Production loss due to new subclinical mastitis in Dutch dairy cows estimated with a test-day model

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ABSTRACT

Milk, fat, and protein loss due to a new subclinical mastitis case may be economically important, and the objective of this study was to estimate this loss. The loss was estimated based on test-day (TD) cow records collected over a 1-yr period from 400 randomly selected Dutch dairy herds. After exclusion of records from cows with clinical mastitis, the data set comprised 251,647 TD records from 43,462 lactations of 39,512 cows. The analysis was carried out using a random regression test-day modeling approach that predicts the cow production at each TD based on the actual production at all previous TD. The definition of new subclinical mastitis was based on the literature and assumed a new subclinical case if somatic cell count (SCC) was >100,000 cells/mL after a TD with SCC <50,000 cells/mL. A second data set was created by applying an adjustment to correct low SCC for the dilution effect when determining if the previous test-day SCC was <50,000 cells/mL. Thereafter, the loss was estimated for records with SCC >100,000 cells/mL. The production (milk, fat, or protein) losses were modeled as the difference between the actual and predicted production (milk, fat, or protein) at the TD of new subclinical mastitis, for 4,382 cow records, and 2,545 cow records after dilution correction. Primiparous cows were predicted to lose 0.31 (0.25–0.37) and 0.28 (0.20–0.35) kg of milk/d at an SCC of 200,000 cells/mL, for unadjusted and adjusted low SCC, respectively. For the same SCC increase, multiparous cows were predicted to lose 0.58 (0.54–0.62) and 0.50 (0.44–0.56) kg of milk/d, respectively. Moreover, it was found that the greater the SCC increase above 100,000 cells/mL, the greater the production losses. The estimated production losses were more precise than previously reported estimates.

INTRODUCTION

Subclinical mastitis affects milk quality and quantity causing great economic loss for producers (Swinkels et al., 2005; Halasa et al., 2007). Several studies have estimated milk production loss due to subclinical mastitis (e.g., Hortet and Seegers, 1998; Koldeweij et al., 1999), but a wide range of estimates have been reported (Seegers et al., 2003). This variation is caused not only by different populations or mastitis indicators (Hortet et al., 1999) but also by the use of different analytical approaches (Hortet and Seegers, 1998). Estimates of changes in milk composites are scarce and not appropriate for economic calculations (Seegers et al., 2003). Recently, a dilution effect due to high production and low SCC was quantified, suggesting an overestimation of SCC-related production loss in earlier research (Green et al., 2006). Economically, it might be important to correct the estimated production loss for the dilution effect to be able to precisely quantify economic effects of subclinical mastitis. Precise estimation of milk production loss and milk composite changes due to a new subclinical mastitis case is important for good economic calculations in light of treatment decisions. Moreover, reliable economic calculations are important to motivate farmers to adopt management practices.

Several approaches have been proposed to estimate milk production loss at the herd level (e.g., De Graaf and Dwinger, 1996). They have focused on comparing the production of infected and uninfected cows or production before and after infection in the same animal (Hortet and Seegers, 1998; Rajala-Schultz et al., 1999). The introduced variation between animals using the first methodology would decrease the precision of the results. Random regression test-day modeling (**RRTM**) has been developed to analyze test-day (**TD**) records of dairy cattle for genetic evaluation (Jamrozik and

Schaeffer, 1997). Besides fixed effects such as parity, lactation stage, and season, the RRTM includes genetic and nongenetic animal effects and herd-specific lactation curves (De Roos et al., 2004). De Roos and De Jong (2006) presented an RRTM to analyze TD milk urea and used that model to extend lactation curves by using only the TD records up to a certain point in time. The predicted TD productions later in lactation were compared with actual TD productions to evaluate whether a cow was producing more or less than initially predicted. Because such predictions are based on cow- and herd-specific lactation curves, they are very accurate, which makes this approach attractive for estimation of the effect of environmental factors, such as diseases, on subsequent lactation production.

The aim of this research was to estimate milk production loss and changes in milk composites following a new subclinical mastitis case based on the RRTM.

