The Effect of Out-Wintering Pad Design on Hoof Health and Locomotion Score of Dairy Cows

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ABSTRACT

This study compared locomotion, hoof health, and lameness of dairy cows confined in either indoor free stalls (FS) or 1 of 3 out-wintering pad (OWP) designs. Out-wintering pad treatments were 1) uncovered OWP with a concrete feed apron (UP); 2) covered OWP with a concrete feed apron (CO); and 3) uncovered OWP on top of which grass was ensiled so that the cows could self-feed (SP). Cows were assigned to treatment at drying off using a randomized complete block design. They remained on treatment until calving, when they were turned out to pasture. Sole lesions, heel erosion, dermatitis, and claw hardness on both hind feet were scored according to severity at assignment to treatment, at calving, and 9 and 14 wk postpartum. Locomotion score was recorded weekly after calving for 14 wk. Incidence of clinical lameness was recorded during the treatment period and in the subsequent lactation. Treatment had no effect on sole lesion score, but scores increased over time (calving = 5.5 ± 1.3 , wk 9 = 10.8 ± 1.3 , wk 14 = 14.2 ± 1.3 , mean $\pm$ SE). Self-fed cows had higher heel erosion scores (6.4 ± 0.4) than FS and CO cows (4.7 ± 0.4 and 4.7 ± 0.4 , respectively) at calving. Cows on SP had the highest dermatitis scores [1.14 (0–2) mean (interquartile range)] and FS cows the lowest [0.51 (0–0)]. Hooves were hardest at assignment to treatment (43.9 ± 0.6) with a significant reduction in hardness at calving (40.0 ± 0.6). The hooves of CO cows were harder than those of SP and UP cows (CO = 43.3 ± 0.7 , SP = 41.7 ± 0.7 , UP = 41.7 ± 0.7 , Shore D scale). There was no treatment effect on locomotion scores or lameness incidence. Higher dermatitis scores and heel erosion in SP may be due to exposure to excreta and moisture, because the SP treatment had no manure removal system at the feed face. In FS, the alleys and the feed face were cleaned regularly by automatic scraper, explaining the lower dermatitis scores recorded indoors. Providing

shelter for OWP likely reduced exposure to environmental moisture. This ensured that the hooves of CO cows remained as hard as those of FS cows. Low correlations between hardness and pathologies indicate that other factors are involved in the development of hoof pathologies. Confining dry dairy cows on OWP does not increase locomotion scores or lameness incidence.

Key words: dairy cow, locomotion, hoof health, accommodation system

INTRODUCTION

Lameness in dairy cows has important financial implications due to the direct costs associated with treatment and culling and the indirect costs associated with reduced reproductive performance and milk production (Kossabati and Esslemont, 1997). Furthermore, the disorder constitutes a significant welfare problem for dairy cows because of the pain involved and its chronic nature (Whay et al., 1997).

Lameness predominantly occurs as a result of injury or disease of the hoof (Murray et al., 1996). Risk factors for lameness associated with housing systems for dairy cows include concrete flooring, inadequate bedding, and lack of exercise (Knott et al., 2006). Soft flooring surfaces such as rubber or straw are beneficial for hoof health (Vanegas et al., 2006). Furthermore, access to pasture appears beneficial in reducing lameness (Hernandez-Mendo et al., 2007). There is evidence that simply walking on softer surfaces improves locomotion in moderately lame cows (Telezhenko and Bergsten, 2005). Another risk factor for lameness is a reduction in daily lying time, due to its association with impaired claw health (Singh et al., 1993). Thus, a housing system that inhibits lying could have a negative impact on hoof health.

Interest in low-cost winter accommodation for dairy cattle is growing, particularly in areas where there is an economic need for expansion (Donnellan et al., 2002). Out-wintering pads (OWP) are one such option. They consist of a woodchip lying area constructed over a drainage system, which may or may not be sheltered.

