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## **A review of the welfare of dairy cows in continuously housed and pasture-based production systems.**

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1 **A review of the welfare of dairy cows in continuously housed and pasture-**  
2 **based production systems.**

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10

11 Short title: Welfare in housed versus pasture-based systems.

12

13

14 **Abstract**

15 There is increasing interest in the use of continuous housing systems for dairy cows,  
16 with various reasons put forward to advocate such systems. However, the welfare of  
17 dairy cows is typically perceived to be better within pasture-based systems, although  
18 such judgements are often not scientifically based. The aim of this review was to  
19 interrogate the existing scientific literature to compare the welfare, including health,  
20 of dairy cows in continuously housed and pasture-based systems. While  
21 summarising existing work, knowledge gaps and directions for future research are  
22 also identified. The scope of the review is broad, examining relevant topics under  
23 three main headings; health, behaviour, and physiology. Regarding health, cows on  
24 pasture-based systems had lower levels of lameness, hoof pathologies, hock  
25 lesions, mastitis, uterine disease, and mortality compared to cows on continuously

26 housed systems. Pasture access also had benefits for dairy cow behaviour, in terms  
27 of grazing, improved lying / resting times, and lower levels of aggression. Moreover,  
28 when given the choice between pasture and indoor housing, cows showed an overall  
29 preference for pasture, particularly at night. However, the review highlighted the  
30 need for a deeper understanding of cow preference and behaviour. Potential areas  
31 for concern within pasture-based systems included physiological indicators of more  
32 severe negative energy balance, and in some situations, the potential for  
33 compromised welfare with exposure to unpredictable weather conditions. In  
34 summary, the results from this review highlight that there remain considerable animal  
35 welfare benefits from incorporating pasture access into dairy production systems.

36

37 **Keywords:** cattle, continuous housing, dairy, health, pasture, welfare

38

39

#### 40 **Implications**

41 This review highlighted important health benefits of pasture-based over continuously  
42 housed systems including; less lameness, hock lesions, mastitis and uterine  
43 disease. Furthermore, pasture access resulted in improved behaviour, with cows  
44 also showing an overall preference for pasture if given the choice between it and  
45 indoor housing. There are considerable welfare benefits from incorporating pasture  
46 access into dairy production systems, challenging the increasing use of continuously  
47 housed systems. Given that the latter are now widely used, future research should  
48 also be directed at finding ways to incorporate the welfare benefits of pasture-based  
49 systems within the housed environment.

50

## 51 **Introduction**

52 Globally, there is increasing interest in the use of continuous housing systems for  
53 dairy cows. For example, in North America most dairy operations (63.9%) comprise  
54 housed systems, with these encompassing 82.2% of dairy cows (NAHMS, 2010).  
55 The use of these systems is also increasing in Europe. For example, the percentage  
56 of Danish dairy cattle that are continuously housed increased from 16 to 70%  
57 between 2001 and the present, and in the Netherlands, this figure increased from  
58 less than 10 to almost 30% since 1992 (Reijs *et al.*, 2013). Similarly in Great Britain,  
59 recent survey work showed that only 31% of farms maintained traditional grazing  
60 systems with no forage feeding indoors during the summer. In addition, on 8% of  
61 farms milking cows were housed all year, while high yielding or early lactation cows  
62 were continually housed on a further 8% of farms (March *et al.*, 2014). These  
63 changes are occurring within the context of a growing human population, predicted  
64 to reach 9.5 billion by 2050, and expanding markets for dairy products (FAO, 2006).  
65 Housed dairy systems have been advocated as a means of intensification to meet  
66 the growing demand for dairy products, although they can also be criticised in this  
67 regard due to their reliance on crops that could be used for direct human  
68 consumption. Other reasons for the development and uptake of continuous housing  
69 include; the ability to manage and provide a consistent feed ration to high-yielding  
70 cows, increases in herd size, limited land availability for pasture-based production,  
71 the uptake of robotic milking, and climatic factors including adverse and  
72 unpredictable weather events. However, the welfare of dairy cows is typically  
73 perceived to be better within pasture-based systems. For example, a British study  
74 (Ellis *et al.*, 2009) found that 95% of consumers questioned did not think it  
75 acceptable to keep cows permanently housed indoors. Similarly, pasture access was

76 viewed as important for welfare in a recent North American survey amongst both  
77 those affiliated and unaffiliated with the dairy industry (Schuppli *et al.*, 2014).

78 The findings of these surveys highlight an apparent conflict between  
79 consumer attitudes and predominant industry reality. In addition, within the context of  
80 increasing global milk price volatility, many dairy farmers are considering their  
81 production system options. The purpose of this review is to interrogate relevant  
82 scientific literature to compare the welfare, including health, of dairy cows in  
83 continuously housed and pasture-based systems. In this review continuous housing  
84 refers to systems typically characterised by all year round housing, non-seasonal  
85 calving, total mixed ration (TMR) feeding, and high milk yield per cow. Various  
86 synonyms are used in the literature including; confinement, zero-grazing, and high-  
87 input/high-output. Comparisons are made to pasture-based systems that are  
88 characterised by access to pasture grazing for the provision of forage, typically for at  
89 least 6 months of the year, with housing over the winter, and a seasonal calving  
90 pattern. In comparing these two production systems, it should be remembered that  
91 they differ in two main ways; nutrition and housing.

92 While summarising existing work, the review also seeks to identify knowledge  
93 gaps and provide direction for future research. The review is structured under the  
94 following welfare relevant categories; health, behaviour, and physiology.

95

## 96 **Health**

97

### 98 *Lameness*

99 Lameness is a major health and welfare problem, the impacts of which have  
100 recently been reviewed (Huxley, 2013) and include; a reduction in the time spent

101 feeding and in milk yield, associations with low body condition scores, substantial  
102 negative effects on reproductive parameters and fertility performance, and increased  
103 culling. Lameness has a multifactorial and complex aetiology, resulting from  
104 interactions between the farm environment, management, nutrition and animal  
105 characteristics. However, a potentially important factor influencing lameness is  
106 whether or not cows can access pasture within a production system.

107         The majority of papers identified comprised observational, epidemiological  
108 studies that detailed various risk factors for lameness/poor hoof health on farms (ten  
109 studies). Only four controlled experiments that compared housed and pasture-based  
110 systems were identified. Two of the controlled studies (Hernandez-Mendo *et al.*,  
111 2007; Olmos *et al.*, 2009a) showed an improvement in locomotion and a reduction in  
112 clinical lameness when cows had access to pasture, while the other two studies  
113 (Baird *et al.*, 2009; Chapinal *et al.*, 2010) showed no significant effect of pasture  
114 access on locomotion. In the studies where a positive effect of pasture access was  
115 observed, this effect occurred quite quickly. For example, the study by Olmos *et al.*  
116 (2009a) involved keeping Holstein-Friesian cows at pasture or in cubicle housing for  
117 a full lactation. They found a divergence in locomotion immediately after calving, with  
118 housed cows showing a deterioration and pasture cows an improvement. In general,  
119 housed cows were more likely to present as being clinically lame (61 vs 17%  
120 prevalence), and this effect was significant from day 180 post calving onwards (odds  
121 ratio, **OR**=2.2). In addition, Hernandez-Mendo *et al.* (2007) compared housed with  
122 pasture systems for lactating Holstein dairy cows over just a 4 week period, and  
123 found a significant increase in clinical lameness in the housed treatment by the end  
124 of the study.

125 Of the on-farm epidemiological studies identified in this review that included a  
126 measure of locomotion (e.g. Haskell *et al.*, 2006 (UK); Barker *et al.*, 2010 (UK);  
127 Chapinal *et al.*, 2013 (USA); de Vries *et al.*, 2015 (The Netherlands)), all suggested  
128 that reduced access to pasture was a risk factor for lameness. For example, Haskell  
129 *et al.* (2006) found that farms that adopted continuous housing had a higher  
130 prevalence of lameness than farms that allowed grazing (39 vs 15% lameness  
131 prevalence). Interestingly, these findings (and those of de Vries *et al.*, 2015)  
132 occurred despite the fact that observations took place during the winter months when  
133 all cows were housed. This highlights the apparent longer term benefits of grazing in  
134 terms of reduced lameness following re-housing.

135 Controlled and on-farm epidemiological studies both indicate increased  
136 prevalence of a range of hoof pathologies (of both infectious and non-infectious  
137 aetiology) within more confined dairy systems (in addition to those discussed below,  
138 see Rodriguez-Lainz *et al.* (1999) and Somers *et al.* (2005)), and this may contribute  
139 to poorer locomotion. For example, in the controlled study referred to above, Olmos  
140 *et al.* (2009a) found increased sole and white line haemorrhages, white line disease,  
141 heel horn erosion, and digital dermatitis in the housed treatment from 85 days post-  
142 calving onwards. Furthermore, housed cows were more likely to present with  
143 traumatic and other disorders (e.g. white line abscess, under-run sole, sole ulcer,  
144 inter-digital growths). This effect was significant across all inspections during  
145 lactation (OR = 2.0), and increased dramatically with time (at 210 days after calving  
146 OR = 22.8). In addition, Somers *et al.* (2003) found that during the pasture period,  
147 continuously housed cows had a significantly higher prevalence of interdigital  
148 dermatitis/heel erosion (40.3 vs 20.7%, OR = 2.59), digital dermatitis (49.0 vs 29.7%,  
149 OR = 2.28), sole haemorrhages (63.2 vs 45.1%, OR 2.10), sole ulcers (7.4 vs 3.3%,

150 OR 2.34) and interdigital hyperplasia (11.1 vs 5.1%, OR = 2.33). Furthermore, Swiss  
151 dairy herds with access to outdoor grazing during the summer period had a reduction  
152 in white line fissures (64 vs 84%, OR = 0.3), a lower prevalence of digital dermatitis  
153 on farms with slatted floors (22 vs 1%), and a reduction in the odds of finding any  
154 subclinical claw lesions at the end of the summer period (OR = 0.72) compared to  
155 those that were continuously housed (Haufe *et al.*, 2012).

