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Prediction of 24-hour milk yield and composition in dairy cows from a single part-day yield and sample

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Abstract

The objective was to evaluate the accuracy of predicting 24-hour milk yield and composition from a single morning (AM) or evening (PM) milk weight and composition. A calibration dataset of 37,481 test-day records with both AM and PM yields and composition was used to generate the prediction equations; equations were validated using 4,644 test-day records. Prediction models were developed within stage of lactation and parity while accounting for the inter-milking time interval. The mean correlation between the predicted 24-hour yields and composition of milk, fat and protein and the respective actual values was 0.97 when based on just an AM milk yield and composition with a mean correlation of 0.95 when based on just a PM milk yield and composition. The regression of predicted 24-hour yield and composition on the respective actual values varied from 0.97 to 1.01 with the exception of 24-hour fat percentage predicted from a PM sample (1.06). A single AM sample is useful to predict 24-hour milk yield and composition when the milking interval is known.

Keywords

AM milking • low cost • milk recording • PM milking

Introduction

The within-herd ranking of cows for milk solids production influences the selection of candidate parents as well as candidates for voluntary culling. A large database of cow milk production records is also a prerequisite for accurate (national) genetic evaluations. Milk recording in dairy cows is usually undertaken several times during lactation by recording consecutive morning (AM) and evening (PM) milk weights per cow as well as obtaining a representative milk sample from each milking for further compositional analyses. Such recording of two milk weights and obtaining two milk samples can, however, be onerous, especially during the busy milking session. In an analysis of 3,850 test-day records from 1,565 Irish lactating dairy cows, Berry *et al*. (2006) demonstrated that 24-hour milk fat and protein yield as well as composition could be accurately predicted based on a milk composition from either an AM or PM sample but with two milk weights; a similar conclusion was also documented by Schaeffer *et al*. (2000). This strategy, however, still required a milk weight record for both the AM and PM milking. Berry *et al*. (2006) cited a reduction in accuracy of predicting 24-hour yields from only either an AM or PM milk weight (and the respective milk composition); their dataset was, however, limited in size, and they did not consider the accuracy of predicting milk composition. The objective therefore of the present study was to use a large dataset to quantify the accuracy of predicting 24-hour yield and composition from a single AM or PM milk weight and composition. The accuracy of prediction will be compared to the currently adopted strategy of obtaining the milk weight from both the AM and PM milking but just a single milk sample, as proposed by Berry *et al*. (2006).

Materials and methods

Data

AM and PM part-day milk weights and composition (i.e. fat and protein composition) were available on 48,737 test days from 23,737 lactations in 17,896 cows recorded between the years 2004 and 2017 in 237 farms; all cows were milked twice daily. All milk production data used in the present study originated from Tru-Test (Auckland, New Zealand) milk meters which record the time of each milking as well as the milk weight for each milking; a representative milk sample for each milking was also taken in line with the manufacturer's guidelines and subjected to mid-infrared spectroscopy for the estimation of fat and protein

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concentration. The total 24-hour milk yield was simply the sum of the AM and PM milk yields; 24-hour fat and protein yield was the sum of the respective AM and PM yields.

Test-day records with a milk yield of <3 kg or >40 kg for either part-day sample were discarded; furthermore, test-day records with at least one part-day sample with a fat concentration of <2% or >8% or a protein concentration of <2% or >6% were discarded. Only milking intervals from AM to PM between 6 and 16 h were retained. Milking interval from AM to PM milking was categorised into 30-minute classes, and records with a recorded milk yield, fat concentration or protein concentration that exceeded 3 s.d. from the mean value within milking interval class were not considered further. Days in milk were broken into seven lactation stages, each representing 50 d (<50 d in milk, 50–99 d in milk, etc.). After edits, 42,125 test days from 22,729 lactations in 16,159 cows residing in 237 herds remained. Of the 16,159 cows, 14,818 were ≥50% Holstein–Friesian while 1,851 cows had some proportion of Jersey. Cow parity was recoded as 1, 2, 3+.

