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2 **Predicting the future reproductive potential of dairy cows Cook**

3 Economic success in dairy herds relies on obtaining pregnancies at an early stage of lactation.

4 In this study we were able to categorise and predict the reproductive performance of dairy
5 cows based on a limited number of data gathered from early lactation milk records.

6 Capability to predict future reproductive outcomes has the potential to assist dairy producers
7 with the planning and targeting of reproductive management strategies such as
8 pharmacological intervention with the possibility for less reliance on such methods and better
9 justification for their use when necessary.

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

12 **J. G. Cook,^{*1} and M. J. Green[†]**

13 ***Yew Tree House, Carleton, Carlisle, CA1 3DP, United Kingdom**

14 **†School of Veterinary Medicine and Science, University of Nottingham, Sutton**
15 **Bonnington Campus, Sutton Bonnington, LE12 5RD, United Kingdom**

16 **¹John George Cook, Yew Tree House, Carleton, Carlisle, CA1 3DP. United Kingdom**

17 **+44 (0)1228 594983 john.cook14@btinternet.com**

18 **ABSTRACT**

19 Economic success in dairy herds is heavily reliant on obtaining pregnancies at an early stage
20 of lactation. Our objective in this study was to attempt to predict the likelihood of conception
21 occurring by the 100th and 150th day of lactation (**DIM**) by Markov chain Monte Carlo
22 (**MCMC**) analysis using milk recording data and reproductive records gathered

23 retrospectively from 8750 cows from 33 dairy herds located in the United Kingdom. Overall
24 65% of cows recalved with 30%, 46% and 65% of cows conceived by 100 DIM, 150 DIM
25 and beyond 150 DIM respectively. Overall conception rate (total cows pregnant/total cows
26 inseminated) was 27.47%. Median and mean calving to conception intervals were 123 d and
27 105 d respectively. The probability of conception by both 100 DIM and 150 DIM was
28 positively associated with week 4 milk production and protein percentage measured at 0-30
29 DIM and 31-60 DIM. Butterfat percentage was negatively associated with the probability of
30 conception by 100 DIM but not at 150 DIM. Increased somatic cell count (SCC) up to 60
31 DIM was negatively associated with the probability of conception by 100 DIM whilst
32 increased somatic cell count at 31-60 DIM was associated with a reduced probability of
33 conception by 150 DIM. Increasing parity was associated with a reduced odds of pregnancy.
34 Posterior predictions of the likelihood of conception for cows categorised as having ‘good’ or
35 ‘poor’ early lactation attributes with actual observed values indicated model fit was good.
36 The likelihood of a ‘good’ cow conceiving by 100 and 150 DIM were 0.39 and 0.57
37 respectively (observed values 0.40 and 0.59). The corresponding values for a ‘poor’ cow
38 were 0.28 and 0.42 (observed values 0.26 and 0.37). Predictions of the future reproductive
39 potential of cows may be possible using a limited number of early lactation attributes.

40 INTRODUCTION

41 Dairy herd profitability is highly dependent on reproductive performance (Louca and
42 Legates, 1968; Oltenacu et al., 1981; Giordano et al., 2011; Giordano et al., 2012) probably
43 because optimising the time cows spend in the most efficient part of the lactation curve has a
44 significant impact on revenues obtained for milk sales (Ferguson and Galligan, 1999) as well
45 as minimising replacement costs due to reproductive failure. The timing at which pregnancy
46 occurs during lactation is of utmost importance in sustaining profitability (Giordano et al.,
47 2011); ideally this should occur between 90 and 130 days of lactation (Giordano et al., 2011).

