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1 **Association between body energy content in the dry period and post calving**
2 **production disease status in dairy cattle**

3

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13

14 Indicators of production disease in dairy cattle

15

16 **Abstract**

17 The transition from gestation to lactation is marked by significant physiological
18 changes for the individual cow such that disease incidence is highest in early
19 lactation. Around the time of calving, cows rely on mobilisation of body energy
20 reserves to fill the energy deficit created by an increase in nutrient demands at a time
21 of restricted feed intake. It is well established that monitoring of body energy reserves
22 in lactation is an important component of herd health management. However, despite
23 their influence on future health and productivity, monitoring of body energy reserves
24 in the dry period is often sparse. Further, there is increasing concern that current dry
25 off management is inappropriate for modern cattle and may influence future disease

26 risk. This study aimed to identify candidate indicators of early lactation production
27 disease from body energy data collected in the dry period and production data
28 recorded at the time of dry off. Retrospective analysis was performed on 482 cow-
29 lactations collected from a long-term Holstein-Friesian genetic and management
30 systems project, the Langhill herd in Scotland. Cow-lactations were assigned to one
31 of four health groups based on health status in the first 30 days of lactation. These
32 four groups were - healthy, reproductive tract disorders (retained placenta and
33 metritis), subclinical mastitis and metabolic disorders (ketosis, hypocalcaemia,
34 hypomagnesaemia and left displaced abomasum). Analysis of variance, employing a
35 generalised linear model was used to determine effects for the candidate indicator
36 traits. Cows which were diagnosed with a reproductive tract disorder in the first 30
37 days of lactation experienced a significantly greater loss in body energy content,
38 body condition score and weight in the preceding dry period than healthy cows. The
39 rate of change in body energy content during the first 15 days of the dry period was -
40 18.26 mega-joules (**MJ**) per day for cows which developed reproductive tract
41 disorder compared to +0.63 MJ per day for healthy cows. Cows diagnosed with
42 subclinical mastitis in the first 30 days of lactation had significantly greater milk yield
43 at dry off in the previous lactation than cows that developed a reproductive tract
44 disorder or metabolic disease in addition to a significantly higher yield to body energy
45 content ratio at dry off than healthy cows. Physiological and production traits
46 recorded in the lactation and dry period preceding a disease event differed between
47 cows which developed different diseases post-calving. Differences in these traits
48 allow the development of new disease indicators for use in models for the prediction
49 of disease risk in the transition period.

50

51 **Keywords:** transition period, lactation management, production disease, disease
52 indicators

53

54 **Implications**

55 The importance of transition cow management has been well documented for some
56 time. However, traditionally the transition period is considered to extend only 30
57 days each side of calving. Further, the assessment of body energy reserves by body
58 condition scoring is mostly conducted during lactation. We hypothesise that
59 monitoring of energy reserves from the end of lactation and throughout the dry period
60 would help mitigate early lactation disease. This paper describes traits which have
61 potential as disease indicators in early lactation, sourced from data recorded in the
62 lactation and dry period.

63

64 **Introduction**

65 Production disease in early lactation poses a threat to animal welfare and the
66 economic viability of dairy production. Diseases in early lactation account for a
67 considerable proportion of health control costs in dairy farming systems, both directly
68 and indirectly (Fourichon *et al.*, 2001). Direct costs include the cost of veterinary
69 treatment whilst indirect costs are incurred through reduced fertility and longevity of
70 affected cows. In 2014 the cost per case of left displaced abomasum and retained
71 placenta were estimated to be £255 and £378, respectively (Cattle Health and
72 Welfare Group, 2014).

73

74 The transition period, traditionally defined as extending from 3 weeks prior until 3
75 weeks post calving, represents a significant physiological challenge for dairy cattle.

76 During this time cows must adapt to the demands of lactation whilst delivering
77 healthy offspring, in the face of reduced feed intake, negative energy balance, insulin
78 resistance and reduced immune function (Loor, 2013). Such is the challenge of the
79 transition period that early lactation is marked by the highest disease incidence of
80 any stage in the lactation-gestation cycle (Ingvarsen *et al.*, 2003). It is estimated
81 that 30 to 50% of cows are affected by some form of metabolic or infectious disease
82 around calving. Disease associated with the early lactation period can be considered
83 as “production disease” and includes diseases which are induced and exacerbated
84 by nutrition and management practices (Markusfeld, 2003). The abrupt cessation of
85 milking at the time of dry off is an example of a widely practiced end of lactation
86 management strategy which can have a significant effect on cow health. It has
87 recently been suggested that this sudden cessation of milk removal causes
88 discomfort and distress to the cow (Zobel *et al.*, 2015). In addition, sudden dietary
89 changes often occur between the lactating and dry periods. The rumen environment
90 must adapt to a change from an energy dense lactation diet to one which meets
91 basic maintenance requirements, before preparation begins in the transition period to
92 adjust back to the lactation ration (Dingwell *et al.*, 2011). Concerns have been raised
93 that such a major change in nutrient supply at dry off may lead to metabolic disorders
94 in the transition period and ensuing lactation, especially among high yielding cows
95 (Odensten *et al.*, 2007).