Analysis

For the purpose of the present study, a calibration dataset and a validation dataset were created. The calibration dataset, which was used to develop the prediction equations, included all test-day records prior to the year 2017; the dataset comprised 37,481 test-day records. The validation dataset included 4,644 test-day records collected in the year 2017 from 24 herds, and these data were used to validate the developed prediction equations; 11 of the 24 herds never appeared in the calibration dataset.

Two separate approaches, reflective of practical reality, were used to predict 24-hour yield and composition. The approach replicated that used by Berry *et al*. (2006), where it was assumed that two milk weights were available but the milk composition was available from either the AM or PM sample. The second approach assumed that a milk weight and milk composition record were available for either the AM or PM milking only. In both approaches, 24-hour yields were predicted and these were subsequently divided by (predicted) 24-hour milk yield to obtain milk fat and protein percentage. Moreover, in both approaches, it was assumed that the milking interval per cow was known without error.

A linear multiple regression model was fitted using PROC GLM in SAS (SAS, 2016) within each class k of stage of lactation by cow parity (1, 2, 3+), to predict true 24-hour yield from AM and/or PM samples as follows (Berry *et al*., 2006):

$$Y_{ik} = (b_0 + b_1[\mathrm{MI}] + b_2[\mathrm{milk}]_i + b_3[\mathrm{fat}]_i + b_4\,[\mathrm{protein}]_i)_k + e_{ik}$$

where

Y_{ik} is the 24-hour milk yield, fat yield or protein yield; MI is the milking interval from AM to PM (in minutes); $[\mathrm{milk}]_i$ is the milk yield on the *i*th milking of the day; $[\mathrm{fat}]_i$ is the fat yield on the *i*th milking of the day; $[\mathrm{protein}]_i$ is the protein yield on the *i*th milking of the day and e_{ik} is the random residual effect.

A supplementary series of analyses were undertaken where milking interval was not considered in the prediction model. Preliminary analyses revealed no benefit in prediction accuracy if month of calving was considered in the model or if milking interval was considered as a class effect of 30-minute intervals or even if the prediction equations were developed within classes of parity by stage of lactation by milking interval (categorised into one-and-a-half hourly intervals).

The residual prediction error per test day in the validation dataset was calculated as the actual yield or composition observation minus the respective predicted value. The statistics used to compare the actual 24-hour yields and composition with the predicted 24-hour yields and composition included the mean bias, the linear regression coefficient of the actual on the predicted values, the correlation between actual and predicted values, the correlation between the residual and the actual values and the s.d. of the prediction errors (i.e. the root mean square error). Whether correlations differed from each other or differed from 0 was based on the Fisher's *r*-to-*Z* transformation.

Results and discussion

Mean AM, PM and daily yields and composition in the entire dataset as well as their intercorrelations are listed in Table 1. The correlations between each 24-hour yield and its component part-day yields were very strong (≥0.93); the correlations

Table 1. Mean and s.d. for milk yield, fat yield and protein yield in the AM milking, PM milking and combined as well the correlations between yield in the AM, PM and combined

	Mean (s.d.)			Correlations		
	Daily	AM	PM	AM–PM	AM–daily	PM–daily
Milk yield (kg)	22.0 (7.73)	12.6 (4.41)	9.4 (3.65)	0.84	0.97	0.95
Fat yield (kg)	0.9 (0.27)	0.47 (0.15)	0.40 (0.15)	0.72	0.93	0.93
Protein yield (kg)	0.8 (0.24)	0.44 (0.14)	0.33 (0.11)	0.81	0.96	0.94
Fat percentage	4.1 (0.74)	3.83 (0.80)	4.37 (0.83)	0.65	0.93	0.88
Protein percentage	3.6 (0.38)	3.56 (0.39)	3.59 (0.40)	0.94	0.99	0.98