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

55 Britt (1992) suggested that the biological environment in the relatively long period of
56 follicular growth prior to ovulation is a major factor contributing to the 'syndrome of sub
57 fertility' in dairy cows however to date the only long term demonstrable adverse effect on
58 fertility is the effect of heat stress (Chebel et al., 2004). Leroy (2008a, 2008b) has reviewed
59 the mechanisms by which the biochemical environment of the cow and in particular the
60 metabolic changes associated with negative energy balance may influence fertility but many
61 of these effects have been investigated only in the short term because in vitro studies
62 examining long term effects of metabolism are difficult to conduct (Leroy et al., 2008a).

63 Therefore, it would seem likely then that negative energy balance in early lactation may at
64 least in part be responsible for the creation of the biological environment that leads to sub
65 fertility in dairy cows. Milk recording data from individual cows has been used in several
66 studies to associate milk composition in early lactation with energy balance (Duffield et al.,
67 1997; De Vries and Veerkamp, 2000; Heuer et al., 2001) and more recently Madouasse et al.
68 (2010) have associated milk components in early lactation with the probability of conception
69 at certain intervals during lactation. In particular Madouasse et al. identified an association
70 between lower milk production on second test day, higher percentage of protein on second
71 test day and higher percentage of lactose on first test day with increased probability of
72 conception before 145 DIM whilst positive associations of a smaller magnitude were

73 identified for percentage of protein at first test day and negative associations with first test
74 butterfat and SCC on both first and second test days.

75 More recently Shahinfar et al. (2014) have used milk yield data amongst a potential 25 other
76 explanatory variables including genetic information and health history to predict insemination
77 outcome success using machine learning algorithms. This research also showed that the
78 quality of data can have a significant effect on the accuracy of predictions particularly where
79 recording of data is subjective traits such as in the recording of health traits.

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

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

92 The objective of this research was to evaluate the usefulness of readily available production
93 data to predict reproductive performance of dairy cows. Of particular interest was the
94 difference between production parameters to predict early pregnancy (by day 100 of
95 lactation) or later pregnancy (by day 150 of lactation).

97 *Herd Selection and Reproductive Management*

98 Herds were identified and selected to be included in this study if they had been referred to the
99 technical services department of Genus ABS (Nantwich, United Kingdom) for consultation
100 because of perceived poor reproductive performance reported in the period 1st September
101 2010-31st December 2010 and as such were part of the normal daily workload of that team.

102

103 Data were available for a total of 8750 cows located in 33 herds. Mean and median herd size
104 was 228 and 265 cows respectively. Overall 65% of cows (5693) became pregnant and re
105 calved. The percentage of cows that had conceived by 100 days, 150 days and beyond 150
106 days of lactation were 30%, 46% and 65% respectively. Overall conception rate (total cows
107 becoming pregnant/total cows served) for cows in this study was 27.47%. Mean and median
108 calving to conception interval was 123 and 105 days respectively.

109

110 All herds practised all year round calving and were composed of Holstein Friesian cows.

111 Herds participated in a commercial reproductive management program for heat detection,
112 insemination and fertility data recording operated by Genus ABS (RMS[®], Genus ABS).

113 Briefly this service involved a daily visit to the farm premises by a trained technician using
114 the tail chalk method to identify cows in oestrus alongside more detailed manual examination
115 per rectum of the reproductive tract of cows showing changes in the distribution of the chalk
116 which are indicative but not conclusive of the animal expressing oestrus since the previous
117 visit. All cows identified in oestrus were then artificially inseminated. Cows scheduled for
118 fixed time insemination (**TAI**) in accordance with veterinary protocols were also
119 inseminated. The technician had responsibility to collect reproductive data on all cows

120 including dates of calving, oestrus, insemination and dates and outcomes of veterinary
121 examinations for pregnancy. In addition to reproductive data, date of dry off and the date
122 when a cow is designated as 'do not breed' and removed from the reproductive management
123 program as well as dates of cow deaths, disposals and exits were also recorded. Data
124 collected was then entered into Dairy Comp 305 (Valley Agricultural Software, Tulare,
125 USA).

