

1 ***Impact of lameness and claw lesions in cows on health and production***

2

3 JN Huxley BVetMed, DCHP, DipECBHM, PhD, MRCVS

4

5 University of Nottingham, School of Veterinary Medicine and Science, Sutton Bonington

6 Campus, Sutton Bonington, Leicestershire, LE12 5RD, United Kingdom. E-mail:

7 jon.huxley@nottingham.ac.uk; Telephone: +44 (0)1159 516419; Fax +44 (0)1159

8 516440.

9 **Abstract**

10 Lameness is one of the most important endemic diseases of cattle, particularly in the
11 dairy sector. It has a significant impact on health and welfare and leads to a range of
12 production losses. This article reviews the English language peer reviewed literature on
13 the impacts of lameness in cattle on measures of health and production.

14 There is a wealth of evidence from around the world demonstrating that lameness
15 reduces milk yield. The extent of the reductions identified is difficult to summarise,
16 however when losses have been calculated across a whole lactation, most are between
17 270 and 574kg. It is noteworthy that there is now strong evidence that lameness is a
18 disease of high milk production i.e. high yielding animals are more likely to become lame.
19 The impacts of lameness on nutrition and body condition appear complex. Overall the
20 literature suggests that lameness leads to a reduction in the time spent feeding. A
21 positive correlation between low body condition score and lameness has been
22 demonstrated in a range of studies. Historically it was considered that lame cows lost
23 weight as a consequence of the largely negative impacts of disease, on nutrition.
24 Increasingly, evidence is appearing which suggests that the association between body
25 condition score and lameness may in fact be the other way around i.e. high yielding
26 cows which loose body condition during periods of negative energy balance become lame.
27 The effect of lameness on fertility, measured in studies from around the world, is
28 unequivocal. Lameness has substantial negative effects on fertility performance and
29 reproductive parameters across a wide range of areas. Evidence on the association
30 between lameness and culling is mixed. The majority of published work suggests that
31 animals which suffer from lameness are more likely to be culled, although the converse
32 has also been demonstrated.

33 A review of the literature in this area demonstrates just how substantial the
34 negative effects of lameness are on cattle health and production. The impacts are wide
35 ranging and significant from both a welfare and an economic performance perspective.
36 Further work is urgently required to control this important and prevalent condition.

38 **Key Words**

39 Lameness, Cattle, Health, Production, Yield, Fertility

40

41

42 **Introduction**

43 Bovine lameness, particularly in dairy cattle, is one of the key endemic diseases causing
44 health and welfare problems and production losses. This disease challenge is only likely
45 to increase over the coming decades as the dairy sector attempts to increase production,
46 to feed a growing world population. Quantifications of the impacts of the disease are
47 vital to highlight its importance to the industry and to calculate the relative cost benefits
48 of control interventions.

49 Lameness in cattle is not a single condition, rather it is a symptom of a wide
50 range of different diseases. The aetiology and pathogenesis of many of these diseases
51 remains relatively poorly understood (Huxley, 2012). This article reviews the English
52 language peer reviewed literature on the impacts of lameness in cattle on measures of
53 health and production. It is not the intention of this review to describe the individual
54 disease conditions, the reader is referred to standard texts or review articles (e.g. Archer
55 et al., 2010a) for further information in this area.

56

57 **Impacts of Lameness on Milk Yield**

58 There is now a wealth of evidence from around the world on the impacts of lameness on
59 milk yield in dairy cows; peer reviewed studies from Bulgaria (Mitev et al., 2011), Chile
60 (Green et al., 2010), Finland (Rajala-Schultz et al., 1999), France (Coulon et al., 1996),
61 Hungary (Gudaj et al., 2012), Israel (Yeruham et al., 2000), Sweden (Pavlenko et al.,
62 2011), the UK (Green et al., 2002; Amory et al., 2008; Onyiro et al., 2008; Archer et al.,
63 2010b; Reader et al., 2011) and the USA (Faust et al., 2001; Hernandez et al., 2002;
64 Juarez et al., 2003; Hernandez et al., 2005a; Bicalho et al., 2008) have all demonstrated
65 that lameness has a negative impact on milk production.

66 In papers which have investigated the impacts of clinical cases of lameness, loss
67 in production has been demonstrated for mixed causes of lameness (Coulon et al., 1996;
68 Rajala-Schultz et al., 1999; Warnick et al., 2001; Green et al., 2002; Bicalho et al., 2008;
69 Mitev et al., 2011) as well as for specific lesions including sole ulcers (SU) (Amory et al.,
70 2008; Green et al., 2010), white line disease (WLD) (Amory et al., 2008), digital
71 dermatitis (DD) (Yeruham et al., 2000; Faust et al., 2001; Pavlenko et al., 2011),
72 interdigital necrobacillosis (Hernandez et al., 2002) and double sole (Green et al., 2010).
73 Losses have also been demonstrated for animals identified as lame by elevated
74 locomotion score (i.e. all animals which are identifiably lame but may not necessarily
75 have been treated), using a range of different scoring systems (Juarez et al., 2003;
76 Hernandez et al., 2005a; Onyiro et al., 2008; Archer et al., 2010b; Reader et al., 2011;
77 Gudaj et al., 2012)

78 The extent of the losses identified are more difficult to summarise and compare
79 because of the wide range of different definitions used to describe the lameness, the
80 methodologies used for the analysis, the way the data are presented and the problems
81 associated with predicting lost yield in animal which become lame. Many papers report
82 the losses as a reduction in daily yield making total losses difficult to quantify. When
83 authors reported milk losses over a whole lactation, with the exception of one outlier
84 (857kg (Hernandez et al., 2002)) the total losses attributed throughout lactation are
85 remarkably similar and in a range between 270 and 574kg (Table 1). A number of
86 papers have described milk losses occurring after the lameness event e.g. (Rajala-
87 Schultz et al., 1999; Warnick et al., 2001; Green et al., 2002; Amory et al., 2008).
88 There are a growing number of papers which describe the loss of production begins
89 before the case is identified and treated (Green et al., 2002; Amory et al., 2008; Reader
90 et al., 2011), in some cases this can be many months before the lameness is identified.