between 24-hour fat percentage and the AM (0.93) and PM (0.88) fat percentage were somewhat weaker, albeit still strong. The correlations between the same yield trait in the AM and PM were 0.72–0.84 while the correlations between the same AM and PM composition traits were 0.65–0.94. A frequency distribution of the number of records in the calibration and validation dataset by week of lactation is shown in Figure 1; the data were relatively evenly distributed across the lactation up until approximately week 36. The mean inter-milking interval was, on average, 842 min with an s.d. of 50 min. The mean (s.d.) duration of AM milking (i.e. time the clusters were put on the last cow minus the time the clusters were put on the first cow) and PM milking was similar at 151 min (18 min).

Prediction using AM and PM milk weights but just a single part-day milk composition

The accuracy of predicting 24-hour yield and composition when the 24-hour milk yield and one composition were available is presented in Table 2. With the exception of predicting 24-hour fat yield from the PM sample, the predicted values were, on average, an underestimate ($P < 0.05$) of the actual values. The accuracy of predicting fat and protein, as represented by the correlation, was greater when predicting yield (the average of correlations was 0.983) than when predicting composition (the average of correlations was 0.954); similarly, the linear regression coefficient of actual on predicted yields was closer to unity (i.e. 0.99–1.00) than the linear regression coefficient of actual on predicted compositions (i.e. 0.98–1.05). A linear regression coefficient greater than one indicates that differences among the predicted values are less than the true differences; the opposite is true for linear regression coefficients less than one. Similarly, positive correlations ($P < 0.05$ when tested against 0) between the residuals and the true values suggest that the predictions tend to systematically overestimate the lower true values and underestimate the higher true values; all correlations were positive suggesting that the prediction models therefore were overestimating low yield (or low composition) test days.

Predictions from the AM milk samples were more accurate than from the PM samples similar to reported elsewhere (Berry *et al*., 2006; Liu *et al*., 2000; Schaeffer *et al*., 2000). The total 24-hour protein yield and composition were more accurately predicted than the respective fat values again corroborating previous studies in dairy cows (Berry *et al*., 2006; Liu *et al*., 2000; Schaeffer *et al*., 2000); this was most obvious for fat percentage where the root mean square error of prediction was 0.239–0.303 percentage units for fat percentage which was 3.7–2.9 times the respective root mean square error for predicted protein percentage. Based on the root mean square

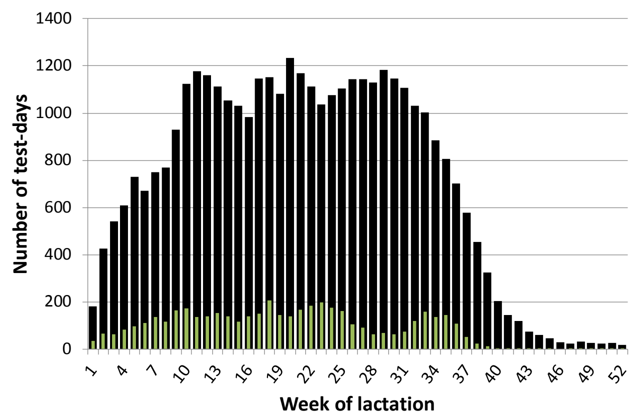

Figure 1. Number of test-day records by week of lactation in the calibration (dark bars) and validation (light bars) datasets.

Table 2. Mean bias (standard error in parenthesis), correlation (*r*), RMSE of prediction and the linear regression coefficient (*b*; s.e.) of the actual and predicted values of 24-hour milk yield and composition and the correlation (r_e) between the prediction residual and 24-hour yield predicted using two milk weights and one milk sample from either the AM or PM milking