126

127 All inseminations were carried out by trans-cervical artificial insemination (**AI**) on a once
128 daily basis at the time of the technicians' daily visit and all herds used a local veterinary
129 practitioner to examine cows for pregnancy from 35 days from the last insemination. All
130 herds undertook milk sampling through National Milk records or The Cattle Information
131 Service on a monthly basis. Milk samples were collected at 2 consecutive milkings and all
132 herds were milked twice daily.

133 *Data Collation and Analysis*

134 Records of individual cow milk composition for each herd were electronically downloaded
135 and merged with reproductive management data in Dairy Comp 305. All data downloads
136 were carried out in January 2012 and data were extracted for all cows with calving dates from
137 1st September 2009 until 1st September 2010. This ensured that every cow included had
138 sufficient time to become pregnant for this analysis (>150 days). For each cow the unique
139 identity, date of calving, lactation number, milk weights recorded at 0-30 DIM and 31-60
140 DIM milk protein percentage at 0-30 DIM and 31-60 DIM, butterfat percentage at 0-30 DIM
141 and somatic cell count recorded at 0-30 DIM and 31-60 DIM were electronically extracted
142 into a spreadsheet (Excel[®], Microsoft Corporation). These data were chosen because previous
143 studies indicated that they may be useful predictors of calving to conception interval in herds
144 of this management type (Madousse et al 2010). In addition to these data the average daily

145 milk weight produced by a cow during the fourth week of lactation (Week 4 Milk) was also
146 extracted. Week 4 milk is a parameter which can be calculated internally in Dairy Comp 305
147 and has been used anecdotally to assess performance in early lactation.

148 To allow the effect of parity and season of calving to be tested as confounding variables,
149 cows were categorised by parity and calving date into groups. Group 1 contained cows only
150 in first parity, group 2 contained cows only in second parity and group 3 containing cows in
151 third parity and above. Cows were also categorised by month of calving.

152 The outcomes of interest were conception by 100 days or by 150 days of lactation.

153 Conception by these times were chosen as the outcomes of interest because previous studies
154 have suggested that pregnancy status at 150 DIM is a composite trait that is relatively robust
155 to the heterogeneity of reproductive programs that occurs between farms (Caraviello et al.,
156 2006). These points in lactation also approximate to the economic optimum time during
157 lactation for a cow to become pregnant (Giordano et al., 2011) as well as allowing the
158 differentiation of covariates that may predict pregnancy at different stages of lactation.

159 Covariates tested in each model were parity group, month of calving, and milk weights at 0-
160 30 DIM and 31-60 DIM, week 4 milk production, percentage of protein at 0-30 DIM and 31-
161 60 DIM, somatic cell count at 0-30 DIM and 31-60 DIM and percentage of fat at 0-30 DIM.
162 Farm was included as a random effect to account for confounding of cows within farm.

163 Initial analysis consisted of descriptive statistics and graphical assessments.

164 Multilevel (random effects) models (Goldstein, 1995) were specified so that correlations
165 within the data (cows within farms) were accounted for appropriately. Model specifications
166 took the form;

167 $\text{Preg}_{ij} \sim \text{Bernoulli}(\text{probability} = \pi_{ij})$

168 $\text{Logit}(\pi_{ij}) = \alpha + \beta_1 X_{ij} + \beta_2 X_j + v_j$

169 $V_j \sim N(0, \sigma_v^2)$

170 where the subscripts i , and j denote the i^{th} cow and the j^{th} farm respectively, Preg_{ij} was the
171 outcome variable (pregnant or not) for cow i in herd j either by day 100 (Model 1) or by day
172 150 (Model 2), α the regression intercept, X_{ij} the matrix of covariates at cow level, β_1 the
173 coefficients for covariates X_{ij} , X_j the matrix of farm-month level covariates, β_2 the
174 coefficients for covariates X_j and v_j the random effect to reflect residual variation between
175 farms.

