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

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

Abstract

There is increasing interest in the use of continuous housing systems for dairy cows, with various reasons put forward to advocate such systems. However, the welfare of dairy cows is typically perceived to be better within pasture-based systems, although such judgements are often not scientifically based. The aim of this review was to interrogate the existing scientific literature to compare the welfare, including health, of dairy cows in continuously housed and pasture-based systems. While summarising existing work, knowledge gaps and directions for future research are also identified. The scope of the review is broad, examining relevant topics under three main headings; health, behaviour, and physiology. Regarding health, cows on pasture-based systems had lower levels of lameness, hoof pathologies, hock lesions, mastitis, uterine disease, and mortality compared to cows on continuously housed systems. Pasture access also had benefits for dairy cow behaviour, in terms of grazing, improved lying / resting times, and lower levels of aggression. Moreover, when given the choice between pasture and indoor housing, cows showed an overall preference for pasture, particularly at night. However, the review highlighted the need for a deeper understanding of cow preference and behaviour. Potential areas for concern within pasture-based systems included physiological indicators of more severe negative energy balance, and in some situations, the potential for compromised welfare with exposure to unpredictable weather conditions. In summary, the results from this review highlight that there remain considerable animal welfare benefits from incorporating pasture access into dairy production systems.

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

Implications

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

Introduction

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

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

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

Health

Lameness

Lameness is a major health and welfare problem, the impacts of which have recently been reviewed (Huxley, 2013) and include; a reduction in the time spent feeding and in milk yield, associations with low body condition scores, substantial negative effects on reproductive parameters and fertility performance, and increased culling. Lameness has a multifactorial and complex aetiology, resulting from interactions between the farm environment, management, nutrition and animal characteristics. However, a potentially important factor influencing lameness is whether or not cows can access pasture within a production system.

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

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

Controlled and on-farm epidemiological studies both indicate increased prevalence of a range of hoof pathologies (of both infectious and non-infectious aetiology) within more confined dairy systems (in addition to those discussed below, see Rodriguez-Lainz *et al.* (1999) and Somers *et al.* (2005)), and this may contribute to poorer locomotion. For example, in the controlled study referred to above, Olmos *et al.* (2009a) found increased sole and white line haemorrhages, white line disease, heel horn erosion, and digital dermatitis in the housed treatment from 85 days post-calving onwards. Furthermore, housed cows were more likely to present with traumatic and other disorders (e.g. white line abscess, under-run sole, sole ulcer, inter-digital growths). This effect was significant across all inspections during lactation (OR = 2.0), and increased dramatically with time (at 210 days after calving OR = 22.8). In addition, Somers *et al.* (2003) found that during the pasture period, continuously housed cows had a significantly higher prevalence of interdigital dermatitis/heel erosion (40.3 vs 20.7%, OR = 2.59), digital dermatitis (49.0 vs 29.7%, OR = 2.28), sole haemorrhages (63.2 vs 45.1%, OR 2.10), sole ulcers (7.4 vs 3.3%, OR 2.34) and interdigital hyperplasia (11.1 vs 5.1%, OR = 2.33). Furthermore, Swiss dairy herds with access to outdoor grazing during the summer period had a reduction in white line fissures (64 vs 84%, OR = 0.3), a lower prevalence of digital dermatitis on farms with slatted floors (22 vs 1%), and a reduction in the odds of finding any subclinical claw lesions at the end of the summer period (OR = 0.72) compared to those that were continuously housed (Haufe *et al.*, 2012).

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

It is worth noting that two studies highlighted in this review found an adverse effect of access to pasture on hoof health. Baird *et al.* (2009) found that cows managed on pasture had poorer claw health than cows kept indoors, while Barker *et al.* (2009) found an increased risk of white line disease when cows were at pasture by day and housed at night, compared with being housed 24 h per day (OR = 1.93). A potential explanation for these results is the quality of cow tracks and lanes used by cows to access pasture (Burow *et al.*, 2014), the herding management of animals at pasture, and the distance walked between pasture and the milking parlour (Laven and Lawrence, 2006). Future studies should seek to quantify the effects of these factors on lameness.

Hock lesions

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

Mastitis

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

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

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

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

Uterine disease

As part of the lameness study outlined previously (Olmos *et al.*, 2009a), Olmos *et al.* (2009b) found evidence of increased dystocia, metritis (see also Bruun *et al.*, 2002) and endometritis in continuously housed cows. It was suggested that since bacterial counts will be higher indoors (Sheldon *et al.*, 2006), this increases the level of contamination of the uterine lumen post-partum, and thus the risk of metritis. Moreover, Olmos *et al.* (2009b) observed a trend for lower plasma calcium levels at calving and post-partum, which, given its role in uterine smooth-muscle contractility, led the authors to speculate that this may have also contributed to the observed findings of increased dystocia and metritis in the housed cows. However, the extent to which this is the case remains to be investigated.