91 Perhaps of note in this section is the now strong evidence that lameness in dairy
92 cattle is a disease associated with high production. Over the last thirty years a range of
93 papers have demonstrated that high producing animals are more likely to become lame
94 (Rowlands and Lucey, 1986; Barkema et al., 1994; Green et al., 2002; Hultgren et al.,

95 2004; Sogstad et al., 2007b; Amory et al., 2008; Bicalho et al., 2008; Archer et al.,
96 2010b). For example, in a Dutch study the odds of becoming lame was 1.06 times higher,
97 per 100kg increase in cumulative 100 days in milk production in the preceding lactation
98 (Barkema et al., 1994). In a later study, high yielding cows were more likely to become
99 lame, animals which were ever lame produced 342kg of milk more (over 305 days)
100 compared with cows which were never lame (Green et al., 2002). This effect seems
101 particularly true for the claw horn lesions SU and WLD (Rowlands and Lucey, 1986;
102 Barkema et al., 1994; Hultgren et al., 2004; Sogstad et al., 2007b; Amory et al., 2008).
103 This finding is important as the true impacts of lameness on production may be masked
104 in studies which do not take this effect into account. It is interesting to note that the
105 increase in production of 342kg per 305 day lactation between ever lame and never
106 lame cows (Green et al., 2002) is very similar to the *loss* of production caused by a
107 lameness event (outlined above) i.e. it suggests that higher yielding cows which become
108 lame return to more average production for the herd. That said, the loss of production
109 associated with a case of lameness will be influenced by lesion severity, the speed with
110 which a lame cow is identified and treated and the treatment protocol employed. It
111 therefore seems likely that early and effective treatment of lesions may limit the
112 associated loss in yield.

113

114 **Impacts of Lameness on Body weight and Carcase Quality**

115 There is limited published data on the impact of lameness caused by claw lesions on
116 carcase quality. This may be because foot lameness is less common in growing cattle. A
117 Norwegian study on 2,645 Norwegian Red cattle sampled from 112 herds investigated
118 the association between lameness and carcase quality if the animals were subsequently
119 culled. Lameness during the first lactation and in the third or greater lactation was
120 associated with a poorer conformation score. Conversely SU in the second lactation were
121 associated with a higher conformation class (Sogstad et al., 2007a).

122 The association between lameness and body condition appears complex.
123 Historically the received wisdoms appears to have been that lame cows lost weight as a

124 consequence of the largely negative impacts on nutrition outlined below. For example, in
125 a US study the prevalence of clinical lameness was significantly higher in cows with a
126 body condition score less than or equal to 2.5 compared with higher condition scores
127 (Espejo et al., 2006), on five Hungarian farms sound cows had condition scores
128 significantly higher than lame cows (Gudaj et al., 2012) and in one UK herd significantly
129 more lame cows had a low body condition score (Walker et al., 2008b). Similarly, in
130 studies conducted in Austria and Germany, cows in the lowest quartile for body condition
131 score were at higher risk of being lame (Dippel et al., 2009b) and Simmental cattle with
132 a condition score of 4 or higher had lower odds of lameness compared to animals in the
133 lowest quartile for body condition score (Dippel et al., 2009a). However a small number
134 of studies have found no association between body condition and lameness (Heuer et al.,
135 1999; Webster, 2001) and in one Scottish study high body condition score was
136 associated with an elevated locomotion score i.e. a more lame animal (Onyiro et al.,
137 2008).

138 Increasingly, evidence is appearing which suggests that the association between
139 body condition score and lameness may in fact be the converse of what had previously
140 been assumed i.e. cows in low body condition go on to become lame. A study in
141 Germany demonstrated that cows with a condition score less than 3 at calving and 4 –
142 10 weeks into lactation were at significantly higher risk of suffering from lameness
143 (Hoedemaker et al., 2009) and a Hungarian study concluded that the body condition
144 score recorded two months previous was higher in non-lame cows compared to lame
145 animals (Gudaj et al., 2012). Poor body condition and lameness may share a common
146 causal risk (e.g. high metabolic load). Alternatively, the association may be mediated
147 through the effects of body weight loss on the size of the digital cushion; the prevalence
148 of WLD and SU was significantly associated with the thickness of the digital cushion and
149 the thickness of the cushion was positively associated with body condition score (Bicalho
150 et al., 2009).

151 Thus there may in fact be a complex vicious cycle involving milk yield, body
152 condition score and nutrition plus a whole host of associated management factors which

153 influence these areas. For example, many high yielding cows mobilise body fat in early
154 lactation to support peak yield, which causes loss of body condition predisposing them to
155 lameness, which then alters their feeding behaviour causing a reduction in milk yield.
156 This may well be an overly simplistic (or incorrect) interpretation of the data but could in
157 part explain some of the complexity and discrepancies in the findings from different
158 studies in these areas.