156 As stated previously, in many studies management (particularly in terms of  
157 diet) also differs between systems with varying degrees of confinement, and this may  
158 independently affect levels of hoof pathologies. However, benefits of access to  
159 pasture have also been speculated to derive from providing a comfortable, soft and  
160 hygienic standing and walking surface (Onyiro and Brotherstone, 2008; Olmos *et al.*,  
161 2009b; Chapinal *et al.*, 2013), promoting exercise (Loberg *et al.*, 2004; Chapinal *et*  
162 *al.*, 2013), reducing restlessness and increasing lying times (Olmos *et al.*, 2009a). As  
163 with findings presented above on clinical lameness (Haskell *et al.*, 2006; De Vries *et*  
164 *al.*, 2015), the beneficial effects of pasture access on claw health appear to persist  
165 into the housing period. For example, using the study population detailed by Somers  
166 *et al.* (2003), Somers *et al.* (2005) indicated a negative effect of days housed at the  
167 end of the pasture season on digital dermatitis risk, with a lower risk for 0-25 days  
168 housed compared to >75 days (24.0 vs 33.3%, OR = 1.95). These authors also  
169 noted that restricted pasture access increased the risk of digital dermatitis being  
170 detected during the subsequent housing period (26.4 vs 32.3%, OR = 1.71).

171 It is worth noting that two studies highlighted in this review found an adverse  
172 effect of access to pasture on hoof health. Baird *et al.* (2009) found that cows  
173 managed on pasture had poorer claw health than cows kept indoors, while Barker *et*  
174 *al.* (2009) found an increased risk of white line disease when cows were at pasture



175 by day and housed at night, compared with being housed 24 h per day (OR = 1.93).  
176 A potential explanation for these results is the quality of cow tracks and lanes used  
177 by cows to access pasture (Burow *et al.*, 2014), the herding management of animals  
178 at pasture, and the distance walked between pasture and the milking parlour (Laven  
179 and Lawrence, 2006). Future studies should seek to quantify the effects of these  
180 factors on lameness.

181

### 182 *Hock lesions*

183 Skin lesions, such as hock and knee lesions, are increasingly being used as an  
184 animal-based welfare indicator and incorporated into indices that seek to objectively  
185 assess dairy cow welfare (e.g. Burow *et al.*, 2013a), with fewer lesions being  
186 associated with better welfare. There is a high prevalence of 'hock lesions' in dairy  
187 cows (see Kester *et al.*, 2014 for a recent review), with the term describing multiple  
188 clinical presentations of hock damage, ranging from mild hair loss to ulceration and  
189 swelling, which can progress to more serious conditions. In addition, there is a  
190 positive association between hock lesions and lameness (Kester *et al.*, 2014),  
191 although the causal relationship is not yet known. Importantly, a number of studies  
192 have found benefits of pasture access for reducing hock lesions (Rutherford *et al.*,  
193 2008; Potterton *et al.*, 2011; Burow *et al.*, 2013b). This is easy to understand, given  
194 hock lesions arise from cows lying on abrasive surfaces, or colliding with cubicle  
195 fittings (Kester *et al.*, 2014).

196

### 197 *Mastitis*

198 While few studies have compared the prevalence of mastitis within continuously  
199 housed and pasture systems, those comparisons which do exist provide evidence of

200 increased mastitis within the former. The most comprehensive research on this topic  
201 was a multiple-year experimental study conducted at North Carolina State University  
202 between 1995 and 1998 (White *et al.*, 2002; Washburn *et al.*, 2002). This revealed  
203 that confined Holstein cows had an increased prevalence of mastitis (cows infected:  
204 51 vs. 31%), a greater number of cases of mastitis per cow (1.1 vs. 0.6), and an  
205 increased risk of being culled due to mastitis (9.7 vs. 1.6%), compared to the  
206 pasture-based cows. A number of epidemiological studies have also implicated a  
207 lack of pasture access with an increased risk of compromised udder health. For  
208 example, Barkema *et al.* (1999) found that in Dutch dairy herds, not having access  
209 to pasture at night was associated with an increased risk of clinical mastitis, and  
210 more specifically, an increase in mastitis caused by *Escherichia coli* (OR = 1.3).  
211 Moreover, in a survey of Vermont dairy farms, Goldberg *et al.* (1992) found fewer  
212 occurrences of udder health problems (clinical mastitis, udder oedema, and teat  
213 injuries) in grazing compared to housed herds, with Swedish studies reporting similar  
214 findings (Bendixen *et al.*, 1986; Bendixen *et al.*, 1988).

215         It has been suggested that the lower levels of mastitis in pastured cows is  
216 because they are exposed to fewer environmental pathogens compared with  
217 confined cows. Consistent with this suggestion, an increased risk of high somatic cell  
218 count and intramammary infections has been associated with cows having dirty  
219 udders and legs (Schreiner and Ruegg, 2003; Ellis *et al.*, 2007; Breen *et al.*, 2009).  
220 Moreover, in a longitudinal study of UK dairy farms, Ellis *et al.* (2007) found that  
221 cows were dirtier during housing than at pasture, while Nielsen *et al.* (2011)  
222 observed an increased risk of cows being dirtier in Danish herds with no pasture  
223 access (OR = 3.75). While noting these general trends, it is of course also the case  
224 that cow cleanliness can be poor within pasture-based systems, being influenced by

225 climatic factors and track conditions to and from pasture. Equally, cow cleanliness  
226 can be good within well managed continuously housed systems.

227 Further experimental evidence supporting reduced udder health in housed  
228 systems is available from production studies that have recorded somatic cell counts  
229 (**SCC**). For example, in a 37 week experiment, Fontaneli *et al.* (2005) observed  
230 continuously housed Holstein cows to have a higher mean SCC than those in two  
231 pasture-based systems (654,000 vs. 223,000 and 364,000 SCC/ml milk). Similarly,  
232 in a full lactation study, Vance *et al.* (2012) reported a trend for a greater SCC in  
233 cows in a high-input continuously housed system compared to those in a medium-  
234 input pasture system. However, it is worth noting that a number of studies failed to  
235 find a significant difference in SCC between housed and pasture systems (Kolver  
236 and Muller, 1998; White *et al.*, 2001; Bargo *et al.*, 2002; AbuGhazaleh *et al.*, 2007).

237 Contrary to the general beneficial effects of pasture access, the risk of so-  
238 called 'summer mastitis' is likely to be a greater problem within pasture-based  
239 systems. Summer mastitis is a severe acute clinical mastitis that occurs in non-  
240 lactating cattle at pasture during the summer. It has a complex aetiology, involving  
241 environmental pathogens (e.g. *Trueperella pyogenes* and *Streptococcus*  
242 *dysgalactiae*) and transmission by the head fly, *Hydrotaea irritans* (Chirico *et al.*,  
243 1997), with control measures including reducing exposure to flies.

244

#### 245 *Uterine disease*

246 As part of the lameness study outlined previously (Olmos *et al.*, 2009a), Olmos *et al.*  
247 (2009b) found evidence of increased dystocia, metritis (see also Bruun *et al.*, 2002)  
248 and endometritis in continuously housed cows. It was suggested that since bacterial  
249 counts will be higher indoors (Sheldon *et al.*, 2006), this increases the level of

250 contamination of the uterine lumen post-partum, and thus the risk of metritis.  
251 Moreover, Olmos *et al.* (2009b) observed a trend for lower plasma calcium levels at  
252 calving and post-partum, which, given its role in uterine smooth-muscle contractility,  
253 led the authors to speculate that this may have also contributed to the observed  
254 findings of increased dystocia and metritis in the housed cows. However, the extent  
255 to which this is the case remains to be investigated.

256

### 257 *Other infectious disease*

258 Studies directly comparing the incidence of infectious disease in continuously  
259 housed and pasture-based systems, are generally lacking, although Veling *et al.*  
260 (2002) found that unrestricted grazing during summer (pastured day and night;  
261 indoors only at milking time) had a protective effect (OR = 0.07) against  
262 salmonellosis.

263 A particular risk factor for infectious disease in pasture-based systems is that  
264 posed by contacting neighbouring cattle (Mee *et al.*, 2012). Cattle are gregarious  
265 animals and many farm boundaries have developed without biosecurity in mind. For  
266 example, Brennan *et al.* (2008) found that in more than half of UK farms surveyed,  
267 nose-to-nose contact was possible between cattle on adjacent farms. Such contact  
268 offers important transmission routes for infections including; infectious bovine  
269 rhinotracheitis, bovine viral diarrhoea, and bovine tuberculosis (**bTB**). Appropriate  
270 biosecurity measures to combat this risk are aimed at preventing the opportunity for  
271 direct contact and straying, and include attention to fencing and hedgerow  
272 maintenance (Mee *et al.*, 2012).

273 Other domestic animals and wildlife offer important infection reservoirs for  
274 cattle in both housed and pasture-based systems. For example, the role of the

275 Eurasian badger (*Meles meles*) in the maintenance and spread of bTB is a matter of  
276 considerable scientific, political and public debate in the UK (e.g. Godfray *et al.*,  
277 2013). Recent evidence using proximity collars indicated that direct contact between  
278 badgers and cattle at pasture did not occur (O'Mahony, 2014), yet indirect  
279 transmission associated with contaminated pasture, setts, latrines and water troughs  
280 present potential sources of infection (Ward *et al.*, 2010). Farmyards and buildings  
281 also represent an important potential source of bTB transmission, since badger visits  
282 can be frequent (Tolhurst *et al.*, 2009; Ward *et al.*, 2010; Judge *et al.*, 2011),  
283 providing opportunities for direct and indirect contact between badgers and cattle.  
284 Relatively simple biosecurity measures can be implemented to exclude badgers from  
285 buildings (Ward *et al.*, 2010; Judge *et al.*, 2011), although the cost-effectiveness and  
286 efficacy of such measures remains to be further investigated.

287         The close contact between cows in continuous housing systems offers an  
288 infection risk, with recent modelling studies highlighting an important role of housing  
289 in facilitating disease spread (Moustakas and Evans, 2015). However, there is a  
290 need for more studies to examine how the type of production system interacts with  
291 disease transmission, including for bTB where the relative importance of  
292 transmission routes are still being debated (e.g. Godfray *et al.*, 2013; Brooks-Pollock  
293 *et al.*, 2014).

294

### 295 *Endoparasites*

296 In contrast to the benefits of pasture access for health, a number of epidemiological  
297 studies demonstrate that grazing is, unsurprisingly, a risk factor for exposure to  
298 gastrointestinal (**GI**) parasites. While dairy cattle develop a degree of immunity to GI  
299 parasites following exposure at pasture during early life, this is not complete. Adult

300 dairy cows still harbour GI nematodes, generally in low numbers, with *Ostertagia*  
301 *ostertagi* being the most prevalent (Agneessens *et al.*, 2000; Borgsteede *et al.*,  
302 2000). Detrimental impacts are illustrated by studies demonstrating a positive  
303 response in adult dairy cows to anthelmintic treatment in terms of milk yield,  
304 increased appetite, improved liveweight, condition score and reproductive  
305 performance (Sanchez *et al.*, 2002, 2004; Forbes *et al.*, 2004; Gibb *et al.*, 2005).  
306 Levels of *O. ostertagi* exposure were lower in continuously housed herds compared  
307 to where cows had access to pasture, and also positively associated with; earlier  
308 turnout, later housing, and longer grazing times per day (Charlier *et al.*, 2005; Forbes  
309 *et al.*, 2008; Bennema *et al.*, 2010; Vanderstichel *et al.*, 2012). Similarly, liver fluke,  
310 *Fasciola hepatica* exposure has been associated with an increased proportion of  
311 grazed grass in the diet, a longer grazing season, and no pasture mowing (Bennema  
312 *et al.*, 2011). These studies highlight the necessity for adequate anthelmintic parasite  
313 control regimens within pasture-based production systems.