Other infectious disease

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

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

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

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

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

Endoparasites

In contrast to the benefits of pasture access for health, a number of epidemiological studies demonstrate that grazing is, unsurprisingly, a risk factor for exposure to gastrointestinal (**GI**) parasites. While dairy cattle develop a degree of immunity to GI parasites following exposure at pasture during early life, this is not complete. Adult dairy cows still harbour GI nematodes, generally in low numbers, with *Ostertagia ostertagi* being the most prevalent (Agneessens *et al.*, 2000; Borgsteede *et al.*, 2000). Detrimental impacts are illustrated by studies demonstrating a positive response in adult dairy cows to anthelmintic treatment in terms of milk yield, increased appetite, improved liveweight, condition score and reproductive performance (Sanchez *et al.*, 2002, 2004; Forbes *et al.*, 2004; Gibb *et al.*, 2005). Levels of *O. ostertagi* exposure were lower in continuously housed herds compared to where cows had access to pasture, and also positively associated with; earlier turnout, later housing, and longer grazing times per day (Charlier *et al.,* 2005; Forbes *et al.,* 2008; Bennema *et al.*, 2010; Vanderstichel *et al.,* 2012). Similarly, liver fluke, *Fasciola hepatica* exposure has been associated with an increased proportion of grazed grass in the diet, a longer grazing season, and no pasture mowing (Bennema *et al.*, 2011). These studies highlight the necessity for adequate anthelmintic parasite control regimens within pasture-based production systems.

Mortality

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

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

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

Behaviour

Pasture-based systems are perceived to offer greater behavioural freedom than continuously housed systems, and as such, interpreted as offering enhanced welfare. The impact of production systems on behaviour is an important component of welfare assessment, comprising one of the “five freedoms”, namely “freedom to express normal behaviour”. This leads to the question of what constitutes “normal” behaviour? While comparisons can be drawn to the wild ancestors of some farmed species to determine “normal” behaviour, this is not the case for cattle. However, a number of studies have examined the behaviour of free-living domesticated cattle at pasture with little human interference (some populations termed feral cattle). In pursuing “normal” cattle behaviour, Kilgour (2012) identified and reviewed 22 such studies. From this review it was evident that cattle have an extensive behavioural repertoire, comprising 40 identifiable categories. Grazing was the most common behaviour, followed by ruminating and resting, with these three categories accounting for 90-95% of an animal’s day. The data revealed most grazing is performed during the hours of daylight, with little grazing at night, and cattle instead spending more time resting and ruminating at night. Moreover, there is a diurnal rhythm of behaviour, characterised by peaks of grazing activity associated with sunrise and sunset.

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

Feeding / grazing

Roca-Fernandez *et al.* (2013) compared the behavioural activities of two dairy cow genotypes (Holstein-Friesian vs. Jersey x Holstein-Friesian) in a pasture-based and continuously housed production system (TMR and cubicles) using a 2 x 2 factorial design. Cow genotype had no effect on behaviour. However, cows in the pasture system spent 68% of their time grazing, while cows in the housed system spent 22% feeding. Moreover, in the pasture group there was synchronization of grazing behaviour, with main bouts occurring after each milking, and being more prolonged in the evening than morning. In contrast, the feeding behaviour of the housed cows was spread throughout the day, with approximately 30% of the animals feeding at any one time. Regarding the feeding patterns observed it is interesting to note that the pasture treatment closely resembles the description of “normal” provided by Kilgour (2012). This is not the case for the housed cows and the implications for welfare remain to be further investigated. For example, are there negative welfare implications of altered time budgets in animals whose ancestors displayed particular patterns of grazing behaviour?