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Animals are generally fed from a concrete area adjacent to the woodchip pad, or they self-feed on top of the woodchip pad. In the latter system forage is ensiled directly on top of the woodchips. Out-wintering pads do not appear to have negative health and welfare implications for beef cattle (Hickey et al., 2002). However, hoof health of dairy cows out-wintered on pads was compromised during the subsequent lactation, particularly when the OWP was unsheltered (our unpublished data). Out-wintered dairy cattle were exposed to more moisture than housed animals, particularly when shelter was not provided. Bovine hooves rapidly absorbed water, which caused softening of the horn and may increase the susceptibility of the hooves to injury (Borderas et al., 2004). This is a particular problem in pasture-based dairy systems in which cows are often turned out to grass soon after calving and are required to walk to and from pasture to the milking parlor, normally twice a day. Soft hooves coupled with the need to resume walking immediately after calving may increase the susceptibility of hoof injury during lactation. Furthermore, the absence of shelter inhibits lying behavior during periods of adverse weather (Tucker et al., 2007). This leads to prolonged exposure of the hooves to moisture as the cows spend more time standing.

O'Driscoll et al. (2006) found that dairy cows on OWP need 12 m² each because udder health problems increase at greater stocking densities. Furthermore, hoof hardness was not measured, so a hypothesis that increased hoof lesions postpartum was related to exposure of the hooves to moisture in the unsheltered OWP could not be supported. To date, no published studies have evaluated the effect that this type of confinement system has on dairy cow hoof health. Because of the importance of lameness in the dairy industry, the aim of this experiment was to examine the effect that 3 OWP designs and indoor free-stall (FS) accommodation had on hoof health and locomotor ability when animals in each OWP design were kept at the same stocking density (12 m²/animal). We hypothesized that out-wintered cows without access to concrete or shelter would have the softest hooves, cows indoors on concrete would have the hardest, and animals in the sheltered and unsheltered OWP with a concrete feed area being intermediate. Our second hypothesis was that cows with softer hooves would be more likely to develop heel erosion during the winter period, and to develop sole bruises after calving. Finally, we hypothesized that cows with reduced hoof health would more likely display signs of lameness during lactation.

MATERIALS AND METHODS

The study was conducted at Teagasc "Ballydaguer" research farm, which is part of Moorepark Dairy Pro-

duction Research Centre, Fermoy, Cork, Ireland (50°07' N; 8°16' W) between December 2005 and December 2006.

Animals and Treatments

Ninety-six pregnant dairy cows (*Bos taurus*; 40 primiparous and 56 multiparous) were blocked according to breed (Holstein-Friesian or Norwegian Red), parity (1.56 ± 1.785 , mean $\pm$ SD), expected calving date (February 22, 2006, ± 20.1 d), and BCS (3.09 ± 0.29) into 8 groups. Animals were randomly assigned to 1 of 2 replicate groups in each of the following treatments; 1) FS, 2) an unsheltered OWP (UP), 3) a covered OWP (CO), and 4) an unsheltered OWP on top of which grass was ensiled so that the cows could self-feed (SP). Both UP and CO had a concrete apron from which cows were fed.

Housing and Management

Indoors, the FS were bedded with rubber mats (23 mm in depth; Super Dutch Comfort design, Farm Mat, Alfco Farm Services Ltd., Trim, Ireland) provided at a ratio of 1:1. Mats were manually cleaned and treated with lime daily. The wood-chipped lying areas were constructed according to Hickey et al. (2002). An impermeable layer of compacted soil was laid down in ridges (3.5 m apart, 0.5 m high), and perforated drainage pipes (80 mm in diameter) were placed in the troughs between the ridges. Round stones (~5 cm in diameter) were then placed to a depth of 20 cm on top of the ridges. A layer of woodchips (pieces $10 \times 3 \times 0.5$ cm) was then spread over the stone to a depth of approximately 30 cm. All animals on the OWP were allocated a total space allowance of 14.52 m²/head. In UP and CO, this allowance was divided between the 12-m² woodchip space allowance and a concrete feed face allowance of 2.52 m²/head. The total allowance in SP consisted of the woodchip area. Animals in FS, UP, and CO were allocated 60 cm/cow at the feed face. The concrete aprons in these treatments were cleaned 6 times daily by an automatic scraper. The silage pit in SP provided cows in each replicate with 13.5 m of feed face. To prevent spoilage of the silage it was necessary for 26 animals to feed from these areas. For this reason 14 "filler" animals were allocated to each replicate. These cows had approximately 50 cm/cow at the feed area.