159

160 **Impacts of Lameness on Nutrition**

161 A number of studies have investigated the impacts of lameness on nutrition and feeding
162 behaviour. Overall it would appear that lameness leads to a reduction in the time spent
163 feeding although the effects appear complex. In a Spanish study, the time spent eating
164 (28 minutes less between locomotion score (LS) 1 and 5) and the number of meals per
165 day decreased as locomotion score increased resulting in a significant reduction in
166 overall dry matter intake in the most lame cows (Bach et al., 2007). In two US studies, a
167 study of 205 cows in 16 herds, increased locomotion score led to a significant reduction
168 in time spent eating (Gomez and Cook, 2010) and whilst Cook et al found a numerical
169 difference in feeding time as locomotion score increased (LS1: 4.5hrs; LS2: 4.2hrs; LS3:
170 3.8 hrs/day) the difference was not significant (Cook et al., 2004). In a UK herd, acute
171 locomotor disorders (predominantly but not exclusively foot lesions) led to a decrease in
172 feeding time and the number of meals per day and an increase in feeding rate (Gonzalez
173 et al., 2008). Conversely, a number of studies have identified no differences between
174 lame and sound animals. Galindo and Broom compared 10 lame and 10 non-lame
175 animals and identified no differences between groups in the time spent feeding (Galindo
176 and Broom, 2002) and in a pasture based UK herd, no difference in grazing or
177 ruminating time was identified between lame and non-lame animals although lame cows
178 had a significantly lower bite rate compared to their sound herd mates (Walker et al.,
179 2008b). A Swedish study did not identify any significant differences in eating behaviour
180 between animals affected by DD or SU compared to healthy controls although animals
181 affected by DD spent longer ruminating whilst standing (Pavlenko et al., 2011). Finally it

182 appears that the interactions between nutrition and lameness can also occur remotely, in
183 a Canadian study, cows diagnosed with a sole lesion in mid lactation ate at a faster rate
184 and had more frequent meals during the two week period before calving. In the 24 hours
185 after calving, cows which developed lesions consumed more feed in more frequent meals
186 and during the first week after calving they consumed more feed in larger meals
187 (Proudfoot et al., 2010).

188 The impacts of lameness on nutrition and feeding behaviour appear complex.
189 Whilst alterations in behaviour at the time the animal is lame can be attributed to the
190 degree of discomfort (dependant on the diagnosis, lesion severity and treatment), the
191 temporally remote effects are more interesting and currently more difficult to explain.
192 Claw horn lesions take many months to develop. Periparturient feeding behaviour may
193 directly increase the risk of a future lameness event by increasing the pressure on the
194 support structures of the foot by altering standing times around calving (the period when
195 the pedal bone is most mobile within the hoof capsule (Tarlton et al., 2002)).
196 Alternatively periparturient feeding behaviours may increase lameness risk indirectly by
197 affecting the rate and extent of body condition score loss in early lactation and therefore
198 the association can be explained by the impacts on the digital cushion (as discussed
199 previously). Finally periparturient feeding behaviour and lameness may share an as yet
200 unidentified causal risk common to both. Further work is needed in this area to help us
201 better understand the aetiology and control of this important and painful condition.

202

203 **Impacts of Lameness on Reproduction**

204 The impact of lameness on fertility is unequivocal; data from around the world including
205 the UK (Lucey et al., 1986; Collick et al., 1989; Peeler et al., 1994; Faust et al., 2001;
206 Walker et al., 2008a; Morris et al., 2009; Walker et al., 2010), other countries in Europe
207 (Barkema et al., 1994; Hultgren et al., 2004; Sogstad et al., 2006; Kilic et al., 2007;
208 Vacek et al., 2007), the USA (Lee et al., 1989; Sprecher et al., 1997; Hernandez et al.,
209 2001; Melendez et al., 2003; Garbarino et al., 2004; Hernandez et al., 2005b; Bicalho et
210 al., 2007; Machado et al., 2010), Mexico (Argaez-Rodriquez et al., 1997), India (Sood

211 and Nanda, 2006; Sood et al., 2009) and New Zealand (Alawneh et al., 2011) have
212 demonstrated that lameness negatively impacts on a wide range of measures of
213 reproductive performance (Table 2). These effects have been demonstrated over a
214 prolonged period of time and in cows managed in a wide range of different production
215 systems.

216 The reasons for the effects on reproductive performance remain unclear, although
217 lameness has been demonstrated to negatively impact on cyclicity and expression of
218 oestrus. In the pre-service period, lame cows had an increased odds of delayed cyclicity
219 (Garbarino et al., 2004), a higher incidence of ovarian cysts (Melendez et al., 2003),
220 receive more hormonal reproductive treatments (Sogstad et al., 2006); a higher odds of
221 receiving a treatment for anoestrus (Hultgren et al., 2004) and were less likely to
222 ovulate (Morris et al., 2009). In three UK studies, lame cows had shorter periods when
223 herd mates attempted to mount them (Walker et al., 2010), oestrus was less likely to be
224 observed (Peeler et al., 1994) and severely lame cows had significantly lower oestrus
225 intensity score and a lower frequency of total mounting activity (Walker et al., 2008a). A
226 study conducted in India demonstrated that the frequency of standing to be mounted
227 was significantly lower in lame animals (2.4 vs 8.0 events (Sood and Nanda, 2006)).