Lying / resting

The study by Olmos *et al.* (2009a), described previously under the lameness section, also provided a comprehensive comparison of the lying behaviour of cows in the two scenarios. Data-loggers were used to examine the lying behaviour of pasture-based and cubicle-housed cows at days 33, 83 and 193 post-calving. This revealed pasture-based cows had greater mean total lying times per 48 h period (42.7 vs. 37.7% of time spent lying) and longer lying bouts (50.3 vs. 39.3 minutes). This was interpreted as a welfare benefit of pasture, as reduced lying times and restlessness associated with housing are indicators of lack of comfort, udder problems, overcrowding, as well as being a risk factor for hoof disorders, especially since decreased lying equates to increased time spent standing (Olmos *et al.*, 2009a). These results are consistent with previous reports of increased lying times at pasture (O’Connell *et al.*, 1989; Singh *et al.*, 1993), although both these studies suffered from confounding effects of season and differing stages of lactation and should be treated with some caution. In addition, O’Connell *et al.* (1989) reported a loss of lying synchrony indoors, with less than 45% of the cows observed lying at any one time, compared with up to 90% of cows lying at any one time on pasture, during the period from sunset to sunrise. A loss of synchrony indoors may be due to reduced space allowance, increased disturbance and competition for lying places, and has been suggested to represent an index of reduced welfare (Miller and Wood-Gush, 1991). In addition, lying deprivation has been shown to be physiologically stressful for lactating cows in terms of elevated cortisol levels, and reduced adrenocorticotrophic hormone (ACTH) and cortisol responses following corticotrophin releasing hormone (CRH) challenge, suggesting a degree of pituitary down-regulation (Fisher *et al.*, 2002).

Aggression

Only two studies (O'Connell *et al.*, 1989; Miller and Wood-Gush, 1991) have compared the aggressive behaviour of cows in the two scenarios. O'Connell *et al.* (1989) reported that agonistic interactions occurred at low levels at pasture, being significantly greater when housed, where two peaks of agonistic activity coincided with the delivery of fresh feed. Furthermore, while there was a significant correlation between the dominance hierarchies in both environments, the outdoor ranking was a rather poor predictor of indoor ranking. This suggests that the nature of agonistic interactions and determinants of dominance differed between the two scenarios, possibly the result of the indoor scenario involving contests for access to food, combined with reductions in space. Consistent with these findings, Miller and Wood-Gush (1991) reporting on a herd of Holstein-Friesian cows, also found higher levels of aggression during the winter cubicle housing period compared with the summer grazing period (this study also suffered from time and stage of lactation confounds). Indeed the average number of agonistic interactions recorded during focal animal observations was 1.1 per h at pasture and 9.5 per h while housed, with the majority of indoor aggression occurring in the feeding area.

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

Behavioural knowledge gaps

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

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

Cow Preference

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

Researchers at the University of British Columbia's dairy research centre (Legrand *et al.*, 2009) offered late lactation Holstein cows the choice between free access to pasture and to cubicle housing, with TMR offered indoors. Cows spent on average 54% of their time on pasture. However, pasture use varied considerably with time of day. Cows preferred to be indoors during the day (outside less than one-third of the time between morning and evening milkings), using this time for feeding, with feeder use peaking following milkings. In contrast, cows showed an almost exclusive preference for pasture at night, and spent more of their lying time on pasture (69% of total lying time/d). Similarly, a more recent study from the same research farm (Falk *et al.*, 2012) also found cows displayed a partial preference for pasture, averaging 57% of their time on pasture, with cows spending more time outside at night (78.5%) than they did during the day (41.5%). In addition, and contrary to predictions, Falk *et al.* (2012) found no effect of cubicle availability on time spent at pasture. It was suggested that the short duration of cubicle availability manipulations (four days) may have explained the lack of effect. Future work should investigate effects of stocking density over longer time periods.

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

A limitation of the preference tests outlined so far is that they do not provide information on the strength of preference. This can be overcome, and motivation measured by imposing an increasing cost on the animal to gain access to a particular resource (Jensen and Pedersen, 2008). Using this principle, Charlton *et al.* (2013) varied the distance cows were required to walk to access pasture (60, 140, or 260 m). Overall, and consistent with the other studies (Legrand *et al.*, 2009; Falk *et al.*, 2012; Charlton *et al.*, 2011b), cows had a partial preference for pasture, spending 58% of their time outside, and spending more time outside during the night (80%) than during the day (44%). Relating to preference strength, at night there was no effect of access distance on pasture use. However, during the day, time spent on pasture declined as distance increased, with cows spending longer on pasture when they had to walk 60m compared with 140 or 260 m (45 vs. 27 vs. 21%). The difference between findings for day and night-time pasture use with distance suggests that cows were more motivated, revealed by walking longer distances, for pasture use during the night compared with during the day. During the day, cows may have preferred to be indoors (overall average of 56% of time spent indoors during the day) to access TMR and meet their nutritional needs, particularly post-milking and following delivery of fresh feed. The necessity of meeting nutritional demands during the day appears to have traded off with the desire to access pasture, revealed when the cost of the latter was increased by having to walk 140 or 260 m.

