New Approaches to Estimating Daily Yield from Single Milking Testing Schemes and Use of AM-PM Records in Test Day Model Genetic Evaluation

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Introduction

Milk recording system is an important factor for herd management and genetic improvement in dairy cattle. Under constantly increasing pressure of reducing costs, numerous milking testing schemes have been developed in many countries in last decades to supplement the standard supervised four-weekly testing scheme (monthly testing). In particular, the alternate morning and evening testing scheme (am-pm testing) has been regarded as an efficient way to achieve reasonable accuracy at a lower cost. Many studies have been conducted to investigate the accuracy of am-pm scheme in comparison to monthly testing (7). Most research work has been focused on the estimation of 305-day lactation records from single milkings (2, 5). As genetic evaluations using test day records become more popular in dairy industries (6), a thorough examination of the impacts of various estimation models on both mean and (co)variance structure of daily yield estimates is needed. The objectives of this study are to develop new statistical models for estimating daily yields, and to calculate accuracy of am-pm scheme for test day model genetic evaluation.

Material and Methods

Data stem from milk recording experiments designed for assessing the accuracy of am-pm scheme in six German states: Meklenburg-Western Pomerania, Lower Saxony, Palatinate, Saxony-Anhalt, Schleswig-Holstein and Thuringia, from 1994 to 1998. About 64,500 test day records of nearly 10,400 lactations of 8,800 cows were available from 1,055 milk tests in 152 herds. After edits on calving date, days in milk (DIM), milking interval (MI), lactation number and cow registration number, 62,459 test day records for Holstein cows remained. MI were grouped into four classes in a 30-minute interval for both morning and evening milking records, because intervals shorter or longer than 30 minutes were considered to be impractical for recording the information.

A few statistical models have been proposed to estimate daily yield (y_{A4}) from partial yield (y_{AT}) from single milkings (2, 3). In this study, seven models have been applied to the same data set in order to compare them in terms of accuracy.

Model 0: Original DeLorenzo factors without consideration of DIM (3), which had been *de facto* the standard method for estimating daily yield in Germany. Heterogeneous means and variances of partial or daily yields from different milking interval class (MIC) are modelled by fitting a separate regression line within each MIC.

Model 1. Doubling method:

$$y_{A4} = 2\,y_{AT} \qquad [1]$$

This model assumes that daily yield is expected to be twice the average of morning and evening milkings. No information from actual milking testing experiments is used in deriving conversion formulae from partial to daily basis.

Model 2. Single regression:

$$y_{A4} = b_0 + b_1\,y_{AT} \qquad [2]$$

Daily yield is regressed on morning or evening partial yield. Only one regression formula is fitted to the whole data set.

Model 3. Single regression plus MI as a covariate:

$$y_{A4} = b_0 + b_1\, y_{AT} + b_2\, MI \qquad [3]$$

Compared to Model 2, an additional regression coefficient on MI is added. Thus the average effect of MI on daily yield is taken into account.

Model 4. Separate regression for MIC *i:*

$$y_{A4}{}^{[i]} = b_0{}^{[i]} + b_1{}^{[i]} y_{AT}{}^{[i]} \qquad [4]$$

A separate regression formula is fitted for each MIC to account for heterogeneous means and variances of partial or daily yield. Models 0 and 4 are equivalent if the intercept term for every MIC is equal to zero. Model 4 makes a less restrictive assumption on the regression formulae than Model 0.

Model 5. Modified DeLorenzo and Wiggans' model:

$$y_{A4}{}^{[i]} = b_0{}^{[i]} + b_1{}^{[i]} y_{AT}{}^{[i]} + b_2{}^{[i]} (DIM - 158) \qquad [5]$$

Similarly to Model 4, there is one regression for each MIC *i*. Additionally, a regression coefficient on DIM is included in order to remove the effect of DIM on the residuals (3).

Model 6. Separate regression for every combination of parity *i*, MIC *j* and lactation stage *k*:

$$y_{A4}{}^{[ijk]} = b_0{}^{[ijk]} + b_1{}^{[ijk]} y_{AT}{}^{[ijk]} \qquad [6]$$

Since different parity and lactation stages have variable means and heterogeneous variances for both partial and daily milking records, the regression coefficients of daily yield on partial yield are likely to be heterogeneous among parity class or lactation stages. Therefore, a separate regression is fitted for each of the 96 levels (2 parity class x 4 MIC x 12 lactation stages).