228 The physiological mechanisms behind this demonstrably strong association
229 remain unclear. The consequences may be mediated through disturbances in
230 reproductive hormone profiles and follicular dynamics which have been demonstrated to
231 be disturbed in lame cows compared to sound animals (Walker et al., 2008a; Sood et al.,
232 2009; Morris et al., 2011). This could be due to the link between lameness and nutrition.
233 If the described changes in feeding behaviour lead to an overall reduction in dry matter
234 intake, the resulting effects on energy status could cause infertility through impaired
235 folliculogenesis and ovulation. Finally, it is increasingly recognised that immune cells play
236 a role in ovarian function (Shirasuna et al., 2013). It is possible that inflammation
237 caused by disease at remote sites, in this example the foot, may directly impact on
238 reproductive function.

239

240 **Impacts of Lameness on Culling**

241 The majority of published work on the association between lameness and culling
242 suggests that animals which suffer from lameness are more likely to be culled, although
243 the converse has also been demonstrated. Studies on small numbers of herds in New
244 York, USA demonstrated that cows with claw horn lesions were 1.7 times more likely to
245 die or be culled (Machado et al., 2010) and the hazard ratio for culling for lame cows
246 diagnosed in the first half of lactation was two times that of non-lame cows (Booth et al.,
247 2004). In a much larger US study, data from 953 farms in 21 states demonstrated that
248 the odds of a herd being in a higher category of dairy cow mortality was higher on farms
249 classified as having a high and moderate level of lameness (McConnel et al., 2008). In a
250 large Canadian study (6500 cows in 157 herds) the median time to culling was 188 days
251 for cows without hoof lesions and 157 days for cows with a lesion. After modelling the
252 data, the culling hazard ratios were significantly higher for animals diagnosed with WLD
253 (1.72), SU (1.26) and SH (1.36) at trimming; infectious foot lesions were not associated
254 with culling (Cramer et al., 2009). Data from 1800 cows in five herds in New York,
255 concluded that being identified as lame in the first 70 days after calving increased the
256 hazard ratio of culling or death, for lame and severely lame cows by 1.45 and 1.74 times
257 respectively, compared to non-lame cows (Bicalho et al., 2007). A smaller study
258 demonstrated that lame cows were 8.4 times more likely to be culled than non-lame
259 herd mates (Sprecher et al., 1997). Two large Scandinavian studies have demonstrated
260 similar findings. In a study which sampled 2645 cows from 112 Norwegian herds,
261 lameness in the first lactation and higher SH scores in second and higher lactation
262 animals was associated with earlier culling (Sogstad et al., 2007a). Data from nearly 40
263 thousand Ayrshire dairy cows in 2338 herds in Finland demonstrated that lameness
264 made it significantly more likely that animal would be culled (Rajala-Schultz and Grohn,
265 1999).

266 A number of studies have not found any significant relationship between
267 lameness and the risk of culling. For example, data from 2368 cows in 102 Swedish
268 herds demonstrated no significant association between the presence of SU at trimming

269 and culling (Hultgren et al., 2004) and data from 13 commercial herds in the
270 Netherlands demonstrated that the proportion of cows culled amongst animals which had
271 a case of lameness was significantly lower than amongst cows which remained sound.
272 The authors postulated that this may be because animals which went lame were higher
273 yielding and thus the owner was less willing to cull them (Barkema et al., 1994).

274 The associations between lameness and culling may at first appear
275 straightforward i.e. animals are culled because they are lame. However, in addition to
276 the fact that owners may be less willing to cull lame animals, the converse could also be
277 true i.e. animals which are scheduled to be culled are more likely to become or remain
278 lame. There are a whole host of possible reasons why this could be the case. For
279 example, animals which are scheduled to be culled may be considered of low value to
280 the farm hence they receive poorer quality management or are housed in the poorest
281 quality accommodation, making them more likely to become lame. Once lame, they may
282 not be prioritised for treatment or they may be treated suboptimally, making them less
283 likely to recover. These interactions could in part explain some of the inconsistencies in
284 the literature in this area. Further work, including more social science type
285 methodologies are required to better understand the culling and management decisions
286 made by farmers.

287

288 **Overall Economic Impact of Lameness**

289 Whilst a number of papers have estimated the costs of various aspects of financial losses
290 attributable to lameness (e.g. veterinary services & therapeutics (New, 1991)), over the
291 last 20 years, only a relatively small number of peer reviewed publications have
292 attempted to calculate the total costs. The total costs include production losses,
293 expenses associated with culling, treatment costs, additional management time and the
294 costs of discarded milk. The published papers all considered that the financial
295 consequence of lameness on milk production, infertility and culling were the most
296 significant. A UK paper published in 1997 based on 1995 prices, calculated the average
297 total cost per affected cow was £273 (~€345). A case of digital lameness, interdigital

298 lameness and a SU were estimated as £213 (~€269), £113 (~€143) and £392 (~€496)
299 respectively and increased to £240 (~€304), £131 (~€166) and £425 (~€538) if
300 calculated as the average total cost per affected cow (Kossaibati and Esslemont, 1997).
301 Using a partial budgeting model based on the data from 21 Dutch farms published in
302 1997, the total costs were calculated as 230 NLG (~€104) per affected cow and 50 NLG
303 (~€23) per animal in the herd (average incidence 21%) (Enting et al., 1997). More
304 recently (papers published in 2010 and 2012), using a dynamic simulation model the
305 total costs due to foot disorders for dairy cows in the Netherlands were estimated as €53
306 per cow per year (Bruijnis et al., 2012) and \$75 (~€60) per cow per year (Bruijnis et al.,
307 2010). The average clinical case was estimated to cost \$95 (~€76) and a subclinical case
308 \$18 (~€14) (Bruijnis et al., 2010).