96

97 Assessment of body energy reserves using body condition scoring is one strategy
98 which can be employed to monitor transition cow management. Body energy content
99 of individual cows is dependent on energy intake, energy output and energy reserves
100 retained from previous lactation stages (Banos *et al.*, 2006). In early lactation, energy

101 output for milk production far exceeds energy intake and thus requires the
102 mobilisation of body energy reserves to meet the energy deficit. Although energy
103 balance, the change in body energy stores, is normally monitored closely in early
104 lactation cows, monitoring of body energy status in the dry period is sparse (Rutten *et*
105 *al.*, 2013). Further, to solely focus on the transition period may mean that vital
106 disease indicators from the end of lactation and throughout the dry period may be
107 missed or excluded.

108

109 The hypotheses of this study were that both a) differences in body energy content
110 traits measured over the dry period and b) differences in physiological and production
111 traits recorded during the change-over period exist between cows that develop
112 different production diseases in the first 30 days of lactation. The change-over period
113 refers to the period in which the switch from a lactating to dry state is made.
114 Therefore, the objective of this study was to determine the association between body
115 energy content in the dry period and post calving production disease status. This was
116 performed with a view to identification of candidate indicators of disease, recorded in
117 the change-over and dry periods, which could be used to distinguish between healthy
118 and non-healthy cows.

119

120 **Materials and methods**

121 Data were collected over an eight-year period (November 2003 - September 2011)
122 during the long-term genetic by environment study at Scotland's Rural College
123 (**SRUC**) Dairy Research and Innovation Centre, Crichton Royal Farm, Dumfries,
124 Scotland. A total of 482 cow-lactations from 399 multiparous cows were analysed.

125 Data from primiparous animals were not included due to differences in physiology
126 and management.

127

128 *Experimental Design and Animals*

129 Experimental design of the long term study has previously been described in detail
130 by Pryce *et al.* 1999). In short, two genetic lines of Holstein-Friesian cattle were
131 selected to represent average UK genetic merit for milk fat and protein (control) and
132 the top five per cent of UK genetic merit for the trait (select). Within each of the
133 genetic lines, cows were assigned to one of two dietary treatments - high forage or
134 low forage. Dietary treatments were described in detail by Chagunda *et al.* (2009). In
135 short, high forage cows were grazed when grass growth permitted and fed a
136 complete diet containing 70 to 75% forage, on a dry matter (**DM**) basis, when
137 housed. Cows in the low forage system were housed continuously and fed a
138 complete diet of 40 to 45% forage on a DM basis. All herd groups were subject to
139 the same procedures with respect to health and fertility management. Cows were
140 dried off at approximately seven months gestation and treated with a long acting
141 intra-mammary antibiotic. In the far-off dry period (from dry off until three weeks
142 before predicted calving date) cows were housed in cubicles and fed a straw based
143 ration. The diet comprised 45% straw, supplemented with grass and maize silages,
144 whole-crop wheat silage, concentrate blend, soya and minerals. Cows were moved
145 to straw pens three weeks before predicted calving date and fed a transition diet
146 which consisted of one third of the lactation ration for their respective production
147 group (i.e. low forage or high forage) supplemented with straw.

148

149 *Data Recording*

150 Cows were milked three times daily and milk yield (**MY**) was recorded at each
151 milking. Proportional milk samples were taken once weekly and analysed for fat,
152 protein and somatic cell count (**SCC**). Body weight (**BW**) was measured three times
153 daily on exit from the milking parlour by means of a walk over weigh scale (Insentec
154 BC, Marknesse, The Netherlands). Body condition score (**BCS**) was assessed and
155 recorded weekly throughout the lactation and dry periods by trained assessors
156 following standardised protocols using a zero to five scale as per Lowman *et al.*,
157 (1973). Assessors alternated weekly to reduce the effect of operator bias, and
158 regular re-training was provided.

159

160 All disease diagnoses were performed by either a veterinarian or a senior
161 stockperson and recorded in the herd database. Standard operating procedures for
162 the identification of diseases were in place throughout the study period to ensure
163 consistency and to reduce human bias. Senior staff were responsible for diagnosing
164 cases of lameness, subclinical and clinical mastitis and retained placenta. Suspected
165 cases of metritis, ketosis, hypocalcaemia, hypomagnesaemia and left displaced
166 abomasum were identified by stock workers prior to formal diagnosis by a
167 veterinarian. All data were held and managed in a SQL database. Analysis was
168 performed in SAS v9.3.

