Journal of Animal Science and Technology 55(6) 489~500, 2013
http://dx.doi.org/10.5187/JAST.2013.55.6.489

Estimation of Daily Milk Yields from AM/PM Milking Records

Deukhwan Lee[1]* and Hongrip Min[2]

[1]Department of Animal Life Resources, Hankyong National University, Anseong 456-749, Republic of Korea,

[2]Dairy Cattle Improvement Center, National Agriculture Cooperatives Federation, Goyang, 412-030, Republic of Korea

ABSTRACT

Daily milk yields on test days were estimated using morning or afternoon partial milk yields collected by official agencies and the accuracy of the estimates was determined. Test-day data for milk yields consisted of 3,156,734 records of AM/PM partial milking measurements of 255,437 milking Holstein cows from 3,708 farms collected from December 2008 to April 2013. A linear regression model (LRM) was applied to estimate daily milk yields using alternate AM/PM milk yield records within lactation stages, milking intervals, and parities on every daily milk yield. The alternate statistical approach was a non-linear hierarchical model (NHM) in which Brody's growth function was implemented by reflecting an animal's physiological milk production cycle. When compared with LRM, daily milk yields predicted by the NHM were assumed to be functionally related to day in milk (or lactation) stage, milking intervals, and partial milk yields. Since the results were in terms of accuracies based on comparisons of different statistical models, accuracies of estimates of daily milk yields by NHM were close to those determined by the LRM. The average of these accuracies was 0.94 for AM partial milk yields and 0.93 for PM partial milk yields for first calving cows. However, the accuracies of AM/PM milk yield estimations from cows under a calving stage higher than the first parity were 0.96 and 0.95, respectively. Correlations between the estimated daily milk yields and the actual daily milk yields ranged from 0.96~0.98. These accuracies were lower for unbalanced AM/PM milking intervals and the first calving cows. Overall, prediction of daily milk yields by NHM would be more appropriate than by LRM due to its flexibility under different milk yield-related circumstances, which provides an idea of the functional relationship between milking intervals and days in milk with daily milk yields from statistical viewpoints.

(**Key words :** AM/PM milk yields, Prediction of daily milk yields, Milking intervals, Brody's function, Accuracy)

INTRODUCTION

In the Korean dairy industry, cows have are milked twice a day on average; however, owing to recent improvements in the milking capability of dairy cows they are now starting to be milked more than twice a day. As robotic milking systems have become commercialized, the practice of milking at least three times a day has increased. In the dairy industry, daily milk yield per dairy cow is used as important index in cattle management and dairy cattle breeding programs. In Korea, milk yield per cow and milk composition analysis have been carried out on an annual basis since 1979 according to the standard set by the Enforcement Guidelines of Agriculture, Forestry, and Fisheries Project (the Korean Ministry of Agriculture, Food and Rural Affairs, 2013) as part of the dairy herd improvement program under the supervision of the National Agricultural Cooperatives Federation. For this analysis, one day a month is designated for milk yield measurement twice a day, as well as sample collection for milk yield recording and milk composition analysis (A4 type). Providing analyzed results to the enrolled farmers has contributed to rationalization of the management of Korean dairy farms. In addition, the milk yield and composition data are used to evaluate the genetic capability of dairy cattle. Moreover, INTERBULL under the ICAR (International Committee for Animal Recording) introduced the International Genetic Evaluation System in 1993, which focuses on countries with advanced dairy industries and includes genetic evaluation services for the international dairy cattle breeding stock (Durr and Reenths, 2013). Korea has participated in the International Genetic Evaluation of INTERBULL by using milk yield records per dairy cattle from 2011 as part of the Dairy Herd Improvement Program (INTERBULL, 2013). Milk production records depend on the milking method and data generation method. ICAR (2011) provides an official standard proposal for a data generation method to predict Daily Milk Yield (MY_D). The milk yield records of the test days of various dairy cattle defined by

* Corresponding author : Deukhwan Lee, Department of Animal Life Resources, Hankyong National University, Chungang-no Anseong-si Gyeonggi-do, Republic of Korea 456-749. Tel: 031-670-5091, Fax: 031-676-5091, E-mail: dhlee@hknu.ac.kr

the dairy herd improvement program in Korea are estimated as sums of milk yields for each milking time. However, method used to predict daily milk yield based on partial test record (s) once or several times a day is generally not available. Conversely, in dairy herd improvement programs of countries with advanced dairy industries, once or multiple-time test methods are used in combination with milk yield measurement and sample collection methods according to the method proposed by ICAR (2011). Accordingly, in countries with advanced dairy industries, the number of farms conducting one milk test a day has gradually increased. This is especially true in the United states, where 4.3 millions cows out of around 9.2 million were included in the DHIA (National Dairy Herd Information Association) program as of 2012. Around 70% of participating dairy farms (15,000) carried out AM/PM partial test sampling and milk yield measurements according to the AP plans of the United states department of agriculture (USDA, 2013). Moreover, countries with advanced dairy industries are currently predicting test-day milk yields for each dairy cow by using an estimated correction factor based on as many milk sampling systems as possible. The estimated data is then used to evaluate the genetic capability of dairy cattle. To accomplish this, a wide range of research has been conducted to develop a correction factor using a partial milk test record (Lee and Wardrop, 1984; DeLorenzo and Wiggans, 1986; Wiggans, 1986; Hargrove, 1994; Lee et al., 1995; Cassandro et al., 1995; Liu et al., 2000; Schaeffer et al., 2000; Jenko et al., 2010). The access method used in these studies is a statistical method for correction of the environmental parameters, and the development of a correction factor that depends on parity, milking interval and lactation stage were the major goals of these studies. The results of these investigations are currently being used as correction factors for the dairy herd improvement project however, these investigations did not consider the physiological characteristics of dairy cattle such as the correlation between milk production time in the mammary and milk yield. When Neal and Thornley (1983) conducted a simulation of the effects of mammary cells and hormone amount with respect to milk production and cattle activity they found that milk yield geometrically increased immediately after milking and then slowed down and converged to a specific upper level. They also found that this trend was similar to the functional formula of the growth curve proposed by Brody (1945). Klopcic et al. (2013) also developed a functional formula that predicts daily milk yields based on which physiological phenomena the cattle reflected. However, they failed to provide an analysis model considering various environmental factors such as lactating stage, parity and breed.

Therefore, the present study was carried out to estimate daily milk yields while taking into account an animal's physiological capability and the milking interval of cows as well as to provide reference data for the execution of an AM/PM milk test for the dairy herd improvement program.