314

### 315 *Mortality*

316 In terms of “iceberg indicators”, mortality (death and euthanasia) can be viewed as  
317 the top of the iceberg, with high herd mortality levels indicating suboptimal health  
318 and welfare conditions (Thomsen and Houe, 2006). Additionally, death may have  
319 been preceded by a period of suffering and is therefore a potential welfare concern.  
320 Thomsen *et al.* (2006) found that mortality risk during the first 100 days of lactation in  
321 Danish dairy herds was reduced when the cows were on pasture during the summer  
322 (OR 0.78) compared to being continuously housed, consistent with the results of  
323 others (e.g. Burow *et al.*, 2011; Alvasen *et al.*, 2012). More recently, Alvasen *et al.*

324 (2014) reported that Swedish dairy herds were more likely to be in a high mortality  
325 group if cows were not on pasture during the summer season (OR = 3.6).

326 Some evidence of possible reasons for higher mortality levels in continuously  
327 housed herds was provided by Danish studies (Thomsen *et al.*, 2007a, b) examining  
328 so-called “loser cows”. A “loser cow score” was generated for each individual based  
329 on a clinical evaluation of body condition, lameness, hock lesions, other cutaneous  
330 lesions, vaginal discharge, condition of hair coat and general condition (Thomsen *et*  
331 *al.*, 2007a), providing a composite measure of health. Loser cows had an increased  
332 risk of death and culling, and a decrease in milk production, while morbidity was  
333 generally twice as high as among non-loser cows (Thomsen *et al.*, 2007a). Cows  
334 were almost twice as likely to become a loser cow if they were in a herd with no  
335 grazing (Thomsen *et al.*, 2007b). Given the loser cow score comprised health  
336 measures shown previously in this review to differ between the two systems, the  
337 increased risk of becoming a loser cow in a continuously housed herd is  
338 unsurprising.

339

## 340 **Behaviour**

341 Pasture-based systems are perceived to offer greater behavioural freedom than  
342 continuously housed systems, and as such, interpreted as offering enhanced  
343 welfare. The impact of production systems on behaviour is an important component  
344 of welfare assessment, comprising one of the “five freedoms”, namely “freedom to  
345 express normal behaviour”. This leads to the question of what constitutes “normal”  
346 behaviour? While comparisons can be drawn to the wild ancestors of some farmed  
347 species to determine “normal” behaviour, this is not the case for cattle. However, a  
348 number of studies have examined the behaviour of free-living domesticated cattle at

349 pasture with little human interference (some populations termed feral cattle). In  
350 pursuing “normal” cattle behaviour, Kilgour (2012) identified and reviewed 22 such  
351 studies. From this review it was evident that cattle have an extensive behavioural  
352 repertoire, comprising 40 identifiable categories. Grazing was the most common  
353 behaviour, followed by ruminating and resting, with these three categories  
354 accounting for 90-95% of an animal’s day. The data revealed most grazing is  
355 performed during the hours of daylight, with little grazing at night, and cattle instead  
356 spending more time resting and ruminating at night. Moreover, there is a diurnal  
357 rhythm of behaviour, characterised by peaks of grazing activity associated with  
358 sunrise and sunset.

359 Few studies have compared dairy cow behaviour in pasture versus  
360 continuously housed production systems. Furthermore, the majority of studies that  
361 have examined the issue were conducted a number of years ago, with cow  
362 genotypes and production environments having changed since then. Nonetheless,  
363 below we examine the available literature, considered under three main behavioural  
364 themes of; feeding / grazing, lying / resting, and aggression.

365

### 366 *Feeding / grazing*

367 Roca-Fernandez *et al.* (2013) compared the behavioural activities of two dairy cow  
368 genotypes (Holstein-Friesian vs. Jersey x Holstein-Friesian) in a pasture-based and  
369 continuously housed production system (TMR and cubicles) using a 2 x 2 factorial  
370 design. Cow genotype had no effect on behaviour. However, cows in the pasture  
371 system spent 68% of their time grazing, while cows in the housed system spent 22%  
372 feeding. Moreover, in the pasture group there was synchronization of grazing  
373 behaviour, with main bouts occurring after each milking, and being more prolonged



374 in the evening than morning. In contrast, the feeding behaviour of the housed cows  
375 was spread throughout the day, with approximately 30% of the animals feeding at  
376 any one time. Regarding the feeding patterns observed it is interesting to note that  
377 the pasture treatment closely resembles the description of “normal” provided by  
378 Kilgour (2012). This is not the case for the housed cows and the implications for  
379 welfare remain to be further investigated. For example, are there negative welfare  
380 implications of altered time budgets in animals whose ancestors displayed particular  
381 patterns of grazing behaviour?

382

### 383 *Lying / resting*

384 The study by Olmos *et al.* (2009a), described previously under the lameness section,  
385 also provided a comprehensive comparison of the lying behaviour of cows in the two  
386 scenarios. Data-loggers were used to examine the lying behaviour of pasture-based  
387 and cubicle-housed cows at days 33, 83 and 193 post-calving. This revealed  
388 pasture-based cows had greater mean total lying times per 48 h period (42.7 vs.  
389 37.7% of time spent lying) and longer lying bouts (50.3 vs. 39.3 minutes). This was  
390 interpreted as a welfare benefit of pasture, as reduced lying times and restlessness  
391 associated with housing are indicators of lack of comfort, udder problems,  
392 overcrowding, as well as being a risk factor for hoof disorders, especially since  
393 decreased lying equates to increased time spent standing (Olmos *et al.*, 2009a).  
394 These results are consistent with previous reports of increased lying times at pasture  
395 (O’Connell *et al.*, 1989; Singh *et al.*, 1993), although both these studies suffered from  
396 confounding effects of season and differing stages of lactation and should be treated  
397 with some caution. In addition, O’Connell *et al.* (1989) reported a loss of lying  
398 synchrony indoors, with less than 45% of the cows observed lying at any one time,

399 compared with up to 90% of cows lying at any one time on pasture, during the period  
400 from sunset to sunrise. A loss of synchrony indoors may be due to reduced space  
401 allowance, increased disturbance and competition for lying places, and has been  
402 suggested to represent an index of reduced welfare (Miller and Wood-Gush, 1991).  
403 In addition, lying deprivation has been shown to be physiologically stressful for  
404 lactating cows in terms of elevated cortisol levels, and reduced adrenocorticotrophic  
405 hormone (ACTH) and cortisol responses following corticotrophin releasing hormone  
406 (CRH) challenge, suggesting a degree of pituitary down-regulation (Fisher *et al.*,  
407 2002).

408

#### 409 *Aggression*

410 Only two studies (O'Connell *et al.*, 1989; Miller and Wood-Gush, 1991) have  
411 compared the aggressive behaviour of cows in the two scenarios. O'Connell *et al.*  
412 (1989) reported that agonistic interactions occurred at low levels at pasture, being  
413 significantly greater when housed, where two peaks of agonistic activity coincided  
414 with the delivery of fresh feed. Furthermore, while there was a significant correlation  
415 between the dominance hierarchies in both environments, the outdoor ranking was a  
416 rather poor predictor of indoor ranking. This suggests that the nature of agonistic  
417 interactions and determinants of dominance differed between the two scenarios,  
418 possibly the result of the indoor scenario involving contests for access to food,  
419 combined with reductions in space. Consistent with these findings, Miller and Wood-  
420 Gush (1991) reporting on a herd of Holstein-Friesian cows, also found higher levels  
421 of aggression during the winter cubicle housing period compared with the summer  
422 grazing period (this study also suffered from time and stage of lactation confounds).  
423 Indeed the average number of agonistic interactions recorded during focal animal

424 observations was 1.1 per h at pasture and 9.5 per h while housed, with the majority  
425 of indoor aggression occurring in the feeding area.

426         Given the welfare concerns of aggression, together with potential adverse  
427 effects on low ranking individuals in terms of health, production and fertility, there is  
428 clearly a need for more work in this area to better understand and quantify the  
429 agonistic behaviour of dairy cows. In this endeavour it may be useful to apply  
430 principles from behavioural ecology, an approach which has previously been  
431 advocated in the study of animal welfare (e.g. Andersen *et al.*, 2006). More  
432 specifically, this approach seeks to better understand the strategies used by animals  
433 to resolve contests (see Arnott and Elwood, 2009 for review), as well as the impact  
434 of the resource being contested (see Arnott and Elwood, 2008 for review).

435

#### 436 *Behavioural knowledge gaps*

437 It is clear from the above summary that there is a lack of detailed up-to-date  
438 research comparing the behaviour of cows in the two contrasting environments. In  
439 addition, although challenging, behavioural research should also be aimed at  
440 examining positive emotional states and how “happy” the cow is in her environment.  
441 For example, the work on cognitive bias used to investigate emotions in other  
442 species (e.g. Harding *et al.*, 2004) could be a useful approach, as could quantifying  
443 play behaviour, which can be used as a positive welfare indicator (Boissy *et al.*,  
444 2007). Furthermore, the welfare implications of the altered time budgets observed  
445 indoors compared to more “normal” settings (Kilgour, 2012) remain to be further  
446 investigated. Studies are also beginning to investigate the potential for environmental  
447 enrichment to improve the housed environment (e.g. Haskell *et al.*, 2013).

448 Technological improvements and increased availability of remote behavioural  
449 recording devices should assist researchers in these endeavours.

450

#### 451 *Cow Preference*

452 An alternative approach to examining whether welfare of dairy cows is better indoors  
453 or at pasture is to ask the cow what she prefers? This can be achieved by  
454 conducting preference tests, whereby the animal is given a choice, in this instance  
455 between pasture and cubicle housing. Preference tests have been successfully used  
456 in a variety of contexts, providing important insights to assess and improve animal  
457 welfare (e.g. Dawkins, 1990; Kirkden and Pajor, 2006). Six studies were identified  
458 (Legrand *et al.*, 2009; Charlton *et al.*, 2011a, b, 2013; Falk *et al.*, 2012; Motupalli *et*  
459 *al.*, 2014) that used this approach to examine if cows had a preference for pasture  
460 over indoor housing (Figure 1). With the exception of Charlton *et al.* (2011a), the  
461 results from these studies were broadly consistent.