309

310 **Conclusions**

311 A review of the literature in this area demonstrates just how substantial the negative
312 effects of lameness are on cattle health and production. The impacts are wide ranging
313 and significant from both a welfare and an economic performance perspective. Further
314 work is urgently required to control this important and prevalent condition.

315

316

317 **Acknowledgements**

318 The work reported here was in part based on a project funded by DairyCo
319 (www.dairyco.org.uk / www.ahdb.org.uk) a levy funded, not for profit organisation
320 working on behalf of British dairy farmers and part of the Agricultural Horticultural
321 Development Body.

322 **Table 1: Reported losses in milk production over a lactation, associated with a**
323 **case of lameness**

Report milk loss (kg)

270-440kg (Coulon et al., 1996)

314-424kg (Bicalho et al., 2008)

350kg (Archer et al., 2010b)

357kg (Green et al., 2002)

369kg (Amory et al., 2008)

372kg (Gudaj et al., 2012)

574kg (Amory et al., 2008)

857kg (Hernandez et al., 2002)

324

325 **Table 2: Reported impact of lameness in cattle on measures of reproductive**
 326 **performance**

Measure of Reproductive Performance	Reported Impact of Lameness
Calving to first service interval	8 days longer (Collick et al., 1989); 2.9 days longer (Barkema et al., 1994); 2.8 times more likely to require an interval greater than the mean (Sprecher et al., 1997); 92 vs 82 days (Kilic et al., 2007); 89 vs 82 days (Vacek et al., 2007)
Calving to conception interval	11 days longer (Lucey et al., 1986); Significantly increased (Collick et al., 1989); 113 vs 93 days (Argaez-Rodriquez et al., 1997); 140 vs 100 days (Hernandez et al., 2001); 180 vs 130 days (Hernandez et al., 2005b); 134 vs 104 days (Kilic et al., 2007); 163 vs 119 days (Machado et al., 2010); 12 days longer (Alawneh et al., 2011)
First service to conception interval	3.4 days longer (Barkema et al., 1994)
Calving interval	2% longer (Hultgren et al., 2004); Significant extended (Sogstad et al., 2006)
Days open	Significantly higher (Argaez-Rodriquez et al., 1997); 15.6 times more likely to require an interval greater than the mean (Sprecher et al., 1997); 162 vs 130 (Vacek et al., 2007); 28 days more (Lee et al., 1989)
Measures of conception	Lower conception rates (41 vs 55% (Kilic et al., 2007)); lower hazard ratio for conception (Lee et al., 1989); 0.52 times as likely to conceive (Hernandez et al., 2001); lower first service conception rate (18 vs 43% (Melendez et al., 2003)); lower first service conception risk (Hultgren et al.,

2004); a lower hazard ratio of being detected pregnant (Bicalho et al., 2007); less likely to conceive (Machado et al., 2010); a lower conception hazard (Alawneh et al., 2011)

Number of services per 9 times more likely to require a number greater than the
conception mean (Sprecher et al., 1997); median 5 vs 3 (Hernandez et al., 2001); 2.45 vs 2.15 (Vacek et al., 2007); 1.35 times higher risk of conception failure (Hernandez et al., 2005b)

328 **References**

- 329 Alawneh, J.I., Laven, R.A., Stevenson, M.A., 2011. The effect of lameness on the fertility
330 of dairy cattle in a seasonally breeding pasture-based system. *Journal of Dairy Science*
331 94, 5487-5493.
- 332 Amory, J.R., Barker, Z.E., Wright, J.L., Mason, S.A., Blowey, R.W., Green, L.E., 2008.
333 Associations between sole ulcer, white line disease and digital dermatitis and the milk
334 yield of 1824 dairy cows on 30 dairy cow farms in England and Wales from February
335 2003-November 2004. *Preventive Veterinary Medicine* 83, 381-391.
- 336 Archer, S.C., Bell, N.J., Huxley, J.N., 2010a. Lameness in UK dairy cows: a review of the
337 current status. *In Practice* 32, 492-504.
- 338 Archer, S.C., Green, M.J., Huxley, J.N., 2010b. Association between milk yield and serial
339 locomotion score assessments in UK dairy cows. *Journal of Dairy Science* 93, 4045-4053.
- 340 Arguez-Rodriguez, F.d.J., Hird, D.W., Hernandez De Anda, J., Read, D.H., Rodriguez-
341 Lainz, A., 1997. Papillomatous digital dermatitis on a commercial dairy farm in Mexicali,
342 Mexico: Incidence and effect on reproduction and milk production. *Preventive Veterinary*
343 *Medicine* 32, 275-286.
- 344 Bach, A., Dinares, M., Devant, M., Carre, X., 2007. Associations between lameness and
345 production, feeding and milking attendance of Holstein cows milked with an automatic
346 milking system. *Journal of Dairy Research* 74, 40-46.
- 347 Barkema, H.W., Westrik, J.D., Vankeulen, K.A.S., Schukken, Y.H., Brand, A., 1994. The
348 effects of lameness on reproductive-performance, milk-production and culling in Dutch
349 dairy farms. *Preventive Veterinary Medicine* 20, 249-259.
- 350 Bicalho, R.C., Machado, V.S., Caixeta, L.S., 2009. Lameness in dairy cattle: A
351 debilitating disease or a disease of debilitated cattle? A cross-sectional study of lameness
352 prevalence and thickness of the digital cushion. *Journal of Dairy Science* 92, 3175-3184.
- 353 Bicalho, R.C., Vokey, F., Erb, H.N., Guard, C.L., 2007. Visual locomotion scoring in the
354 first seventy days in milk: Impact on pregnancy and survival. *Journal of Dairy Science* 90,
355 4586-4591.