MATERIALS AND METHODS

1. Data

The materials used in the present study were AM/PM milk yield records collected as part of the dairy herd improvement program supervised by the National Livestock Cooperatives Federation from December 2008 until April 2013. For AM and PM records, the milking starting times in the morning and afternoon hours were recorded by inspectors, with one hour as the effective unit per dairy farm. Additionally, the difference between the previous and current milking starting time was calculated as the milking interval (MI) based on a total milking time consumed of one to one and a half hours for a herd of around 30 cattle. Since observation data by MI was in short supply, valid records of AM/PM milking interval were categorized as 11/13h, 12/12h, 13/11h, and 14/10h. One time milk yields of less than 3 kg per cattle, more than 51 kg, and cases in which the milk yield record for the AM was more than double or less than half of the PM record were excluded. Additionally, data collected from cattle with Day in Milk (DIM) values of more than 411 days after calf delivery were excluded from the analysis. Test-day records with greater than 20 per Herd-Test-Dates (HTD) were retained. After excluding abnormal data by using AM/PM milk yields, milk yields on the test day were estimated and the actual milk yield was compared with the estimated milk yield to verify the accuracy of estimates. Finally, 3,156,734 AM/PM records from a total of 3,708 dairy farms were used for this analysis.

2. Statistical method

When the physiological characteristics of cows are considered, health status, parity (or age), lactation stage, milking time, and genetic factors can affect the daily milk yield (MY_D) on

Table 1. Description of abbreviations used in this study

Abbreviation	Description
AM/PM	Before noon/after noon
MI	Milking interval between previous milking time and current milking time on the same test-day
DIM	Days in milk
LS	Lactation stage (defined in Table 2)
C_1	Milking cows with first parity
$C_{2\leq}$	Milking cows with greater than or equal to the second parity
MY_A	Observed milk yields at AM milking
MY_P	Observed milk yields at PM milking
MY_D	Observed daily milk yields on test day ($MY_A + MY_P$)
LRM	Linear regression model
NHM	Non-linear hierarchical model
SMF	Systematic milk production function with factors
PMF	Physiological milk production function with MI
k	Curvature rate on PMF
MY_{12h}	Parameter of milk yields with MI of 12h on PMF
$\widehat{MY}_{D(A)}$	Predicted daily milk yields obtained using the observed AM milk yields
$\widehat{MY}_{D(P)}$	Predicted daily milk yields obtained using the observed PM milk yields

the test day of each dairy cow. Additionally, management factors such as feeding management, milking type, and milking method can be considered, as can the effects of seasonal environment and feeding management. When daily milk yield is categorized into partial AM or PM milk yields, the various factors listed above influence the estimates of daily milk yield using AM or PM milk yields. However, since farm management or environmental factors commonly affect the HTD category, daily milk yields based on AM/PM milk yields according to parity, lactation stage, and milking interval taking into account the physiological aspect of the dairy cattle were estimated after adjusting environmental factors. The statistical methods used in the present study estimated daily milk yields (MY_D) by applying a Linear Regression Model (LRM) considering the parity of cows, lactation stage, milking time, etc. and MY_D by setting a Non-linear Hierarchical Model (NHM) in which the growth curve function formula suggested by Brody (1945) is used to reflect milk production capability and the physiological characteristics of MI. The efficiencies of analyzed estimates for both models were compared. Additionally, when estimating MY_D on the test day based on a one time measurement record, a linear model for AM/PM milk yield was set up as below and advance calibration was conducted for the seasonal factor to remove bias by farms and seasons. Daily actual milk yields were calibrated and then defined as a sum of AM/PM milk yields. The statistical analysis model for pre-calibration is as below.

$$y_{ijklmn} = (H_j + SN_k + MI_l + LS_m)_i + e_{ijklmhn} \quad \cdots\cdots (1)$$

where, y_{ijklmn} is the nth milk yield record during the AM (or PM) that belongs to the jth herd (level 3,708), which overlapped in the ith parity (level 2: 1 = one parity, 2 = more than two parities), kth is the season (level 4: 1 = March-May, 2 = June-August, 3 = September-November, and 4 = December-February), lth is the milking interval (level 4: 1 = 11/13h, 2 = 12/12h, 3 = 13/11h, and 4 = 14/10h), and mth is the lactation stage (level 12, see Table 2). H_j, SN_k, MI_l, and LS_m are the herd, season, milking interval, and effect of lactation stage overlapped in the ith parity, respectively, and $e_{ijklmhn}$ is the arbitrary residual variation effect.

1) Linear Regression Model (LRM)

There have been many studies conducted to evaluate MY_D estimation by LRM (Lee and Wardrop, 1984; DeLorenzo and Wiggans, 1986; Wiggans, 1986; Hargrove, 1994; Lee et al., 1995; Cassandro et al., 1995; Liu et al., 2000; Schaeffer et al., 2000). In the present study, LRM was set by modifying the model that had the best MY_D estimate among various models proposed by Liu et al. (2000) as below:

$$M^{24}_{ijmn} = [b_1 M^{AT}]_{ijm} + e_{ijmn} \quad \cdots\cdots (2)$$

where, M^{24}_{ijmn} is the MY_D of the n^{th} cows that belong to the i^{th} parity, j^{th} lactating stage, and m^{th} milking interval. M^{AT} is

Table 2. Definition of lactation stage by days in milk and number of records of AM/PM milking in Korean Holstein cows

LS	Range of DIM	No. Records	
		AM	PM
1	4~ 30d	73,083	164,079
2	31~ 50d	59,480	128,161
3	51~ 70d	59,426	125,119
4	71~ 90d	60,353	123,990
5	91~110d	61,699	123,835
6	111~130d	61,053	120,642
7	131~150d	61,770	119,812
8	151~180d	93,545	177,225
9	181~220d	124,164	231,605
10	221~260d	124,006	226,412
11	261~300d	111,483	204,086
12	301~260d	124,396	225,509
13	360~410d	70,601	119,547

the AM (or PM) milk yields measured from the ith parity, jth lactation stage, and mth milking interval, b_1 is the estimate by the simple regression coefficient, and e_{ijmn} is the arbitrary residual variation factor.