462         Researchers at the University of British Columbia's dairy research centre  
463 (Legrand *et al.*, 2009) offered late lactation Holstein cows the choice between free  
464 access to pasture and to cubicle housing, with TMR offered indoors. Cows spent on  
465 average 54% of their time on pasture. However, pasture use varied considerably  
466 with time of day. Cows preferred to be indoors during the day (outside less than one-  
467 third of the time between morning and evening milkings), using this time for feeding,  
468 with feeder use peaking following milkings. In contrast, cows showed an almost  
469 exclusive preference for pasture at night, and spent more of their lying time on  
470 pasture (69% of total lying time/d). Similarly, a more recent study from the same  
471 research farm (Falk *et al.*, 2012) also found cows displayed a partial preference for  
472 pasture, averaging 57% of their time on pasture, with cows spending more time

473 outside at night (78.5%) than they did during the day (41.5%). In addition, and  
474 contrary to predictions, Falk *et al.* (2012) found no effect of cubicle availability on  
475 time spent at pasture. It was suggested that the short duration of cubicle availability  
476 manipulations (four days) may have explained the lack of effect. Future work should  
477 investigate effects of stocking density over longer time periods.

478 A series of studies have also been conducted by researchers in the UK  
479 (Charlton *et al.*, 2011a, b, 2013; Motupalli *et al.*, 2014). Charlton *et al.* (2011b)  
480 provided Holstein-Friesian cows in late lactation, the choice between indoor cubicle  
481 housing (with access to TMR) and pasture (with half of the trials also offering TMR  
482 on pasture to see how this influenced the choice). Consistent with the Canadian  
483 studies, the cows spent more time on pasture than indoors (71 vs. 29%), with more  
484 time spent on pasture at night than during the day (84 vs. 51%). Contrary to initial  
485 predictions, there was no TMR treatment effect. That is to say, providing the cows  
486 with TMR both indoors and outdoors did not increase pasture use, despite an  
487 increase in TMR consumption when this was offered in both locations.

488 A limitation of the preference tests outlined so far is that they do not provide  
489 information on the strength of preference. This can be overcome, and motivation  
490 measured by imposing an increasing cost on the animal to gain access to a  
491 particular resource (Jensen and Pedersen, 2008). Using this principle, Charlton *et al.*  
492 (2013) varied the distance cows were required to walk to access pasture (60, 140, or  
493 260 m). Overall, and consistent with the other studies (Legrand *et al.*, 2009; Falk *et*  
494 *al.*, 2012; Charlton *et al.*, 2011b), cows had a partial preference for pasture,  
495 spending 58% of their time outside, and spending more time outside during the night  
496 (80%) than during the day (44%). Relating to preference strength, at night there was  
497 no effect of access distance on pasture use. However, during the day, time spent on

498 pasture declined as distance increased, with cows spending longer on pasture when  
499 they had to walk 60m compared with 140 or 260 m (45 vs. 27 vs. 21%). The  
500 difference between findings for day and night-time pasture use with distance  
501 suggests that cows were more motivated, revealed by walking longer distances, for  
502 pasture use during the night compared with during the day. During the day, cows  
503 may have preferred to be indoors (overall average of 56% of time spent indoors  
504 during the day) to access TMR and meet their nutritional needs, particularly post-  
505 milking and following delivery of fresh feed. The necessity of meeting nutritional  
506 demands during the day appears to have traded off with the desire to access  
507 pasture, revealed when the cost of the latter was increased by having to walk 140 or  
508 260 m.

509         Recently, in a study investigating effects of herbage mass and distance to  
510 pasture, Motupalli *et al.* (2014) found results consistent with those of Charlton *et al.*  
511 (2013). Distance affected pasture use during the day, with cows spending more time  
512 at pasture in the near (38 m) compared to far distance (254 m), but had no effect on  
513 pasture use at night. Moreover, also in line with previous findings, the cows showed  
514 an overall partial preference to be at pasture, spending almost 70% of their time at  
515 pasture. Herbage mass did not influence preference, nor did it interact with distance  
516 to pasture. The lack of a herbage mass effect was most likely due to the fact that  
517 high quality TMR feed was available ad libitum indoors, with low pasture intakes in  
518 general indicating that cows only used pasture to supplement their high TMR intake.  
519 Motupalli *et al.* (2014) also found no difference in TMR intake between the cows  
520 given free access to pasture and a control group of continuously housed cows, and  
521 the former group actually recorded higher daily milk yields. There were also  
522 indications of increased comfort in the free choice cows, which had increased lying

523 times compared to the continuously housed cows. Results of this study suggest that  
524 providing cows with the opportunity to access pasture, and thus greater control over  
525 their own environment, has welfare and production benefits.

526 The results of Charlton *et al.* (2011a) are in complete contrast to those  
527 discussed above, with cows displaying a preference to be indoors compared to on  
528 pasture (92 vs. 8%). The preference for housing in this study may have been due to  
529 the cows' prior experience, as they had been housed indoors and fed TMR in the  
530 months preceding the study. Furthermore, all the cows had been reared indoors, and  
531 it was only two weeks prior to the onset of the first study period that cows were given  
532 experience of pasture, while still receiving indoor TMR. It was also speculated that  
533 the distance to access pasture from the choice point (48 m) may have had an  
534 impact.

535 Summarising the results of these preference test studies (Figure 1), reveals,  
536 with one exception (Charlton *et al.*, 2011a), that dairy cows have an overall partial  
537 preference for pasture (Legrand *et al.*, 2009; Charlton *et al.*, 2011b, 2013; Falk *et al.*,  
538 2012; Motupalli *et al.*, 2014). During the day, cows had a partial preference for indoor  
539 housing (Legrand *et al.*, 2009; Falk *et al.*, 2012; Charlton *et al.*, 2013), or spent  
540 similar time periods indoors and on pasture (Charlton *et al.*, 2011b, Motupalli *et al.*,  
541 2014). This was explained by the presence of fresh TMR indoors enabling cows to  
542 meet their nutritional demands following milking. However, at night cows displayed a  
543 preference for pasture (Legrand *et al.*, 2009; Charlton *et al.*, 2011b, 2013; Falk *et al.*,  
544 2012; Motupalli *et al.*, 2014). Indeed, the studies by Charlton *et al.* (2013) and  
545 Motupalli *et al.* (2014) revealed that cows seemed particularly motivated to access  
546 pasture at night, since there was no effect of distance on their preference for  
547 pasture, yet during the day cows spent less time on pasture when they had to walk

548 greater distances. The preference for pasture at night is most easily explained by a  
549 desire for a comfortable lying area, supported by findings of time spent lying while at  
550 pasture (e.g. Legrand *et al.*, 2009; Charlton *et al.*, 2013). However, the preferences  
551 were also complex, being influenced by environmental parameters, and time of day.  
552 For example, unsurprisingly, climatic variables influence preferences, with pasture  
553 use decreasing with increasing rainfall (Legrand *et al.*, 2009; Falk *et al.*, 2012;  
554 Charlton *et al.*, 2011a, 2013) and being influenced by the temperature-humidity index  
555 (Legrand *et al.*, 2009, Charlton *et al.*, 2011b; Falk *et al.*, 2012) and season (Charlton  
556 *et al.*, 2011b). Cow factors including milk yield and lameness score also influenced  
557 preference, with Charlton *et al.* (2011a) reporting that higher yielding cows spent  
558 more time indoors than lower yielders, while Charlton *et al.* (2011b) report that cows  
559 with a poorer lameness score spent more time indoors.

560         The preference test studies also highlight knowledge gaps. For example,  
561 Charlton *et al.* (2011a) suggested previous experience may have explained their  
562 contradictory results, while Legrand *et al.* (2009) also highlighted that previous  
563 experience may have accounted for the relatively low partial preference (54%) for  
564 pasture found in their study, since prior to the beginning of the experiment, cows had  
565 spent their entire lactation housed in the barn. However, the role of prior experience  
566 and rearing history remains to be further investigated. Furthermore, in the tests  
567 examining the strength of motivation to access pasture, only a restricted range of  
568 distances have been used (60-260 m) and there is a need to investigate preference  
569 over a greater distance range. Stage of lactation is an additional area for preference  
570 test investigation. Existing studies have used mid or late lactation cows. No studies  
571 have examined cows in early lactation when it might be expected that the higher milk  
572 yield and nutritional demands would bias cows towards an indoor environment if



573 TMR was available. Thus, future studies should quantify the role of nutrition on  
574 preference, both in terms of pasture quality, and indoor TMR quality and how these  
575 could trade-off against each other. Indeed, all the preference tests have involved  
576 offering TMR indoors and therefore offering an incentive for cows to come inside. It  
577 would be revealing to examine the preference if freshly harvested pasture only was  
578 offered indoors. Such a scenario would reveal if cows have an underlying desire to  
579 graze outside per se. Also, in countries where summer heat stress is a problem there  
580 is a need to examine how pasture preference is influenced by the availability of  
581 shade. It is also interesting to note that a number of the above studies documented  
582 considerable variation between individual cows in their pasture preferences (e.g.  
583 ranging from 5% to 90% of time on pasture, Charlton *et al.*, 2013), and this, together  
584 with the influence of herd mates, should be investigated further. Moreover, existing  
585 studies have focussed on Holstein / Holstein-Friesians, and it would be interesting to  
586 identify if any breed / genotype differences in pasture preference exist. Would  
587 Jerseys, crossbreds, and NZ genotypes show a greater preference for pasture?