169

170 *Data Handling*

171 *Classification of cow-lactations.* Cow-lactations were assigned to one of four groups
172 based on disease incidence in the first 30 days of lactation. These groups were
173 healthy cows (**HC**), reproductive tract disorder (**REP**), subclinical mastitis (**SCM**) and

174 metabolic (**MET**). Cow-lactations with clinical mastitis were not included in the
175 analysis. Definitions for each of these groups are outlined in Table 1.

176

177 **[TABLE 1 TO BE INSERTED]**

178 Low incidence rates for hypocalcaemia, hypomagnesaemia, left displaced
179 abomasum and ketosis necessitated their combination to form the 'metabolic' group.
180 Cows diagnosed with multiple diseases, which accounted for 0.2% of the cow-
181 lactation records, used in this study, were assigned to the health group of the most
182 severe health event. For the purposes of this study metabolic diseases were
183 categorised as the most severe, followed by reproductive tract disorders and then
184 subclinical mastitis. Metabolic disorders were categorised as the most severe due to
185 their systemic nature and their long lasting effects on health and productivity
186 (Stangaferro et al., 2016). Clinical incidences of reproductive tract disorders were
187 classified as more severe than subclinical mastitis. Classification of cow-lactations
188 by production system and parity are given in Table 2.

189

190 **[TABLE 2 TO BE INSERTED]**

191

192 *Calculation of candidate indicator traits.* Body energy content (**BEC**) was calculated
193 using standard equations using weekly BW and BCS data for each week of the dry
194 period (Banos *et al.*, 2006). The arithmetical difference in BW, BCS and BEC
195 between dry off and calving were calculated for each cow-lactation. The rate of
196 change in BW, BCS and BEC during the first 15 days of the dry period was
197 calculated by fitting a regression model to recorded data for each trait. The ratio of
198 daily energy corrected milk yield (**ECM**) to daily BEC was calculated as ECM (L) on

199 the day of dry off per 100 MJ of the cows BEC on the day of dry off (**MBER**). MBER
200 represented the propensity of an individual cow to sustain high milk yields at the end
201 of the lactation while maintaining high body condition to support milk production and
202 the growing foetus (Wathes *et al.* 2007). Milk yield was converted to ECM, using the
203 method by Sjaunja *et al.* (1990).

204

205 *Statistical analysis*

206 Analysis of variance, employing a generalised linear model was used to determine
207 effects for the candidate indicator traits. The model included fixed effects of health
208 group, production system, dry period length, parity and calendar year. Cow-lactation
209 was included as a random effect. Calendar year was included to account for year-to-
210 year variations in weather and feed resources over the 8 year study period. The
211 same model was used to analyse each trait which were treated in turn as outcome
212 variables. The model statement also initially included calf weight and sex but these
213 were later removed from the model as they were found not to influence the measured
214 variable. Further, calf weight was correlated with dry period length. Significant
215 differences between variables were determined by pair wise comparisons using the
216 Tukey method. Data were analysed using the GLM procedure of SAS (SAS software
217 version 9.3; SAS Institute Inc., Cary, NC, USA).

218

219 **Results**

220 *Effects of production system and parity on dry period traits*

221

222 **[TABLE 3 TO BE INSERTED]**

223

224 There were significant effects of production system on all traits (BW, BCS and BEC)
225 ($p<0.05$) (Table 3). Low forage cows had significantly greater BEC at drying ($p<0.05$)
226 and incurred a loss in BEC of more than double that of high forage cows across the
227 dry period. During the first two weeks of the dry period high forage control cows
228 gained 9.97 MJ/day, whereas low forage select cows lost 13.7 MJ/day. BCS was
229 significantly lower in high forage select cows at the time of drying than in all other
230 groups ($p<0.01$). At calving, a significant difference in BCS existed between cows
231 from the low forage control group and the high forage select group ($p<0.01$). The
232 difference in BCS between dry off and calving was significantly different between
233 cows of different production systems ($p<0.001$). Low forage control cows lost more
234 than double that of cows from both high forage groups. BW was similarly
235 significantly different between cows from different production systems. At dry off
236 cows in the high forage control system were significantly ($p<0.001$) lighter than cows
237 from all other systems. They remained the lightest throughout the dry period
238 however; their weight was not significantly different to cows from the low forage
239 system at calving. Cows fed a low forage diet, irrespective of genetic merit, had a
240 negative slope of change in body weight during the first 15 days of the dry period.
241 However, the only significant difference which existed among the systems was
242 between low forage control and high forage control cows ($p<0.001$). Throughout the
243 dry period, cows in the low forage control group lost significantly more body weight
244 (57.5kg) than cows in either of the high forage systems ($p<0.001$). There were
245 significant effects of parity on BEC and BW at drying and calving, with parity three
246 cows having significantly higher average BEC at BW than those in parity two
247 ($p<0.001$). Parity three cows lost significantly ($p<0.001$) more BEC over the dry
248 period than cows in parity two. Body condition score was significantly higher at dry off

249 in parity three cows ($p < 0.01$). In the first 15 days of the dry period, parity 3 cows
250 gained on average 0.82 kg/day whereas parity 2 cows lost 0.58 kg/day.