176 Initial covariate assessment was carried out using MLwiN (Centre for Multilevel
177 modelling, University of Bristol) (Browne, 2009) with penalised quasi-likelihood for
178 parameter estimation (Rasbash et al., 2005). Final models, with the same specification as that
179 above, were constructed in a Bayesian framework using MCMC for parameter estimation in
180 WinBUGS (Spiegelhalter et al., 2004), to avoid the potential biased estimates that can arise
181 from quasi-likelihood methods with binary data (Browne and Draper, 2006). Final model
182 parameters were estimated using MCMC with a burn-in of at least 2,000 iterations during
183 which time model convergence had occurred. Parameter estimates were based on a minimum
184 further 8,000 iterations. Vague prior distributions were used for β (Normal $(0, 10^6)$) and σ_v^2
185 (Gamma $(0.001, 0.001)$) (Green et al., 2004). Investigation of model fit was made from plots
186 of cumulated fitted probabilities and residuals (Langford and Lewis, 1998; Green et al.,
187 2004). To further assess model fit and predictive value, posterior predictive assessments were
188 used (Gelman et al., 1996; Green et al., 2008) to evaluate the probabilities of pregnancy for
189 cows with different production characteristics. This allowed ready comparisons to be made
190 between cows with ‘good’ and ‘poor’ production attributes, as identified in the statistical
191 models, and to place these into a clinical context.

192 **RESULTS**

193 The final models are presented in Tables 1 and 2. Increased milk yield in the fourth week of
194 lactation was associated with an increased odds of a cow becoming pregnant by day 100 and
195 150 of lactation. Protein percentage up to 60 days of lactation remained in both models with
196 increased protein percentage being associated with an increased odds of pregnancy. Fat
197 percentage was associated with reduced odds of a cow becoming pregnant by day 100 but not
198 by day 150. Increased somatic cell count up to 60 days of lactation was associated with a
199 decreased odds of a cow becoming pregnant by day 100 of lactation and increased somatic
200 cell count 31- 60 days of lactation was associated with a decreased odds of a cow becoming
201 pregnant by day 150 of lactation. In both models, increasing parity was associated with a
202 reduced odds of pregnancy.

203 Posterior predictive assessments indicated model fit for both models was good. Posterior
204 predictions for the likelihood of pregnancy were made from both models using cows with
205 relatively good and poor production attributes. ‘Good’ cows were defined as those with a
206 milk yield in week four >30Kg, protein percentage 0-30 days in milk >3.2% and protein
207 percentage 31-60 days in milk >3.2%. 1337 cows were classified as ‘good’. ‘Poor’ cows were
208 defined as those with a milk yield in week four <21Kg, protein percentage 0-30 days in
209 milk >3.0% and protein percentage 31-60 days in milk >3.0%. The posterior predicted
210 probability of a ‘good’ cow becoming pregnant by day 100 of lactation was 0.39 (95%
211 credible interval 0.35-0.43) and this compared to the observed value of 0.40. The posterior
212 predicted probability of a ‘poor’ cow becoming pregnant by day 100 of lactation was 0.28
213 (95% credible interval 0.23-0.33) and this compared to the observed value of 0.26. The
214 posterior predicted relative risk of pregnancy in a ‘good’ cow in relation to a ‘poor’ cow was
215 1.40 (95% credible interval 1.14-1.76).

216 The posterior predicted probability of a ‘good’ cow becoming pregnant by day 150 of
217 lactation was 0.57 (95% credible interval 0.54-0.61) and this compared to the observed value

218 of 0.59. The posterior predicted probability of a ‘poor’ cow becoming pregnant by day 150 of
219 lactation was 0.42 (95% credible interval 0.37-0.48) and this compared to the observed value
220 of 0.37. The posterior predicted relative risk of pregnancy in a ‘good’ cow in relation to a
221 ‘poor’ cow was 1.36 (95% credible interval 1.18-1.59).

