Use of early lactation milk recording data to predict the calving to conception interval in dairy herds

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ABSTRACT

Economic success in dairy herds is heavily reliant on obtaining pregnancies at an early stage of lactation. Our objective in this study was to attempt to predict the likelihood of conception occurring by d 100 and 150 of lactation (days in milk, DIM) by Markov chain Monte Carlo analysis using test day milk recording data and reproductive records gathered retrospectively from 8,750 cows from 33 dairy herds located in the United Kingdom. Overall, 65% of cows recalved with 30, 46, and 65% of cows conceiving by 100 DIM, 150 DIM, and beyond 150 DIM, respectively. Overall conception rate (total cows pregnant/total number of inseminations) was 27.47%. Median and mean calving to conception intervals were 123 and 105 d, respectively. The probability of conception by both 100 DIM and 150 DIM was positively associated with the average daily milk weight produced during the fourth week of lactation (W4MK) and protein percentage for test day samples collected between 0 to 30 and 31 to 60 DIM. Butterfat percentage at 0 to 30 DIM was negatively associated with the probability of conception by 100 DIM but not at 150 DIM. High somatic cell count (SCC) at both 0 to 30 and 31 to 60 DIM was negatively associated with the probability of conception by 100 DIM, whereas high SCC at 31 to 60 DIM was associated with a reduced probability of conception by 150 DIM. Increasing parity was associated with a reduced odds of pregnancy. Posterior predictions of the likelihood of conception for cows categorized as having “good” (W4MK >30 kg and protein percentage at 0 to 30 and 31 to 60 DIM >3.2%) or “poor” (W4MK <25 kg and protein percentage at 0 to 30 and 31 to 60 DIM <3.0%) early lactation attributes with actual observed values indicated model fit was good. The predicted likelihood of a “good” cow conceiving by 100 and 150 DIM was 0.39 and 0.57,

respectively (actual observed values 0.40 and 0.59). The corresponding values for a “poor” cow were 0.28 and 0.42 (actual observed values 0.26 and 0.37). Predictions of the future reproductive success of cows may be possible using a limited number of early lactation attributes.

Key words: dairy cow, pregnancy, early lactation, milk recording data

INTRODUCTION

Dairy herd profitability is highly dependent on reproductive performance (Louca and Legates, 1968; Olteneacu et al., 1981; Giordano et al., 2011, 2012) because optimizing the time cows spend in the most efficient part of the lactation curve has a significant effect on revenues obtained for milk sales (Ferguson and Galligan, 1999) as well as minimizing replacement costs due to reproductive failure. The timing at which pregnancy occurs during lactation is of utmost importance in sustaining profitability (Giordano et al., 2011); ideally this should occur between 90 and 130 DIM (Giordano et al., 2011).

In this context, the transition period has been recognized as a time when the dairy cow experiences an abrupt and severe change in demand for energy during the transition from the dry period to the onset of lactation (Bauman and Currie, 1980). At this time the cow's DMI may be limited and so the demand for energy cannot be met by DMI and most cows will experience a period of negative energy balance (**NEB**). The extent of NEB increases with energy output and increasing milk yield and has been linked to poor reproduction (Buckley et al., 2003; Patton et al., 2007).

Britt (1992) suggested that the biological environment in the relatively long period of follicular growth before ovulation is a major factor contributing to the syndrome of subfertility in dairy cows; however, to date the only long-term demonstrable adverse effect on fertility is the effect of heat stress (Chebel et al., 2004). Leroy et al. (2008a,b) have reviewed the mechanisms by which the biochemical environment of the cow and in

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particular the metabolic changes associated with NEB may influence fertility, but many of these effects have been investigated only in the short term because in vitro studies examining long-term effects of metabolism are difficult to conduct (Leroy et al., 2008a).