2) Non-linear Hierarchical Model (NHM)

The NHM model, which considers the milk production capability of the mammary cells of cows and the elapsed time after milking, was set by modifying the statistical analysis model at the physiological aspect suggested by Klopcic et al.(2013) as below:

$$M^{AT}_{ijmn(t)} = \left[(M_{12h})^{\left(\frac{t}{1+k(t-1)}\right)} - 1\right]_{ij} + e_{ijmn} \quad \cdots\cdots (3)$$

where, $M^{AT}_{ijmn(t)}$ is the AM (or PM) milk yields of the cows that belong to the ith parity and jth lactation stage, M_{12h} is the parameter for the 12h milk yields at the ith parity and jth lactation stage, k is the parameter for the coefficient of the lactation curve at the ith parity and jth lactation stage. These are the values after data conversion, so that MI, which overlaps the parity and lactation stages, has a value in the range of 0~2.

The linear approximation for the coefficient of the lactation curve ($\hat{k}$) by parity, lactation stage, and AM/PM was carried out by multiple regression analysis for the test day (DIM) as shown below:

$$\hat{k} = f(d_i) = b_0 + b_1 d_i + b_2 d_i^2 + e_i \quad \cdots\cdots (4)$$

where, $d_i = DIM_i/410$ is the rescaled value within a range of 0~1.

3) Accuracy

To predict the accuracies of the estimates, the variation and variance of differences (residual value) between observation and estimation before data calibration were analyzed for each model and parameter. The accuracy of an estimate was calculated using the following equation:

$$Accuracy(R^2) = \frac{\sigma^2_{MY_D}}{\left(\sigma^2_{MY_D} + \sigma^2_e\right)} \quad \cdots\cdots (5)$$

where, $\sigma^2_{MY_D}$ is the variance of actual MY_D observations and σ^2_e is the variance of the difference (error) between estimated and observed values.

The estimate of milk yield on test day was estimated by equation (6)

$$\widehat{M^{24}_{in(t,d)}} = \left[2\left\{\left(M^{24}_{n(t,d)}\right)^{\left(\frac{1+\hat{\hat{k}}(t-1)}{t}\right)} - 1\right\}\right]_i \quad \cdots\cdots (6)$$

where, $M^{AT}_{n(t,d)}$ is the AM (or PM) milk yields for nth cows on a test-day d of ith parity $t = MI/720$, $\hat{\hat{k}}$ is the linear approximation of the estimates of the lactation curve coefficient of the AM/PM record by parity and test-day based on equation (4), and $\widehat{M^{24}_{in(t,d)}}$ is the estimate of milk yield on the test-day. This statistical model was analyzed using the SAS statistical analysis program (SAS, 2012).

RESULTS AND DISCUSSION

1. AM/PM milk yields by test-day and MI

AM/PM milk yields and test day according to MI are presented in Table 3. The test-day milking records investigated according to the A4 method for the five most recent years showed that AM/PM milking records with equal MI (12/12h) values were around 64.1% of the total, while records with milking intervals of 13/11h were around 31%, and other milking intervals were 4.7%. The milk yields showed that the average milk yield (standard deviation) of AM and PM records were 15.70 (4.56) and 14.79 (4.42), respectively, indicating that AM milk yield was about 8% higher than PM milk yield. In the MI of 12/12h, AM milk yields were 15.60 kg, which were about 5% higher than PM milk yields of 15.05

Table 3. Means and standard deviations of AM/PM and daily milk yields by milking interval and parity in Korean Holstein cows

MI (AM/PM)	No. records	MI_{AM}/ MI_{PM}	MY_A		MY_P		MY_D		MY_A / MY_P	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD
All Cows										
11/13h	69,752	0.86	15.05	4.66	15.46	4.71	30.52	9.09	0.98	0.16
12/12h	2,023,739	1.00	15.60	4.54	15.05	4.46	30.65	8.79	1.05	0.14
13/11h	978,222	1.13	15.92	4.60	14.31	4.31	30.23	8.69	1.13	0.16
14/10h	85,021	1.33	16.11	4.70	13.54	4.31	29.65	8.66	1.22	0.22
Overall	**3,156,734**	**1.05**	**15.70**	**4.56**	**14.79**	**4.42**	**30.49**	**8.76**	**1.08**	**0.15**
C_1										
11/13h	23,874	0.86	13.81	3.57	14.21	3.59	28.02	6.86	0.98	0.15
12/12h	697,531	1.00	14.30	3.31	13.76	3.28	28.07	6.36	1.05	0.14
13/11h	328,623	1.13	14.59	3.37	13.07	3.19	27.66	6.32	1.13	0.15
14/10h	28,616	1.33	14.80	3.49	12.42	3.25	27.22	6.35	1.22	0.21
Overall	**1,078,644**	**1.05**	**14.39**	**3.34**	**13.52**	**3.26**	**27.92**	**6.36**	**1.08**	**0.14**
$C_{2\leq}$										
11/13h	45,878	0.86	15.70	5.02	16.12	5.08	31.82	9.81	0.99	0.16
12/12h	1,326,208	1.00	16.28	4.93	15.72	4.84	32.00	9.55	1.05	0.14
13/11h	649,599	1.13	16.59	4.98	14.94	4.65	31.53	9.41	1.12	0.16
14/10h	56,405	1.33	16.77	5.08	14.10	4.65	30.88	9.39	1.22	0.22
Overall	**2,078,090**	**1.05**	**16.38**	**4.95**	**15.44**	**4.78**	**31.82**	**9.51**	**1.07**	**0.15**

C_1 : first calving cows; $C_{2\leq}$: greater than or equal second calving cows.

kg. These results are in accordance with those of previous studies (DeLorenzo and Wiggans, 1986; Liuet al., 2000). For example, DeLorenzo and Wiggans (1986) reported that AM milk yields contributed 50.5% of daily milk yields when conducted at 12 hour intervals. Similarly, Plaut and Casey (2012) reported that the milk yields of dairy cows of AM (MY_A) and PM (MY_P) differed due to the effects of endocrine systems regulated by the hypothalamus according to a circadian rhythm of 24 hours. They also found that milk yield was affected by circadian rhythm according to the appearance of a day and night regulatory gene (BMAL1 gene). The AM/PM milk yield by MI per parity showed that the milk yield trend estimated by MI was not greatly affected by parity. However, when the absolute milk yield was determined, the milk yield from multiparous cows ($C_{2\leq}$) was around 14% higher than that of the first calving cow (C_1) in cases in which the parity was higher than two. Conversely, after two parities there was not much difference in milk yield; thus, multiparous cows greater than or equal to the second calving were also categorized as the same population to estimate milk yield on the test day using AM/PM milking records.