MATERIALS AND METHODS

Data

For the purpose of improving udder health in the Netherlands, the Dutch Udder Health Center (Deventer, the Netherlands) in cooperation with dairy herd improvement organizations (CR Delta and NRS, Arnhem, the Netherlands) collected cow production and clinical mastitis records. Initially, 600 farms were selected randomly from the Dutch dairy herd improvement association records. To be selected, farm size had to be at least 50 cows, age of the farmer had to be <57 yr, and farmers had to complete a questionnaire and agree to data collection. The data collection took place in 400 farms from July 1, 2004, to June 30, 2005, on the basis of a herd TD interval (**TDInt**) of 3 to 6 wk. For the present study, if clinical mastitis occurred, TD records of the remainder of the lactation were excluded. Clinical records were based on farmer diagnosis of inflamed udder, abnormal milk color, and (or) presence of clots in the milk. The data set consisted of 251,647 TD records from 43,462 lactations of 39,512 cows. The NRS provided cow identification number, herd identification number, SCC $\times 10^3$ cells/mL, milk (kg), fat (g), and protein (g) production, calving date, and test date. Clinical mastitis dates were provided by the Dutch Udder Health Center.

Definition of a New Subclinical Mastitis Case

The definition of a new case of subclinical mastitis was as follows: If at TD_{i-1} SCC <50,000 cells/mL and at TD_i SCC >100,000 cells/mL, a cow was considered to have a new subclinical mastitis case at TD_i, where

TD_i is the record of the new subclinical mastitis TD and TD_{i-1} is the previous TD. Cases were included only when both TD_{i-1} and TD_i were within the same lactation. Moreover, only lactations that started with a calving during the trial period were included in the definition of a new subclinical mastitis case. Only records of the first subclinical mastitis case were included in the analysis.

Dilution Effect

Recently, it has been noted that low SCC has an inverse relationship with high milk production because of a dilution effect (Green et al., 2006). The dilution was apparent for low SCC (<50,000 cells/mL) and high-producing cows, which indicated that the high yield caused underestimation of the true concentration of the SCC. For SCC >100,000 cells/mL, the inflammation caused high SCC and dilution was negligible. For the current analysis, the lambda (λ) value (0.485) of Green et al. (2006) was used to correct for dilution effect for animals with crude SCC <50,000 cells/mL and milk production >10 kg/d as follows:

$$\text{Adjusted SCC} = \text{crude SCC}$$
$$+ (-\lambda \times \text{actual milk production}). \qquad [1]$$

After adjustment, SCC at TD_{i-1} would increase relative to actual milk production above 10 kg/d. This means that the SCC of some cows that were selected to be free of subclinical mastitis with SCC <50,000 cells/mL at TD_{i-1} actually exceeded this limit after SCC adjustment. Those cows were therefore excluded and the resulting smaller data set was analyzed separately.

Data Set Construction Based on the RRTM

Predicted milk, fat, and protein production were calculated by the NRS (Arnhem, the Netherlands) based on the RRTM (De Roos et al., 2004; De Roos and De Jong, 2006). The model is based on a combined analysis of TD production (known means and variances), herd-specific regression curves, and standard lactation curves. Predictions of milk, fat, or protein production were provided for TD_i based on the production at all previous TD corrected for random genetic and fixed environmental effects, parity, DIM, and other important effects. The RRTM is presented and explained in more detail in the Appendix.

The predicted production at TD_i represents the production of the cow assuming that the SCC and all other factors remained the same as for at TD_{i-1}. The difference (**ΔProd**) between the actual and predicted

production (kilograms of milk, grams of fat, or grams of protein) at TD_i would reflect the effect of SCC (cells/mL) increase, as a marker of new subclinical mastitis, on production:

$$\Delta Prod = \text{actual production at } TD_i$$
$$- \text{ predicted production at } TD_i, \qquad [2]$$

where $\Delta Prod$ represents the change in production (kilograms of milk, grams of fat, or grams of protein) at the TD of new subclinical mastitis (TD_i). Only the first subclinical mastitis case per cow was considered in the analysis in order not to bias the results due to the effect of previous subclinical cases. Cows that started the lactation with SCC >50,000 cells/mL were excluded to be able to use predicted production based only on healthy TD before the new case.