Therefore, it would seem likely then that NEB in early lactation may at least in part be responsible for the creation of the biological environment that leads to sub fertility in dairy cows. Milk recording data from individual cows has been used in several studies to associate milk composition in early lactation with energy balance (Duffield et al., 1997; de Vries and Veerkamp, 2000; Heuer et al., 2001) and Madouasse et al. (2010) have associated milk components in early lactation with the probability of conception at certain intervals during lactation. In particular, Madouasse et al. (2010) identified an association between lower milk production on the second test day, higher percentage of protein on the second test day, and higher percentage of lactose on the first test day with increased probability of conception before 145 DIM, whereas positive associations of a smaller magnitude were identified for percentage of protein at the first test day and negative associations with first test butterfat and SCC on the first and second test days.

In cases of NEB, increases in milk fat percentage and decreases in milk protein percentage along with increases in milk fat to protein ratio have been a consistent finding (Duffield et al., 1997; de Vries and Veerkamp, 2000; Heuer et al., 2001). A consistent negative relationship between SCC and reproductive performance has also been found in more recent studies (Hudson et al., 2012, 2015; Bijker et al., 2015).

Milk protein yield, although tightly regulated (Jennens, 1979), has been shown to be associated with both nutritional and endocrine factors that influence protein metabolism in the mammary gland (DePeters and Cant, 1992; Mackle et al., 2000; Burgos et al., 2010). In particular, studies on animal and cell culture models have demonstrated that nutrient availability plays a role in regulating protein synthesis as both a substrate and via direct signaling to the protein synthetic machinery (Proud, 2007). Milk fat content is derived from both de novo synthesis of short- and medium-chain fatty acids by the mammary gland (Bauman et al., 2006) and long-chain fatty acids taken up from the bloodstream. Cows in NEB mobilize fat reserves and the milk percentage of C16:0 and C18:0 fatty acids increases (Stoop et al., 2009). The effects of changes in SCC may reflect the direct effect of subclinical mammary infection on reproductive function (Lavon et al., 2011b) or may simply be an indicator of metabolic issues (van Straten et al., 2009).

Shahinfar et al. (2015) successfully used milk yield data among 25 other explanatory variables including genetic information and health history to predict insemination outcome success using machine learning algorithm research, which also showed that the quality of data can have a significant effect on the accuracy of predictions particularly where recording of data is subjective such as in the recording of health traits.

Transition management success using early lactation milk yield data was also studied by Lukas et al. (2015); however, in this study transition management success was not linked to future reproductive outcomes.

Data from individual cow milk recordings is easily measured and readily accessible to both producers and consultants in the dairy industry globally and offers both a noninvasive and affordable method at both individual cow and herd level of assessing and monitoring energy status in early lactation as well as future reproductive potential. Readily accessible information that predicts an individual cow or herd's future reproductive performance would be of use to producers in managing reproductive programs as it affords the opportunity to alter management programs to potentially optimize the use of hormonal synchronization protocols, insemination methods (e.g., the use of sexed semen), or environmental management.

The objective of this research was to evaluate the usefulness of readily available production data to predict reproductive performance of dairy cows. Of particular interest was the difference between production characteristics to predict early pregnancy (by 100 DIM) or later pregnancy (by 150 DIM).

MATERIALS AND METHODS

Herd Selection and Reproductive Management

Herds were identified and selected to be included in this study if they had been referred to the technical services department of Genus ABS (Nantwich, UK) for consultation because of perceived poor reproductive performance reported in the period from September 1 to December 31, 2010; as such, they were part of the normal daily workload for that team.

Data were available for a total of 8,750 cows located in 33 herds. Mean and median herd sizes were 228 and 265 cows, respectively. Overall, 65% of cows (5,693) became pregnant and calved. The percentages of cows that conceived by 100 DIM, 150 DIM, and beyond 150 DIM were 30, 46, and 65%, respectively. Overall conception rate (total cows becoming pregnant/total number of inseminations) for cows in this study was 27.47%. Mean and median calving to conception interval (days from

calving to conception only for those cows that became pregnant) were 123 and 105 d, respectively.