Daily milk yield according to days in milk (DIM) is generally defined as a lactation curve. In the dairy industry in Korea, total milk yield during the lactation stage increased due to the high capability of dairy cows. Additionally, the average breeding interval is undergoing an increasing trend with around 451 days being average (National Agricultural Cooperatives Federation, 2011); therefore, the estimated daily milk yields using partial records should be applicable up to 410 days after parturition. Generally, milk yield is higher in $C_{2\leq}$ than in C_1. The milk yield increased as parity increased and then decreased after the fifth or sixth calving. In this study, milk yield was low in C_1 until DIM250 relative to that of $C_{2\leq}$. However, milk yield after this point was greater than the average milk yield of $C_{2\leq}$ (Fig. 1). That is, C_1 showed a higher lactation persistence than $C_{2\leq}$. Daily milk yield and AM/PM milk yield trends also differed. Specifically, AM milk yield was somewhat higher than PM milk yield throughout the lactation period. The phenomena of higher lactation persistency in C_1 than $C_{2\leq}$ has been officially published in the Canadian dairy network (www.cdn.ca) from Canada and the dairy records management systems (www.drms.org) from the United States. This phenomenon was also reported by Muir et al. (2004). It is possible that this occurs because mammary cells simultaneously

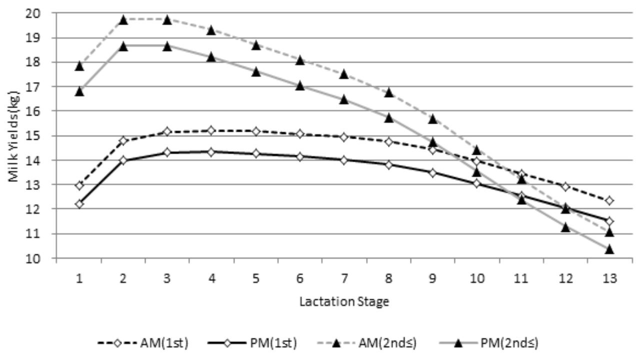

Fig. 1. Average milk yields of AM/PM milking by lactation stage in first calving cows and greater than or equal to second calving cows in the Korean Holstein population.

develop with body growth in cows that are calving for the first time.

It was assumed that AM milk yields and PM milk yields have a correlation of around 0.89 (Table 4); however, the observed correlation was only 0.84 in C_1 and 0.90 in $C_{2\leq}$. Regression analysis for AM and PM milk yields by statistical model (1) (Table 5) showed that farm, season, milking interval, and lactation period all differed significantly ($p<0.01$). Among these factors, lactation period exerted the largest effect on milk yields, although it was also affected by season. Specifically, milk yield was higher during spring (March-May) than autumn (September-November), with the greatest difference occurring during winter (December- February). This might have occurred due to changes in temperature by season as well as differences in length of day. Specifically, heat stress and high humidity might decrease milk yield (Barash et al., 2001). Indeed, Silanikove et al. (1997) defined the optimum temperature for dairy cattle as 13~14ºC, while Barash et al. (2001) reported that milk yield was reduced by 0.38 kg as temperature increased by one degree, even in the optimum temperature range. The difference in AM/PM milk yield by season estimated in the present study was applied in the parameter estimation of lactation.

Table 4. Correlation coefficients between AM/PM and daily milk yields in Korean Holstein cows

	$MY_A : MY_P$	$MY_A : MY_D$	$MY_P : MY_D$
Overall	0.89	0.97	0.97
C_1	0.84	0.96	0.96
$C_{2\leq}$	0.90	0.98	0.97

C_1 : first calving cows;
$C_{2\leq}$: greater than or equal second calving cows.

2. Estimation of AM/PM lactation curve

In the regression model described above (2), estimates by parity, MI, and lactation stage for the MY_A or MY_P are provided in Appendix 1. The estimate of a regression coefficient can be utilized as a correction factor to estimate daily milk yields on the test day using one time test records. The estimate of AM milk yields and PM milk yields using a correction factor by MI for each different lactation stage for the milking cows ($C_{2\leq}$) with more than two calvings are provided in Fig. 3. The average AM/PM milk yields ratio with a milking interval of 11/13h was 0.975, while the average ratio of AM/PM milk yields with a milking interval of 12/12h was 1.034. The ratio of AM/PM milk yields with a milking interval of 14/10h was 1.181, in which AM milk yields were 18.1% higher than PM milk yields. This tendency did not vary greatly bylactation stage and the same tendency appeared in first calving cows (C_1). Furthermore, in the regression analysis model set up, if both MY_A and MY_P records are not available, MY_D was analyzed by being set as a regression formula with no intercept. Based on these results, MY_A was higher than MY_P when the milking interval was 12/12h because of physiological factors

Table 5. Mean squares of AM/PM and daily milk yields of first calving and greater than or equal to second calving cows in the Korean Holstein population determined by generalized linear models

Class	DF	C_1			$C_{2\leq}$		
		MY_A	MY_P	MY_D	MY_A	MY_P	MY_D
Herd	3,694	637	650	2,474	1,677	1,766	6,652
Season	3	8,858	25,094	56,339	22,135	86,922	188,498
MI	3	4,878	5,129	−	11,565	11,174	−
LS	12	75,754	71,874	294,978	1,299,928	1,186,226	4,969,594
Residual		8.12	7.51	28.49	13.93	12.77	49.50

C_1: first calving cows; $C_{2\leq}$: greater than or equal second calving cows; MI: milking interval; LS: lactation stage.

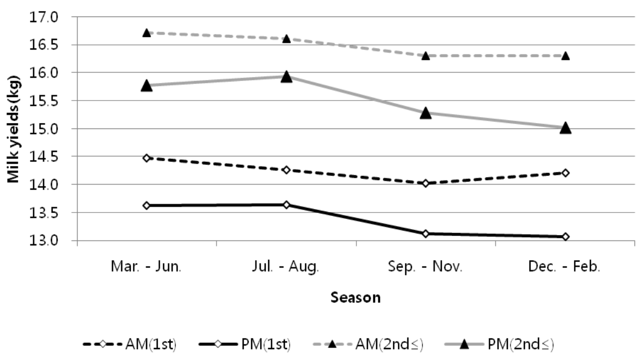

Fig. 2. Average milk yields of AM/PM milking by season in first calving cows and greater than or equal to second calving cows in the Korean Holstein population.