As models become complex, more information is utilised in analysis, and this results in an improvement in accuracy of estimation.

In contrary to the other models, Model 0 uses the ratio of daily to partial yield from single milkings, instead of daily yield itself, as dependent variable in regression analysis. Thus Model 0 implicitly assumes that the regression lines go through point zero, $y_{A4} = 0$ if $y_{AT} = 0$, which may be unrealistic, because the lower limit of yields is always greater than zero. Since no regression factors for evening milkings were provided in DeLorenzo and Wiggans' study, these factors are usually derived mathematically based on those for morning milkings without analysing actual evening milking data. As shown later, such derived factors for evening milkings lead to large error in daily yield estimates. As Models 1 to 5, Model 0 does not consider the effect of parity. Due to lack of individual cow information on sample day fat or protein content as well as preceding MI for single milkings, the authors (3) had to use tank percentages for fat and protein and herd average MI to derive factors for estimating daily yield of fat and protein. As shown in a study by Averdunk et al. (1), using MI information on individual cows can improve the accuracy of estimation. Because of heterogeneous variances during the course of lactation for both partial and daily yields, fitting a single regression line to test day records from various lactation stages in Model 0 as well as Models 1 to 5 may not be optimal.

The accuracy of am-pm testing scheme for estimating daily yield is defined as (4):

$$R^2 = \sigma^2 / (\sigma^2 + MSE) \qquad [7]$$

where σ^2 is phenotypic variance of daily yield, and MSE is mean squared error. Phenotypic variance of daily yield (σ^2) were estimated using REML method under a test day model containing the fixed effects part of the model proposed by Reents et al. (6).

Results and Discussion

Goodness of fit of the models: Table 1 shows correlations between true and estimated daily yields ($r_{y_{A4},\hat{y}_{A4}}$), MSE and standard deviations of daily yield estimates ($\sigma_{\hat{y}_{A4}}$) from morning or evening milkings. Model with the smallest MSE and highest correlation gives the best fit to the data. Standard deviation $\sigma_{\hat{y}_{A4}}$ should be close to standard deviation of actual daily yield. But $\sigma_{\hat{y}_{A4}}$ must not be greater. Though the correlations improve along with the complexity of the models, with Model 6 achieving the highest correlations, differences between the models are small, except that Model 0 leads to low correlation for evening milk yield. In contrary, relatively evident differences in the correlations were observed among the three traits. The low correlation for fat yield indicates that there may be factors influencing fat yield or content that were not accounted for in the model. Evening milkings give slightly lower correlations than morning ones. All models, except Models 0 and 1, have smaller $\sigma_{\hat{y}_{A4}}$ than the true value. Overestimation of $\sigma_{y_{A4}}$ indicates that Models 0 and 1 are inappropriate for estimating daily yield. By definition, MSE measures both unbiasedness and variance of estimates, thus is the most appropriate statistic for ranking models. Based on MSE, Model 6 achieves the best fit, whereas Models 0 and 1 the worst.

Table 1. Correlations ($r_{y_{A4},\hat{y}_{A4}}$) between true and estimated daily yields, mean squared errors (*MSE*) and standard deviations ($\sigma_{\hat{y}_{A4}}$) of daily yield estimates from single milkings