222 **DISCUSSION**

223 Many studies have reported associations between milk yields, constituents and energy
224 balance, consistent with the idea that milk composition reflects energy status (Grieve et al.,
225 1986; Duffield et al., 1997; De Vries and Veerkamp, 2000; Heuer et al., 2001) and NEB has
226 been linked to poor reproduction (Buckley et al., 2003; Patton et al., 2007).

227 In this study we were able to use a limited number of early lactation production
228 characteristics to accurately assess and predict the risk of pregnancy occurring by 100 or 150
229 DIM. Clear and sizeable differences were also demonstrated in the risk of pregnancy
230 occurring at either 100 or 150 DIM between cows categorised as showing either ‘good’ or
231 ‘poor’ early lactation production characteristics suggesting that these parameters may be of
232 use for incorporation into decision support models to allow early identification of a cow’s
233 likely reproductive potential soon after calving and importantly, before the breeding period
234 begins. Management interventions such as feeding strategies, synchronisation protocols and
235 the use of sexed semen could then be targeted with better efficiency.

236 In contrast to some other studies (Shahinfar et al., 2014) this study sought to predict future
237 reproductive outcomes from a limited number of early lactation production characteristics
238 that are readily available on most dairies. Week 4 Milk in particular can be calculated from
239 milk weights automatically collected at every milking from every cow via milk meters
240 located in the milking parlour and as such is less subject to data quality issues.

241 More notably the findings of this study and in particular the large difference between ‘good’
242 and ‘poor’ cow’s demonstrates that a cows reproductive potential may be determined some
243 weeks in advance of the breeding period before the active efforts by managers to obtain a
244 pregnancy begins and that the overall reproductive success of these herds is at least in part
245 determined by the proportion of cows falling into each category. Although outside the scope
246 of this study it is also interesting to speculate upon which factors may interact to determine
247 which category a cow falls into and over what time period that impact occurs. The 33 herds
248 participating in this study all reported recent disappointing reproductive outcomes but it
249 seems highly unlikely that the same combinations of management factors were present on
250 each dairy at a similar time.

251 In particular the degree and extent to which TAI was used in different herds and at different
252 times may have produced a bias in our findings as cows subjected to TAI may be more likely
253 to become pregnant earlier in lactation. However it is also likely that any bias would have
254 been in favour of the ‘poor’ cows as they are perhaps less likely to have resumed normal
255 oestrus cyclicity post-partum and been inseminated to a natural oestrus (Santos et al., 2010).
256 Pregnancy status at 150 DIM is also a composite trait that is relatively robust to the
257 heterogeneity to the extent of hormonal synchronisation and duration of the voluntary waiting
258 period (Caraviello et al., 2006). Giordano et al (2012) have also shown that the influence of
259 the extent of hormonal synchronisation on overall herd reproductive performance as
260 measured by 21d pregnancy rate (Ferguson and Galligan, 1999) is minimal at the conception
261 rates achieved by the herds in this study unless 100% of inseminations are carried out to TAI.

262 Reductions in milk proteins are a consistent feature of cases of NEB. Milk protein is
263 synthesised in the mammary gland, a process requiring energy and amino acids supplied via
264 the blood stream. Attempts to predict milk protein content from amino acid supply however
265 have been disappointing and it is now becoming clearer that the signalling pathways

266 responsible for milk protein synthesis are capable of responding to a variety of nutritional and
267 hormonal signals such that activation of the pathways responsible for protein translation in
268 bovine mammary epithelial cells are capable of being modulated by signals other than simple
269 amino acid supply (Burgos et al., 2010). During the physiological change from the dry period
270 to the lactating state there are substantial changes to both the nutrient supply and hormonal
271 environment and it is not unreasonable to suggest that at this time these factors become
272 limiting for the production of milk protein synthesis resulting in cows with poor transition
273 demonstrating lower milk protein production in early lactation which may then allow for
274 early lactation milk proteins to be used as an indicator of both the nutrient and hormonal state
275 of the cow as she entered lactation and her future reproductive potential.

