	R^2
BS	1	13,470	0.004159	-4.48E-07	2.53E-11	0.89*	15.477	0.006	-1.00E-07	0.91*	2.226	3.33E-03	0.99*
	2	10,655	0.004388	-3.33E-07	2.35E-11	0.52*	11.398	0.006	-3.17E-07	0.72*	1.554	3.68E-03	0.99*
	≥3	30,860	0.004160	-1.19E-07	1.12E-12	0.83*	19.244	0.003	-2.07E-08	0.88*	2.256	3.65E-03	0.99*
SM	1	30,540	0.003369	-2.06E-07	1.30E-11	0.69*	17.256	0.005	3.77E-08	0.96*	1.706	3.53E-03	0.99*
	2	23,695	0.003581	-9.38E-08	8.89E-12	0.04ns	33.404	-0.002	3.43E-07	0.85*	0.940	3.98E-03	0.99*
	≥3	59,954	0.003424	1.20E-08	2.77E-12	0.66*	20.682	0.002	9.33E-08	0.96*	1.275	3.97E-03	0.99*
HO	1	45,032	0.003155	-1.55E-07	9.80E-12	0.36*	38.194	0.001	2.70E-07	0.96*	1.330	3.56E-03	0.99*
	2	34,021	0.003145	5.06E-08	-1.37E-12	0.33*	53.203	-0.005	4.57E-07	0.78*	0.557	3.99E-03	0.99*
	≥3	58,650	0.003676	5.97E-09	3.63E-13	0.15*	40.388	-0.002	2.64E-07	0.95*	1.356	3.94E-03	0.99*
Overall	1	89,042	0.003905	-4.08E-07	3.01E-11	0.89*	17.497	0.005	8.06E-08	0.99*	1.793	3.50E-03	0.99*
	≥2	217,835	0.003385	2.20E-08	5.78E-13	0.74*	19.016	0.003	1.13E-08	0.99*	1.604	3.89E-03	0.99*

[1]β_0, β_1, β_2 – regression coefficients; R^2 – coefficient of determination (* =P ≤ 0.01, ns = not significant);
[2] BS = Brown Swiss; SM = Simmental; HO = Holstein.

Comparison of the conformity of the curves for the same milk yields in which the parameters of the Wood's curve were determined by a set of regression equations taking into consideration the breed and consecutive lactations (1, 2, ≥ 3) with the curves in which the parameters of the Wood's curve were determined only by two sets of regression equations (separately for 1st and ≥ 2nd lactations without considering breed) is presented in the form of a graph (Figure 2). It is evident that the reduction in the number of regression equations does not have a crucial impact on the precision of the estimation of lactation curve. When the conformity of the curves gives a value for H > 80, the average differences in daily milk yield are below 0.4 kg in all breeds. Our model seems to be accurate enough: the 0.4 kg quantity of milk corresponds to approximately 0.2 kg of concentrates fed, which is also a limiting value in practice. For the BS breed, the average daily differences at a milk yield above 8000 kg in a standard lactation are greater than 0.4 kg, with the SM breed they are higher at milk yields above 9500 kg, and with the HO breed they are higher at milk yields below 4000 kg and above 9500 kg. The poorer conformity of the curves for the HO breed may be attributed mainly to the fact that the number of data points which were used for the estimation of regression coefficients in these ranges were relatively small, which led to the lower reliability of the estimates.