All multiparous cows were dried off by November 17, 2005. Between November 17 and December 5, 2005, multiparous animals in each treatment were kept as a single group. On December 5, 2005, the primiparous animals were added and groups were divided into 2 replicates. The mean calving date was February 21,

2006. Approximately 3 d precalving (3.2 ± 5.51 d), animals were removed to a group-housed, straw-bedded calving shed. The space allowance was adjusted to maintain the correct stocking density for the remaining animals in each treatment. The area of the OWP treatments was adjusted using a metal wire, and in FS using a gate. After parturition cows remained with their calf until the next milking after which they were returned to a different straw shed for 1 night. Thereafter, cows that calved between January 24 and February 13, 2006 ($n = 40$) were kept on an additional UP with a concrete feed area by night and were at pasture by day until February 14, 2006, when they were turned out to pasture full time. Cows calving from February 14 onwards were at pasture both day and night. Cows were milked twice daily at approximately 0800 and 1530 h.

Woodchip Scoring System

The woodchips were scored weekly using a published scoring system (1 = clean woodchip to 4 = thick fecal layer; Hickey et al., 2002). The percentage area of each OWP containing woodchips that conformed to each point on the scale was estimated. To attempt a consistent estimation and to remove the effect of OWP area size, each SP replicate was divided in 2, and both areas were estimated separately and the results averaged. The overall score for each OWP replicate was calculated using weighted averages; that is, the percentage area of each score was multiplied by that score, and the results totaled. A score of 1 or 2 constituted an acceptable level of cleanliness. Pads were managed so that each cow had a clean lying area of $2.2 \text{ m}^2/\text{cow}$. When this level was breached, dirty woodchips were removed and replaced with a clean layer. The OWP were cleaned and woodchips replaced on January 20 and March 3, 2006.

Nutrition

Cows were fed grass silage during the winter accommodation period. Silage for FS, UP, and CO treatments was obtained from the same silage pit each morning and delivered using a diet feeder. Chemical composition of the silage was 16.9% CP, 77.0% DM digestibility, 41.9% NDF, and 11.1 MJ of ME/kg. Silage was offered ad libitum daily in the morning at 1.0 kg above requirement to ensure animals were not restricted. An electric wire above the feed area of SP was adjusted daily to permit access to fresh feed. Composition of this silage was 16.2% CP, 77.1% DM digestibility, 43.0% NDF, and 11.1 MJ of ME/kg. Fresh water was available from self-filling troughs for each treatment. Each replicate was provided with an individual water bowl.

Cows were managed as a single herd while at pasture; pasture consisted primarily of perennial ryegrass (*Lolium perenne*). Cows were allocated fresh grass daily, and pregrazing yield was maintained between 1,800 and 2,200 kg of DM/ha (>4 cm). Cows were supplemented with concentrate. All concentrate feeding was offered in individual stalls in the milking parlor in 2 equal feedings daily. The average daily allowance was 4.2 ± 1.88 kg/d, and by the time the final hoof examination took place, the average concentrate intake in each treatment was: FS = 437.1 ± 18.5 kg, UP = 424.9 ± 19.9 kg, SP = 445.3 ± 19.2 kg, and CO = 436.6 ± 18.8 kg ($P > 0.05$). The ingredient composition of the concentrate offered (kg/t) was as follows: barley 250, corn gluten 260, beet pulp 350, soybean meal 110, and minerals plus vitamins 30. The chemical composition was 16.8% CP, 79.7% DM digestibility, 32.2% NDF, and 11.6 MJ of ME/kg. Furthermore, there was no difference in concentrate intake between breeds (Norwegian Red = 437.8 ± 14.5 kg, Holstein-Friesian = 434.2 ± 12.6 kg; $P > 0.05$).

Environmental Measurements

Local rainfall and mean daily wind speed data were obtained from a weather station located at Moorepark Dairy Production Research Centre approximately 16 km from the experimental site. Ambient temperature in each treatment was recorded using electronic temperature dataloggers (Tinytag Extra Dual Channel Temperature/Relative Humidity, Gemini Dataloggers (UK) Ltd., Chichester, UK). The dataloggers were suspended approximately 2 m above the ground, 1 between the 2 FS replicates, 1 outdoors adjacent to both the UP and SP treatments, and 1 between the 2 CO replicates. They were programmed to record at 10-min intervals.

Animal Measurements

Hoof Scoring. Animals were restrained in a metal crate and their hind feet lifted, the claws individually examined, and, if necessary, correctively trimmed at the beginning of the experiment (December 8 to 13, 2005). Approximately 89 ± 26 d elapsed between the time that cows went on treatment and calving. Cows were examined again immediately (6 ± 3 d) after calving. Subsequent examinations were carried out approximately 9 (62 ± 4 d) and 14 wk (104 ± 3 d) after the postcalving inspection.