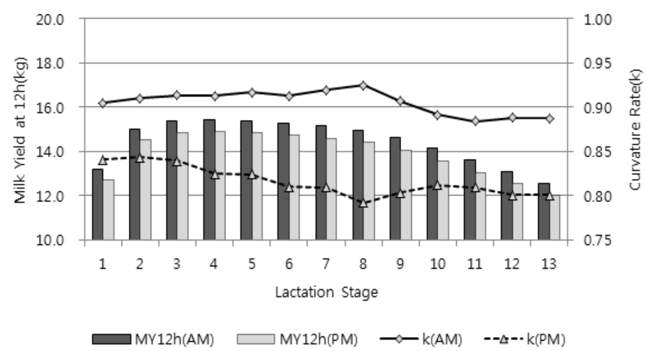

Fig. 4. Estimates of milk yields at 12h (MY_{12h}) and curvature rate (k) for AM/PM milk yields using the modified Brody growth function in first calving Korean Holstein cows.

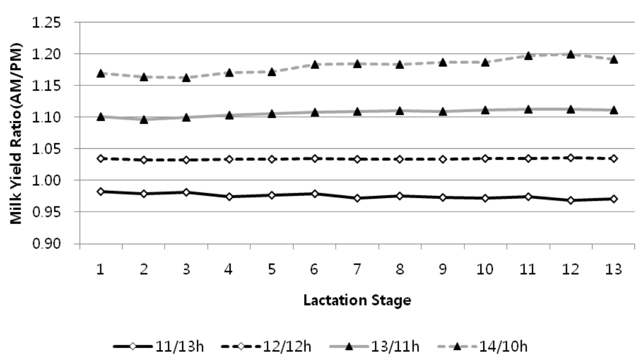

Fig. 3. Milk yield ratio (AM/PM) calculated by estimates of regression coefficients according to lactation stage in a linear regression model in greater than or equal to second calving cows in the Korean Holstein population.

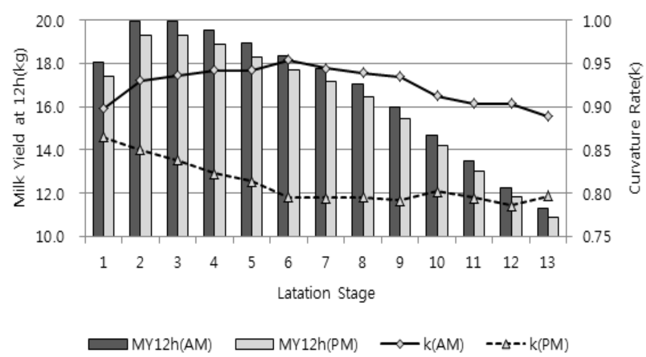

Fig. 5. Estimates of milk yields at 12h (MY_{12h}) and curvature rate (k) for AM/PM milk yields using the modified Brody growth function in greater than or equal to second calving Korean Holstein cows.

influencing the dairy cattle due to changes in their circadian rhythm, which would affect milk yields (Paut and Casey 2012).

According to model (3), which used a NHM (Fig. 4 and 5), estimated milk yield with a milking interval of 12h per lactation stage was similar to the lactation curve. Additionally, the AM milk yield estimate ($\widehat{MY}_A$) was higher than the PM milk estimate ($\widehat{MY}_P$) in both C_1 and $C_{2\leq}$ dairy cows. Although the absolute value of the estimate from C_1 cattle was lower than that of $C_{2\leq}$ cows, lactation persistence was higher. The coefficient of lactation curve in model (3) is also important to estimation of milk yield by the milking time of each cow and it was assumed that it would have similar trends to that defined in the growth curve function proposed by Brody (1945). The standard lactation curve estimated in the present study would be an estimate that reflects the milk yield characteristics of mammary tissues by milking time without taking into account the characteristics of each milking cow. The MY_D of each cow can be estimated using an estimate of the standard lactation curve applied differently per lactation stage and one time milking amount recorded during either AM or PM, in which the characteristics of the cow itself are reflected. To examine the standard curve of milk producing capability by MI from an estimated lactation curve function, the formula for estimation based on AM values for the $C_{2\leq}$ cows was adopted to determine milk producing capability by milking time by implementing the milk yields on DIM60 and DIM240 (Fig. 6). Even if the function that decides the gradient of the lactation curve on different test days is the same as that shown in Fig. 6, if the parameter estimates are different for the milk yield at 12h milking intervals (DIM60 = 19.95 and DIM240 = 14.69 in Fig. 6), the milk yields per milking time of MI showed a great difference. These findings indicate that

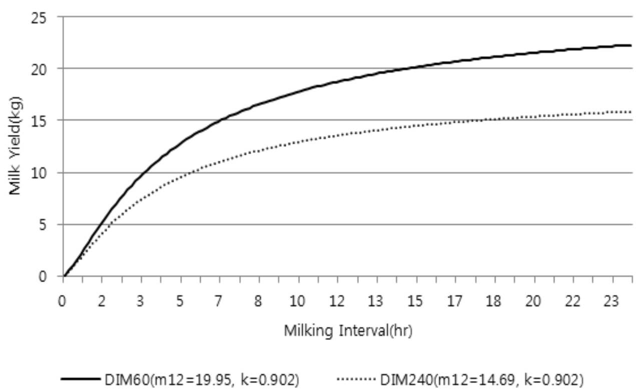

Fig. 6. Estimated milk production curves by milking intervals when greater than or equal to second calving cows were milked in the morning and Days in milk of 60d/240d by using the parameter estimates of the modified Brody milking function.

parameter estimates with 12h milking intervals significantly influence the actual AM/PM milk yields. Moreover, the milk yields have to be examined by cows and milking time of the same DIM by MI and cow, but this is practically very difficult. Thus, in the present study, a reference value was used by grouping the milk yield by milking stage and parity. The $\widehat{MY}_D$ for each cow can be estimated by using estimates from AM/PM milk yield information and from the gradient of the standard lactation curve.

