Estimation of daily milk yield based on morning and evening milking*

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The aim of the study was to compare several methods for estimating daily milk yield on the basis of one milking – morning or evening – of cows evaluated by the AT4 method. The material consisted of data from milking robots, obtained from the Polish Federation of Cattle Breeders and Dairy Farmers (PFCBDF). A total of 43,309 milkings carried out between the 5th and 305th day of milking in cows milked once or twice a day were selected. The intervals between a given milking and the previous one were assigned to classes (MIC), and the lactations were divided into 10 one-month stages. Daily yield was estimated on the basis of linear regression equations. Three equations were compared: for first and later milkings (variant 1, models 1-3) or for all lactations combined (variant 2, models 4-6). The coefficients for model 1 were determined for time of milking, MIC and stage of lactation. The coefficients for model 2 were calculated for time of milking, while the interval between a given milking and the previous one was taken into account as an additional covariate. The coefficients for model 3 were determined for time of milking and MIC, while stage of lactation was replaced with day of milking. Implementation of model 1 is recommended, as it is a simple regression model that is easy to implement in practice. Determination of coefficients for lactations divided into first and later lactations allows for more precise estimation of daily milk yield.

KEY WORDS: AT4 method / morning milking / evening milking

Three A group methods are used in Poland to assess the milk performance of cows, A4, AT4 and A8, which have been accepted by the International Committee for Animal

Recording (ICAR). The reference method is A4. Using the A4 method the assessing zootechnician visits the cow barn every month and conducts test-day milking 11 to 13 times a year. The amount of milk obtained is measured for each milking during a 24-hour period. The AT4 method is similar, but test-day milking is conducted only once during the 24-hour period, in the morning one month and in the evening the next month. Daily milk yield is calculated as the amount of milk obtained during test-day milking multiplied by two. In the A8 method the system for recording milk obtained during test-day milking is the same as in the A4 reference method, except that test-day milking is conducted every 8 weeks [5]. To reduce costs many farmers choose less expensive methods, mainly AT4, instead of A4. In Poland about 67% of assessed cows are currently evaluated by the AT4 method, 28% by the A4 method, and 5% by the A8 method [4].

Because the AT4 method is used so often to assess the milk yield of cows, in recent years an attempt has been made to estimate daily yield of milk and its components on the basis of one milking record by a method more accurate than simply multiplying by two. Research evaluating the accuracy of the AT4 method as compared to the standard A4 method has been conducted by authors such as DeLorenzo and Wiggans [2], Cassandro et al. [1] and Liu et al. [3]. Most studies have shown that regression methods give more accurate estimates of daily yield than doubling the amount of milk from milking performed once in a 24-day period. This research has confirmed the substantial effect of the milking interval on estimated daily yield, whereas consideration of factors such as day in milk or lactation number is less significant in estimating daily yield.

The aim of the study was to compare several methods of estimating the daily milk yield of Polish Black-and-White Holstein Friesian cows on the basis of morning and evening milking.

Material and methods

The calculations were based on data on the daily yield of milk, fat and protein of 4,349 Polish Black-and-White Holstein Friesian cows. The data were obtained from milking robots and were provided by the Polish Federation of Cattle Breeders and Dairy Farmers (PFCBDF). We selected 43,309 test-day milking records from between days 5 and 305 of lactation for cows that were milked once or twice a day. Data on cows that were milked more often than twice a day were not considered. The data came from 9 lactations, which were divided into first and subsequent lactations (1, ≥2).

Data from morning milking (AM) accounted for 66% of the data (n=28,677), and data from evening milking (PM) for 34% (n=14,632). There were fewer milking records from first lactations (n=16,204, 37%) than from later ones (n=27,105, 63%). The intervals between a given milking record and the previous one were divided into classes (MIC). Eight MIC classes were formed for AM milking, i.e. ‹6-7), ‹7-8), ‹8-9), ‹9-10),

⟨10-11), ⟨11-12), ⟨12-13), and ⟨13-18) hours, and six classes for PM milking: ⟨6-7), ⟨7-8), ⟨8-9), ⟨9-10), ⟨10-11), and ⟨11-18) hours. A criterion used to form the MIC classes was a similar number in each class, and therefore fewer classes were formed in the case of PM milking than for AM milking. Each lactation was divided into ten 30-day stages.