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

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

Summarising the results of these preference test studies (Figure 1), reveals, with one exception (Charlton *et al.*, 2011a), that dairy cows have an overall partial preference for pasture (Legrand *et al.*, 2009; Charlton *et al.*, 2011b, 2013; Falk *et al.*, 2012; Motupalli *et al.*, 2014). During the day, cows had a partial preference for indoor housing (Legrand *et al.*, 2009; Falk *et al.*, 2012; Charlton *et al.*, 2013), or spent similar time periods indoors and on pasture (Charlton *et al.*, 2011b, Motupalli *et al.*, 2014). This was explained by the presence of fresh TMR indoors enabling cows to meet their nutritional demands following milking. However, at night cows displayed a preference for pasture (Legrand *et al.*, 2009; Charlton *et al.*, 2011b, 2013; Falk *et al.*, 2012; Motupalli *et al.*, 2014). Indeed, the studies by Charlton *et al.* (2013) and Motupalli *et al.* (2014) revealed that cows seemed particularly motivated to access pasture at night, since there was no effect of distance on their preference for pasture, yet during the day cows spent less time on pasture when they had to walk greater distances. The preference for pasture at night is most easily explained by a desire for a comfortable lying area, supported by findings of time spent lying while at pasture (e.g. Legrand *et al.*, 2009; Charlton *et al.*, 2013). However, the preferences were also complex, being influenced by environmental parameters, and time of day. For example, unsurprisingly, climatic variables influence preferences, with pasture use decreasing with increasing rainfall (Legrand *et al.*, 2009; Falk *et al.*, 2012; Charlton *et al.*, 2011a, 2013) and being influenced by the temperature-humidity index (Legrand *et al.*, 2009, Charlton *et al.*, 2011b; Falk *et al.*, 2012) and season (Charlton *et al.*, 2011b). Cow factors including milk yield and lameness score also influenced preference, with Charlton *et al.* (2011a) reporting that higher yielding cows spent more time indoors than lower yielders, while Charlton *et al.* (2011b) report that cows with a poorer lameness score spent more time indoors.

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

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

Physiology

Few studies have used physiological measures to compare the welfare of dairy cows in pasture compared to continuously housed systems. Indeed, the only comprehensive example in the context of welfare is provided by Olmos *et al.* (2009b) who examined blood levels of acute phase proteins (APP), cortisol, white blood cell (WBC) differential and counts, and other biochemical metabolites as non-specific indicators of sub-clinical ill-health and nutritional stress. While there were no differences in APP, cortisol, or WBC counts between treatments, pasture-based cows had higher levels of NEFA, beta-hydroxybutyrate and triglyceride post-partum, consistent with a limited energy supply. In addition, pasture cows showed a tendency for higher concentrations of bilirubin and numerically higher bile acid concentrations, both indicative of greater hepatic lipidosis. Put together, these findings indicate a greater degree of negative energy balance in cows on pasture than in housed cows, as has been reported for a number of production performance studies (Kolver and Muller, 1998; Bargo *et al.*, 2002; Boken *et al.*, 2005; Fontaneli *et al.*, 2005; Kay *et al.*, 2005; Vance *et al.*, 2012). Nutritional and metabolic stress in the peripartum period is a welfare concern, with negative implications for immune function and cow health in early lactation, and further negative downstream effects on fertility (Ingvartsen, 2006; Butler, 2014; Drackley and Cardoso, 2014). However, although the pasture cows in the study by Olmos *et al.* (2009b) had evidence of greater nutritional and metabolic stress, they had better reproductive health. Clearly, there is a need for more research using biomarkers to assess the welfare of dairy cows in various production scenarios.

Thermal Stressors

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

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

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

Heat stress can be a problem in both housed and pasture-based systems, with negative consequences for production, fertility and welfare. In the preference tests discussed previously, cows spent more time on pasture as the temperature-humidity index increased indoors and outdoors in the UK based study (Charlton *et al.*, 2011b) indicating that in this temperate region cows found the outdoor pasture more comfortable than the indoor housing. However, in the North American based preference studies (Legrand *et al.*, 2009; Falk *et al.*, 2012) time spent on pasture during the day decreased as the outdoor temperature-humidity index increased, likely reflecting the shade and ventilation offered in the housed environment. In those circumstances where heat stress can be a problem a variety of mitigation strategies can be successfully used to ensure adequate thermal comfort (Van laer *et al.*, 2014).