Statistical Analysis

Change in production ($\Delta Prod$) at TD_i was modeled using Proc Mixed (SAS Institute, 2004). The models were fitted using the REML method and a backward stepwise regression procedure for the change (Δ) in milk, fat, or protein production, according to the following model equation:

$$Y_{hjkl} = \beta_0 + \beta_1 \times \text{LnSCC} + \beta_2 \times \text{Parity}_h + \beta_3$$
$$\times \text{TDInt}_j + \beta_4 \times \text{DIM}_k + \text{Herd}_l + e_{hjkl}, \qquad [3]$$

where Y_{hjkl} is the $\Delta Prod$ at the new subclinical mastitis TD (TD_i) for each cow in herd l in parity h with a TD interval class j, and in DIM class k; β_0 is the overall mean $\Delta Prod$ at TD_i; β_1 is the regression coefficient of the natural logarithm of the SCC $\times 10^3$ cells/mL (**LnSCC**); LnSCC is the fixed effect of LnSCC at TD_i on $\Delta Prod$; β_2 is the regression coefficient of the hth class of parity; Parity$_h$ is the fixed effect of class h of parity (5 classes, parity = 1, 2, 3, 4, and ≥ 5) on $\Delta Prod$; β_3 is the regression coefficient of the jth class of TD interval; TDInt is the fixed effect of class j of the time interval between TD_{i-1} and TD_i (4 classes, 3, 4, 5, and ≥ 6 wk interval); β_4 is the regression coefficient of the kth class of DIM; DIM$_k$ is the fixed effect of class k of DIM (30 classes) at TD_i; Herd$_l$ is the random effect of herd l; and e_{hjkl} is the residual error.

Separate models were run for each production parameter (milk, fat, or protein). No correlation structure was fitted because only one record per cow existed in the model, which is the $\Delta Prod$ corresponding to the new subclinical mastitis TD (TD_i). For the same reason, a cow as a random effect was not included. The estimated loss from each model was assumed to exist in the interval around TD_i, from halfway between TD_{i-1} and TD_i to halfway between TD_i and TD_{i+1}, which is the TDInt of a specific herd. The fit of the models was examined using normality of the residuals and homoscedasticity of the fitted values.

The analysis was carried out on 2 subsets of the final data set that included records at TD_i; 1) all TD records at TD_i were included to represent the effect of new subclinical mastitis on production without adjustment of SCC at TD_{i-1} for dilution effect; 2) a subset of data set 1 where records with SCC at TD_{i-1} >50,000 cells/mL after adjustment for the dilution effect were removed. The 2 subsets were analyzed separately according to equation [3] to show results when adjustment of SCC to dilution was considered and when adjustment was ignored.

RESULTS

Descriptive Analysis

Number of cows, TD records, and distribution of milk production parameters per parity are shown in Table 1; TD records following clinical mastitis were excluded from that lactation. Of the total number of lactations, 13.3% of the heifers and cows had a first clinical mastitis case in lactation and 77% occurred during the first 60 d of the lactation. No information was available about second or more clinical cases per cow. Mean (SD) milk production for primiparous cows was 23.2 kg/d (6 kg/d) with a geometric mean SCC of 65,000 cells/mL (2,660 cells/mL). For multiparous cows mean, milk production was 28.3 kg/d (9.2 kg/d) with a geometric mean SCC 105,000 cells/mL (3,230 cells/mL) (Table 1). Primiparous cows comprised 31.6% of the whole study population. Test-day interval varied on the cow level between 3 wk (1.2% of the records), 4 wk (69.9%), 5 wk (15.2%), 6 wk (10.6%), and >6 wk (3.1%) intervals.

Milk, Fat, and Protein Production Losses

The new subclinical mastitis cases were distributed throughout the lactation, where 31, 37, 22, and 10% of the cases occurred in the first 100 DIM, between 100 and 200 DIM, between 200 and 300 DIM, and >300 DIM; respectively. There was no significant difference in production loss among different parities of multiparous cows; thus, the results are presented for primiparous (parity = 1) and multiparous (parity ≥ 2) cows. The TDInt classes did not significantly affect the change in milk, fat, or protein production. For instance, when adjustment to dilution was not considered and for the

Table 1. Number, mean, and standard deviation of test-day (TD) records of milk (kg/d), fat (g/d), and protein (g/d) production and the geometric mean and standard deviation of SCC per parity for 1-yr data on 400 Dutch dairy farms

Parity	Cows, n	TD records, n	Milk (kg)		Fat (g)		Protein (g)		SCC[1]	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	13,751	80,816	23.1	6.00	1,062	239	817	186	64.89	2.66
2	10,920	63,898	27.36	8.66	1,209	348	971	263	76.12	2.89
3	7,616	43,901	28.96	9.60	1,283	393	1,017	287	94.00	3.08
4	4,976	28,552	29.29	9.68	1,303	406	1,023	293	112.2	3.21
≥5	6,199	34,480	28.71	9.69	1,271	408	990	290	138.3	3.46