251

252 *Effects of health group on dry period traits*

253

254 **[TABLE 4 TO BE INSERTED]**

255

256 No significant differences existed between BEC, BCS or BW at drying or calving of
257 cows of different health groups (Table 4). The slope of change in BEC during the first
258 15 days of the dry period was significantly ($p < 0.05$) affected by health group. Cows
259 that developed reproductive tract disorders lost on average -18.26 MJ/day which was
260 significantly different ($p < 0.05$) to the rate of change in healthy cows (0.63 MJ/day).
261 The differences in BEC, BCS and BW between drying and calving were significantly
262 different between health groups. Cows that developed reproductive tract disorders
263 lost significantly more ($p < 0.05$) BEC, significantly more ($p < 0.001$) BCS and
264 significantly more ($p < 0.001$) BW than healthy cows. In all cases, no differences
265 existed between cows with metabolic disease and any other diseased group.

266

267 *Effects of production system and parity on dry off traits*

268

269 **[TABLE 5 TO BE INSERTED]**

270

271 Production system had a significant effect on milk yield at dry off ($p < 0.001$). Low
272 forage cows had the highest yield at dry off (23.6 litres), which was significantly
273 greater than that of cows from all other systems (Table 5). MBER was significantly

274 greater in low forage cows compared to high forage control cows ($p < 0.05$). Parity
275 had no effect on yield at dry off but did have a significant effect on MBER. Cows
276 completing lactation one had greater MBER than those completing lactation two
277 ($p < 0.001$).

278

279 *Effects of health group on dry off traits*

280

281 **[TABLE 6 TO BE INSERTED]**

282

283 Yield at dry off was significantly different between cows belonging to different health
284 groups ($p < 0.05$) (Table 6). Of the cows that developed disease in the first 30 days of
285 lactation, those that developed subclinical mastitis had significantly higher yields
286 (21.3 litres per day) than those that developed reproductive tract disorders or
287 metabolic disease. Average dry off yield of healthy cows was not significantly
288 different from the dry off yield of any other health group. Cows that developed
289 subclinical mastitis in the first 30 days of lactation had a significantly higher MBER
290 (0.92) than healthy cows and those that developed reproductive tract disorders (p
291 < 0.05).

292

293 **Discussion**

294 This study has demonstrated that cows which develop different production diseases
295 in early lactation exhibit different physiological and production characteristics during
296 the change-over and dry periods. Measurable differences in physiology and
297 production can be exploited in such a way as to extract indicators of a risk of future
298 disease. In the current analysis, dry off yield, MBER, the rate of change in BEC

299 during the first 15 days of the dry period and the difference in body weight, condition
300 and energy content across the dry period were significantly different between healthy
301 cows and those that develop post-calving production disease. Therefore, these traits
302 are potential disease indicators. MBER and yield at dry off are significantly higher in
303 cows which go on to develop early lactation subclinical mastitis; this suggests that
304 these traits may be useful as indicators of early lactation subclinical mastitis from as
305 early as the end of the previous lactation. The rate of change in BEC during the first
306 15 days of the dry period -'the change-over period'- is significantly different between
307 cows that developed reproductive tract disorders post-calving and cows that did not
308 develop clinical disease. Similarly, loss in body weight, BCS and BEC from dry off to
309 calving could be used to identify cows which go on to develop post-calving
310 reproductive tract conditions. Cows which went on to develop reproductive tract
311 disorders lost significantly more body weight, condition and energy content than
312 healthy cows. The current study highlights that on average different loss patterns are
313 experienced at critical time-points in the lactation-gestation cycle between cows that
314 go on to develop different diseases.