All herds practiced year-round calving and were composed of Holstein-Friesian cows. Herds participated in a commercial reproductive management program for heat detection, insemination, and fertility data recording operated by Genus ABS. Briefly this service involved a daily visit to the farm premises by a trained technician using the tail chalk method to identify cows in estrus alongside more detailed manual examination per rectum of the reproductive tract of cows showing changes in the distribution of the chalk, which are indicative but not conclusive of the animal expressing estrus since the previous visit. All cows identified in estrus were then artificially inseminated. Cows scheduled for fixed time insemination (**TAI**) in accordance with veterinary protocols were also inseminated. The technician had responsibility to collect reproductive data on all cows including dates of calving, estrus, insemination, and dates and outcomes of veterinary examinations for pregnancy. In addition to reproductive data, the date when a cow is designated as “do not breed” and removed from the reproductive management program as well as dates of cow deaths, disposals, and exits were also recorded. Data collected was then entered into DairyComp305 (Valley Agricultural Software, Tulare, CA).

All inseminations were carried out by trans-cervical AI on a once daily basis at the time of the technicians' daily visit, and all herds used a local veterinary practitioner to examine cows for pregnancy from 35 d from the last insemination. All herds undertook milk sampling through National Milk Records or The Cattle Information Service on a monthly basis. Milk samples were collected at 2 consecutive milkings, and all herds were milked twice daily.

Data Collection and Analysis

Records of individual cow milk composition for each herd were electronically downloaded and merged with reproductive management data in DairyComp305. All data downloads were carried out in January 2012, and data were extracted for all cows with calving dates from September 1, 2009, until September 1, 2010. This ensured that every cow included had sufficient time to become pregnant for this analysis (>150 d). For each cow the unique identity, date of calving, lactation number, milk weights recorded at 0 to 30 DIM (34.0 ± 9.9 kg, mean $\pm$ SD) and 31 to 60 DIM (36.0 ± 10.0 kg), milk protein percentage at 0 to 30 DIM ($3.00 \pm 0.33\%$) and 31 to 60 DIM ($3.00 \pm 0.27\%$), butterfat percentage at 0 to 30 DIM ($4.00 \pm 0.89\%$), and SCC transformed by natural log and recorded at 0 to 30 DIM (4.3 ± 1.3) and 31 to 60 DIM (4.1 ± 1.3) were electronically

extracted into a spreadsheet (Excel, Microsoft Corporation, Redmond, WA). These data were chosen because previous studies indicated that they may be useful predictors of calving to conception interval in herds of this management type (Madouasse et al., 2010). In addition to these data, the average daily milk weight produced by a cow during the fourth week of lactation (**W4MK**; 33.3 ± 9.5 kg) was also extracted. Average daily milk weight produced during the fourth week of lactation is a parameter that can be calculated internally in DairyComp305 and has been used anecdotally to assess performance in early lactation.

To allow the effect of parity and season of calving to be tested as confounding variables, cows were categorized by parity and calving date into groups. Group 1 contained cows only in first parity, group 2 contained cows only in second parity, and group 3 contained cows in third parity and above. Cows were also categorized by month of calving. Cows were retained in the study until they died, were culled, or were declared as no longer eligible for insemination and so were considered in the analysis while they remained eligible to become pregnant.

The outcomes of interest were conception by 100 DIM or by 150 DIM. Conception by these times were chosen as the outcomes of interest because previous studies have suggested that pregnancy status at 150 DIM is a composite trait that is relatively robust to the heterogeneity of reproductive programs that occurs between farms (Caraviello et al., 2006). These points in lactation also approximate to the economic optimum time during lactation for a cow to become pregnant (Giordano et al., 2011) as well as allowing the differentiation of covariates that may predict pregnancy at different stages of lactation. Covariates tested in each model were parity group, month of calving, and milk weights at 0 to 30 DIM and 31 to 60 DIM, W4MK, percentage of protein at 0 to 30 DIM and 31 to 60 DIM, natural logarithm of the SCC at 0 to 30 DIM and 31 to 60 DIM and percentage of fat at 0 to 30 DIM. Farm was included as a random effect to account for correlations of cows within farm. Biologically plausible interactions for each covariate were also tested in each model.