588

## 589 **Physiology**

590 Few studies have used physiological measures to compare the welfare of dairy cows  
591 in pasture compared to continuously housed systems. Indeed, the only  
592 comprehensive example in the context of welfare is provided by Olmos *et al.* (2009b)  
593 who examined blood levels of acute phase proteins (APP), cortisol, white blood cell  
594 (WBC) differential and counts, and other biochemical metabolites as non-specific  
595 indicators of sub-clinical ill-health and nutritional stress. While there were no  
596 differences in APP, cortisol, or WBC counts between treatments, pasture-based  
597 cows had higher levels of NEFA, beta-hydroxybutyrate and triglyceride post-partum,

598 consistent with a limited energy supply. In addition, pasture cows showed a tendency  
599 for higher concentrations of bilirubin and numerically higher bile acid concentrations,  
600 both indicative of greater hepatic lipidosis. Put together, these findings indicate a  
601 greater degree of negative energy balance in cows on pasture than in housed cows,  
602 as has been reported for a number of production performance studies (Kolver and  
603 Muller, 1998; Bargo *et al.*, 2002; Boken *et al.*, 2005; Fontaneli *et al.*, 2005; Kay *et al.*,  
604 2005; Vance *et al.*, 2012). Nutritional and metabolic stress in the peripartum period is  
605 a welfare concern, with negative implications for immune function and cow health in  
606 early lactation, and further negative downstream effects on fertility (Ingvarlsen, 2006;  
607 Butler, 2014; Drackley and Cardoso, 2014). However, although the pasture cows in  
608 the study by Olmos *et al.* (2009b) had evidence of greater nutritional and metabolic  
609 stress, they had better reproductive health. Clearly, there is a need for more  
610 research using biomarkers to assess the welfare of dairy cows in various production  
611 scenarios.

612

### 613 *Thermal Stressors*

614 The thermal environment can act as a stressor for cattle, with negative effects of cold  
615 and heat stress (e.g. Hemsworth *et al.*, 1995 for review). A potential welfare concern  
616 in pasture-based systems is the exposure of cows to adverse climatic conditions.  
617 Within many of these systems cows will be housed during the winter and therefore  
618 protected from adverse weather. However, a particular problem in some countries,  
619 such as New Zealand and Ireland, is the changeable nature of the weather, with  
620 cows being exposed to sudden, relatively brief periods of cold and wet weather. The  
621 intermittent nature of such exposure may prevent adaptation to cold (Bergen *et al.*,  
622 2001; Kennedy *et al.*, 2005).

623 In this context, a number of studies (Tucker *et al.*, 2007; Webster *et al.*, 2008;  
624 Schutz *et al.*, 2010) report indicators of cold stress in New Zealand dairy cows  
625 exposed to periods of experimentally induced wet and windy weather, compared to  
626 those sheltered from such conditions. The behavioural indicators comprised  
627 decreased feeding, increased standing, and decreased lying. For example, Tucker *et al.*  
628 *al.* (2007) found an average outdoor lying time (4/24 h) well below normal levels for  
629 dairy cattle (12-13 h/d, Jensen *et al.*, 2005) when exposed to experimentally induced  
630 wet and windy conditions. This study also found differences in lying posture, with  
631 cows spending less time with their head rested against their flank or on the ground  
632 when outside, interpreted as indicating less opportunity for rapid-eye-movement  
633 (REM) sleep compared to indoors, as the neck muscles must be supported and the  
634 head rested against the body or the ground for cattle to experience REM sleep  
635 (Ruckebusch *et al.*, 1974). In contrast, when outdoors they spent more time lying in  
636 postures that reduced the surface area exposed to wind and rain (front legs bent and  
637 hind legs touching their body). Evidence of a classic stress response, involving  
638 activation of the hypothalamic-pituitary-adrenal (HPA) axis, was also found (Tucker  
639 *et al.*, 2007; Webster *et al.*, 2008), with greater cortisol levels in response to cold and  
640 wet conditions, and thinner cows being particularly susceptible (Tucker *et al.*, 2007).  
641 The cold and wet conditions may have invoked the stress response directly, but  
642 there may also have been an indirect effect of reduced lying time, as this is known to  
643 invoke a stress response (Fisher *et al.*, 2002). Furthermore, Webster *et al.* (2008)  
644 found evidence of immunosuppression in cows managed under the cold and wet  
645 conditions, with a reduction in WBC counts, due mainly to a reduction in lymphocytes  
646 and basophils. Alterations in circadian body temperature rhythm were also  
647 documented, with an increased amplitude resulting from a lower minimum and

648 higher maximum (Tucker *et al.*, 2007; Webster *et al.*, 2008), and thinner cows having  
649 a lower minimum (Tucker *et al.*, 2007). It was suggested that the altered temperature  
650 rhythm in response to cold stress may be an indicator of reduced welfare, as  
651 disturbed circadian rhythms are a consistent response to stress (e.g. Meerlo *et al.*,  
652 2002).

653         The above studies indicate that exposure of cows to wind and rain can reduce  
654 welfare, with cows in poor body condition being most susceptible (Tucker *et al.*,  
655 2007). However, the extent to which the experimentally induced conditions translate  
656 to real on-farm conditions is uncertain. In addition, cows have behavioural coping  
657 strategies to deal with periods of adverse weather, selecting microclimates that  
658 provide protection (Olson and Wallander, 2002), including sheltering along hedge  
659 rows and tree-lined areas, that may suffice in all but very extreme conditions. In this  
660 regard, the preference test results of decreasing pasture use with increasing rainfall  
661 (Legrand *et al.*, 2009; Falk *et al.*, 2012; Charlton *et al.*, 2011a, 2013) are also  
662 relevant.

663         Heat stress can be a problem in both housed and pasture-based systems,  
664 with negative consequences for production, fertility and welfare. In the preference  
665 tests discussed previously, cows spent more time on pasture as the temperature-  
666 humidity index increased indoors and outdoors in the UK based study (Charlton *et*  
667 *al.*, 2011b) indicating that in this temperate region cows found the outdoor pasture  
668 more comfortable than the indoor housing. However, in the North American based  
669 preference studies (Legrand *et al.*, 2009; Falk *et al.*, 2012) time spent on pasture  
670 during the day decreased as the outdoor temperature-humidity index increased,  
671 likely reflecting the shade and ventilation offered in the housed environment. In those

672 circumstances where heat stress can be a problem a variety of mitigation strategies  
673 can be successfully used to ensure adequate thermal comfort (Van laer *et al.*, 2014).

674

#### 675 *The impact of sunlight*

676 Do cows derive health and welfare benefits from exposure to sunlight when  
677 outdoors? Exposure of skin to sunshine is an important source of vitamin D and  
678 higher levels reported in summer compared to winter (Jakobsen and Saxholt, 2009)  
679 have been attributed to outdoor grazing during the pasture period, with vitamin D  
680 status showing a positive relationship with time on pasture during the summer  
681 (Hymoller and Jensen, 2012). Does this confer a health benefit to cows? For  
682 example, recent experimental studies in biomedical research have found sun  
683 exposure to have positive effects on cardiovascular health, lowering blood pressure  
684 (Liu *et al.*, 2014), and on immune function (Hart *et al.*, 2011). Moreover, sunlight  
685 exposure is apparently rewarding, with hedonic and addictive properties (e.g. Fell *et*  
686 *al.*, 2014). Could these factors contribute to a positive emotional state in cows with  
687 outdoor access? Such factors remain to be investigated.

688

#### 689 **Conclusions**

690 Animal welfare is a multi-criteria characteristic (Rushen and de Passille, 1992). In  
691 this review we compared the welfare of dairy cows in pasture-based versus  
692 continuously housed systems. Lower levels of lameness, hoof pathologies and hock  
693 lesions were observed in pasture-based compared to continuously housed systems.  
694 These benefits likely derive from providing a comfortable, soft and hygienic standing,  
695 walking and lying surface, with additional benefits associated with exercise in terms  
696 of grazing and walking to and from pasture. The prevalence of mastitis and uterine

697 disease was generally lower within pasture-based systems, thought to derive from  
698 reduced exposure to environmental pathogens and improved cow cleanliness. Given  
699 the detrimental impact of uterine disease on subsequent fertility and lactation  
700 performance (e.g. see LeBlanc, 2014 for a review) this is an important issue (Mee,  
701 2012). By contrast, there are some risks posed by contacting neighbouring cattle in  
702 pasture-based systems, highlighting the need for appropriate biosecurity measures,  
703 and grazing is unsurprisingly a risk factor for endoparasite infection. However,  
704 overall, pasture access has a positive effect on dairy cow health. Indeed, mortality is  
705 lower in herds having access to pasture than in continuously housed herds.

706         Pasture-based systems offer increased freedom for cows to express their full  
707 behavioural repertoire, a grazing pattern and level of group synchrony more akin to  
708 their wild counterparts, improved lying / resting and lower levels of aggression. Dairy  
709 cows typically experience a period of negative energy balance during early lactation.  
710 The severity of this may be increased within pasture-based systems. Meeting the  
711 nutritional needs of modern dairy cows has been one of the drivers for the adoption  
712 of continuously housed systems. However, cows managed exclusively indoors still  
713 undergo a period of negative energy balance, so neither system is ideal in this  
714 context.

715         The risk of thermal stressors compromising welfare was highlighted for both  
716 systems. Wind and rain have the potential to reduce welfare, but there is a need for  
717 studies to investigate this under real on-farm conditions. We also hypothesised that  
718 cows may derive health and welfare benefits from exposure to sunlight when  
719 outdoors but this remains to be investigated.

720         Our review indicates that there are considerable welfare benefits from  
721 incorporating pasture access within milk production systems in terms of health and

722 behaviour. This view is consistent with the view of cows themselves: in preference  
723 tests, when offered the choice between pasture and indoor housing, cows tend to  
724 prefer pasture. It is also consistent with Burow *et al.* (2013a) that used an integrated  
725 welfare assessment covering feeding, housing and health, finding that Danish dairy  
726 herds had improved welfare during the summer grazing period, with a positive effect  
727 of daily grazing time. The European Food Safety Authority (EFSA) also stated in a  
728 report on dairy cow welfare and disease (EFSA, 2009a) that “at present, it is not  
729 possible to guarantee that indoor housing without access to pasture will result in the  
730 same or better level of welfare that could be achieved if the cows could have access  
731 to pasture”. In an opinion article, the recommendation of EFSA (2009b) was that  
732 “when possible, dairy cows and heifers should be given access to well managed  
733 pasture or other suitable outdoor conditions, at least during summer or dry weather.”  
734 Here we note the use of the term “well managed pasture”, and we acknowledge that  
735 within each type of production system there will be large variation in standards and  
736 quality. In other words, a poorly managed pasture-based system will have a  
737 detrimental impact on welfare.

738         As continuously housed systems are a commercial reality, it will be important  
739 to build on existing research that has aimed to improve aspects of dairy housing  
740 including; cubicle design (e.g. Bernardi *et al.*, 2009; Abade *et al.*, 2015), floor type  
741 (e.g. Schutz and Cox, 2014), loafing areas (e.g. Haskell *et al.*, 2013), and  
742 environmental enrichment (Mandel *et al.*, 2016). The influence of grazing behaviour  
743 and potential benefits of exercise should also be investigated. Results from this  
744 review advocate seeking ways to incorporate the welfare benefits of pasture-based  
745 systems within the housed environment.