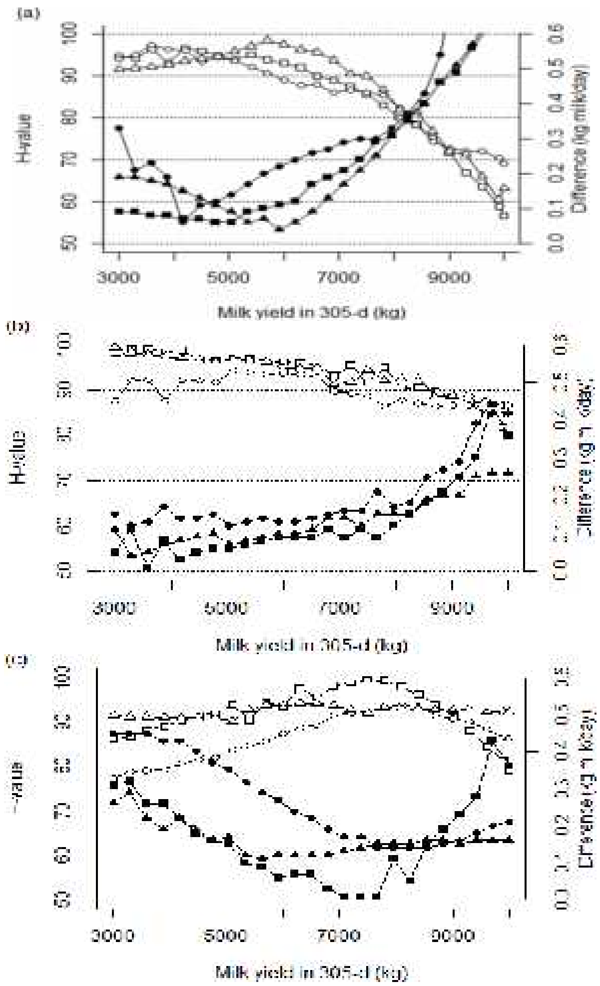


Figure 2. Comparison of curves similarity (H-value) of LCS predicted by regression equations irrespective of breeds for 1^{th} and ≥ 2^{nd} parity cows and regression equations considering breeds for 1^{th}, 2^{nd} and ≥ 3^{rd} parity cows for (a) Brown Swiss, (b) Simmental and (c) Holstein cows. H values (□ = 1^{th} parity, ○ = 2^{nd} parity, Δ = ≥ 3^{rd} parity) and daily milk yieldaverage differences (■ = 1^{th} parity, ● = 2^{nd} parity, ▲ = ≥ 3^{rd} parity)

Regression equations were also checked on the test data set, in which Wood's curves were calculated for standard lactations and compared with LCS estimated on the basis of regression equations (Table 4). Average daily differences between the Wood's curves and LCS for milk yield are expressed in absolute values of kg milk a day with 95% confidence intervals (CI). Within the limits of a standard lactation, these values ranged between 1.05 kg and 1.86 kg. According to the present results it can be concluded that appropriate regression equations for estimation of Wood`s model parameters were chosen. Much higher values have been reported by Rekik *et al*. (2003). They found a difference between the mean predicted test-day yield and actual test-day yield for the same cow in the same test-day and in the same type of herd ranged from 1.5 to 3.2 kg. Comparison of nine lactation models showed for the US Holstein first-parity cows that most of models predicted the average milk yield error margin <2 kg, except the Grossman models (MONO, DIPH, LPM). For cow in third and greater parities prediction errors were less than 10% of the daily yield and it is evident that even three parameter models such as Wood can be used with extended lactation with reasonable accuracy (Dematawewa *et al*., 2007). Pérochon *et al.* (1996) hypothesized that a maximum prediction error less than 2 kg/day is necessary to estimate the effects of feeding practices or of health disorders on milk production through an individual lactation model and some individual predictions were not accurate as required (i.e. Holstein cows).

The first 100 days of lactation the absolute values were higher (from 1.48 kg to 2.69 kg) than those in the later lactation periods (from 0.60 kg to 1.79 kg). In this period after calving inadequate feed management is related to lower milk yield and fertility disorders. Later, the smallest differences in milk yield were obtained in the period between 101 and 200 days, when they ranged between 0.60 kg and 1.10 kg, and in the period from 201 to 305 days when they ranged between 1.07 kg and 1.79 kg. Deviations in milk yield between the Wood's curve and LCS for the third category of milk yield were greatest for the HO breed (from 1.37 kg to 1.86 kg), then the SM (1.05 kg–1.33 kg), and they were smallest for the BS breed (1.07 kg–1.38 kg). In the first 100 days of lactation, the LCS showed higher absolute daily milk yield differences to Wood's curvesfor the HO breed (from 1.93 kg to 2.69 kg). The BS and SM breeds showed lower deviations in milk yield and better fit between the Wood's curves and LCS than the HO breed. The reason for this may be found mainly in the smaller R^2 for the c value in the regression equations used for the estimation of LCS for the HO cows (Table 3).

Table 4. Absolute daily milk yield differences (95% CI) based on Wood curves and LCS for particular lactation stages (DIM) at different breeds and parities