Initial analysis consisted of descriptive statistics and graphical assessments. Multilevel (random effects) models (Goldstein and Rasbash, 1995) were specified so that correlations within the data (cows within farms) were accounted for appropriately. Model specifications took the form

$$\text{Preg}_{ij} \sim \text{Bernoulli}(\text{probability} = \pi_{ij})$$

$$\text{Logit}(\pi_{ij}) = \alpha + \beta_1 X_{ij} + \beta_2 X_j + v_j$$

$$V_j \sim N(0, \sigma_v^2),$$

where the subscripts *i* and *j* denote the *i*th cow and the *j*th farm, respectively, Preg_{*ij*} was the outcome variable (pregnant or not) for cow *i* in herd *j* either by d 100 (model 1) or by d 150 (model 2), α was the regression intercept, X_{ij} was the matrix of covariates at cow level, β_1 was the coefficients for covariates X_{ij} , X_j the matrix of farm-month level covariates, β_2 was the coefficients for covariates X_j , v_j was the random effect to reflect residual variation between farms, and σ^2 was the farm level variance..

Initial covariate assessment was carried out using MLwiN (Centre for Multilevel modeling, University of Bristol; Browne, 2009) with penalized quasi-likelihood for parameter estimation (Rasbash et al., 2005). Final models with the same specification as that above were constructed in a Bayesian framework using Markov chain Monte Carlo sampling (MCMC) for parameter estimation in WinBUGS (Spiegelhalter et al., 2004) to avoid the potential biased estimates that can arise from quasi-likelihood methods with binary data (Browne and Draper, 2006). Covariates were retained in the final model if their coefficient was at least twice its standard error and their inclusion resulted in a decrease in the deviance. Final model parameters were estimated using MCMC with a burn-in of at least 2,000 iterations during which time model convergence had occurred. Convergence was evaluated using visual assessment of 3 MCMC chains starting from 3 overdispersed initial values and also using the Gelman-Rubin statistic (as modified by Brooks and Gelman, 1998). Parameter estimates were based on a minimum further 8,000 iterations. Vague prior distributions were used for β [normal (0, 10⁶)] and σ^2_v [gamma (0.001, 0.001)] (Green et al., 2004). Investigation of model fit was made from plots of cumulated fitted probabilities and residuals (Langford and Lewis, 1998; Green et al., 2004). To further assess model fit and predictive value, posterior predictive as-

sessments were used (Gelman et al., 1996; Green et al., 2004) to evaluate the probabilities of pregnancy for cows with different production characteristics. “Good” cows were defined as those with a W4MK >30 kg and protein percentage at 0 to 30 and 31 to 60 DIM >3.2%. “Poor” cows were defined as those with a W4MK <25 kg and protein percentage at 0 to 30 and 31 to 60 DIM <3.0%. These categories represented the top and bottom 10% of cows for the values of these covariates. This allowed ready comparisons to be made between cows with “good” and “poor” production attributes, as identified in the statistical models, and to place these into a clinical context.

RESULTS

The final models are presented in Tables 1 and 2. Increased W4MK was associated with an increased odds of a cow becoming pregnant by 100 DIM and 150 DIM. Protein percentage up to 60 DIM remained in both models with increased protein percentage being associated with an increased odds of pregnancy. Fat percentage was associated with reduced odds of a cow becoming pregnant by 100 DIM but not by 150 DIM. Increased SCC up to 60 DIM was associated with a decreased odds of a cow becoming pregnant by 100 DIM, and increased SCC at 31 to 60 DIM was associated with a decreased odds of a cow becoming pregnant by 150 DIM. In both models, increasing parity was associated with a reduced odds of pregnancy.