746

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751

752 **References**

753 Abade CC, Fregonesi JA, von Keyserlingk MAG and Weary DM 2015. Dairy cow preference  
754 and usage of an alternative freestall design. *Journal of Dairy Science* 98, 960-965.

755 AbuGhazaleh AA, Felton DO and Ibrahim SA 2007. Milk conjugated linoleic acid response  
756 to fish oil and sunflower oil supplementation to dairy cows managed under two  
757 feeding systems. *Journal of Dairy Science* 90, 4763-4769.

758 Agneessens J, Claerebout E, Dorny P, Borgsteede FHM and Vercruyse J 2000. Nematode  
759 parasitism in adult dairy cows in Belgium. *Veterinary Parasitology* 90, 83-92.

760 Alvasen K, Mork MJ, Sandgren CH, Thomsen PT and Emanuelson U 2012. Herd-level risk  
761 factors associated with cow mortality in Swedish dairy herds. *Journal of Dairy*  
762 *Science* 95, 4352-4362.

763 Alvasen K, Roth A, Mork, MJ, Sandgren CH, Thomsen PT and Emanuelson, U 2014. Farm  
764 characteristics related to on-farm cow mortality in dairy herds: a questionnaire study.  
765 *Animal* 8, 1735-1742.

766 Andersen IL, Naevdal E, Boe KE and Bakken M 2006. The significance of theories in  
767 behavioural ecology for solving problems in applied ethology: Possibilities and  
768 limitations. *Applied Animal Behaviour Science* 97, 85-104.

769 Arnott G and Elwood RW 2008. Information gathering and decision making about resource  
770 value in animal contests. *Animal Behaviour*, 76, 529-542.

771 Arnott G and Elwood RW 2009. Assessment of fighting ability in animal contests. *Animal*  
772 *Behaviour*, 77, 991-1004.

773 Baird LG, O'Connell NE, McCoy MA, Keady TWJ and Kilpatrick DJ 2009. Effects of breed



774 and production system on lameness parameters in dairy cattle. Journal of Dairy  
775 Science 92, 2174-2182.

776 Bargo F, Muller LD, Delahoy JE and Cassidy TW 2002. Performance of high producing  
777 dairy cows with three different feeding systems combining pasture and total mixed  
778 rations. Journal of Dairy Science 85, 2948-2963.

779 Barkema HW, Schukken YH, Lam TJGM, Beiboer ML, Benedictus G and Brand A 1999.  
780 Management practices associated with the incidence rate of clinical mastitis. Journal  
781 of Dairy Science 82, 1643-1654.

782 Barker ZE, Amory JR, Wright JL, Mason SA, Blowey RW and Green LE 2009. Risk factors  
783 for increased rates of sole ulcers, white line disease, and digital dermatitis in dairy  
784 cattle from twenty-seven farms in England and Wales. Journal of Dairy Science 92,  
785 1971-1978.

786 Barker ZE, Leach KA, Whay HR, Bell NJ and Main DCJ 2010. Assessment of lameness  
787 prevalence and associated risk factors in dairy herds in England and Wales. Journal  
788 of Dairy Science 93, 932-941.

789 Bendixen PH, Vilson B, Ekesbo I and Astrand DB 1986. Disease frequencies of tied zero-  
790 grazing dairy cows and of dairy cows on pasture during summer and tied during  
791 winter. Preventive Veterinary Medicine 4, 291-306.

792 Bendixen PH, Vilson B, Ekesbo I and Astrand DB 1988. Disease frequencies in dairy cows  
793 in Sweden. 5. Mastitis. Preventive Veterinary Medicine 5, 263-274.

794 Bennema SC, Vercruyssen J, Morgan E, Stafford K, Hoglund J, Demeler J, von Samson-  
795 Himmelstjerna G. and Charlier J. 2010. Epidemiology and risk factors for exposure to  
796 gastrointestinal nematodes in dairy herds in northwestern Europe. Veterinary  
797 Parasitology 173, 247-254.

798 Bennema SC, Ducheyne E, Vercruyssen J, Claerebout E, Hendrickx G and Charlier J 2011.  
799 Relative importance of management, meteorological and environmental factors in the  
800 spatial distribution of *Fasciola hepatica* in dairy cattle in a temperate climate zone.  
801 International Journal for Parasitology 41, 225-233.

802 Bergen RD, Kennedy AD and Christopherson RJ 2001. Effects of intermittent cold exposure  
803 varying in intensity on core body temperature and resting heat production of beef  
804 cattle. *Canadian Journal of Animal Science* 81, 459-465.

805 Bernardi F, Fregonesi J, Winckler C, Veira DM, von Keyserlingk MAG and Weary DM 2009.  
806 The stall-design paradox: Neck rails increase lameness but improve udder and stall  
807 hygiene. *Journal of Dairy Science* 92, 3074-3080.

808 Boissy A, Manteuffel G, Jensen MB, Moe RO, Spruijt B, Keeling LJ, Winckler C, Forkman  
809 B, Dimitrov I, Langbein J, Bakken M, Veisser I and Aubert A 2007. Assessment of  
810 positive emotions in animals to improve their welfare. *Physiology and Behavior* 92,  
811 375-397.

812 Boken SL, Staples CR, Sollenberger LE, Jenkins TC and Thatcher WW 2005. Effect of  
813 grazing and fat supplementation on production and reproduction of Holstein cows.  
814 *Journal of Dairy Science* 88, 4258-4272.

815 Borgsteede FHM, Tibben J, Cornelissen JBWJ, Agneessens J and Gaasenbeek CPH 2000.  
816 Nematode parasites of adult dairy cattle in the Netherlands. *Veterinary Parasitology*  
817 89, 287-296.

818 Breen JE, Green MJ and Bradley AJ 2009. Quarter and cow risk factors associated with the  
819 occurrence of clinical mastitis in dairy cows in the United Kingdom. *Journal of Dairy*  
820 *Science* 92, 2551-2561.

821 Brennan ML, Kemp R and Christley RM 2008. Direct and indirect contacts between cattle  
822 farms in north-west England. *Preventive Veterinary Medicine* 84, 242-260.

823 Brooks-Pollock E, Roberts GO and Keeling MJ 2014. A dynamic model of bovine  
824 tuberculosis spread and control in Great Britain. *Nature* 511, 228-231.

825 Bruun J, Ersboll AK and Alban L 2002. Risk factors for metritis in Danish dairy cows.  
826 *Preventive Veterinary Medicine* 54, 179-190.

827 Burow E, Thomsen PT, Sorensen JT and Rousing T 2011. The effect of grazing on cow  
828 mortality in Danish dairy herds. *Preventive Veterinary Medicine* 100, 237-241.

829 Burow E, Rousing T, Thomsen PT, Otten ND and Sorensen JT 2013a. Effect of grazing on

830 the cow welfare of dairy herds evaluated by a multidimensional welfare index. *Animal*  
831 7, 834-842.

832 Burow E, Thomsen PT, Rousing T and Sorensen JT 2013b. Daily grazing time as a risk  
833 factor for alterations at the hock joint integument in dairy cows. *Animal* 7, 160-166.

834 Burow E, Thomsen PT, Rousing T and Sorensen JT 2014. Track way distance and cover as  
835 risk factors for lameness in Danish dairy cows. *Preventive Veterinary Medicine* 113,  
836 625-628.

837 Butler ST 2014. Nutritional management to optimize fertility of dairy cows in pasture-based  
838 systems. *Animal* 8, 15-26.

839 Chapinal N, Goldhawk C, de Passille AM, von Keyserlingk MAG, Weary DM and Rushen J  
840 2010. Overnight access to pasture does not reduce milk production or feed intake in  
841 dairy cattle. *Livestock Science* 129, 104-110.

842 Chapinal N, Barrientos AK, von Keyserlingk MAG, Galo E and Weary DM 2013. Herd-level  
843 risk factors for lameness in freestall farms in the northeastern United States and  
844 California. *Journal of Dairy Science* 96, 318-328.

845 Charlier J, Claerebout E, De Muelenaere E and Vercruyse J 2005. Associations between  
846 dairy herd management factors and bulk tank milk antibody levels against *Ostertagia*  
847 *ostertagi*. *Veterinary Parasitology* 133, 91-100.

848 Charlton GL, Rutter SM, East M and Sinclair LA 2011a. Preference of dairy cows: Indoor  
849 cubicle housing with access to a total mixed ration vs. access to pasture. *Applied*  
850 *Animal Behaviour Science* 130, 1-9.

851 Charlton GL, Rutter SM, East M and Sinclair LA 2011b. Effects of providing total mixed  
852 rations indoors and on pasture on the behavior of lactating dairy cattle and their  
853 preference to be indoors or on pasture. *Journal of Dairy Science* 94, 3875-3884.

854 Charlton GL, Rutter SM, East M and Sinclair LA 2013. The motivation of dairy cows for  
855 access to pasture. *Journal of Dairy Science* 96, 4387-4396.

856 Chirico J, Jonsson P, Kjellberg S and Thomas G 1997. Summer mastitis experimentally

857 induced by *Hydrotaea irritans* exposed to bacteria. Medical and Veterinary  
858 Entomology 11, 187-192.

859 Dawkins MS 1990. From an animal's point of view: Motivation, fitness, and animal welfare.  
860 Behavioral and Brain Sciences 13, 1-9.

861 De Vries M, Bokkers EAM, van Reenen CG, Engel B, van Schaik G, Dijkstra T and de Boer  
862 IJM 2015. Housing and management factors associated with indicators of dairy cattle  
863 welfare. Preventive Veterinary Medicine 118, 80-92.

864 Drackley JK and Cardoso FC 2014. *Prepartum* and *postpartum* nutritional management to  
865 optimize fertility in high-yielding dairy cows in confined TMR systems. Animal 8, 5-14.

866 EFSA. 2009a. Scientific report on the effects of farming systems on dairy cow welfare and  
867 disease, Report of the Panel on Animal Health and Welfare. The EFSA Journal 1143,  
868 1-284.

869 EFSA. 2009b. Scientific opinion on the overall effects of farming systems on dairy cow  
870 welfare and disease, Scientific opinion of the Panel on Animal Health and Animal  
871 Welfare. The EFSA Journal 1143, 1-38.

872 Ellis KA, Innocent GT, Mihm M, Cripps P, McLean WG, Howard CV and Grove-White D  
873 2007. Dairy cow cleanliness and milk quality on organic and conventional farms in  
874 the UK. Journal of Dairy Research 74, 302-310.

875 Ellis KA, Billington K, McNeil B and McKeegan DEF 2009. Public opinion on UK milk  
876 marketing and dairy cow welfare. Animal Welfare 18, 267-282.