Item	Model	Milk, kg			Fat x100, kg			Protein x 100, kg		
		$r_{y_{A4},\hat{y}_{A4}}$	$\sigma_{\hat{y}_{A4}}$	$\sqrt{MSE}$	$r_{y_{A4},\hat{y}_{A4}}$	$\sigma_{\hat{y}_{A4}}$	$\sqrt{MSE}$	$r_{y_{A4},\hat{y}_{A4}}$	$\sigma_{\hat{y}_{A4}}$	$\sqrt{MSE}$
AM	0	97.6	<u>8.050</u>*	1.764	92.6	<u>35.29</u>	13.30			
	1	97.2	<u>8.550</u>	2.033	93.9	<u>35.09</u>	12.08	96.5	<u>25.69</u>	6.80
	2	97.2	7.812	1.895	93.9	30.03	10.97	96.5	23.23	6.34
	3	97.6	7.844	1.757	93.9	30.04	10.96	97.0	23.35	5.89
	4	97.6	7.847	1.746	94.3	30.05	10.93	97.0	23.36	5.86
	5	97.6	7.849	1.736	94.1	30.10	10.79	97.0	23.37	5.83
	6	97.7	7.852	1.720	94.3	30.16	10.60	97.1	23.38	5.77
PM	0	95.8	<u>9.355</u>	2.842	93.3	31.88	11.67			
	1	96.8	8.025	2.033	93.2	<u>33.24</u>	12.08	96.1	<u>24.33</u>	6.80
	2	96.8	7.781	2.019	93.3	29.83	11.51	96.1	23.13	6.69
	3	97.1	7.805	1.925	93.4	29.86	11.43	96.4	23.21	6.42
	4	97.1	7.806	1.919	93.4	29.87	11.42	96.4	23.22	6.40
	5	97.2	7.814	1.889	93.7	29.95	11.19	96.5	23.23	6.33
	6	97.4	7.826	1.838	94.0	30.06	10.90	96.6	23.27	6.18

* Standard deviations of daily yield estimates that are greater than those of true daily yield, 8.039, 31.97 and 24.08 for milk, fat and protein yield respectively, are underscored.

Figures 1 and 2 show averaged errors: $y_{A4} - \hat{y}_{A4}$, in daily milk yield estimated from morning or evening milkings, respectively. Since Model 6 fits an individual regression formula for each lactation stage, an average estimation error by lactation stage is expected to be zero. However, for the rest of the models, daily milk yield is underestimated at the beginning of lactation and overestimated at the end of lactation. This systematic pattern of estimation error does not have a significant effect on the estimation of 305-day lactation records, except for short lactations, because the over- and underestimation are cancelled out, to a large extent. However, for estimating yield on daily basis, this systematic pattern of estimation error cannot be eliminated by alternating morning and evening testings.

The impacts of season of test or calving, herd production level, parity as well as MIC were also studied. All the models tend to overestimate daily yields from low producing test or calving seasons from morning milkings and to underestimate yields from low producing test seasons from evening milkings. By alternating morning and evening testings, this estimation error in different test or calving seasons can be cancelled out, to a great extent. This was also observed for parity and MIC. Since none of the seven models accounts for herd production level, which is partially confounding with MIC, yields from high producing herds were on average slightly underestimated, whereas yields from low producing herds were overestimated. As mentioned before, the estimation error by herd level can be partially removed by alternating morning and evening milkings. Since only Model 6 allows for variable means and variances at different parities by fitting separate regression lines within parity, the rest models tend to over- and underestimate daily yields from first or later parities, respectively, though the magnitude of the estimation error is small.

Cross validation of the models: The robustness of the models was examined by applying regression formulae estimated from one subset to the rest of the data set. Table 2 shows the results of the cross validation of the models. In general, all of the models seem to be robust towards different datasets with respect to the correlation between actual and estimated daily yields. Due to higher production level in the state from which the regression formulae were derived, daily milk yields from the rest states were slightly overestimated. The ranking of the models based on MSE remains very similar to the ranking based on data from all states. Model 6 is proven to be the best among all in the cross validation study.

Table 2. Results of the cross validation study

Item	Model	Milk, kg			
		$r_{y_{A4},\hat{y}_{A4}}$	Averaged error	$\sigma_{\hat{y}_{A4}}$	$\sqrt{MSE}$
AM	1	97.6	-1.316	7.567	1.777
	2	97.6	.472	6.962	1.685
	3	97.7	-.051	6.962	1.647
	4	97.7	.005	7.066	1.644
	5	97.7	.002	7.072	1.655
	6	97.7	-.079	7.037	1.657
PM	1	97.4	1.316	7.337	1.777
	2	97.4	-.680	7.280	1.770
	3	97.4	-.273	7.315	1.756
	4	97.4	-.265	7.293	1.758
	5	97.6	-.253	7.281	1.713
	6	97.6	-.300	7.310	1.713