3. Estimation of daily milk yield on test day

The residual difference ($\widehat{MY}_D - MY_D$), which is the difference between $\widehat{MY}_D$ and MY_D by parity, lactation stage, MI, and AM/PM milk yield (Table 6), showed that the average estimate ($\widehat{MY}_{D(A)}$) using an AM record was reduced by around 0.09 kg. Conversely, the estimate ($\widehat{MY}_{D(P)}$) by PM record was reduced by around 0.15 kg. The variation was larger in $C_{2\leq}$ cows than in C_1 cows, and the same trend was observed as the deviation of MI became higher. Nevertheless, the size of the absolute deviation (less than 0.33 kg) could be ignored. However, the accuracy of $\widehat{MY}_D$ estimated by the formula described above (5) became as high as 0.95 in both the AM and PM milk yield records, and the error of actual daily milk yield was within a standard deviation of ±0.8 kg. This accuracy in estimates is similar to that obtained by Liu et al. (2001). The accuracy of the estimate from $C_{2\leq}$ cows was about 2% higher than that of C_1 cows and higher in AM records than PM records. In addition, the greater the AM/PM milking interval was, the higher the accuracy was (C_1-14/10h-PM: 0.87, $C_{2\leq}$-12/12h-AM: 0.96).

When the parameter estimate ($\hat{k}$) for the lactation curve estimated by NHM, in which lactation physiological characteristics for each milking time is reflected, was the secondary value estimated with a polynomial regression by

Table 6. Means and standard deviations of the residuals of predicted daily milk yields of AM/PM milk yields and accuracies by milking interval criteria for first and greater than or equal to second calving Korean Holstein cows obtained using a linear regression model

	$\widehat{MY}_{D(A)} - MY_D$		$\widehat{MY}_{D(P)} - MY_D$		Accuracy	
	Mean	SD	Mean	SD	AM	PM
Overall	−0.09	1.92	−0.15	2.03	0.95	0.95
C_1	−0.08	1.71	−0.14	1.82	0.94	0.93
$C_{2\leq}$	−0.10	2.02	−0.16	2.14	0.96	0.95
C_1						
11/13h	−0.16	2.04	−0.12	1.99	0.92	0.92
12/12h	−0.08	1.69	−0.12	1.76	0.93	0.93
13/11h	−0.07	1.68	−0.15	1.87	0.93	0.92
14/10h	−0.10	2.07	−0.28	2.44	0.91	0.87
$C_{2\leq}$						
11/13h	−0.18	2.42	−0.15	2.36	0.94	0.95
12/12h	−0.10	2.01	−0.15	2.08	0.96	0.96
13/11h	−0.09	1.98	−0.18	2.19	0.96	0.95
14/10h	−0.10	2.40	−0.33	2.82	0.94	0.92

C_1: first calving cows; $C_{2\leq}$: greater than or equal second calving cows.

Table 7. Correlations ($r_{\widehat{MY}_{D(A,P)} - MY_D}$) between true and estimated daily milk yields, means, and standard deviations (SD) of predicted daily milk yields ($\widehat{MY}_D$) and residuals ($\widehat{MY}_D - MY_D$) from AM/PM milk yields in first (C_1) and greater than or equal to second ($C_{2\leq}$) calving Korean Holstein cows obtained using a non-linear hierarchical model

Milking time	Cows	$r_{\widehat{MY}_{D(A,P)} - MY_D}$	$\widehat{MY}_D$		$\widehat{MY}_D - MY_D$	
			Mean	SD	Bias	SD
AM	C_1	96.4	28.58	6.63	0.658	1.76
	$C_{2\leq}$	97.7	32.57	9.85	0.753	2.10
	Overall	**97.6**	**31.21**	**9.08**	**0.720**	**1.99**
PM	C_1	96.2	27.47	6.64	−0.448	1.82
	$C_{2\leq}$	97.5	31.43	9.75	−0.393	2.17
	Overall	**97.4**	**30.08**	**9.01**	**−0.412**	**2.06**

C_1 : first calving cows; $C_{2\leq}$: greater than or equal second calving cows.

model equation (4) and when the milk yield was examined on the test day using this secondary estimated value ($\hat{\hat{k}}$) and partial (AM or PM) milk yield by model (6) (Table 7), the deviation was similar on all test days for parity (C_1 vs $C_{2\leq}$) and AM/PM milk yields. Based on these findings, the average residual variation of estimates of AM/PM milk yields by model equation (3) was considered to be in conformity with the model having a value of 0. While deviation was generated due to the second estimation by model equation (6) of $\hat{k}$, the standard deviation ($\sqrt{MSE}$) of residual variation was significantly reduced. For example, the standard deviation (SD) of $\widehat{MY}_D$ by AM milk yield was estimated to be 4.27 kg, but the standard deviation of $\widehat{MY}_D$ was reduced to 1.99 kg by assuming that $\hat{\hat{k}}$ was the linear approximation of the relationship between the parameter for the coefficient of the lactation curve and days in milk. When the AM or PM milk yield records for all cows were used, the residual variations were reduced in all cases. Therefore, the present research using NHM could increase the accuracy of estimated daily milk yields by using the estimated lactation curve of formula (6); however, this generated some deviations in milk yield. When the average value for the size of deviation by each parameter from this model was compared, the estimate obtained using the AM milk yield for C_1 was overestimated by 0.658 kg relative to the actual test. Conversely, the estimate obtained using PM milk yield was overestimated by 0.753 kg and the estimate acquired using PM milk yield was underestimated by 0.393 kg (Appendix 2). After calibrating the size of these deviations, the correlation between the estimated and actual measurement for daily milk yield using MY_A and MY_P for each parameter was examined (Table 7). The results showed that a correlation estimate of 0.96 was observed for C_1 cows, while the accuracy of the estimate obtained using formula (5) was 0.93 (Table 8). In addition, the correlation between estimates and actual milk yields for $C_{2\leq}$ was highest (0.98) in both MY_A and MY_P records, while the accuracies of estimates were 0.96 and 0.95, respectively. These estimates were either very similar to the accuracy of estimates by LRM or about 1% lower. In addition, the tendency by parity and MI by lactation stage were also quite similar (Table 8). As shown in Table 8, in the case of residual variation, which is the difference between estimated and actual milk yield, the average by milking time varied instead of showing 0. This might have been because MI was regarded as a variation, as suggested in model equation (6). Therefore, a link function that can connect model equation (3) with model equation (6) by the use of a function equation would be required. The residual variation of $\widehat{MY}_D$ estimated by model equation (6) showed a similar shape as the lactation curve (Fig. 7). The estimate obtained using MY_A was lower in C_1 and $C_{2\leq}$ cows than that obtained using MY_P; therefore, the accuracy of the estimate using MY_A was relatively higher (Fig. 8). In addition, a relatively low accuracy was observed during the middle period of lactation, which accounted for a large portion of the variation between cows during this period.