Posterior predictive assessments indicated model fit for both models was good; observed values were always within the 95% credible interval (CrI) of model predictions. Posterior predictions for the likelihood of pregnancy were made from both models using cows with relatively good and poor production attributes. The posterior predicted probability of a “good” cow becom-

Table 1. Final multilevel logistic regression model with response variable pregnant by 100 DIM¹

Model term ²	Coefficient	Odds ratio	Lower limit 95% CrI	Upper limit 95% CrI
Intercept	−2.87			
W4MK (kg/d)		1.02	1.01	1.02
Protein % 0 to 30 DIM		1.35	1.30	1.39
Protein % 31 to 60 DIM		1.91	1.86	1.96
Fat % 0 to 30 DIM		0.92	0.90	0.95
Parity 1 reference category				
Parity 2		0.67	0.61	0.74
Parity 3+		0.53	0.47	0.60
ln SCC 0 to 30 DIM		0.92	0.91	0.93
ln SCC 31 to 60 DIM		0.95	0.93	0.96
Random effect; between-farm variance	0.38			

¹Variables retained in the model and their associated odds ratios and credible intervals (CrI).

²W4MK = average daily milk production by a cow in the fourth week of lactation; ln = natural logarithm.

ing pregnant by 100 DIM was 0.39 (95% CrI = 0.35 to 0.43) and this compared with the observed value of 0.40. The posterior predicted probability of a “poor” cow becoming pregnant by 100 DIM was 0.28 (95% CrI = 0.23 to 0.33), and this compared with the observed value of 0.26. The posterior predicted relative risk of pregnancy in a “good” cow in relation to a “poor” cow was 1.39 (95% CrI = 1.14 to 1.76).

The posterior predicted probability of a “good” cow becoming pregnant by 150 DIM was 0.57 (95% CrI = 0.54 to 0.61) and this compared with the observed value of 0.59. The posterior predicted probability of a “poor” cow becoming pregnant by 150 DIM was 0.42 (95% CrI = 0.37 to 0.48) and this compared with the observed value of 0.37. The posterior predicted relative risk of pregnancy in a “good” cow in relation to a “poor” cow was 1.36 (95% CrI = 1.18 to 1.59).

DISCUSSION

Many studies have reported associations between milk yields, constituents, and energy balance, consistent with the idea that milk composition reflects energy status (Grieve et al., 1986; Duffield et al., 1997; de Vries and Veerkamp, 2000; Heuer et al., 2001) and NEB has been linked to poor reproduction (Buckley et al., 2003; Patton et al., 2007).

In this study we were able to use a limited number of early lactation production characteristics to accurately assess and predict the risk of pregnancy occurring by

100 or 150 DIM. Clear and sizeable differences were also demonstrated in the risk of pregnancy occurring at either 100 or 150 DIM between cows categorized as showing either “good” or “poor” early lactation production characteristics, suggesting that these parameters may be of use for incorporation into decision support models to allow early identification of a cow’s likely reproductive potential soon after calving and, importantly, before the breeding period begins. Management interventions such as feeding strategies, synchronization protocols, and the use of sexed semen could then be targeted with better efficiency.

In contrast to some other studies (Shahinfar et al., 2015), this study sought to predict future reproductive outcomes from a limited number of early lactation production characteristics that are readily available on most dairies. Average daily milk weight in the fourth week of lactation in particular can be calculated from milk weights automatically collected at every milking from every cow via milk meters located in the milking parlor and as such is less subject to data quality issues.

More notably the findings of this study and in particular the large difference between “good” and “poor” cows demonstrate that a cow’s reproductive potential may be determined some weeks in advance of the breeding period before the active efforts by managers to obtain a pregnancy begins and that the overall reproductive success of these herds is at least in part determined by the proportion of cows falling into each category. Although outside the scope of this study it is also interesting to

Table 2. Final multilevel logistic regression model with response variable pregnant by 150 DIM¹

Model term ²	Coefficient	Odds ratio	Lower limit 95% CrI	Upper limit 95% CrI
Intercept	−2.95			
W4MK (kg/d)		1.02	1.02	1.03
Protein % 0 to 30 DIM		1.27	1.17	1.37
Protein % 31 to 60 DIM		2.17	2.05	2.30
Parity 1 reference category				
Parity 2		0.68	0.60	0.77
Parity 3+		0.47	0.43	0.52
ln SCC 31 to 60 DIM		0.92	0.89	0.95
January		0.94	0.75	1.17
February		0.87	0.70	1.08
March		0.99	0.80	1.23
April		0.84	0.68	1.04
May		1.01	0.80	1.27
June		1.05	0.82	1.34
July		0.84	0.65	1.07
August		0.76	0.61	0.96
September		0.89	0.70	1.13
October		0.99	0.80	1.22
November		0.99	0.78	1.25
December reference category				
Random effect; between-farm variance	0.57			

¹Variables retained in the model and their associated odds ratios and credible intervals (CrI).