315 The energy status of the cow during the dry and transition periods is critical in
316 determining the success of the lactation-gestation cycle. During this time, late term
317 foetal growth, parturition and the initiation of lactation are accompanied by significant
318 endocrine changes which are in excess of those occurring at any other stage in the
319 dairy cows' production cycle (Grummer *et al.*, 2004). The sudden increase in nutrient
320 demands required to facilitate these physiological tasks, coupled with suppressed
321 dietary intake potential, results in a state of negative energy balance (**NEB**) (Frigo *et*
322 *al.*, 2010). During late term pregnancy, the cows' priority is to prepare for the next
323 lactation; hence her strategy is to build up body reserves. Rapid mobilisation of

324 these reserves post-calving facilitates milk production and allows the cow to reach
325 optimal condition for re-breeding. These sequential priorities and strategies mean
326 that the cow transitions through a cyclic and genetically driven pattern of lipid
327 reserves (Friggens *et al.*, 2007). It is critical that the cow is supported, through
328 optimum feeding and management, in order that she is allowed to follow this natural
329 cycle of body reserve mobilisation and accretion. Disruptions to this cycle not only
330 can have negative consequences for the offspring and productivity but those that
331 cause extended or more severe periods of NEB have been shown to be linked with
332 increased levels of metabolic and production disease in early lactation (Roche and
333 Berry, 2006).

334

335 In the current study, cows with a high dry off yield developed early lactation
336 subclinical mastitis. It has previously been reported that cows which have not had a
337 significant reduction in milk yield prior to dry off have higher levels of intramammary
338 infection compared to cows whose daily yield had reduced in the period before dry
339 off, although the optimal level of production at dry off is not clear (Dingwell *et al.*,
340 2001). The majority of epidemiological studies of mastitis, including that of Dingwell
341 *et al.* (2001) focus mainly on dry period acquired infections however, in the current
342 study, no distinction was made between cases of persistent infection and cases of
343 dry period acquired infection. Similar to milk yield, cows with a high MBER developed
344 early lactation subclinical mastitis. In theory, this may indicate that cows with a high
345 MBER value would benefit from a shortened dry period whilst those with a low MBER
346 value would benefit from an extended dry period in order to relieve them of the
347 energy demands for milk production and to allow them to modulate their body
348 reserves in preparation for parturition and the following lactation (Friggens *et al.*,

349 2004). Further research to address the effect of shortened and extended dry period
350 lengths on physiology and production are necessary.

351 Relative to healthy cows, animals that lost condition at the highest rate during the first
352 15 days of the dry period went on to develop reproductive tract disorders in the *post-*
353 *partum* period. Cows that developed retained placenta or metritis lost, on average,
354 18.26 MJ of BEC per day for this 15 day period whilst cows which did not develop
355 clinical disease gained an average of 0.63 MJ per day. Garnsworthy (2006) argued
356 that the rate of mobilisation of body reserves may be of greater importance in
357 managing the risk of disease in the transition period than over-conditioning, as had
358 been previously been thought. Rapid mobilisation of reserves causes physiological
359 stress which manifests itself in suppressed dry matter intake and milk yield in early
360 lactation alongside an increased incidence of health and reproductive problems
361 (Roche and Berry, 2006). This may explain the biology which underpins the results
362 obtained in this study; that cows that developed reproductive tract disorders post-
363 calving experienced rapid mobilisation of body reserves in the early dry period.
364 Similarly, Kim and Suh (2003) found that cows that experienced a marked loss in
365 condition over the dry period (1-1.5 point loss) took longer to regain condition post-
366 calving than those that experienced only a moderate loss in condition (0 - 0.75 point
367 loss). Incidence of metritis and metabolic diseases was significantly greater amongst
368 the cows that had lost between 1 and 1.5 points of BCS, compared to those who lost
369 between 0 and 0.75. Cows which experienced rapid loss of condition in the change-
370 over period went on to develop retained placenta and metritis after calving. This
371 finding highlights the importance of the far-off dry period and the relevance of
372 studying the whole dry period when considering disease risk in the following
373 lactation. As such, attention should not focus solely on the transition period. The

374 early stage of the dry period is as important since cows undergo significant
375 physiological change as they change from lactating to dry cows.

376 Additionally, the rate of change in BEC in the change-over period was significantly
377 affected by production system. Irrespective of genetic merit, cows fed a low forage
378 diet mobilised reserves throughout this period whereas those fed a high forage diet
379 accreted reserves. This may be explained by the significantly greater BEC of cows
380 fed a low forage diet at dry off, compared to those fed a high forage diet.
381 Garnsworthy and Topps (1982) demonstrated that cows with a higher BCS at calving
382 lost more body weight and condition in early lactation than cows of modest condition
383 at calving. This relationship was further investigated by Broster and Broster (1998),
384 who indicated that over-conditioned cows were shown to experience more rapid
385 mobilisation of body energy reserves in early lactation than those in optimum
386 condition. In the current study, higher BEC at drying appears to be associated with a
387 greater loss in condition in the early dry period.