[1]Geometric mean of the crude SCC $\times 10^3$ cells/mL.

classes 3, 4, 5 and ≥6 wk intervals, and using the 3 wk interval as the reference class, the coefficient and standard errors were 0.23 (0.19), 0.21 (0.17), 0.22 (0.18), respectively. Moreover, changing the reference class did not change the insignificance of TDInt classes toward the change in milk, fat, or protein production models. Similarly, none of the 30 classes of DIM were found to affect the change in milk, fat, or protein production significantly (lowest *P*-value = 0.65). Therefore, TDInt and DIM were not included in the reduced final models.

The number of new subclinical mastitis cases was 1,372 and 3,010 for primiparous and multiparous cows, respectively. The regression coefficient λ was found to be -0.491. After adjustment to dilution effect, the number of primiparous and multiparous cows that had adjusted SCC <50,000 cells/mL was 989 and 1,556, respectively. The median SCC before adjustment was 40,000 cells/mL, but after adjusting the SCC values according to equation [1] the median value (including cows that exceeded 50,000 cells/mL after adjustment) was 48,000 cells/mL.

The parameter estimates are presented in Table 2 based on the final models as reduced from equation [3] for the 2 subsets with or without adjusted SCC. The prediction of each model represents the loss in production estimated for TD_i; that is, per day. In Table 3 the predicted loss in milk production is presented for different crude SCC values together with the 95% confidence intervals. For example, a primiparous and a multiparous cow with a SCC of 200,000 cells/mL were predicted to lose 0.31 (0.25–0.37) and 0.58 (0.54–0.62) kg of milk per day, respectively, when dilution effect was not considered to select healthy cows at TD_{i-1}. When the dilution effect was considered to select healthy cows at TD_{i-1}, a primiparous and a multiparous cow with a SCC 200,000 cells/mL were predicted to lose 0.28 (0.20–0.35) and 0.50 (0.44–0.56) kg of milk per day, respectively. Table 3 also shows the dose-effect relationship between the increase of SCC and production loss. When the SCC increase exceeds 100,000 cells/mL, the production losses increase.

Fit of the Models

Figures 1a and b show the distribution of the standardized Pearson residuals of the models for 2 data sets, for Δ kilograms of milk. A long tail exists on the right side, which might have caused disturbance of the normality. However, the normality of the residuals is acceptable in both situations. In Figures 2a and b the fitted values of the same models are shown. A slight

Table 2. The intercept (β_0) and coefficient (β_1) of the natural logarithm of SCC $\times 10^3$ cells/mL (LnSCC) with standard errors for the models of the change (Δ) of milk (kg), fat (g), and protein (g) production for primiparous and multiparous cows using unadjusted SCC or adjusted SCC values to selected healthy cows according to the definition of new subclinical mastitis cases[1]

Change	Unadjusted SCC to dilution effect (n = 4,382)				Adjusted SCC to dilution effect (n = 2,545)			
	Parity 1		Parity ≥2		Parity 1		Parity ≥2	
	β_0(SE)	β_1(SE)	β_0(SE)	β_1(SE)	β_0(SE)	β_1(SE)	β_0(SE)	β_1(SE)
Δ Milk	0.80	−0.21	1.59	−0.41	0.78	−0.20	1.62	−0.40
	(0.20)	(0.03)	(0.18)	(0.02)	(0.22)	(0.04)	(0.20)	(0.03)
Δ Fat	33.70	−7.40	62.24	−13.59	33.10	−7.20	54.62	−12.20
	(17.20)	(2.30)	(16.11)	(2.81)	(18.12)	(2.42)	(16.73)	(3.21)
Δ Protein	17.70	−5.10	44.80	−10.72	17.52	−4.85	39.45	−9.90
	(12.61)	(1.61)	(9.72)	(2.01)	(13.20)	(1.94)	(9.84)	(2.43)

[1]If at test-day $(TD)_{i-1}$ SCC <50,000 cells/mL and at TD_i SCC >100,000 cells/mL, a cow was considered to have a new subclinical mastitis case at TD_i, where TD_i is the record at the new subclinical mastitis TD and TD_{i-1} is the previous TD.