356 Bicalho, R.C., Warnick, L.D., Guard, C.L., 2008. Strategies to analyze milk losses caused
357 by diseases with potential incidence throughout the lactation: A lameness example.
358 *Journal of Dairy Science* 91, 2653-2661.

359 Booth, C.J., Warnick, L.D., Grohn, Y.T., Maizon, D.O., Guard, C.L., Janssen, D., 2004.
360 Effect of lameness on culling in dairy cows. *Journal of Dairy Science* 87, 4115-4122.

361 Bruijnis, M.R.N., Beerda, B., Hogeveen, H., Stassen, E.N., 2012. Foot disorders in dairy
362 cattle: impact on cow and dairy farmer. *Animal Welfare* 21, 33-40.

363 Bruijnis, M.R.N., Hogeveen, H., Stassen, E.N., 2010. Assessing economic consequences
364 of foot disorders in dairy cattle using a dynamic stochastic simulation model. *Journal of*
365 *Dairy Science* 93, 2419-2432.

366 Collick, D.W., Ward, W.R., Dobson, H., 1989. Associations between types of lameness
367 and fertility. *The Veterinary Record* 125, 103-106.

368 Cook, N.B., Bennett, T.B., Nordlund, K.V., 2004. Effect of free stall surface on daily
369 activity patterns in dairy cows with relevance to lameness prevalence. *Journal of Dairy*
370 *Science* 87, 2912-2922.

371 Coulon, J.B., Lescourret, F., Fonty, A., 1996. Effect of foot lesions on milk production by
372 dairy cows. *Journal of Dairy Science* 79, 44-49.

373 Cramer, G., Lissemore, K.D., Guard, C.L., Leslie, K.E., Kelton, D.F., 2009. The
374 association between foot lesions and culling risk in Ontario Holstein cows. *Journal of*
375 *Dairy Science* 92, 2572-2579.

376 Dippel, S., Dolezal, M., Brenninkmeyer, C., Brinkmann, J., March, S., Knierim, U.,
377 Winckler, C., 2009a. Risk factors for lameness in cubicle housed Austrian Simmental
378 dairy cows. *Preventive Veterinary Medicine* 90, 102-112.

379 Dippel, S., Dolezal, M., Brenninkmeyer, C., Brinkmann, J., March, S., Knierim, U.,
380 Winckler, C., 2009b. Risk factors for lameness in freestall-housed dairy cows across two
381 breeds, farming systems, and countries. *Journal of Dairy Science* 92, 5476-5486.

382 Enting, H., Kooij, D., Dijkhuizen, A.A., Huirne, R.B.M., NoordhuizenStassen, E.N., 1997.
383 Economic losses due to clinical lameness in dairy cattle. *Livestock Production Science* 49,
384 259-267.

385 Espejo, L.A., Endres, M.I., Salfer, J.A., 2006. Prevalence of lameness in high-producing
386 Holstein cows housed in freestall barns in Minnesota. *Journal of Dairy Science* 89, 3052-
387 3058.

388 Faust, M.A., Kinsel, M.L., Kirkpatrick, M.A., 2001. Characterizing biosecurity, health, and
389 culling during dairy herd expansions. *Journal of Dairy Science* 84, 955-965.

390 Galindo, F., Broom, D.M., 2002. The effects of lameness on social and individual
391 behavior of dairy cows. *Journal of Applied Animal Welfare Science* 5, 193-201.

392 Garbarino, E.J., Hernandez, J.A., Shearer, J.K., Risco, C.A., Thatcher, W.W., 2004. Effect
393 of lameness on ovarian activity in postpartum Holstein cows. *Journal of Dairy Science* 87,
394 4123-4131.

395 Gomez, A., Cook, N.B., 2010. Time budgets of lactating dairy cattle in commercial
396 freestall herds. *Journal of Dairy Science* 93, 5772-5781.

397 Gonzalez, L.A., Tolkamp, B.J., Coffey, M.P., Ferret, A., Kyriazakis, I., 2008. Changes in
398 feeding behavior as possible indicators for the automatic monitoring of health disorders
399 in dairy cows. *Journal of Dairy Science* 91, 1017-1028.

400 Green, L.E., Borkert, J., Monti, G., Tadich, N., 2010. Associations between lesion-specific
401 lameness and the milk yield of 1,635 dairy cows from seven herds in the Xth region of
402 Chile and implications for management of lame dairy cows worldwide. *Animal Welfare* 19,
403 419-427.