Accuracy of the alternating scheme: Results of am-pm scheme accuracy are summarised in Table 3. It is obvious that Model 6 has the highest accuracy for all traits. There is a difference of about 2% in R^2 between morning and evening milkings for the yield traits. Accuracy of am-pm testing scheme comprises 91% of monthly testing scheme for milk yield, which means a reduction of 9% phenotypic variance of estimated daily yields from single milkings in comparison to actual daily yields. The accuracy for daily yield is lower than for 305-day lactation records as given by VanRaden (7). However, the high repeatability of test day yields results in a higher accuracy of a lactation record estimate than that of a daily yield estimate (Liu et al. 1998, unpublished data). Differences in R^2 exist among the traits, with milk yield having the highest R^2 value 91%, and fat yield the lowest 83%. R^2 for later parities is about 2% higher than that for first parity data, which suggests using separate R^2 for different parity test day records.

Use of single milking data in test day model genetic evaluation: Daily yield estimates from single milkings have smaller phenotypic variance than actual daily yields, and have an accuracy (R^2) of less than unity. For test day model genetic evaluation using both actual and estimated daily yields, estimates from single milkings must be first scaled to have the same genetic or phenotypic variance as the actual yields (7), and then they would be assigned to larger error variance in genetic evaluation (Liu et al. 1998, unpublished data). Depending on computational feasibility, it should be decided whether parity specific accuracy needs to be considered in genetic evaluation, in addition to different R^2 for each of the yield traits as well as for morning or evening milkings.

Table 3. Accuracy (R^2 in percent) of the alternate a.m.-p.m. milk testing scheme

		Milk yield from parity			Fat yield from parity			Protein yield from parity		
Item	Model	1	>1	All	1	>1	All	1	>1	All
AM	0	88.2	91.5	91.1	77.9	80.3	75.6			
	1	85.9	88.8	88.5	76.8	79.2	79.0	83.0	86.7	86.3
	2	87.2	90.2	89.9	78.4	80.6	82.0	84.6	88.3	87.9
	3	88.5	91.5	91.2	78.7	80.9	82.0	86.0	89.7	89.4
	4	88.5	91.6	91.3	78.7	80.9	82.1	86.0	89.8	89.5
	5	88.7	91.7	91.4	79.3	81.5	82.5	86.3	90.0	89.6
	6	89.3	91.8	91.5	80.5	82.0	83.0	87.0	90.1	89.7
PM	0	76.8	80.2	79.8	73.5	75.8	80.1			
	1	85.9	88.8	88.5	76.9	79.2	79.0	83.0	86.7	86.3
	2	86.4	89.0	88.7	80.8	82.1	80.5	84.0	87.0	86.7
	3	87.0	89.9	89.6	80.8	82.2	80.7	84.4	88.0	87.6
	4	87.1	90.0	89.7	81.0	82.2	80.8	84.6	88.1	87.7
	5	87.3	90.3	90.0	80.7	82.7	81.4	84.6	88.3	87.9
	6	88.8	90.6	90.4	82.3	83.0	82.2	86.2	88.6	88.4

Summary

Statistical models were presented for estimating daily yields from single milkings. Model 6, that accounts for heterogeneous variances due to parity, MIC and lactation stages by fitting separate regression formula within each combination of the three factors gives the best fit to the data, in terms of MSE, correlation between estimated and actual daily yields and variance of the estimates. Using a cross validation study, the resulting regression formulae of Model 6 are also proven to be robust towards different datasets. Daily yields estimated from evening milkings or first parity are less accurate than those from morning milkings or later parities. Alternating morning and evening milkings can partially remove the estimation errors caused by some factors, like test and calving seasons, MIC, herd production level or parity. However, the systematic under- or overestimation at the beginning and at the end of lactation observed for all models, except Model 6, cannot be cancelled out. DeLorenzo and Wiggans model which is currently widely used was shown not to be as accurate as Model 6, particularly for evening milking data. Smoothing Model 6 regression formulae across lactation stages results in a systematic pattern of estimation error, although there is nearly no loss in accuracy despite fitting much fewer parameters. The reduction in phenotypic variance as well as in autocorrelation of daily yield estimates from single milkings must be considered in test day model genetic evaluation.