388

389 Cows that developed reproductive tract disorders immediately post-calving lost more
390 than double the amount of BCS and BEC in the preceding dry period than cows that
391 that did not develop clinical disease. In terms of body weight, cows that developed
392 reproductive tract disorders lost 55% more body weight than the cows which did not
393 develop any disease in the early lactation period. Given that there is no significant
394 difference in BW, BCS or BEC of cows with and without disease at dry off and
395 calving, it would seem that it is the change in these traits during the dry period that
396 exert an influence on future disease risk rather than the absolute level of each of the
397 traits. The fact that no difference exists between healthy and diseased cows in BCS
398 at dry off and calving supports the theory of Garnsworthy and Topps (1982) that all

399 cows strive to achieve similar body energy targets at critical points in the lactation-
400 gestation cycle.

401

402 During lactation, cows can be forced from their natural body energy cycle by
403 environmental factors specific to the lactation period. In the dry period when milk
404 production ceases and management is less intensive, cows are offered the
405 opportunity to modulate their body energy reserves according to their genetic
406 predispositions. However, in previous studies weight loss in the dry period has been
407 associated with increased mortality and *post-partum* complications and even
408 moderate levels of fat mobilisation can induce negative energy balance and have an
409 adverse effect on health (Gearheart *et al.*, 1990). In their study Gearheart *et al.*
410 (1990) found that cows that lost the most condition in the dry period developed
411 dystocia or were culled in the subsequent lactation. It would be logical to assume
412 that these cows were over-conditioned at dry off and therefore were mobilising
413 reserves in order to reach optimal calving condition. However, similar to the results
414 in the current study, cows which lost the most condition over the dry period were
415 assessed to be of the same body condition as healthy cows at dry off (Gearheart *et*
416 *al.*, 1990). Markusfeld *et al.* (1997) report similar results; cows that lost most
417 condition during the dry period had an increased incidence of retained placenta and
418 metritis. The mean loss of condition incurred by multiparous cows was 0.33 BCS
419 units. In contrast to the work of Gearheart *et al.* (1990) and to this study, Markusfeld
420 *et al.* (1997) additionally reported a significant relationship between BCS at drying off
421 and condition change in the dry period. The heaviest cows at dry off lost more
422 weight during the dry period.

423

424 Although no significant differences existed in absolute body weight, BCS and energy
425 content at dry off between healthy and diseased cows in this study, their importance
426 cannot be entirely dismissed. Ranges between the minimum and maximum BCS, in
427 the current study, were small and therefore the power to assess the effect of true
428 over and under-conditioning was limited. The findings of this study may have differed
429 under different herd size, management or feed systems. However, although data
430 used in this study was sourced from one farm, the four dairy production systems in
431 operation throughout the course of this study represented contrasting approaches to
432 dairy herd management and reflected a range of possible dairy systems. Inclusion of
433 production system in the analyses allowed the effect of genotype and environment to
434 be accounted for in addition to other factors. Further, the rich longitudinal nature of
435 the database afforded the opportunity to access body weight and body condition
436 score data for individual cows over an extended period of time, throughout which all
437 aspects of management and production were recorded.

438

439 **Conclusion**

440 This study has demonstrated that cows which developed different diseases in the
441 first 30 days of lactation had different characteristics in their physiology and
442 production traits during the change-over and dry periods. The change-over from the
443 previous lactation to the dry period has been identified as a critical time in the
444 lactation cycle. Thus, the change-over period requires careful management so as to
445 avoid rapid mobilisation of body energy reserves which have been associated with
446 increased risk of disease in the following lactation. It has been generally accepted
447 that nutritional management in the dry period affects the metabolic status of the cow
448 in the subsequent lactation (Andersen *et al.*, 2008). However, monitoring should not

449 be limited to the dry period. It should rather be a continuous process including the
450 change-over period between lactations. The results from the current study have
451 important implications for the inclusion of on-farm data in models for the prediction of
452 disease risk. Further, this analysis contributes to the development of precision
453 farming tools which may utilise routinely recorded farm data. Overall, this study lays
454 the foundation for the increased use of data which is easily recordable on-farm to be
455 used in disease risk calculation.

456

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462

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564 lactation: Effects on animal welfare. Journal of Dairy Science 98, 8263-8277.