Breed[1]	Parity	N	0-305 DIM	0-100 DIM	101-200 DIM	201-305 DIM
			Mean±CI	Mean±CI	Mean±CI	Mean±CI
BS	1	1,497	1.07±0.03	1.52±0.05[b]	0.62±0.02	1.07±0.04[c]
	2	1,186	1.37±0.05[a]	1.98±0.08	0.76±0.03[a,b]	1.37±0.06[a]
	≥3	3,430	1.38±0.03[a]	2.01±0.04[a]	0.80±0.02[b]	1.34±0.03[a]
SM	1	3,461	1.05±0.02	1.48±0.03[b]	0.60±0.02	1.07±0.03[c]
	2	2,647	1.30±0.03[b]	1.87±0.05[c]	0.72±0.02[a]	1.31±0.04[a]
	≥3	6,633	1.33±0.02[a,b]	1.93±0.03[c]	0.76±0.01	1.31±0.02[a]
HO	1	5,130	1.37±0.02[a]	1.93±0.04[c]	0.83±0.02	1.35±0.03[a]
	2	3,801	1.75±0.03	2.51±0.06	1.01±0.02	1.73±0.04[b]
	≥3	6,589	1.86±0.03	2.69±0.05	1.10±0.02	1.79±0.03[b]
Overall	1	10,088	1.22±0.02	1.72±0.03	0.72±0.01	1.21±0.02
	≥2	24,286	1.55±0.01	2.23±0.02	0.89±0.01	1.51±0.01

[a,b,c] – values with equal signs within lactation stages are not different (α=5%)
[1] BS = Brown Swiss; SM = Simmental; HO = Holstein;

The results showed similar deviations for the estimation of LCS on the basis of regression equations, without considering breed, for the 1[st] and ≥ 2[nd] lactations. For the entire period of a standard lactation, these values were 1.22 kg in the 1[st] lactation and 1.55 kg in the ≥ 2[nd] lactation. The differences in the deviations for the entire interval and individual lactation periods in comparison with the HO breed were slightly smaller. The conformity of the Wood's curves with LCS for these milk yields in individual intervals was tested using the L_p norm (Figure 3).

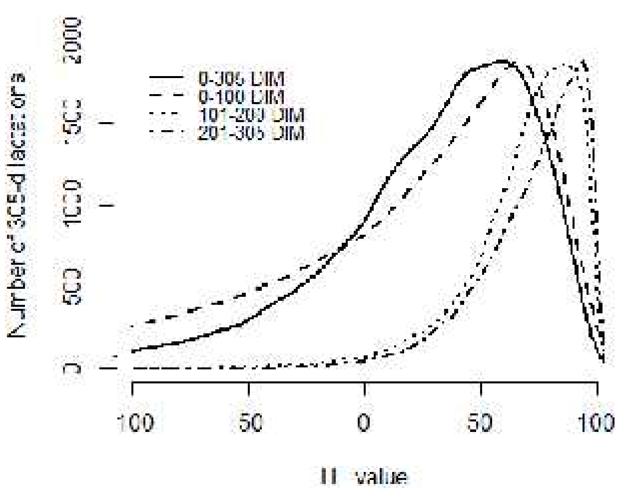


Figure 3. Leastpower norm (L_p) frequency of verificationdataforlactationcurvesestimatedbyWoodandpredictedbyregressionequations

The curves were compared for the entire interval of 305 days and in individual sections (the first 100 days, 102–200 days and 201–305 days). The calculated mode of the frequency distribution of the L_p norm for the first 100 days of lactation equals 64. In the second 100 days the conformity of the lactation curves with LCS is better, and the calculated mode amounts to 85. In the last part of lactation the curve is practically completely compliant with the LCS, and the calculated mode is 98. Conformities of curves in first 100 days with LSC clearly demonstrated an unbalanced herd management according to needs of cows in this stage. Among the more important factors are the negative energetic balance of cows and, consequently, frequent disorders of metabolism caused by unsuitable breeding conditions in that period and the small amount of data on daily milk yields prior to the lactation peak (Gross *et al*., 2011). In the later lactation period there are more data on daily milk yield available. This fact provides better management of the energy requirements of the cows and improves their health.

The shape of the lactation curve is a reflection of physiological processes in the epithelial cells of the mammary gland (Knight and Wilde, 1987), influenced by environmental factors (Stanton *et al*., 1992; Knight, 2000; Pollott, 2000; Grossman and Koops, 2003). Determination of a suitable LCS for an individual cow allows the needs of the animals to be traced on a daily basis using appropriate herd management system. The regression equation system and/or the calculated regression coefficients in the present study allow determination of the parameters of Wood's curve for an arbitrary milk yield in a standard lactation.

Conclusions: A system of regression equations was developed that allows determination of LCS for arbitrary milk yield, according to the method of Wood. From the known daily yield of the first records the LCS can be adjusted closest to these values to predict standard lactation curve shape. Greater differences in the shape of the lactation curves were found only between the first calving heifers and cows. Therefore, the use of different regression equations for the first calving heifers and cowsis recommended, without taking into consideration the impact of breed.

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