Table 3. Estimates of predicted milk production loss (kg/d) together with the 95% confidence interval at different high crude SCC ($\times 10^3$ cells/mL) levels for primiparous and multiparous cows using unadjusted SCC or adjusted SCC values to selected healthy cows according to the definition of new subclinical mastitis cases[1]

Crude SCC	Unadjusted SCC to dilution effect (n = 4,382)		Adjusted SCC to dilution effect (n = 2,545)	
	Parity 1	Parity $\geq$2	Parity 1	Parity $\geq$2
100	0.17 (0.03–0.31)	0.30 (0.21–0.39)	0.14 (−0.04–0.33)	0.22 (0.09–0.41)
200	0.31 (0.25–0.37)	0.58 (0.54–0.62)	0.28 (0.20–0.35)	0.50 (0.44–0.56)
300	0.40 (0.34–0.47)	0.75 (0.71–0.78)	0.36 (0.28–0.44)	0.66 (0.61–0.72)
400	0.46 (0.4–0.52)	0.87 (0.83–0.91)	0.42 (0.34–0.50)	0.78 (0.72–0.83)
500	0.51 (0.45–0.56)	0.96 (0.92–1.00)	0.46 (0.38–0.54)	0.87 (0.81–0.92)
600	0.55 (0.49–0.60)	1.03 (0.99–1.07)	0.50 (0.42–0.58)	0.94 (0.88–1.00)

[1]If at test-day (TD)$_{i-1}$ SCC <50,000 cells/mL and at TD$_i$ SCC >100,000 cells/mL, a cow was considered to have a new subclinical mastitis case at TD$_i$, where TD$_i$ is the record at the new subclinical mastitis TD and TD$_{i-1}$ is the previous TD.

clustering to the right side exists in both figures, but the variances seem to be equal in both sides of the plots reflecting homoscedastic values. Figures of Δ fat and Δ protein models were similar (results not shown).

DISCUSSION

The approach used in this study (RRTM) is based on within-animal comparison, which compares the actual versus predicted production of a cow. Using this approach, the variability that is introduced because of differences between animals in different herds is eliminated. Studies that estimated production loss within cow by comparison of production before and after infection misestimated the loss, because of the effect of lactation stage on the cow-specific lactation curve as explained by Rajala-Schultz et al. (1999). Studies that estimated milk production loss due to subclinical mastitis showed low precision of the estimated loss (Hortet and Seegers, 1998). In 2 studies, the number of observations in the analysis was larger than the current study. Nevertheless, the current study estimated production loss more precisely, based on the reported standard errors in these 2 studies (Hortet et al., 1999; Koldeweij et al., 1999).

The standardized Pearson residuals showed a slightly long tail to the right side (Figures 1a and b). Although this tail might have disturbed the normality, there is no dramatic deviation from normality. Normality tests could be very sensitive to residual values, which makes the graphical demonstration the reference test (Dohoo et al., 2003). Slight disturbance might have influenced the homoscedasticity because of more observations on the right side; otherwise, the fitted values are quite homoscedastic (Figures 2a and b). Because the number of observations is different between the 2 presented analyses, comparison between model fits using the deviance or Akaike information criterion would not be correct.

Nevertheless, in both situations, the models appeared to fit the data adequately.

Fitting a specific LnSCC level in the models in Table 2 reveals the production loss at that level of LnSCC for milk, fat, and protein. Literature estimates of milk production loss for a 2-fold increase in crude SCC are 0.40 and 0.60 kg/d for primiparous and multiparous cows, respectively, as reviewed by Seegers et al. (2003), which is close to the estimates in this study (would be 0.38 and 0.46 kg/d for the same relationship). In this study, the clinical records were excluded from the analysis, consistent with Hortet et al. (1999) and Koldeweij et al. (1999). Reksen et al. (2007) estimated milk loss from cows with an intramammary infection in a recent pathogen-specific study. The study focused on comparing sparse and rich bacterial growth correcting for the clinical mastitis history of the cows. They found that, on average, primiparous and multiparous cows lose 0.30 and 0.66 kg of milk per day, respectively, corresponding to an increase of SCC to 200,000 cells/mL from the healthy level (<50,000 cells/mL), which is close to the estimates of this study, but no estimates of precision in relation to SCC were provided. Moreover, Reksen et al. (2007) did not estimate the fat and protein production losses.