	Bias (s.e.)	r	RMSE	b (s.e.)	r_e
From AM					
Fat (kg)	0.005 (0.0009)	0.974	0.061	1.00 (0.003)	0.24
Fat (%)	0.021 (0.0035)	0.944	0.239	0.98 (0.005)	0.27
Protein (kg)	0.002 (0.0002)	0.998	0.015	1.00 (0.001)	0.10
Protein (%)	0.009 (0.0009)	0.987	0.062	1.01 (0.002)	0.21
From PM					
Fat (kg)	0.002 (0.0011)	0.961	0.074	0.99 (0.004)	0.24
Fat (%)	0.015 (0.0045)	0.908	0.303	1.05 (0.007)	0.51
Protein (kg)	0.001 (0.0003)	0.997	0.020	1.00 (0.001)	0.05
Protein (%)	0.005 (0.0012)	0.977	0.082	0.99 (0.003)	0.16

RMSE = root mean square error.

error of prediction, 68–74% of predicted 24-hour fat percentage was expected to differ by more than ±0.1 percentage unit from the true 24-hour fat percentage; in contrast, only 10–22% of predicted 24-hour protein percentage was expected to differ by more than ±0.1 percentage unit from the true 24-hour protein percentage.

The prediction accuracies achieved in the present study were in general agreement with those of Berry *et al*. (2006) who adopted a similar approach but on a smaller dataset; the correlation between the true and predicted 24-hour fat yield was, however, stronger in the present study reflected also in a reduced root mean square error of prediction. The accuracy of prediction was also superior to that reported by Schaeffer *et al*. (2000) based on 10,288 test-day records from Canadian cows. Neither Berry *et al*. (2006) nor Schaeffer *et al*. (2000) presented prediction accuracy statistics for either fat or protein concentration nor did they present mean bias, the linear regression coefficient of actual and predicted 24-hour values and the correlation between the prediction residuals and the true values.

Prediction accuracy from just a single part-day sample

The accuracy of predicting 24-hour yields and composition from just a single AM or PM observation is listed in Table 3. With the exception of fat yield predicted from the AM sample without the consideration of milking interval, the predicted yields and composition were, on average, underestimated ($P < 0.05$) relative to the true values. The correlation between actual and predicted 24-hour yields and composition from AM samples was superior to that predicted from PM samples consistent with the results of both Berry *et al*. (2006) and Liu *et al*. (2000), although the linear regression coefficients of the actual and predicted values in the present study was not always superior for the AM samples; the residual correlations were also weakest (yet different from zero; $P < 0.05$) for the AM-based predictions. Based on the root mean square error of prediction for 24-hour milk yield in the present study, 10–16% of predictions are expected to be >2 kg from the actual value.

With respect to the fact that when two milk weights were available, the correlation weakened between the actual and predicted values, with the exception of protein percentage which strengthened slightly. The correlation between actual and predicted values was 0.963 when based on PM records and 0.978 when based on AM records. Using a calibration dataset of 2,888 test days, Berry *et al*. (2006) also reported a weakening in the correlation between 24-hour actual and predicted yields when only one part-day milk weight was available in comparison to when two part-day milk weights were available which is consistent with the conclusions of Schaeffer *et al*. (2000) in Canadian Holsteins; nonetheless, the strength of the correlations in the present study between actual and predicted 24-hour yields was up to 6% more accurate than those reported by Berry *et al*. (2006).

Table 3. Mean bias (standard error in parenthesis), correlation (*r*), RMSE of prediction and the linear regression coefficient (*b*; s.e.) of the actual and predicted values of 24-hour milk yield and composition and the correlation (r_e) between the prediction residual and 24-hour yield predicted using just one milk part-day weight and the corresponding part-day milk sample, with or without consideration for the milking interval in the statistical model