565 **Table 1** Criteria used to classify cow-lactations by health group

Health group	Definition
Healthy cows (HC)	No clinical disease diagnosis and somatic cell count no greater than 250,000 cells/millilitre in the first 30 days of lactation
Subclinical mastitis	At least one recorded somatic cell count greater than 250,000 cells/millilitre in the first 30 days of lactation
Reproductive tract disorders	Clinical cases of metritis (abnormally enlarged uterus, vaginal discharge and systemic illness/fever with a temperature >102.5°F) and retained placenta (failure to expel foetal membranes within 6 hours of calving) – diagnosed by veterinarian in the first 30 days of lactation.
Metabolic disorders	Clinical cases of hypocalcaemia (low blood calcium levels, lack of rumen activity and recumbency), hypomagnesaemia (low blood magnesium levels, excitability/hypomagnesaemic tetany), left displaced abomasum (sudden decrease in milk yield, reduced feed intake secondary ketosis) and ketosis (decreased concentrate intake, lethargy and abnormal behaviour) – all diagnoses confirmed by veterinarian in the first 30 days of lactation.

566

567 **Table 2** Health group classifications in early lactation by production system and parity for 482
568 cow-lactations from the Holstein Friesian dairy herd, Crichton Royal Farm, SRUC Dairy
569 Research and Innovation centre (November 2003 to September 2011)

	Health classification				
	Healthy cows (n)	Subclinical mastitis (n)	Reproductive track disorders ¹ (n)	Metabolic disorders ² (n)	
Production system					
Low forage control ³	93	14	20	4	
Low forage select ⁴	63	16	19	3	
High forage control ³	106	13	19	3	
High forage select ⁴	73	10	19	7	
Parity					
2	203	25	42	5	
3	132	28	35	12	
Total	335	53	77	17	482

570 ¹Includes cases of retained placenta and metritis

571 ²Includes cases of left displaced abomasum, hypocalcaemia, hypomagnesaemia and ketosis

572 ³Control cows were selected to represent average UK genetic merit for milk fat and protein

573 ⁴Select cows were selected to represent the top five per cent of UK genetic merit for milk fat
574 and protein

575 **Table 3** Least squares means and associated standard errors of the effect of production systems and parity on body energy content, body condition score and
576 body weight at drying, calving, the rate of change in the first 15 days of the dry period and the arithmetical difference in the traits between drying and calving in
577 Holstein dairy cattle

	Production system								Parity					
	Low forage control		Low forage select		High forage control		High forage select			2		3		
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	⁵	Mean	SE	Mean	SE	⁵
Body energy content														
Drying ¹ (MJ)	3443 ^a	133	3340 ^a	141	2948 ^b	136	2808 ^b	138	*	2929 ^B	119	3353 ^A	120	***
Calving ² (MJ)	2818 ^{ab}	104	2852 ^a	109	2673 ^{ab}	106	2602 ^b	108	*	2586 ^B	93	2887 ^A	97	***
Difference ⁴ (MJ)	-612 ^a	107	-493 ^a	112	-222 ^b	108	-149 ^b	110	**	-311 ^A	98	-427 ^B	98	***
Slope ³ (MJ/day)	-7.44 ^{ac}	7.28	-13.7 ^a	7.58	9.97 ^b	7.38	6.25 ^{bc}	7.50	**	-3.51	6.57	1.03	6.57	ns
Body condition score														
Drying ¹	2.53 ^a	0.06	2.44 ^{ab}	0.06	2.34 ^b	0.06	2.19 ^c	0.06	**	2.34 ^b	0.06	2.42 ^a	0.06	**
Calving ²	2.26 ^a	0.05	2.19 ^{ab}	0.05	2.22 ^{ab}	0.05	2.09 ^b	0.05	**	2.17	0.04	2.21	0.04	ns
Difference ⁴	-0.28 ^A	0.05	-0.26 ^A	0.05	-0.11 ^B	0.05	-0.09 ^C	0.05	***	-0.17	0.04	-0.200	0.04	ns
Slope ³	0.002 ^{ab}	0.004	-0.007 ^a	0.004	0.010 ^b	0.004	0.008 ^{ab}	0.004	**	0.004	0.001	0.006	0.001	ns
Body weight														
Drying ¹ (kg)	686 ^A	11	695 ^A	11	646 ^B	11	671 ^A	11	***	645 ^B	9	704 ^A	9	***
Calving ² (kg)	626 ^{ac}	10	652 ^b	10	610 ^c	10	639 ^{ab}	10	*	605 ^B	9	659 ^A	9	***
Difference ⁴ (kg)	-57.5 ^A	7.8	-41.7 ^{AB}	8.2	-35.1 ^B	7.9	-27.7 ^B	8.1	***	-36.9	7.2	-44.0	7.2	ns
Slope ³ (kg/day)	-1.13 ^A	0.85	-0.38 ^{AB}	0.89	1.38 ^B	0.86	0.59 ^{AB}	0.87	***	-0.58 ^b	0.76	0.82 ^a	0.77	**

606 ¹As measured on day of dry off
607 ²As measured on day of calving
608 ³Slope of change during the first 15 days of the dry period
609 ⁴Arithmetical difference between dry off and calving (mega-joules)
610 ⁵ns not significant, * P<0.05; ** P<0.01; *** P<0.001