404 Green, L.E., Hedges, V.J., Schukken, Y.H., Blowey, R.W., Packington, A.J., 2002. The
405 impact of clinical lameness on the milk yield of dairy cows. *Journal of Dairy Science* 85,
406 2250-2256.

407 Gudaj, R., Brydl, E., Posta, J., Komlosi, I., 2012. Effect of lameness on milk production in
408 Holstein-Friesian farms in Hungary. *Allattenyésztes es Takarmanyozas* 61, 66-77.

409 Hernandez, J., Shearer, J.K., Webb, D.W., 2001. Effect of lameness on the calving-to-
410 conception interval in dairy cows. *Journal of the American Veterinary Medical Association*
411 218, 1611-1614.

412 Hernandez, J., Shearer, J.K., Webb, D.W., 2002. Effect of lameness on milk yield in dairy
413 cows. *Journal of the American Veterinary Medical Association* 220, 640-644.

414 Hernandez, J.A., Garbarino, E.J., Shearer, J.K., Risco, C.A., Thatcher, W.W., 2005a.
415 Comparison of milk yield in dairy cows with different degrees of lameness. Journal of the
416 American Veterinary Medical Association 227, 1292-1296.

417 Hernandez, J.A., Garbarino, E.J., Shearer, J.K., Risco, C.A., Thatcher, W.W., 2005b.
418 Comparison of the calving-to-conception interval in dairy cows with different degrees of
419 lameness during the prebreeding postpartum period. Journal of the American Veterinary
420 Medical Association 227, 1284-1291.

421 Heuer, C., Schukken, Y.H., Dobbelaar, P., 1999. Postpartum body condition score and
422 results from the first test day milk as predictors of disease, fertility, yield, and culling in
423 commercial dairy herds. Journal of Dairy Science 82, 295-304.

424 Hoedemaker, M., Prange, D., Gundelach, Y., 2009. Body Condition Change Ante- and
425 Postpartum, Health and Reproductive Performance in German Holstein Cows.
426 Reproduction in Domestic Animals 44, 167-173.

427 Hultgren, J., Manske, T., Bergsten, C., 2004. Associations of sole ulcer at claw trimming
428 with reproductive performance, udder health, milk yield, and culling in Swedish dairy
429 cattle. Preventive Veterinary Medicine 62, 233-251.

430 Huxley, J.N., 2012. Lameness in cattle: An ongoing concern. The Veterinary Journal 193,
431 610-611.

432 Juarez, S.T., Robinson, P.H., DePeters, E.J., Price, E.O., 2003. Impact of lameness on
433 behavior and productivity of lactating Holstein cows. Applied Animal Behaviour Science
434 83, 1-14.

435 Kilic, N., Ceylan, A., Serin, I., Gokbulut, C., 2007. Possible interaction between lameness,
436 fertility, some minerals, and vitamin E in dairy cows. Bulletin of the Veterinary Institute
437 in Pulawy 51, 425-429.

438 Kossaibati, M.A., Esslemont, R.J., 1997. The costs of production diseases in dairy herds
439 in England. The Veterinary Journal 154, 41-51.

440 Lee, L.A., Ferguson, J.D., Galligan, D.T., 1989. Effect of disease on days open assessed
441 by survival analysis. Journal of Dairy Science 72, 1020-1026.

442 Lucey, S., Rowlands, G.J., Russell, A.M., 1986. The association between lameness and
443 fertility in dairy cows. *The Veterinary Record* 118, 628-631.

444 Machado, V.S., Caixeta, L.S., McArt, J.A.A., Bicalho, R.C., 2010. The effect of claw horn
445 disruption lesions and body condition score at dry-off on survivability, reproductive
446 performance, and milk production in the subsequent lactation. *Journal of Dairy Science*
447 93, 4071-4078.

448 McConnel, C.S., Lombard, J.E., Wagner, B.A., Garry, F.B., 2008. Evaluation of factors
449 associated with increased dairy cow mortality on United States dairy operations. *Journal*
450 *of Dairy Science* 91, 1423-1432.

451 Melendez, P., Bartolome, J., Archbald, L.F., Donovan, A., 2003. The association between
452 lameness, ovarian cysts and fertility in lactating dairy cows. *Theriogenology* 59, 927-937.

453 Mitev, J., Gergovska, Z., Miteva, T., Penev, T., 2011. Influence of lameness on daily milk
454 yield, lactation curve and body condition score during lactation in Black-and White cows.
455 *Bulgarian Journal of Agricultural Science* 17, 704-711.

456 Morris, M.J., Kaneko, K., Walker, S.L., Jones, D.N., Routly, J.E., Smith, R.F., Dobson, H.,
457 2011. Influence of lameness on follicular growth, ovulation, reproductive hormone
458 concentrations and estrus behavior in dairy cows. *Theriogenology* 76, 658-668.

459 Morris, M.J., Walker, S.L., Jones, D.N., Routly, J.E., Smith, R.F., Dobson, H., 2009.
460 Influence of somatic cell count, body condition and lameness on follicular growth and
461 ovulation in dairy cows. *Theriogenology* 71, 801-806.

462 New, J.C., 1991. Costs of veterinary services and vaccines drugs used for prevention and
463 treatment of diseases in 60 Tennessee cow-calf operations (1987-1988). *Journal of the*
464 *American Veterinary Medical Association* 198, 1334-1340.