There was no large difference in the accuracy of estimation by correction factor (Appendix 1) by LRM and correction factor (Appendix 2) by NHM, and the obtained values matched. However, the correction method obtained by LRM led to inaccurate daily milk yield estimation when the

Table 8. Means and standard deviations for residuals of predicted daily milk yields of AM/PM milk yields and accuracies by milking interval criteria for first and greater than or equal to second calving Korean Holstein cows obtained using a non-linear hierarchical model after adjusting for bias by lactation stage

	$\widehat{MY}_{D(A)} - MY_D$		$\widehat{MY}_{D(P)} - MY_D$		Accuracy	
	Mean	SD	Mean	SD	AM	PM
Overall	0.00	1.99	0.00	2.06	0.95	0.95
C_1	0.00	1.76	0.00	1.83	0.93	0.93
$C_{2\leq}$	0.00	2.10	0.00	2.18	0.96	0.95
C_1						
11/13h	−0.33	2.10	−0.28	1.95	0.91	0.93
12/12h	−0.11	1.73	−0.10	1.73	0.93	0.93
13/11h	0.22	1.72	0.16	1.89	0.93	0.92
14/10h	0.51	2.13	0.71	2.61	0.90	0.86
$C_{2\leq}$						
11/13h	−0.57	2.46	−0.57	2.31	0.94	0.95
12/12h	−0.19	2.05	−0.17	2.05	0.96	0.96
13/11h	0.35	2.05	0.30	2.24	0.95	0.95
14/10h	0.91	2.52	0.97	3.10	0.93	0.90

C_1 : first calving cows; $C_{2\leq}$: greater than or equal second calving cows.

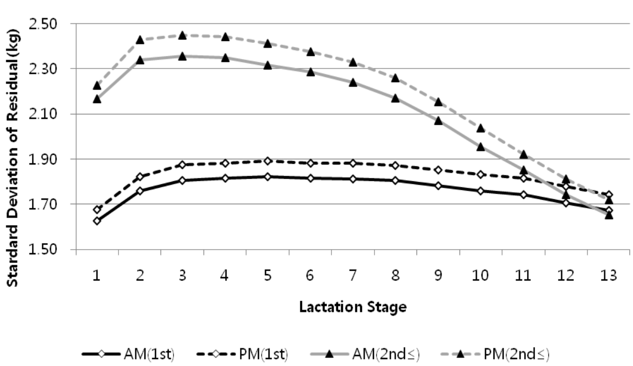

Fig. 7. Standard deviations of residuals from fitting a non-linear hierarchical model for predicting milk yields by AM/PM milk yields in first and greater than or equal to second calving Korean Holstein cows.

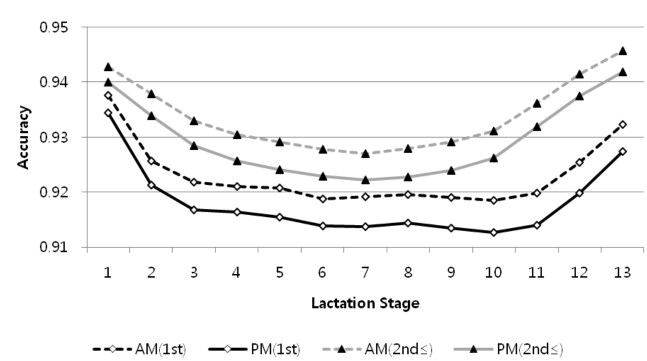

Fig. 8. Accuracies for predicting milk yields by AM/PM milk yields in first and greater than or equal to second calving Korean Holstein cows according to lactation stage using a non-linear hierarchical model.

milking interval was out of the range provided in Appendix 1 or when a test day was out of the specified range. On the other hand, the correction method by NHM was applied as a function that included the physiological milk production capability of cows and the milking interval. Finally, test-day data were used to estimate the daily milk yields and found to be useful for solving these problems. Therefore, the correction method by NHM was found to be more valuable than that of LRM.

Klopcic et al. (2013) developed a formula that estimates milk yields on a test day according to milking time. However, their method does not reflect the lactation characteristics of cows; thus, it is difficult to implement in the field. Conversely, milk yield estimation on a test day using the formula developed in the present study could be applied in industry. Nevertheless, additional work is needed to develop a model for estimation of milk composition and milk yield to predict milk production using AM/PM records.

ACKNOWLEDGEMENTS

The present study was supported by Korea Institute of Planning & Evaluation for Technology in Food, Agriculture, Forestry & Fisheries (Grant No: PJ008997). We thank the Dairy Cattle Improvement Center under the National Agricultural Cooperatives Federation for providing data for this project.

REFERENCES

Barash, H., Silanikove, N., Shamay, A. and Ezra, E. 2001. Interrelationships among ambient temperature, day length, and milk yield in dairy cows under a Mediterranean climate. J. Dairy Sci. 84:2314-2320.

Brody, S. 1945. Bioenergetics and growth. Reinhold Publishing Co., New York, NY.

Cassandro, M., Carnier, P., Gallo, L., Mantovani, R., Contiero, B. and Bittante, G. 1995. Bias and accuracy of single milking testing schemes to estimate daily and lactation milk yield. J. Daily Sci. 78:2884-2893.

DeLorenzo, M. H. and Winggans, G. R. 1986. Factors for estimating daily yield of milk, fat and protein from a single milking for herds milked twice a day. J. Dairy Sci. 69:2386-2394.

DHIA. 2010. Simplifying DHI test plans. National DHIA, National Dairy Herd Information Association (www.dhia.org, accessed by Jul. 2013).

Durr, J. and Reents, R. 2013. INTERBULL-30 years of history. (www-interbull.slu.se, accessed by Jul. 2013).

Hargrove, G. L. 1994. Bias in composite milk samples with unequal milking intervals. J. Dairy Sci. 77:1917-1921.

ICAR. 2011. International agreement of recording practices. ICAR Guidelines. International Committee for Animal Recording (ICAR), Rome, Italy.

INTERBULL. 2013. National GES information. (http://www-interbull.slu.se/national_ges_info2/ framesida-ges.htm, accessed by Jul. 2013).

Jenko, J., Perpar, T., Gorjanc, G. and Babnik, D. 2010. Evaluation of different approaches for the estimation of daily yield from single milk testing scheme in cattle. J. Dairy Res. 77:137-143.

Klopcic, M., Koops, W. J. and Kuipers, A. 2013. A mathematical function to predict daily milk yield of dairy cows in relation to the interval between milkings. J. Dairy Sci. 96:6084-6090.