	With milking interval					Without milking interval				
	Bias (s.e.)	**r**	**RMSE**	**b (s.e.)**	**r_e**	**Bias (s.e.)**	**r**	**RMSE**	**b (s.e.)**	**r_e**
From AM										
Milk (kg)	0.151 (0.0230)	0.978	1.564	0.99 (0.003)	0.18	0.151 (1.5644)	0.969	1.841	0.98 (0.004)	0.18
Fat (kg)	0.011 (0.0013)	0.945	0.088	0.99 (0.005)	0.31	0.015 (0.0902)	0.942	0.090	0.98 (0.005)	0.29
Fat (%)	0.019 (0.0035)	0.945	0.238	0.97 (0.005)	0.26	0.001 (0.2482)	0.940	0.247	0.97 (0.005)	0.25
Protein (kg)	0.007 (0.0008)	0.973	0.054	1.00 (0.003)	0.22	0.014 (0.0642)	0.963	0.064	0.98 (0.004)	0.19
Protein(%)	0.007 (0.0009)	0.987	0.061	1.01 (0.002)	0.19	0.005 (0.0582)	0.988	0.058	1.00 (0.002)	0.15
From PM										
Milk (kg)	0.400 (0.0295)	0.963	2.013	1.01 (0.004)	0.30	0.400 (2.0136)	0.946	2.415	1.00 (0.005)	0.30
Fat (kg)	0.015 (0.0015)	0.925	0.102	0.97 (0.005)	0.35	0.013 (0.1061)	0.919	0.106	0.99 (0.006)	0.37
Fat (%)	0.012 (0.0045)	0.907	0.306	1.06 (0.007)	0.53	0.026 (0.3237)	0.896	0.321	1.07 (0.008)	0.55
Protein (kg)	0.014 (0.0010)	0.955	0.070	1.00 (0.005)	0.31	0.011 (0.0846)	0.934	0.085	1.00 (0.006)	0.36
Protein (%)	0.003 (0.0012)	0.978	0.079	1.00 (0.003)	0.22	0.004 (0.0779)	0.979	0.078	1.01 (0.003)	0.27

RMSE, root mean square error.

The regression coefficients on milking interval in minutes from the multiple regression models in the 21 different population strata (i.e. seven stages of lactation by three parity groups) varied from 0.000079229 to 0.000615619 for 24-hour fat predicted from AM samples and from 0.000048616 to 0.000531153 for 24-hour fat predicted from PM samples. The regression coefficients on milking interval for 24-hour predicted protein yield varied from -0.000055849 to 0.000010848 when predicted from the AM samples and from -0.00006932 to 0.000012744 when predicted from PM samples. The time of each milking is automatically recorded by many electronic milk recording meters facilitating the accurate calculation of the milking interval. If only one milk weight (and sample) is taken, then the reliance is on the producer to report the milking interval; the relatively small regression coefficients on milking interval suggest a relatively small effect of inaccurate recording of the milking interval on the resulting predicted yields. For example, based on the largest regression coefficient on milking interval of 0.000615619 (i.e. fat yield predicted from AM), overstating the time duration from the previous PM milking by 2 h would add 0.074 kg to the predicted 24-hour fat yield which represents 9% of the mean 24-hour fat yield; the effect is just 1% of the mean if applied to the smallest regression coefficient on milking interval for predicting fat yield from the AM sample. Nonetheless, because of the statistical approach applied, an inaccurate record of the milking interval will affect the prediction of all animals in a stratum equally and thus the effect on the within-herd ranking of animals is expected to be minimum; hence, minimal impact is also expected on genetic evaluations where herd-test-day, parity and days in milk are included as adjustment factors in the genetic evaluation model. With the exception of the prediction of 24-hour protein concentration, not including the milking interval in the prediction model, resulted in a weakening of the correlation between the actual and predicted values. However, the actual impact on predictive ability from removing milking interval from the model was small again substantiating the small effect that misreporting of the milking interval is likely to have.

Conclusions

Relative to the original study of Berry *et al*. (2006) with 2,888 test days in the calibration dataset, the more than 12 times larger dataset in the present study contributed to more robust prediction equations, especially those based on just a single milk weight and milk sample. A single AM sample is useful to predict 24-hour milk yield and composition when the milking interval is known. Nonetheless, the continued recording of two milk weights and two milk samples from a (small) selection of herds should continue and the accuracy of prediction should be monitored.

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