465 Onyiro, O.M., Offer, J., Brotherstone, S., 2008. Risk factors and milk yield losses
466 associated with lameness in Holstein-Friesian dairy cattle. *Animal* 2, 1230-1237.

467 Pavlenko, A., Bergsten, C., Ekesbo, I., Kaart, T., Aland, A., Lidfors, L., 2011. Influence of
468 digital dermatitis and sole ulcer on dairy cow behaviour and milk production. *Animal* 5,
469 1259-1269.

470 Peeler, E.J., Otte, M.J., Esslemont, R.J., 1994. Interrelationships of periparturient
471 diseases in dairy-cows. *Veterinary Record* 134, 129-132.

472 Proudfoot, K.L., Weary, D.M., von Keyserlingk, M.A.G., 2010. Behavior during transition
473 differs for cows diagnosed with claw horn lesions in mid lactation. *Journal of Dairy*
474 *Science* 93, 3970-3978.

475 Rajala-Schultz, P.J., Grohn, Y.T., 1999. Culling of dairy cows. Part I. Effects of diseases
476 on culling in Finnish Ayrshire cows. *Preventive Veterinary Medicine* 41, 195-208.

477 Rajala-Schultz, P.J., Grohn, Y.T., McCulloch, C.E., 1999. Effects of milk fever, ketosis,
478 and lameness on milk yield in dairy cows. *Journal of Dairy Science* 82, 288-294.

479 Reader, J.D., Green, M.J., Kaler, J., Mason, S.A., Green, L.E., 2011. Effect of mobility
480 score on milk yield and activity in dairy cattle. *Journal of Dairy Science* 94, 5045-5052.

481 Rowlands, G.J., Lucey, S., 1986. Changes in milk-yield in dairy-cows associated with
482 metabolic and reproductive disease and lameness. *Preventive Veterinary Medicine* 4,
483 205-221.

484 Shirasuna, K., Shimizu, T., Matsui, M., Miyamoto, A., 2013. Emerging roles of immune
485 cells in luteal angiogenesis. *Reproduction, Fertility and Development* 25, 351-361.

486 Sogstad, A.M., Osteras, O., Fjeldaas, T., 2006. Bovine claw and limb disorders related to
487 reproductive performance and production diseases. *Journal of Dairy Science* 89, 2519-
488 2528.

489 Sogstad, A.M., Osteras, O., Fjeldaas, T., Nafstad, O., 2007a. Bovine claw and limb
490 disorders related to culling and carcass characteristics. *Livestock Science* 106, 87-95.

491 Sogstad, A.M., Osteras, O., Fjeldaas, T., Refsdal, A.O., 2007b. Bovine claw and limb
492 disorders at claw trimming related to milk yield. *Journal of Dairy Science* 90, 749-759.

493 Sood, P., Nanda, A.S., 2006. Effect of lameness on estrous behavior in crossbred cows.
494 *Theriogenology* 66, 1375-1380.

495 Sood, P., Nanda, A.S., Singh, N., 2009. Effect of lameness on follicular dynamics in
496 postpartum anestrous crossbred cows. *Veterinarski Arhiv* 79, 531-542.

497 Sprecher, D.J., Hostetler, D.E., Kaneene, J.B., 1997. A lameness scoring system that
498 uses posture and gait to predict dairy cattle reproductive performance. *Theriogenology*
499 47, 1179-1187.

500 Tarlton, J.F., Holah, D.E., Evans, K.M., Jones, S., Pearson, G.R., Webster, A.J.F., 2002.
501 Biomechanical and histopathological changes in the support structures of bovine hooves
502 around the time of first calving. *Veterinary Journal* 163, 196-204.

503 Vacek, M., Stadnik, L., Stipkova, M., 2007. Relationships between the incidence of health
504 disorders and the reproduction traits of Holstein cows in the Czech Republic. *Czech*
505 *Journal of Animal Science* 52, 227-235.

506 Walker, S.L., Smith, R.F., Jones, D.N., Routly, J.E., Dobson, H., 2008a. Chronic stress,
507 hormone profiles and estrus intensity in dairy cattle. *Hormones and Behavior* 53, 493-
508 501.

509 Walker, S.L., Smith, R.F., Jones, D.N., Routly, J.E., Morris, M.J., Dobson, H., 2010. The
510 Effect of a Chronic Stressor, Lameness, on Detailed Sexual Behaviour and Hormonal
511 Profiles in Milk and Plasma of Dairy Cattle. *Reproduction in Domestic Animals* 45, 109-
512 117.

513 Walker, S.L., Smith, R.F., Routly, J.E., Jones, D.N., Morris, M.J., Dobson, H., 2008b.
514 Lameness, Activity Time-Budgets, and Estrus Expression in Dairy Cattle. *Journal of Dairy*
515 *Science* 91, 4552-4559.

516 Warnick, L.D., Janssen, D., Guard, C.L., Grohn, Y.T., 2001. The effect of lameness on
517 milk production in dairy cows. *Journal of Dairy Science* 84, 1988-1997.

518 Webster, A.J.F., 2001. Effects of housing and two forage diets on the development of
519 claw horn lesions in dairy cows at first calving and in first lactation. *Veterinary Journal*
520 162, 56-65.

521 Yeruham, I., Friedman, S., Elad, D., Perl, S., 2000. Association between milk production,
522 somatic cell count and bacterial dermatoses in three dairy cattle herds. *Australian*
523 *Veterinary Journal* 78, 250-253.