Lee, A. J. and Wardrop, J. 1984. Predicting daily milk yield, fat present, and protein present from morning and afternoon tests. J. Dairy Sci. 67:351-360.

Lee, C., Pollak, E. J. and Everett, R. W. 1995. Multiplicative factors for estimation of daily milk and component yields from single morning or afternoon tests. J. Daily Sci. 78:221-235.

Liu, Z., Reents, R., Reinhardt, F. and Kuwan, K. 2000. Approaches to estimating daily yield from single milk test schemes and use of a.m.-p.m. records in test-day model genetic evaluation in dairy cattle. J. Dairy Sci. 83:2672-2682.

Ministry of agriculture, food and rural affairs (MAFRA). 2013. Enforcement Guidelines for agriculture, food and rural affairs, Livestock Improvement (Public affairs). MAFRA.

Muir, B. L., Fatehi, J. and Schaeffer, L. R. 2004. Genetic relationships between persistency and reproductive performance in first-lactation Canadian Holsteins. J. Dairy Sci. 87:3029-3037.

National Agriculture Cooperatives Federation. 2011. Yearly report for National Dairy Herd Improvement (2011). P90. National Agriculture Cooperatives Federation.

Neal, H. D. and Thornley, J. H. M. 1983. The lactation curve in cattle: A mathematical model of the mammary gland. J. Agric. Sci. 101:389-400.

Plaut, K. and Casey, T. 2012. Does the circadian system regulate lactation? Animal 6:394-402.

Schaeffer, L. R., Jamrozik, J., VanDorp, R., Kelton, D. F. and Lazenby, D. W. 2000. Estimating daily yields of cows from different milking schemes. Livest. Prod. Sci. 65:219-227.

Silanikove, N., Maltz, E., Halevi, A. and Shinder, D. 1997. Metabolism of water, sodium, potassium and chlorine by high yielding dairy cows at the onset of lactation. J. Dairy Sci. 80:949-956.

USDA. 2013. Estimating daily yields when not all milkings are weighed and sampled (AP Plans). USDA-AIPL (www.aipl.arsusda.gov, accessed by Jul. 2013).

Wiggans, G. R. 1986. Estimating daily yields of cows milked three times a day. J. Dairy Sci. 69:2935-2940.

(Received Sep. 6, 2013; Revised Oct. 10, 2013; Accepted Oct. 24, 2013)

Appendix 1. Multiplicative correction factor for estimating daily milk yields using partial (AM/PM) milk yields by parity, milking interval, lactation stage in Korean Holstein cows

	11/13h		12/12h		13/11h		14/10h	
	AM	PM	AM	PM	AM	PM	AM	PM
1st Parity								
1	2.0164	1.9642	1.9589	2.0278	1.9016	2.0922	1.8507	2.1481
2	2.0229	1.9604	1.9631	2.0246	1.9057	2.0888	1.8499	2.1501
3	2.0160	1.9657	1.9621	2.0257	1.9028	2.0915	1.8506	2.1486
4	2.0187	1.9640	1.9613	2.0263	1.8980	2.0978	1.8442	2.1579
5	2.0185	1.9651	1.9588	2.0289	1.8958	2.1000	1.8454	2.1540
6	2.0240	1.9582	1.9592	2.0285	1.8920	2.1047	1.8400	2.1616
7	2.0107	1.9709	1.9581	2.0295	1.8916	2.1050	1.8371	2.1639
8	2.0218	1.9600	1.9569	2.0305	1.8902	2.1063	1.8291	2.1766
9	2.0169	1.9644	1.9557	2.0315	1.8875	2.1093	1.8302	2.1725
10	2.0134	1.9668	1.9533	2.0334	1.8852	2.1116	1.8250	2.1787
11	2.0180	1.9626	1.9512	2.0350	1.8821	2.1143	1.8210	2.1818
12	2.0166	1.9618	1.9512	2.0345	1.8823	2.1131	1.8176	2.1863
13	2.0100	1.9668	1.9517	2.0330	1.8830	2.1117	1.8220	2.1802
Over 2nd Parity								
1	2.0085	1.9728	1.9603	2.0272	1.9015	2.0933	1.8448	2.1565
2	2.0120	1.9706	1.9619	2.0260	1.9057	2.0888	1.8495	2.1516
3	2.0101	1.9715	1.9618	2.0260	1.9024	2.0923	1.8496	2.1503
4	2.0170	1.9649	1.9604	2.0270	1.8999	2.0950	1.8435	2.1579
5	2.0140	1.9672	1.9601	2.0269	1.8973	2.0975	1.8421	2.1582
6	2.0111	1.9685	1.9595	2.0271	1.8957	2.0990	1.8334	2.1688
7	2.0188	1.9615	1.9601	2.0262	1.8945	2.1000	1.8326	2.1695
8	2.0146	1.9648	1.9597	2.0263	1.8934	2.1010	1.8329	2.1680
9	2.0166	1.9637	1.9597	2.0257	1.8934	2.1007	1.8292	2.1715
10	2.0177	1.9605	1.9583	2.0264	1.8918	2.1018	1.8289	2.1706
11	2.0142	1.9630	1.9583	2.0253	1.8901	2.1028	1.8218	2.1801
12	2.0201	1.9560	1.9567	2.0259	1.8897	2.1019	1.8186	2.1808
13	2.0171	1.9585	1.9562	2.0251	1.8899	2.1005	1.8237	2.1726

Appendix 2. Estimates of regression coefficients for k, which is a parameter of the physiological milk production function for standardized days in milk using AM/PM milk yields and bias due to circadian system effects in 1st and over 2nd calving Korean Holstein cows

Class		Intercept	Linear	Quadratic	Bias
1st calving cows	AM	0.90641	0.03130	−0.07015	0.658
	PM	0.86162	−0.15924	0.11838	−0.448
Over 2nd calving cows	AM	0.91859	0.13091	−0.17887	0.753
	PM	0.87403	−0.27378	0.21927	−0.393

Where equations for estimating the parameters

$$k = b_0 + b_1 x + b_2 x^2 + e \quad (x = DIM/410)$$

$$\widehat{MY}_D = 2\left\{ MY_{A(P)}^{\left(\frac{1+\hat{k}(t-1)}{t}\right)} - 1 \right\} - Bias \quad (t = MI/720,\ MY_{A(P)} \text{ is AM(or PM) observed milk yields})$$