The daily yield of cows was estimated on the basis of three linear regression equations [2, 3]:

(1) $$y_{TD} = b_0 + b_1 \times y_{AM/PM}$$

(2) $$y_{TD} = b_0 + b_1 \times y_{AM/PM} + b_2 \times MI$$

(3) $$y_{TD} = b_0 + b_1 \times y_{AM/PM} + b_2 \times (DIM - 153)$$

In each regression equation (1)-(3) the independent variable was the yield of milk, fat or protein from morning or evening milking ($y_{AM/PM}$), and the dependent variable was the daily yield of these same features (y_{TD}). Equation (2) also took into account the milking interval (in minutes) as covariate *MI*, and equation (3) took into account covariate *DIM*, i.e. the day in milk, with respect to the middle day of lactation (i.e. day 153 in milk). The coefficients b_0, b_1 and b_2 represented regression coefficients.

Regression coefficients were determined for six different models, using equations (1)-(3) in two variants: with a division into first and subsequent lactations (variant 1) or for all lactations combined (variant 2). Coefficients for model 1 were based on equation (1) within the following subclasses: lactation number (1, ≥2) x milking time (AM, PM) x milking interval (MIC) x stage of lactation. Coefficients for model 2 were estimated using equation (2) within the subclasses lactation number x milking time, and the milking interval (MI) was a covariant. Coefficients for model 3 were obtained using equation (3) within the subclasses lactation number x milking time x milking interval (MIC), and the stage of lactation was replaced by an additional covariate, i.e. the day in milk (DIM). Models 4-6 correspond to models 1-3 described above, but in these models regression coefficients were determined for all lactations combined, with no distinction between first and subsequent lactations.

In the case of each model (1-6) the linear regression coefficients for yield of milk, fat and protein were used to calculate the daily yield of these features. Daily yield estimated in this manner was compared with the milk yield determined by the currently used method, i.e. $y_{TD} = 2 \cdot y_{AM/PM}$, and with actual yield, using the following criteria:

– linear regression coefficient between estimated $(\hat{y}_{TD})$ and actual (y_{TD}) daily yield

– mean squared error (where the error = $y_{TD} - \hat{y}_{TD}$)

– standard deviation of estimated daily yields

– mean error in each stage of lactation

The model characterized by the highest correlation coefficient, the lowest mean squared error and the standard deviation closest to the value of this deviation for actual yields is the one that most accurately estimates the daily yield of cows. In addition, a standard deviation for the estimated yields which is lower than the value of this deviation for actual yields indicates a better estimation of daily yield, and for this reason such a model is recommended for implementation.

The computations were performed using the SAS/STAT procedures of the SAS statistics package [6].

Results and discussion

Tables 1 and 2 present the means, standard deviations and coefficients of variation for daily yield of milk, fat, and protein, estimated using each of the models and arranged according to the time of day and lactation number. Means for daily yield of the three traits calculated by models 1-3 are similar to actual yields. The standard deviations (SD) for yield estimated using each of the six models and the currently used method are about 2-4% lower than the SD for actual yield. Models 4-6 somewhat overestimate daily yield of all traits in the case of first lactations, especially model 5. In the case of later lactations actual yields are slightly underestimated by the models which do not distinguish between first and subsequent lactations (models 4-6). The results obtained for the current method differ most from actual daily yield. In this case there is a substantial underestimation of daily yield, even up to 9 kg of milk (for lactations ≥2 and PM milking). The coefficient of variation for the currently used method is highest (Tab. 1 and 2).

The ranking of the models (1-6) according to each of the criteria presented in Table 3 is similar. Linear correlation coefficients (r) between estimated and actual yields of milk and protein are high: from 0.88-0.91 (model 5) to 0.92-0.94 (model 1). The values for r for fat yield are lower, ranging from 0.83 (model 5) to 0.87 (model 1). Ranking of the models taking into account the accuracy of the fit, measured as the size of the mean squared error (MSE), is the same as according to the size of correlations, i.e. model 1 has the smallest error and model 5 the largest. In the case of each of the 6 models and each of the three traits, the standard deviation for estimated daily yield is lower than the SD for actual yield. Standard deviations estimated using model 1 are the most similar to the standard deviations for actual yield. The greatest difference between the standard deviations for actual yield and estimated yield were observed for model 5. This means that model 1 best approximates the actual distribution of yield of milk, fat and protein, with the most accurate estimate in the case of daily yield of milk, followed by protein and then fat.