The impact of sunlight

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

Conclusions

Animal welfare is a multi-criteria characteristic (Rushen and de Passille, 1992). In this review we compared the welfare of dairy cows in pasture-based versus continuously housed systems. Lower levels of lameness, hoof pathologies and hock lesions were observed in pasture-based compared to continuously housed systems. These benefits likely derive from providing a comfortable, soft and hygienic standing, walking and lying surface, with additional benefits associated with exercise in terms of grazing and walking to and from pasture. The prevalence of mastitis and uterine disease was generally lower within pasture-based systems, thought to derive from reduced exposure to environmental pathogens and improved cow cleanliness. Given the detrimental impact of uterine disease on subsequent fertility and lactation performance (e.g. see LeBlanc, 2014 for a review) this is an important issue (Mee, 2012). By contrast, there are some risks posed by contacting neighbouring cattle in pasture-based systems, highlighting the need for appropriate biosecurity measures, and grazing is unsurprisingly a risk factor for endoparasite infection. However, overall, pasture access has a positive effect on dairy cow health. Indeed, mortality is lower in herds having access to pasture than in continuously housed herds.

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

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

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

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

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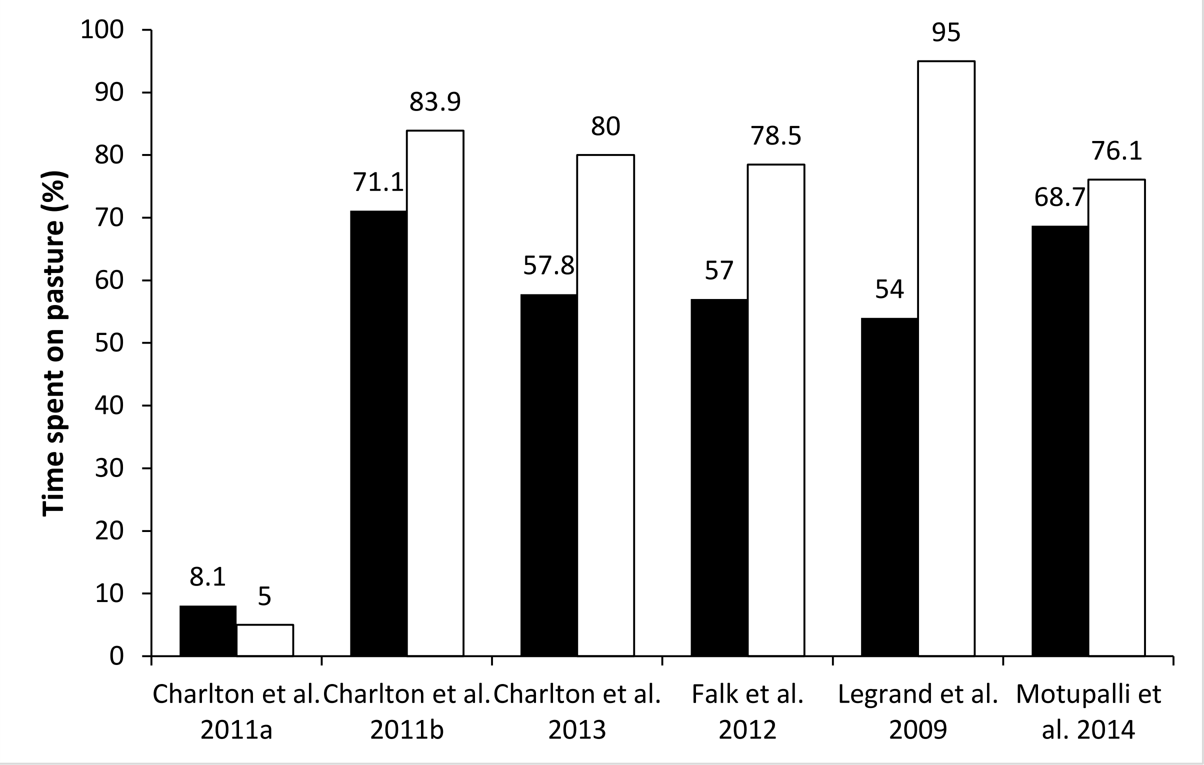
Figure captions

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

Figure 1.


Time spent on pasture (%)
100
90
80
70
60
50
40
30
20
10
0
8.1
5
71.1
83.9
57.8
80
57
78.5
54
95
68.7
76.1
Charlton et al. 2011a
Charlton et al. 2011b
Charlton et al. 2013
Falk et al. 2012
Legrand et al. 2009
Motupalli et al. 2014