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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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4

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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 (Ingvarsen, 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

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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.