The model currently used to estimate milk yield in the AT4 method differs from the regression models and gives the least accurate estimates of daily yield. In the case of this model the correlation coefficient ranges from 0.66 to 0.75, and MSE is over 5 times

Table 1
Means ($\bar{x}$), standard deviations (SD) and coefficients of variation (CV) of true (y_{TD}) and estimated daily yield using selected models in first lactation

Trait	Time of day		y_{TD}	Model						Current method
				1	2	3	4	5	6	
Milk (kg)	AM – a.m. milking	$\bar{x}$	27.045	27.045	27.043	27.045	27.469	27.740	27.450	21.425
		SD	6.648	6.046	5.778	6.015	6.287	6.353	6.252	5.950
		CV	24.580	22.350	21.370	22.240	22.890	22.900	22.780	27.770
	PM – p.m. milking	$\bar{x}$	27.534	27.534	27.531	27.534	27.985	28.185	27.969	20.212
		SD	6.661	6.089	5.862	6.060	6.364	6.448	6.336	5.537
		CV	24.190	22.120	21.290	22.010	22.740	22.880	22.650	27.400
Fat (kg)	AM – a.m. milking	$\bar{x}$	1.054	1.054	1.052	1.054	1.092	1.097	1.091	0.836
		SD	0.237	0.197	0.189	0.195	0.212	0.215	0.211	0.240
		CV	22.450	18.670	18.000	18.500	19.390	19.620	19.300	28.730
	PM – p.m. milking	$\bar{x}$	1.065	1.065	1.064	1.065	1.103	1.107	1.102	0.805
		SD	0.237	0.196	0.190	0.194	0.208	0.210	0.206	0.226
		CV	22.300	18.440	17.830	18.240	18.850	19.000	18.690	28.090
Protein (kg)	AM – a.m. milking	$\bar{x}$	0.899	0.899	0.897	0.899	0.913	0.923	0.913	0.712
		SD	0.204	0.183	0.175	0.182	0.189	0.192	0.188	0.194
		CV	22.660	20.340	19.480	20.230	20.690	20.760	20.610	27.250
	PM – p.m. milking	$\bar{x}$	0.911	0.911	0.912	0.911	0.927	0.934	0.926	0.675
		SD	0.204	0.184	0.176	0.183	0.190	0.194	0.189	0.181
		CV	22.400	20.170	19.350	20.070	20.510	20.790	20.440	26.840

Table 2

Means ($\bar{x}$), standard deviations (SD) and coefficients of variation (CV) of true (y_{TD}) and estimated daily yield using selected models in later lactations

Trait	Time of day		y_{TD}	Model						Current method
				1	2	3	4	5	6	
Milk (kg)	AM – a.m. milking	$\bar{x}$	32.145	32.145	32.145	32.145	31.885	31.719	31.897	25.517
		SD	9.801	9.096	8.784	9.082	9.105	8.705	9.097	7.818
		CV	30.490	28.300	27.330	28.250	28.560	27.440	28.520	30.640
	PM – p.m. milking	$\bar{x}$	33.100	33.100	33.102	33.100	32.844	32.727	32.853	24.088
		SD	9.854	9.273	9.040	9.256	9.283	8.972	9.273	7.186
		CV	29.770	28.010	27.310	27.960	28.260	27.410	28.230	29.830
Fat (kg)	AM – a.m. milking	$\bar{x}$	1.268	1.268	1.268	1.268	1.244	1.238	1.245	1.004
		SD	0.359	0.307	0.295	0.305	0.310	0.296	0.309	0.314
		CV	28.340	24.210	23.270	24.080	24.900	23.900	24.810	31.270
	PM – p.m. milking	$\bar{x}$	1.299	1.299	1.297	1.299	1.277	1.278	1.278	0.985
		SD	0.356	0.304	0.295	0.302	0.310	0.299	0.309	0.302
		CV	27.400	23.400	22.750	23.290	24.230	23.390	24.160	30.650
Protein (kg)	AM – a.m. milking	$\bar{x}$	1.062	1.062	1.064	1.062	1.053	1.046	1.053	0.845
		SD	0.287	0.262	0.252	0.262	0.263	0.251	0.263	0.243
		CV	27.070	24.690	23.690	24.640	25.030	23.990	24.990	28.780
	PM – p.m. milking	$\bar{x}$	1.091	1.091	1.092	1.091	1.082	1.078	1.082	0.803
		SD	0.286	0.265	0.258	0.265	0.267	0.257	0.267	0.224
		CV	26.240	24.300	23.590	24.250	24.680	23.820	24.640	27.850