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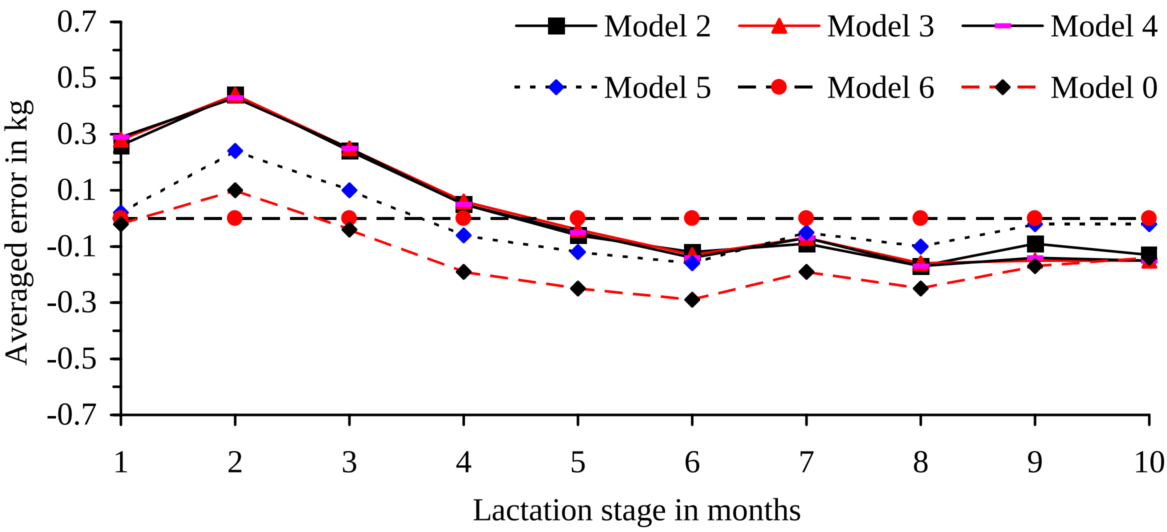

Figure 1. Averaged error in estimated daily milk yield from morning milkings. (Due to
large value of estimation errors, Model 1 is not shown.).

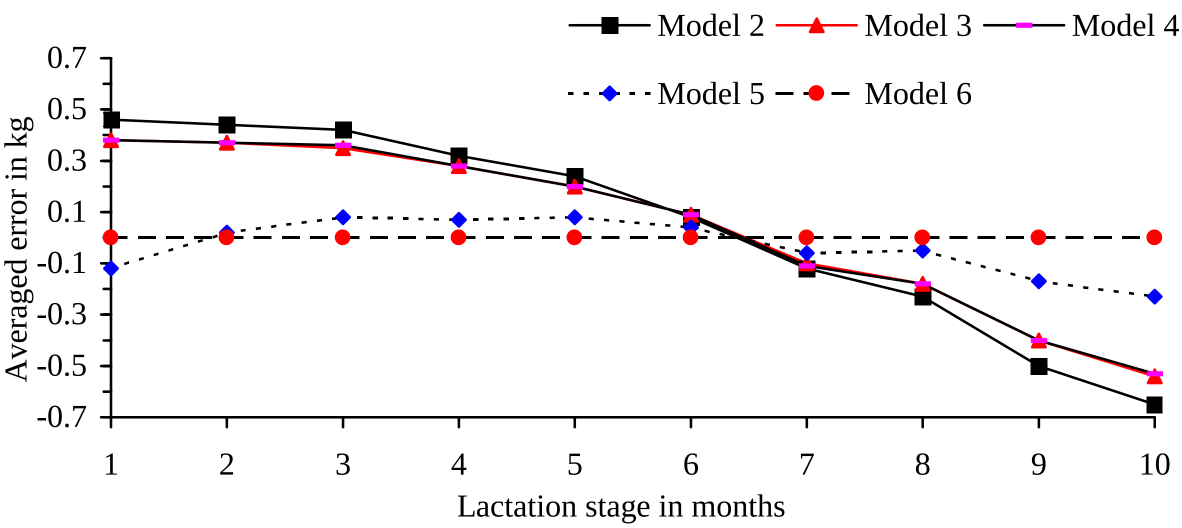

Figure 2. Averaged error in estimated daily milk yield from evening milkings. (Due to large value of estimation errors, Models 0 and 1 are not shown.).