²W4MK = average daily milk production by a cow in the fourth week of lactation; ln = natural logarithm.

speculate upon which factors may interact to determine which category a cow falls into and over what time period that effect occurs. The 33 herds participating in this study all reported recent disappointing reproductive outcomes, but it seems highly unlikely that the same combinations of management factors were present on each dairy at a similar time.

In particular, the degree and extent to which TAI was used in different herds and at different times may have produced a bias in our findings. However, it is also likely that any bias would have been in favor of the “poor” cows as they are perhaps less likely to have resumed normal estrus cyclicity postpartum and been inseminated at a natural estrus (Santos et al., 2010). Pregnancy status at 150 DIM is also a composite trait that is relatively robust to the heterogeneity in the extent of hormonal synchronization and duration of the voluntary waiting period as by this time all cows have equal opportunity to conceive either by natural estrus detection or TAI (Caraviello et al., 2006). Giordano et al. (2012) have also shown that the influence of the extent of hormonal synchronization on overall herd reproductive performance as measured by 21-d pregnancy rate (Ferguson and Galligan, 1999) is minimal at the conception rates achieved by the herds in this study unless 100% of inseminations are carried out to TAI.

Reductions in milk proteins are a consistent feature of cases of NEB. Milk protein is synthesized in the mammary gland, a process requiring energy and AA supplied via the blood stream. Attempts to predict milk protein content from AA supply, however, have been disappointing and it is now becoming clearer that the signaling pathways responsible for milk protein synthesis are capable of responding to a variety of nutritional and hormonal signals such that activation of the pathways responsible for protein translation in bovine mammary epithelial cells are capable of being modulated by signals other than simple AA supply (Burgos et al., 2010). During the physiological change from the dry period to the lactating state, substantial changes occur to both the nutrient supply and hormonal environment and it is not unreasonable to suggest that at this time these factors become limiting for milk protein synthesis, resulting in cows with poor transition demonstrating lower milk protein production in early lactation, which may then allow for early lactation milk proteins to be used as an indicator of both the nutrient and hormonal state of the cow as she enters lactation and her future reproductive potential.

The link between high milk production and poorer reproduction is equivocal with some studies indicating a negative effect whereas others show no effect (Lucy, 2001). Uniquely in this study, W4MK was used as an

early indicator of production and a positive association was identified between W4MK and the probability of pregnancy at both 100 and 150 DIM. Lactose is the major sugar in milk, composed of a single molecule of glucose and one of galactose. Synthesis takes place in the mammary gland from glucose supplied via the blood stream and secretion of lactose by the mammary epithelial cell into milk has a major effect on milk volume via its osmotic effect. Cows in good energy balance will be able to sustain better supplies of glucose to the mammary gland to drive lactose synthesis and milk volume.

The changes in milk yield and constituents and their association with energy balance has also become a basis for on-farm monitoring. In this study, fat percentage at 0 to 30 DIM was negatively associated with the probability of pregnancy at 100 DIM but not at 150 DIM, a finding which suggests that the use of fat percentage in predicting reproductive outcomes may be limited and that early lactation changes in fat percentage may be indicative of energy balance problems but that the impairment may be relatively mild and appears to be recoverable deeper into lactation, whereas protein percentage in early lactation shows a stronger and longer lasting association with the predicted probability of pregnancy possibly indicative of a more serious and damaging effect on energy balance during transition. Fat percentage may also be confounded as seasonal variations are substantial (Madouasse et al., 2010).