611 **Table 4** Least squares means and associated standard errors of the effect of health status in
612 early lactation on body energy content, body condition score and body weight at drying,
613 calving, the rate of change in the first 15 days of the dry period and the arithmetical
614 difference in the traits between drying and calving in Holstein dairy cattle

615

	Health group								
	Healthy cows		Subclinical mastitis		Reproductive track disorders ¹		Metabolic disorders ²		⁷
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	
Body energy content									
Drying ³ (MJ)	3059	103	3058	157	3278	133	3144	221	ns
Calving ⁴ (MJ)	2817	79	2821	125	2735	105	2573	179	ns
Difference ⁵ (MJ)	-235 ^a	74	-222 ^a	107	-596 ^b	101	-422 ^{ab}	171	*
Slope ⁶ (MJ/day)	0.63 ^a	5.11	3.00 ^{ab}	9.60	-18.26 ^b	7.44	9.66 ^{ab}	13.95	*
Body condition score									
Drying ³	2.36	0.045	2.35	0.069	2.46	0.06	2.34	0.1	ns
Calving ⁴	2.24	0.04	2.22	0.06	2.2	0.05	2.1	0.08	ns
Difference ⁵	-0.110 ^A	0.036	-0.130 ^{AB}	0.058	-0.270 ^B	0.048	-0.240 ^{AB}	0.082	***
Slope ⁶	0.039	0.001	0.003	0.001	-0.002	0.001	0.014	0.001	ns
Body weight									
Drying ³ (kg)	667	7.99	666	10.31	674	9.86	693	15.36	ns
Calving ⁴ (kg)	632	7.52	642	10.26	624	9.69	628	16.20	ns
Difference ⁵ (kg)	-35.6 ^A	6.1	-20.1 ^A	9.6	-55.2 ^B	8.1	-51.1 ^{AB}	13.9	***
Slope ⁶ (kg/day)	0.59	0.59	0.66	1.11	-1.18	0.87	0.40	1.64	ns

616 ¹ Includes cases of retained placenta and metritis

617 ² Includes cases of hypocalcaemia, hypomagnesaemia, ketosis and left displaced abomasum

618 ³ As measured on day of dry off

619 ⁴ As measured on day of calving

620 ⁵ Arithmerical difference between dry off and calving (mega-joules)

621 ⁶ Slope of change during the first 15 days of the dry period

622 ⁷ ns not significant, * P<0.05; ** P<0.01; *** P<0

623 **Table 5** Least squares means and associated standard errors of the effect of production system and parity on milk yield at dry off and the ratio
 624 of milk yield to body energy content on the day of dry off in Holstein dairy cattle

	Production system									Parity at dry off				
	Low forage control ²		Low forage select ³		High forage control ²		High forage select ³			1	2			
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	⁴	Mean	SE	Mean	SE	⁴
Yield at dry off (litres)	23.6 ^A	1.1	18.4 ^{BC}	1.1	19.2 ^B	1.0	16.3 ^C	1.1	***	19.6	0.9	19.2	0.9	ns
MBER ¹ (litres/100 MJ)	0.91 ^a	0.06	0.81 ^{ab}	0.06	0.68 ^b	0.06	0.68 ^{ab}	0.06	*	0.82 ^A	0.05	0.73 ^B	0.05	***

625 ¹Ratio of energy corrected milk yield to body energy content on day of dry off

626 ²Control cows were selected to represent average UK genetic merit for milk fat and protein

627 ³Select cows were selected to represent the top five per cent of UK genetic merit for milk fat and protein

628 ⁴ns not significant, * P<0.05; ** P<0.01; *** P<0.001

629

630 **Table 6** Least squares means and associated standard errors of the effect of health status in
 631 early lactation on milk yield at dry off and the ratio of milk yield to body energy content on the
 632 day of dry off in Holstein dairy cattle

	Health group								4
	Healthy cows		Subclinical mastitis		Reproductive track disorders ¹		Metabolic disorders ²		
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	
Yield at dry off (litres)	19.9 ^a _b	0.78	21.3 ^b	1.08	18.6 ^a	1.00	17.8 ^a	1.69	*
MBER ³ (litres/100 MJ)	0.81 ^a	0.044	0.92 ^b	0.059	0.74 ^a	0.055	0.70 ^{ab}	0.093	*

633 ¹ Includes cases of retained placenta and metritis

634 ² Includes cases of hypocalcaemia, hypomagnesaemia, ketosis and left displaced abomasum

635 ³ Ratio of energy corrected milk yield to body energy content on day of dry off

636 ⁴ ns not significant, *P<0.05; ** P<0.01; *** P<0.001