Table 3

Correlations (r) between true and estimated yields, mean squared errors (MSE), standard deviations (σ) of daily yields estimated using morning or evening milkings

| Trait	Time of day		Model						Current method	σ_{yTD}
			1	2	3	4	5	6		
Milk (kg)	AM – a.m. milking	r	0.93	0.90	0.93	0.93	0.90	0.93	0.70	
		σ	8.44	8.16	8.43	8.43	8.13	8.42	7.44	9.080
		MSE	11.16	15.83	11.47	11.47	16.43	11.66	82.29	
	PM – p.m. milking	r	0.94	0.92	0.94	0.94	0.91	0.94	0.75	
		σ	8.69	8.47	8.67	8.67	8.44	8.65	6.89	9.230
		MSE	9.73	13.43	10.05	10.07	14.00	10.27	107.97	
Fat (kg)	AM – a.m. milking	r	0.87	0.84	0.86	0.86	0.83	0.85	0.65	
		σ	0.29	0.28	0.29	0.29	0.28	0.29	0.30	0.335
		MSE	0.03	0.03	0.03	0.03	0.04	0.03	0.13	
	PM – p.m. milking	r	0.87	0.85	0.86	0.86	0.84	0.86	0.70	
		σ	0.29	0.29	0.29	0.29	0.28	0.29	0.29	0.337
		MSE	0.03	0.03	0.03	0.03	0.03	0.03	0.15	
Protein (kg)	AM – a.m. milking	r	0.92	0.88	0.92	0.91	0.88	0.91	0.66	
		σ	0.25	0.24	0.25	0.25	0.24	0.25	0.24	0.271
		MSE	0.01	0.02	0.01	0.01	0.02	0.01	0.09	
	PM – p.m. milking	r	0.93	0.90	0.93	0.93	0.90	0.93	0.71	
		σ	0.25	0.25	0.25	0.25	0.25	0.25	0.22	0.274
		MSE	0.01	0.01	0.01	0.01	0.01	0.01	0.11	

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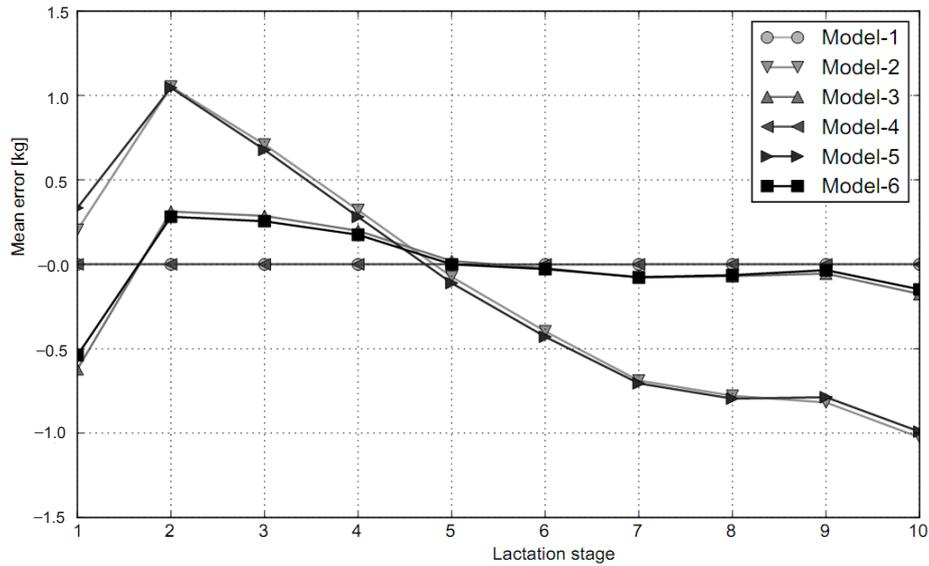
Fig. Mean errors of daily milk yield in successive lactation stages estimated using six models

higher (milk and protein) and 3 times higher (fat) than the MSE for model 5, which was the least accurate of the models analysed.