The SCC around the time of insemination has been shown to influence the probability of conception (Lavon et al., 2011a); however, in this study the SCC in early lactation was shown to have an influence on the probability of pregnancy much deeper into lactation and several explanations for this finding are possible. Changes in SCC were not tracked into lactation in this study, and it is possible that cows with high SCC early in lactation are infected and retain their infected status into lactation so that the SCC remains high around the time of insemination. Alternatively, it may be that the elevated SCC observed in early lactation in these cows may be indicative of excess body condition loss, more severe NEB, and more severe metabolic issues in early lactation (van Straten et al. 2009), which predisposes them to udder inflammation. It is interesting to note that in this study high SCC at both 0 to 30 and 31 to 60 DIM had a negative effect on pregnancy outcome by 100 DIM, but only SCC at 31 to 60 DIM had a negative effect on pregnancy outcome by 150 DIM, perhaps suggesting that in cows with elevated SCC only at 0 to 30 DIM the SCC indicates mild early lactation body condition loss, which recovers as lactation progresses, whereas cows with elevated SCC at 31 to 60 DIM may

be cows with either persistent mammary infections or cows that suffered a more severe body condition loss requiring a more prolonged recovery.

The final models also indicated that month of calving had no influence on the probability of pregnancy occurring by 100 DIM but did have an influence at 150 DIM. This finding is difficult to explain but may be related to several factors. First, it has been shown that both milk yield and constituents vary with season in dairy herds located in England and Wales where the herds in this study were located (Madouasse et al., 2010) and that feeding regimen is known to influence butterfat (Bauman and Griinari, 2003). The grazing practices of the herds in this study may have varied considerably and it is common for seasonal grazing and pasture to form a part of the feeding management of dairy herds in England and Wales. This was not accounted for in the study design and may have contributed to this finding. All the herds in this study used a program of tail chalking to identify cows expressing heat, and it is known that cows which remain metabolically stable around calving are likely to return to cycling behavior and be detected in heat and inseminated well before 100 DIM (Santos et al., 2010). The reproductive behavior of these cows is predictable. In the United Kingdom it is not common practice for cows that fail to express heat and be inseminated by a threshold DIM to be enrolled to synchronization programs to ensure a timely first insemination (Higgins et al., 2013). Instead they are more commonly presented for veterinary examination by ultrasound when individual treatments would be applied to each cow based on the ultrasonic appearance of the ovaries and uterus. It is likely that the cows presented for such examination are cows that passed through transition in a relatively poor metabolic state and so fail to return to normal cycling behavior. The reproductive behavior of these cows will be less predictable, and they will be less likely to be detected in heat by the chalking program and perhaps more exposed to seasonal influences. In the United Kingdom, it is also common practice for lists of cows scheduled for veterinary examination to be heavily edited by herdsman and also for routine veterinary visits to be rescheduled when there is a conflict with staff holidays or other farm tasks considered of greater importance such as silage making are taking place. Any or all of these circumstances could have been present at differing times on the farms represented in this study.

The findings of this study should be interpreted with caution because the small number of farms in this study were recruited because of perceived poor reproductive performance and as such may not be representative of all herds. Further work would be needed to clarify if these findings are truly representative of all herds.

CONCLUSIONS

Positive associations were identified between milk protein percentage at 0 to 30 and 31 to 60 DIM, W4MK, and the probability of pregnancy by 100 DIM. A negative association was identified for milk fat percentage in the first 30 DIM, parity, and SCC at 0 to 30 DIM and 31 to 60 DIM. Of these, only protein percentage at 0 to 30 DIM and 31 to 60 DIM and W4MK showed positive associations with the probability of pregnancy by 150 DIM, whereas parity and SCC were shown to be negatively associated with the probability of pregnancy by 150 DIM. Month of calving was also shown to be associated with the probability of pregnancy by 150 DIM. Selecting a limited number of these parameters with the strongest associations with the outcomes of interest, we were then able to categorize cows and use posterior predictions to accurately predict the probabilities of the occurrence of pregnancy. Sizeable and significant differences in reproductive potential were shown between cows categorized as having “good” or “poor” production characteristics in early lactation.

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