877 Falk AC, Weary DM, Winckler C and von Keyserlingk MAG 2012. Preference for pasture  
878 versus freestall housing by dairy cattle when stall availability indoors is reduced.  
879 Journal of Dairy Science 95, 6409-6415.

880 FAO. 2006. Livestock's long shadow. <http://www.fao.org/docrep/010/a0701e/a701e00.HTM>.

881 Fell GL, Robinson KC, Mao J, Woolf CJ and Fisher DE 2014. Skin  $\beta$ -endorphin mediates  
882 addiction to UV light. Cell 157, 1527-1534.

883 Fisher AD, Verkerk GA, Morrow CJ and Matthews LR 2002. The effects of feed restriction

884 and lying deprivation on pituitary-adrenal axis regulation in lactating cows. *Livestock*  
885 *Production Science* 73, 255-263.

886 Fontaneli RS, Sollenberger LE, Littell RC and Staples CR 2005. Performance of lactating  
887 dairy cows managed on pasture-based or in freestall barn-feeding systems. *Journal*  
888 *of Dairy Science* 88, 1264-1276.

889 Forbes AB, Huckle CA and Gibb MJ 2004. Impact of eprinomectin on grazing behaviour and  
890 performance in dairy cattle with sub-clinical gastrointestinal nematode infections  
891 under continuous stocking management. *Veterinary Parasitology* 125, 353-364.

892 Forbes AB, Vercruyssen J and Charlier J 2008. A survey of the exposure to *Ostertagia*  
893 *ostertagi* in dairy cow herds in Europe through the measurement of antibodies in milk  
894 samples from the bulk tank. *Veterinary Parasitology* 157, 100-107.

895 Gibb MJ, Huckle CA and Forbes AB 2005. Effects of sequential treatments with  
896 eprinomectin on performance and grazing behaviour in dairy cattle under daily-  
897 paddock stocking management. *Veterinary Parasitology* 133, 79-90.

898 Godfray HCJ, Donnelly CA, Kao RR, Macdonald W, McDonald RA, Petrokofsky G, Wood  
899 JLN, Woodroffe R, Young DB and McLean AR 2013. A restatement of the natural  
900 science evidence base relevant to the control of bovine tuberculosis in Great Britain.  
901 *Proceedings of the Royal Society B-Biological Sciences* 280, 20131634.

902 Goldberg JJ, Wildman EE, Pankey JW, Kunkel JR, Howard DB and Murphy BM 1992. The  
903 influence of intensively managed rotational grazing, traditional continuous grazing,  
904 and confinement housing on bulk tank milk quality and udder health. *Journal of Dairy*  
905 *Science* 75, 96-104.

906 Harding EJ, Paul ES and Mendl M 2004. Animal behaviour: Cognitive bias and affective  
907 state. *Nature* 427, 312.

908 Hart PH, Gorman S and Finlay-Jones JJ 2011. Modulation of the immune system by UV  
909 radiation: more than just the effects of vitamin D? *Nature Reviews Immunology* 11,  
910 584-596

911 Haskell MJ, Rennie LJ, Howell VA, Bell MJ and Lawrence AB 2006. Housing system, milk

912 production, and zero-grazing effects on lameness and leg injury in dairy cows.  
913 Journal of Dairy Science 89, 4259-4266.

914 Haskell MJ, Maslowska K, Bell DJ, Roberts DJ and Langford FM 2013. The effect of a view  
915 to the surroundings and microclimate variables on use of a loafing area in housed  
916 dairy cattle. Applied Animal Behaviour Science 147, 28-33.

917 Haufe HC, Gygax L, Wechsler B, Stauffacher M and Friedli K 2012. Influence of floor  
918 surface and access to pasture on claw health in dairy cows kept in cubicle housing  
919 systems. Preventive Veterinary Medicine 105, 85-92.

920 Hemsworth PH, Barnett JL, Beveridge L and Matthews LR 1995. The welfare of extensively  
921 managed dairy cattle: a review. Applied Animal Behaviour Science 42, 161-182.

922 Hernandez-Mendo O, von Keyserlingk MAG, Veira DM and Weary DM 2007. Effects of  
923 pasture on lameness in dairy cows. Journal of Dairy Science 90, 1209-1214.

924 Holzhauer M, Brummelman B, Frankena K and Lam TJGM 2012. A longitudinal study into  
925 the effect of grazing on claw disorders in female calves and young dairy cows.  
926 Veterinary Journal 193, 633-638.

927 Huxley JN 2013. Impact of lameness and claw lesions in cows on health and production.  
928 Livestock Science, 156, 64-70.

929 Hymoller L and Jensen SK 2012. 25-Hydroxycholecalciferol status in plasma is linearly  
930 correlated to daily summer pasture time in cattle at 56°N. British Journal of Nutrition  
931 108, 666-671.

932 Ingvarstsen KL 2006. Feeding- and management-related diseases in the transition cow:  
933 Physiological adaptations around calving and strategies to reduce feeding-related  
934 diseases. Animal Feed Science and Technology 126, 175-213.

935 Jakobsen J and Saxholt E 2009. Vitamin D metabolites in bovine milk and butter. Journal of  
936 Food Composition and Analysis 22, 472-478.

937 Jensen MB and Pedersen LJ 2008. Using motivation tests to assess ethological needs and  
938 preferences. Applied Animal Behaviour Science 113, 340-356.

939 Judge J, McDonald RA, Walker N and Delahay RJ 2011. Effectiveness of biosecurity

940 measures in preventing badger visits to farm buildings. PLoS One 6, e28941.

941 Kay JK, Roche JR, Kolver ES, Thomson NA and Baumgard LH 2005. A comparison  
942 between feeding systems (pasture and TMR) and the effect of vitamin E  
943 supplementation on plasma and milk fatty acid profiles in dairy cows. Journal of Dairy  
944 Research 72, 322-332.

945 Kennedy AD, Bergen RD, Christopherson RJ, Glover ND and Small JA 2005. Effect of once  
946 daily 5-h or 10-h cold-exposures on body temperature and resting heat production of  
947 beef cattle. Canadian Journal of Animal Science 85, 177-183.

948 Kester E, Holzhauser M and Frankena K 2014. A descriptive review of the prevalence and  
949 risk factors of hock lesions in dairy cows. The Veterinary Journal 202, 222-228.

950 Kilgour RJ 2012. In pursuit of "normal": A review of the behaviour of cattle at pasture.  
951 Applied Animal Behaviour Science 138, 1-11.

952 Kirkden RD and Pajor EA 2006. Using preference, motivation and aversion tests to ask  
953 scientific questions about animals' feelings. Applied Animal Behaviour Science, 100,  
954 29-47.

955 Kolver ES and Muller LD 1998. Performance and nutrient intake of high producing Holstein  
956 cows consuming pasture or a total mixed ration. Journal of Dairy Science 81, 1403-  
957 1411.

958 Laven RA and Lawrence KR 2006. An evaluation of the seasonality of veterinary treatments  
959 for lameness in UK dairy cattle. Journal of Dairy Science 89, 3858-3865.

960 LeBlanc SJ 2014. Reproductive tract inflammatory disease in *postpartum* dairy cows. Animal  
961 8, 54-63.

962 Legrand AL, von Keyserlingk MAG and Weary DM 2009. Preference and usage of pasture  
963 versus free-stall housing by lactating dairy cattle. Journal of Dairy Science 92, 3651-  
964 3658.

965 Liu D, Fernandez BO, Hamilton A, Lang NN, Gallagher JMC, Newby DE, Feelisch M and

966 Weller RB 2014. UVA irradiation of human skin vasodilates arterial vasculature and  
967 lowers blood pressure independently of nitric oxide synthase. *Journal of Investigative*  
968 *Dermatology* 134, 1839-1846.

969 Loberg J, Telezhenko E, Bergsten C and Lidfors L 2004. Behaviour and claw health in tied  
970 dairy cows with varying access to exercise in an outdoor paddock. *Applied Animal*  
971 *Behaviour Science* 89, 1-16.

972 Mandel R, Whay HR, Klement E and Nicol CJ 2016. *Invited review*: Environmental  
973 enrichment of dairy cows and calves in indoor housing. *Journal of Dairy Science* 99,  
974 1695-1715.

975 March MD, Haskell MJ, Chagunda MGG, Langford FM and Roberts DJ 2014. Current trends  
976 in British dairy management regimens. *Journal of Dairy Science* 97, 7985-7994.

977 Mee JF 2012. Reproductive issues arising from different management systems in the dairy  
978 industry. *Reproduction in Domestic Animals* 47, 42-50.

979 Mee JF, Geraghty T, O'Neill R and More SJ 2012. Bioexclusion of diseases from dairy and  
980 beef farms: Risks of introducing infectious agents and risk reduction strategies. *The*  
981 *Veterinary Journal* 194, 143-150.

982 Meerlo P, Sgoifo A and Turek FW 2002. The effects of social defeat and other stressors on  
983 the expression of circadian rhythms. *Stress: The International Journal on the Biology*  
984 *of Stress* 5, 15-22.

985 Miller K and Woodgush DGM 1991. Some effects of housing on the social behavior of dairy  
986 cows. *Animal Production* 53, 271-278.

987 Motupalli PR, Sinclair LA, Charlton GL, Bleach EC and Rutter SM 2014. Preference and  
988 behavior of lactating dairy cows given free access to pasture at two herbage masses  
989 and two distances. *Journal of Animal Science* 92, 5175-5184.

990 Moustakas A and Evans MR 2015. Coupling models of cattle and farms with models of  
991 badgers for predicting the dynamics of *bovine tuberculosis* (TB). *Stochastic*  
992 *Environmental Research and Risk Assessment* 29, 623-636.

993 NAHMS. 2010. Dairy 2007. Facility characteristics and cow comfort on U.S. dairy



994 operations 2007. Accessed August 7, 2015.  
995 [http://www.aphis.usda.gov/animal\\_health/nahms/dairy/downloads/dairy07/Dairy07\\_ir](http://www.aphis.usda.gov/animal_health/nahms/dairy/downloads/dairy07/Dairy07_ir)  
996 [\\_Facilities.pdf](http://www.aphis.usda.gov/animal_health/nahms/dairy/downloads/dairy07/Dairy07_ir)

997 Nielsen BH, Thomsen PT and Sorensen JT 2011. Identifying risk factors for poor hind limb  
998 cleanliness in Danish loose-housed dairy cows. *Animal* 5, 1613-1619.