The figure presents the mean errors in estimating daily milk yield in successive stages of lactation. For clarity, the results for the currently used method are not included in the chart. It should be noted that in the currently used method all daily yields are underestimated; for example, the mean underestimation of daily milk yield ranges from 3.5 to 9.5 kg in successive stages of lactation (our own information), as compared to ±1 kg in the regression models (1-6). Models 1 and 4 are fitted to AM or PM yield within the largest number of subclasses which include the stage of lactation, which means that the mean error of the estimates is close to zero in each month (stage) of lactation. The remaining models (2, 3, 5 and 6) underestimate daily yields in the first months of lactation (stages 1-5) and overestimate these yields in the second half of lactation (stages 6-10). The least accurate is estimation of daily yields based on the simplest models (2 and 5), which do not take into account the stage of lactation. In this case the errors in estimating yield reach up to ±1 kg for milk (Fig.), ±0.06 kg for fat and ±0.03 kg for protein (our own information). Models 3 and 6, which are modified versions of the model by DeLorenzo

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and Wiggans [2], only slightly overestimate or underestimate daily milk yield. A similar tendency for all models compared (1-6) was also observed in the case of daily yield of fat and protein (our own information).

Model 1 is recommended due to its simplicity and ease of implementation in practice. This is confirmed by Liu et al. [3], who compared several regression models and found that model 1 most accurately estimates daily yields on the basis of morning and evening milking. These authors observed that the model by DeLorenzo and Wiggans [2], which corresponds to models 3 and 6 in the present study, less accurately estimated daily yields than model 1. Moreover, Liu et al. [3] found that model 1 least accurately estimated daily yields from afternoon milking during the first lactation.

Regression coefficients within lactations divided into two classes, first and subsequent, enable more accurate estimates of daily yield of the traits analysed than combined treatment of all lactations (as in model 4). There are two arguments in favour of fitting regression equations separately for AM and PM: 1) higher values for correlation coefficients and lower MSE in the case of the use of PM milking than for AM milking, and 2) the differences in the size of estimated parameters of simple regressions within MIC classes in individual models (our own information). It seems advisable to shorten the milking interval, because the accuracy of the daily yield estimate was low if the milking interval was less than 8 or more than 13 hours. Cassandro et al. [1] found that the milking interval is the main source of variation in estimating milk yield.

It should also be added that the percentage content of milk components (fat and protein) should be calculated on the basis of estimated daily yields of milk, fat and protein, and estimated regression coefficients should be periodically re-estimated.

REFERENCES

1. CASSANDRO M., CARNIER P., GALLO L., MANTOVANI R., CONTIERO B., BITTANTE G., JANSEN G.B., 1995 – Bias and accuracy of single milking testing schemes to estimate daily and lactation milk yield. ***Journal of Dairy Science*** 78, 2884-2893.

2. DE LORENZO M.A., WIGGANS G.R., 1986 – Factors for estimating daily yield of milk, fat, and protein from a single milking for herds milked twice a day. ***Journal of Dairy Science*** 69, 2386-2394.

3. LIU Z., REENTS R., REINHARDT F., KUWAN K., 2000 – Approaches to estimating daily yield from single milk testing schemes and use of a.m.-p.m. records in test-day model genetic evaluation in dairy cattle. ***Journal of Dairy Science*** 83, 2627-2682.

4. Polska Federacja Hodowców Bydła i Producentów Mleka (PFHBiPM), 2013 – Ocena i Hodowla Bydła Mlecznego. Dane za rok 2012. Warszawa.

5. Polska Federacja Hodowców Bydła i Producentów Mleka (PFHBiPM), 2014 – Raporty wynikowe z oceny wartości użytkowej i ich wykorzystanie w zarządzaniu stadem bydła mlecznego. www.pfhb.pl/dokumenty_ocena/.

6. SAS Institute, 2004 – SAS® 9.1.2 Qualification Tools User's Guide. Cary, NC: SAS Institute Inc.