There was no significant effect of DIM class and season of calving on the change of milk, fat, or protein production. This was most likely because predictions of milk, fat, or protein were already corrected for DIM and season of calving. The TDInt classes did not significantly affect the change in production. This could indicate that the longer the TD interval the greater the total loss, because we assume that the loss continues from halfway between TD$_{i-1}$ and TD$_i$ to halfway between TD$_i$ and TD$_{i+1}$. The level of SCC increase appears to be the most determinant factor of the production loss (Table 3), as an indicator of the severity of inflammation (Schukken et al., 2003). The greater
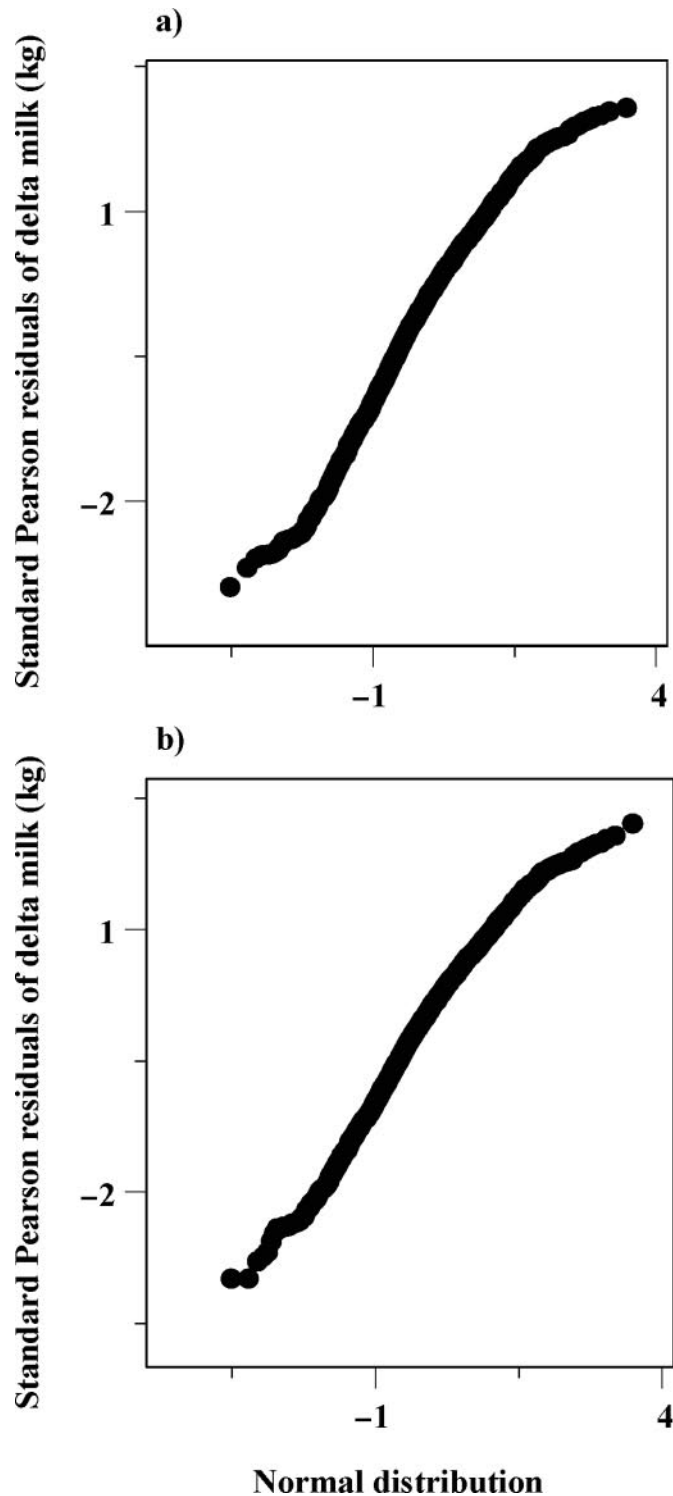
Figure 1. Distribution of standard Pearson residuals of the change in milk (kg) production models at the new subclinical mastitis test-day (TD$_i$) based on new subclinical mastitis definition, which considers a case if SCC >100,000 cells/mL at TD$_i$ and was preceded by a test-day SCC <50,000 cells/mL; a) unadjusted SCC values were used to select healthy cows at TD$_{i-1}$; records were 4,382; b) only when dilution-adjusted SCC values were used to select healthy cows at TD$_{i-1}$; records were 2,545.

the SCC increase >100,000 cells/mL, the greater the production loss (Table 3).