276 The link between high milk production and poorer reproduction is equivocal with some
277 studies indicating a negative effect whilst others show no effect (Lucy, 2001). Uniquely in
278 this study week 4 milk production was used as an early indicator of production and a positive
279 association was identified between week 4 milk and the probability of pregnancy at both 100
280 and 150 DIM. Lactose is the major sugar in milk composed of a single molecule of glucose
281 and one of galactose. Synthesis takes place in the mammary gland from glucose supplied via
282 the blood stream and secretion of lactose by the mammary epithelial cell into milk has a
283 major impact on milk volume via its osmotic effect. Cows in good energy balance will be
284 able to sustain better supplies of glucose to the mammary gland to drive lactose synthesis and
285 milk volume.

286 The changes in milk yield and constituents and their association with energy balance has also
287 become a basis for on farm monitoring using indicators such as fat to protein ratio. In this
288 study fat percentage at 0-30 DIM was negatively associated with the probability of pregnancy
289 at 100 DIM but not at 150 DIM, a finding which suggests that the use of fat percentage in
290 predicting energy balance may be limited and that early lactation changes in fat percentage

291 may be indicative of energy balance problems but that the impairment may be relatively mild
292 and appears to be recoverable deeper into lactation whereas protein percentage in early
293 lactation shows a stronger and longer lasting association with the predicted probability of
294 pregnancy possibly indicative of a more serious and damaging impact on energy balance
295 during transition. The findings of this study also indicate that fat to protein ratio may be
296 confounded as variations may be due to changes in fat percentage, protein percentage or both
297 and will be further affected as the normal variations in fat percentage observed throughout
298 lactation and season are of greater magnitude than changes in protein percentage and will
299 have a greater influence on changes in the ratio observed.

300 Somatic cell count around the time of insemination has been shown to influence the
301 probability of conception (Lavon et al., 2011) however in this study the somatic cell count in
302 early lactation was shown to have an influence on the probability of pregnancy much deeper
303 into lactation and there may be a number of explanations for this finding. Changes in cell
304 count were not tracked into lactation in this study and it is possible that cows with high
305 somatic cell counts early in lactation are infected and retain their infected status into lactation
306 so that the cell count remains high around the time of insemination. Alternatively it may be
307 that the elevated cell count observed in early lactation in these cows may be indicative of
308 excess body condition loss, more severe NEB and more severe metabolic issues in early
309 lactation (Van Straten et al 2009) which predisposes them to udder inflammation. It is
310 interesting to note that in this study high somatic cell count at both 0-30 DIM and 31-60 DIM
311 had a negative effect on pregnancy outcome by 100 d and 150 d of lactation but only cell
312 count at 31-60 DIM had an influence on pregnancy outcome by 150 d, perhaps suggesting
313 that in cows with elevated cell counts only at 0-31 days the cell count indicates mild early
314 lactation body condition loss which recovers as lactation progresses whilst cows with

315 elevated cell counts at 31-60 days may be either cows with persistent mammary infections or
316 cows that suffered a more severe body condition loss requiring a more prolonged recovery.