999 O'Connell J, Giller PS and Meaney W 1989. A comparison of dairy cattle behavioural  
1000 patterns at pasture and during confinement. *Irish Journal of Agricultural Research* 28,  
1001 65-72.

1002 Olmos G, Boyle L, Hanlon A, Patton J, Murphy JJ and Mee JF 2009a. Hoof disorders,  
1003 locomotion ability and lying times of cubicle-housed compared to pasture-based dairy  
1004 cows. *Livestock Science* 125, 199-207.

1005 Olmos G, Mee JF, Hanlon A, Patton J, Murphy JJ and Boyle L 2009b. Peripartum health and  
1006 welfare of Holstein-Friesian cows in a confinement-TMR system compared to a  
1007 pasture-based system. *Animal Welfare* 18, 467-476.

1008 Olson BE and Wallander RT 2002. Influence of winter weather and shelter on activity  
1009 patterns of beef cows. *Canadian Journal of Animal Science* 82, 491-501.

1010 O'Mahony DT 2014. Badger-cattle interactions in the rural environment: Implications for  
1011 bovine tuberculosis transmission. Report for Department of Agriculture and Rural  
1012 Development, Northern Ireland.

1013 Onyiro OM and Brotherstone S 2008. Genetic analysis of locomotion and associated  
1014 conformation traits of Holstein-Friesian dairy cows managed in different housing  
1015 systems. *Journal of dairy Science* 91, 322-328.

1016 Potterton SL, Green MJ, Harris J, Millar KM, Whay HR and Huxley JN 2011. Risk factors  
1017 associated with hair loss, ulceration, and swelling at the hock in freestall-housed UK  
1018 dairy herds. *Journal of Dairy Science* 94, 2952-2963.

1019 Reijs JW, Daatselaar CHG, Helming JFM, Jager J and Beldman ACG 2013. Grazing dairy  
1020 cows in North-West Europe; Economic farm performance and future developments  
1021 with emphasis on the Dutch situation. LEI Report 2013-001. LEI (Landbouw

1022 Economisch Instituut), Wageningen University and Research Centre, The Hague, the  
1023 Netherlands.

1024 Roca-Fernandez AI, Ferris CP and Gonzalez-Rodriguez A 2013. Short communication.  
1025 Behavioural activities of two dairy cow genotypes (Holstein-Friesian vs. Jersey x  
1026 Holstein-Friesian) in two milk production systems (grazing vs. confinement). Spanish  
1027 Journal of Agricultural Research 11, 120-126.

1028 Rodriguez-Lainz A, Melendez-Retamal P, Hird DW, Read DH and Walker RL 1999. Farm  
1029 and host-level risk factors for papillomatous digital dermatitis in Chilean dairy cattle.  
1030 Preventive Veterinary Medicine 42, 87-97.

1031 Ruckebusch Y, Dougherty RW and Cook HM 1974. Jaw movements and rumen motility as  
1032 criteria for measurement of deep sleep in cattle. American Journal of Veterinary  
1033 Research 35, 1309-1312.

1034 Rushen J and de Passille AMB 1992. The scientific assessment of the impact of housing on  
1035 animal welfare: A critical review. Canadian Journal of Animal Science 72, 721-743.

1036 Rutherford KMD, Langford FM, Jack MC, Sherwood L, Lawrence AB and Haskell MJ 2008.  
1037 Hock injury prevalence and associated risk factors on organic and nonorganic dairy  
1038 farms in the United Kingdom. Journal of Dairy Science 91, 2265-2274.

1039 Sanchez J, Nodtvedt A, Dohoo I and DesCoteaux L 2002. The effect of eprinomectin  
1040 treatment at calving on reproduction parameters in adult dairy cows in Canada.  
1041 Preventive Veterinary Medicine 56, 165-177.

1042 Sanchez J, Dohoo I, Carrier J and DesCoteaux L 2004. A meta-analysis of the milk  
1043 production response after anthelmintic treatment in naturally infected adult dairy  
1044 cows. Preventive Veterinary Medicine 63, 237-256.

1045 Schreiner DA and Ruegg PL 2003. Relationship between udder and leg hygiene scores and  
1046 subclinical mastitis. Journal of Dairy Science 86, 3460-3465.

1047 Schutz KE, Clark KV, Cox NR, Matthews LR and Tucker CB 2010. Responses to short-term  
1048 exposure to simulated rain and wind by dairy cattle: time budgets, shelter use, body  
1049 temperature and feed intake. Animal Welfare 19, 375-383.

1050 Schuppli CA, von Keyserlingk MAG and Weary DM 2014. Access to pasture for dairy cows:  
1051 Responses from an online engagement. *Journal of Animal Science* 92, 5185-5192.

1052 Schutz KE and Cox NR 2014. Effects of short-term repeated exposure to different flooring  
1053 surfaces on the behavior and physiology of dairy cattle. *Journal of Dairy Science* 97,  
1054 2753-2762.

1055 Scott VE, Thomson PC, Kerrisk KL and Garcia SC 2014. Influence of provision of  
1056 concentrate at milking on voluntary cow traffic in a pasture-based automatic milking  
1057 system. *Journal of Dairy Science* 97, 1481-1490.

1058 Sheldon IM, Lewis GS, LeBlanc S and Gilbert RO 2006. Defining postpartum uterine disease  
1059 in cattle. *Theriogenology* 65, 1516-1530.

1060 Singh SS, Ward WR, Lautenbach K, Hughes JW and Murray RD 1993. Behavior of 1<sup>st</sup>  
1061 lactation and adult dairy cows while housed and at pasture and its relationship with  
1062 sole lesions. *Veterinary Record* 133, 469-474.

1063 Somers JGCJ, Frankena K, Noordhuizen-Stassen EN and Metz JHM 2003. Prevalence of  
1064 claw disorders in Dutch dairy cows exposed to several floor systems. *Journal of Dairy*  
1065 *Science* 86, 2082-2093.

1066 Somers JGCJ, Frankena, K, Noordhuizen-Stassen EN and Metz JHM 2005. Risk factors for  
1067 digital dermatitis in dairy cows kept in cubicle houses in The Netherlands. *Preventive*  
1068 *Veterinary Medicine* 71, 11-21.

1069 Thomsen PT and Houe H 2006. Dairy cow mortality. A review. *Veterinary Quarterly* 28,  
1070 122-129.

1071 Thomsen PT, Kjeldsen AM, Sorensen JT, Houe H and Ersboll AK 2006. Herd-level risk  
1072 factors for the mortality of cows in Danish dairy herds. *Veterinary Record* 158, 622-  
1073 626.

1074 Thomsen PT, Ostergaard S, Sorensen JT and Houe H 2007a. Loser cows in Danish dairy  
1075 herds: Definition, prevalence and consequences. *Preventive Veterinary Medicine* 79,  
1076 116-135.

1077 Thomsen PT, Ostergaard S, Houe H and Sorensen JT 2007b. Loser cows in Danish dairy

1078 herds: Risk factors. Preventive Veterinary Medicine 79, 136-154.

1079 Tolhurst BA, Delahay RJ, Walker NJ, Ward AI and Roper TJ 2009. Behaviour of badgers  
1080 (*Meles meles*) in farm buildings: Opportunities for the transmission of *Mycobacterium*  
1081 *bovis* to cattle? Applied Animal Behaviour Science 117, 103-113.

1082 Tucker CB, Rogers AR, Verkerk GA, Kendall PE, Webster JR and Matthews LR 2007.  
1083 Effects of shelter and body condition on the behaviour and physiology of dairy cattle  
1084 in winter. Applied Animal Behaviour Science 105, 1-13.

1085 Vance ER, Ferris CP, Elliott CT, McGettrick SA and Kilpatrick DJ 2012. Food intake, milk  
1086 production, and tissue changes of Holstein-Friesian and Jersey x Holstein-Friesian  
1087 dairy cows within a medium-input grazing system and a high-input total confinement  
1088 system. Journal of Dairy Science 95, 1527-1544.

1089 Vanderstichel R, Dohoo I, Sanchez J and Conboy G 2012. Effects of farm management  
1090 practices and environmental factors on bulk tank milk antibodies against  
1091 gastrointestinal nematodes in dairy farms across Canada. Preventive veterinary  
1092 medicine 104, 53-64.

1093 Van laer E, Moons CPH, Sonck B and Tuytens FAM 2014. Importance of outdoor shelter  
1094 for cattle in temperate climates. Livestock Science 159, 87-101.

1095 Veling J, Wilpshaar H, Frankena K, Bartels C and Barkema HW 2002. Risk factors for  
1096 clinical *Salmonella enterica* subsp *enterica* serovar Typhimurium infection on Dutch  
1097 dairy farms. Preventive Veterinary Medicine 54, 157-168.

1098 Waage S, Sviland S and Odegaard SA 1998. Identification of risk factors for clinical mastitis  
1099 in dairy heifers. Journal of Dairy Science 81, 1275-1284.

1100 Ward AI, Judge J and Delahay RJ 2010. Farm husbandry and badger behaviour:  
1101 Opportunities to manage badger to cattle transmission of *Mycobacterium bovis*?  
1102 Preventive Veterinary Medicine 93, 2-10.

1103 Washburn SP, White SL, Green JT and Benson GA 2002. Reproduction, mastitis, and body  
1104 condition of seasonally calved Holstein and Jersey cows in confinement or pasture  
1105 systems. Journal of Dairy Science 85, 105-111.

1106 Webster JR, Stewart M, Rogers AR and Verkerk GA 2008. Assessment of welfare from  
1107 physiological and behavioural responses of New Zealand dairy cows exposed to cold  
1108 and wet conditions. *Animal Welfare* 17, 19-26.

1109 Welfare Quality (WQ). 2009. Welfare Quality assessment protocol for cattle; ISBN/EAN  
1110 978-90-78240-04-4. Welfare Quality Consortium, Lelystad, The Netherlands.

1111 White SL, Bertrand JA, Wade MR, Washburn SP, Green JT and Jenkins TC 2001.  
1112 Comparison of fatty acid content of milk from jersey and Holstein cows consuming  
1113 pasture or a total mixed ration. *Journal of Dairy Science* 84, 2295-2301.

1114 White SL, Benson GA, Washburn SP and Green JT 2002. Milk production and economic  
1115 measures in confinement or pasture systems using seasonally calved Holstein and  
1116 Jersey cows. *Journal of Dairy Science* 85, 95-104.

1117

1118 **Figure captions**

1119

1120 **Figure 1.** Summary of studies investigating pasture preference of cows. Black bars  
1121 represent the overall percentage of time on pasture (day and night), and white bars  
1122 represent the time on pasture at night.

1123

**Figure 1.**