Fat and protein production were also affected negatively by a new case of subclinical mastitis. In many countries, farmers are paid for the fat and protein content of the milk, which makes fat and protein loss more economically important than the loss of kilograms of milk. Primiparous and multiparous cows were estimated to lose around 6 and 10 g/d of fat, respectively, during a new subclinical mastitis with SCC of 200,000 cells/mL (Table 2). The 2 subsets showed very similar predicted losses. At the same level of SCC increase, primiparous and multiparous cows are estimated to lose 9 and 13 g/d of protein, respectively. Previous research found fat and protein losses of 5 and 4 g/d, respectively (assuming a cow produces 25 kg of milk per day) per 2-fold increase in SCC, regardless of the parity of the cow and ignoring other risk factors (Hortet and Seegers, 1998). Koldeweij et al. (1999) found a protein loss of 42 and 67 g/d for a 1-fold increase in log$_{10}$ SCC for primiparous and multiparous cows, respectively, which is close to the estimates in the current study.

The estimated coefficient λ in the current study was very close to the value (−0.485) found by Green et al. (2006). The coefficient means that for 1-kg-greater milk yield above 10 kg/d for cows that had SCC <50,000 cells/mL, the SCC is underestimated by 0.491 × 10^3 cells/kg of milk due to dilution. Therefore, after adjustment, the SCC could be >50,000 cells/mL at the TD$_{i-1}$. The predicted milk production loss based on SCC count adjusted to dilution effect was slightly lower than the predicted loss when unadjusted SCC was used (Table 3). However, both results were presented to allow economic calculations to further investigate the importance of considering the dilution effect. Roughly, milk production loss was 13% less using the adjusted SCC compared with the crude SCC, which is in close agreement with Green et al. (2006) who found that production loss would be overestimated by 15% for crude SCC.

A general debate about the definition of a healthy cow in relation to SCC level can be inferred from the literature. Hillerton (1999) considered an udder healthy if SCC was <100,000 cells/mL. Djabri et al. (2002) found that the average SCC for culture-negative quarters was 68,000 cells/mL. Seegers et al. (2003), Leitner et al. (2003), and Hamann (2005) considered an udder healthy when SCC <50,000 cells/mL. We assumed a new subclinical mastitis case at a specific TD if the SCC >100,000 cells/mL at that TD, which was preceded by healthy TD for which the SCC was always <50,000 cells/mL. This seems consistent with the recent literature on the definition of a healthy udder. The definition considered a subclinical case if a low
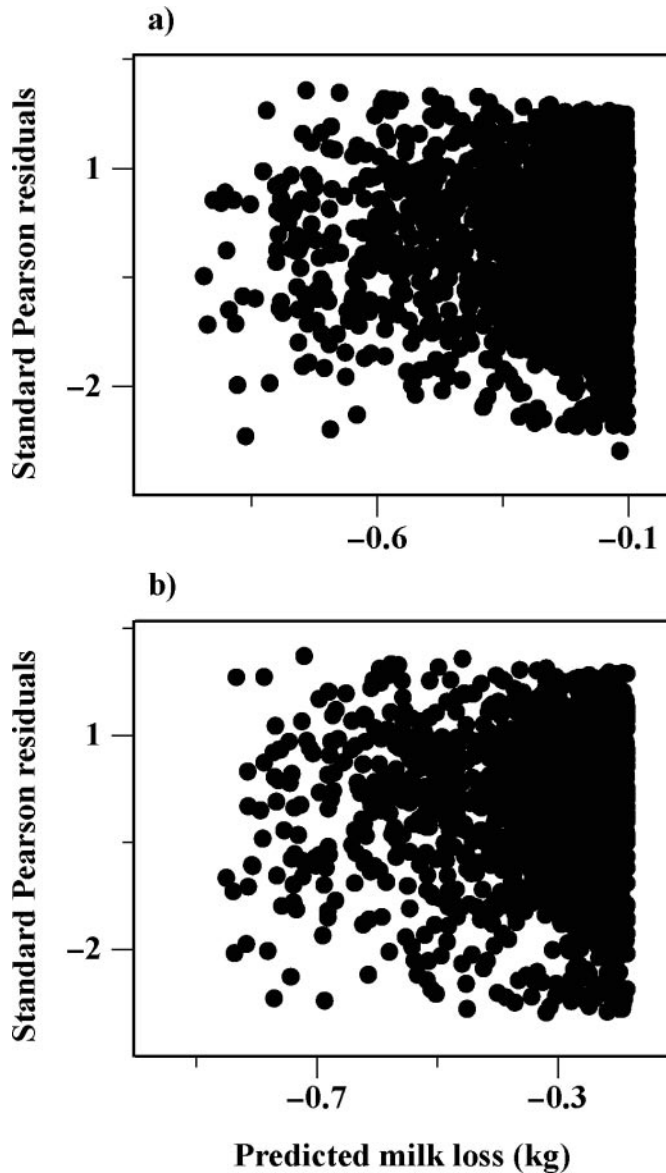
Figure 2. Fitted values of the change in milk (kg) production models at the new subclinical mastitis test-day (TD_i) based on new subclinical mastitis definition, which considers a case if SCC >100,000 cells/mL at TD_i and was preceded by a test-day SCC <50,000 cells/mL; a) unadjusted SCC values were used to select healthy cows at TD_{i-1}; records were 4,382; b) only when dilution-adjusted SCC values were used to select healthy cows at TD_{i-1}; records were 2,545.