317 The final models also indicated that month of calving had no influence on the probability of
318 pregnancy occurring by 100 DIM but did have an influence at 150 DIM. This finding is
319 difficult to explain but may be related to several factors. Firstly it has been shown that both
320 milk yield and constituents vary with season in dairy herds located in England and Wales
321 where the herds in this study were located (Madouasse et al 2010) and that feeding regimen is
322 known to influence butterfat (Baumann and Griinari, 2003). The grazing practices of the
323 herds in this study may have varied considerably and it is common for seasonal grazing and
324 pasture to form a part of the feeding management of dairy herds in England and Wales. This
325 was not accounted for in the study design and may have contributed to this finding. All the
326 herds in this study utilized a program of tail chalking (RMS®, Genus ABS) to identify cows
327 expressing heat and it is known that cows which remain metabolically stable around calving
328 are likely to return to cycling behaviour and be detected in heat and inseminated well before
329 100 days of lactation (Santos et al., 2010). The reproductive behaviour of these cows is
330 predictable. In the UK it is not common practice for cows that fail to express heat and be
331 inseminated by a certain days in milk to be enrolled to synchronisation programs to ensure a
332 timely first insemination (Higgins et al., 2013). Instead they are more commonly presented
333 for veterinary examination by ultrasound when individual treatments would be applied to
334 each cow based on the ultrasonic appearance of the ovaries and uterus. It is likely that the
335 cows presented for such examination are cows that passed through transition in a relatively
336 poor metabolic state and so fail to return to normal cycling behaviour. The reproductive
337 behaviour of these cows will be less predictable, they will be less likely to be detected in heat
338 by the chalking program and perhaps more exposed to seasonal influences. In the UK it is
339 also common practice for lists of cows scheduled for veterinary examination to be heavily

340 edited by herdsman and also for routine veterinary visits to be rescheduled when there is a
341 conflict with staff holidays or other farm tasks considered of greater importance such as
342 silage making are taking place. Any or all of these circumstances could have been present at
343 differing times on the farms represented in this study.

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

348

349

CONCLUSIONS

350 Milk protein percentage between 0-30 and 30-60 days in milk, week 4 milk yield, milk fat
351 percentage in the first 30 days of lactation, parity and somatic cell count at 0-30 days and 30-
352 60 days of lactation were found to be significant predictors of the probability of pregnancy by
353 100 days of lactation. Of these only 0-30 day and 30-60 day milk protein percentage, week 4
354 milk, parity and somatic cell count along with month of calving were shown to be significant
355 predictors of pregnancy by 150 days of lactation. Selecting a limited number of these
356 parameters with the strongest associations with the outcomes of interest we were then able to
357 categorise cows and use posterior predictions to accurately predict the probabilities of the
358 occurrence of pregnancy. Sizeable and significant differences in reproductive potential were
359 shown between cows categorised as having 'good' or 'poor' production characteristics in
360 early lactation.

361

362 **Table 1. Final multilevel logistic regression model with response variable pregnant by**
 363 **100 days in milk**

Model terms	Coefficient	Odds Ratio	Credible Interval	
			2.5%	97.5%
Intercept	-2.87			
Week 4 milk yield (Kg)		1.02	1.01	1.02
Protein % 0-30 DIM		1.35	1.30	1.39
Protein % 31-60 DIM		1.91	1.86	1.96
Fat % 0-30 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
Log SCC 0-30 DIM		0.92	0.91	0.93
Log SCC 31-60 DIM		0.95	0.93	0.96
Random effect; between farm variance	0.38			

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373 **Table 2. Final multilevel logistic regression model with response variable pregnant by**
 374 **150 days in milk**

Model terms	Coefficient	Odds Ratio	Credible Interval	
			2.5%	97.5%
Intercept	-2.95			
Week 4 milk yield (Kg)		1.02	1.02	1.03
Protein % 0-30 DIM		1.27	1.17	1.37
Protein % 31-60 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
Log SCC 31-60 DIM		0.92	0.89	0.95
MONTH 1		0.94	0.75	1.17
MONTH 2		0.87	0.70	1.08
MONTH 3		0.99	0.80	1.23
MONTH 4		0.84	0.68	1.04
MONTH 5		1.01	0.80	1.27
MONTH 6		1.05	0.82	1.34
MONTH 7		0.84	0.65	1.07
MONTH 8		0.76	0.61	0.96
MONTH 9		0.89	0.70	1.13
MONTH 10		0.99	0.80	1.22
MONTH 11		0.99	0.78	1.25
MONTH 12 Reference category				
Random effect; between farm variance	0.57			

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