SCC TD was followed by a high SCC TD within parity. This means, by definition, that a cow must initiate the lactation with a low SCC TD to be a new case of subclinical mastitis at the subsequent TD. This selection bias might have caused an underestimation of the loss because cows that start the lactation with high SCC TD were excluded. The analysis included only the first subclinical mastitis case per cow as an indication of new subclinical mastitis. This was imposed because we

wanted to calculate the change in production based on the RRTM prediction of a healthy udder only.

CONCLUSIONS

Random regression test-day modeling is a useful method to estimate effects of a disease on production. There was a significant loss in milk, fat, and protein production of dairy cows with new subclinical mastitis, and the predicted production losses were more precise than those of earlier studies. The magnitude of losses was mainly determined by the SCC elevation of the new subclinical mastitis. The predicted losses were slightly lower when the SCC dilution effect was considered in the definition of healthy cows.

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APPENDIX

The RRTM used data of approximately 1,000 herds in the Netherlands to predict the milk, fat, and protein production for the study data set. The model included fixed, random, and random regression effects as shown in Table A1.

Differences between cows are described by the fixed and the additive genetic effects in the model. The random effect describes the day-to-day variation within a herd. The random regression effect of herd × rolling year of test describes herd-specific lactation curves that model both differences in level of production between herds as well as differences in shape of the lactation curve between herds. The lactation curves of individual cows are described by an additive genetic effect and 2 nongenetic effects (the common and lactation-specific permanent environment effects). The cow's genetic and permanent environmental effects are also random regression effects, so they describe differences not only in level of production in each lactation, but also in shape of the lactation curve (persistency).

The accuracy of prediction is high because

1. A large number of cows in the population is used to estimate the fixed effects, so fixed effects are described in great detail and with high accuracy.
2. Records from herdmates that are not in the current trial are used to estimate the herd test date effect; that is, the day-to-day variation and seasonal patterns within the herd.
3. The additive genetic effect of the cow is used to predict production and level of production, shape of the lactation curve, and progress in production across lactations.
4. Additive genetic effects of cows are estimated accurately because most cows have sires with many progeny, and heritabilities for milk production traits are high.
5. By taking into account the permanent environmental effect of the cow, the level and shape of the lactation curve in lactations prior to the current trial is taken into account in the prediction.
6. The herd and cow effects are modeled with random regression effects, so variances and correlations within and across lactations are taken into account.

Table A1. Effects and variables included in the model

Effects	Variables included
Fixed	Parity × DIM
	Parity × age at calving × month of calving × rolling 3 yr of calving × lactation stage
	Parity × age at calving × rolling year of calving
	Parity × stage of pregnancy × lactation stage
	Parity × length of dry period × lactation stage
	Parity × % heterosis × lactation stage
	Parity × % recombination × lactation stage
	Year × week of test
Random	Herd × test date
Random regression	Herd × rolling year of test (lactation curves for parity 1, 2, and ≥3)
	Additive genetic effect for cow (lactation curves for parity 1, 2, and ≥3)
	Common permanent environment of cow (lactation curves for parity 1, 2, and ≥3)
	Lactation-specific permanent environment of cow (lactation curves for parity 3, 4, 5, and higher)