Hoof scoring was carried out by the same person throughout the trial. The hind claws were cleaned and a sliver of horn was trimmed using a Quittor knife (Hauptner Quittor Hoof Knife, Channelle Vet Products, Loughrea, Ireland) from the entire area of the weight-bearing surface to expose fresh horn. Pigmented soles

Table 1. The scoring systems used for recording severity of hoof lesions

Scoring system/score	Description
Heel erosion	
0	Normal heels
1	Multiple shallow depressions
2	Multiple deep irregular depressions
3	Shallow oblique grooves
4	Deep oblique grooves with complete heel disappearance
5	Heel disappearance to the extent that corium was exposed
Dermatitis	
0	No appearance
1	Slight irritation of the skin (roughened appearance)
2	Irritation of the skin with rough, thickened appearance (may be evidence of grayish exudates)
3	Irritation of the skin with rough, thickened, moist appearance and swelling
4	Swelling of the skin with grayish exudates and signs of hyperkeratosis
5	Dermis no longer intact, moist eczema and hyperkeratotic lesions
White line disease	
0	Normal
1	Striated appearance of white line
2	Slight separation
3	Moderate separation
4	Complete separation of the white line

were recorded, because dark pigmentation affected identification of bruises.

Sole Lesions. Sole hemorrhages were localized to the zone of the sole (6 regions; Greenough and Vermunt, 1991), and their severity scored on the following scale: 1 = diffuse red, 2 = stronger red coloration, 3 = deep dense red, 4 = port coloration, and 5 = red raw, possibly fresh blood (Leach et al., 1998). Sole ulcers were scored from 6 to 8 (6 = corium exposed, 7 = severe sole ulcer, major loss of horn, and 8 = infected sole ulcer; Leach et al., 1998). Both sole hemorrhage and sole ulcer scores were geometrically adjusted to produce a severity score (sole hemorrhage: 1, 2, 4, 8, and 16, sole ulcer: 32, 64, and 128). This method of scoring recognizes the greater clinical significance of higher scores (Greenough and Vermunt, 1991). The scores for all 4 hooves were added to give a total sole lesion score for each animal at each inspection.

Heel Erosion. Heel bulbs on both claws were cleaned and examined for the presence of heel horn erosion according to the scale (Table 1). Scores from all 4 heel bulbs were added to give total heel erosion scores for each animal.

Dermatitis. Although digital and interdigital dermatitis were described as separate conditions, it can be difficult to distinguish between them, so both were simply classified as dermatitis (Manske et al., 2002). The interdigital space and skin around the heels was cleaned and examined for presence and severity of dermatitis (Table 1). The scores from each hind hoof were added to give a single dermatitis score for each animal at each inspection.

The scoring system for white line disease is described in Table 1.

Hoof Hardness

Hardness (Shore D scale) of all claws on the hind feet was recorded at each inspection using an analog durometer (HP-DS Shore D Analog Durometer, ASTM D2240; Qualitest International Inc., Richmond Hill, Ontario, Canada). Recordings were taken from area 5 of the sole (Greenough and Vermunt, 1991), because this area was an accurate representation of sole hardness (Borderas et al., 2004). Because of the uneven nature of the surface of the sole, the area was trimmed flat using a Quittor knife before measurement. The operating principle of a durometer was that the resistance force was measured by recording the degree to which a sensing pin was pushed into the body of the durometer when pressed against a test substrate. The hardness value was obtained from the work required to make an indentation divided by the volume of the indentation (Koji, 1999). The sensing tip was pressed to the hoof until the flat area of the durometer was against the horn. The maximum recording, as indicated by a maximum recording indicator on the durometer, was taken at each examination.

Locomotion Scoring

Cows were scored for locomotion every 8 ± 4 d for 14 wk after calving using the scoring system described by Gleeson et al. (2007). Six aspects of locomotion were scored and then added to give a total score. Immediately

after milking the cows were released individually from a squeeze chute and scored as they walked past (lateral view) and then away (posterior view) from the observer.

Lameness Incidence

Cows were inspected daily during the winter accommodation period and twice daily at milking. Lameness was diagnosed by the stockperson when locomotion was visibly impaired. Details on each case of lameness were then recorded. These recorded cases were based solely on the herdsman's interpretation of lameness. On identification of a case of clinical lameness the hoof was lifted, cleaned, and trimmed.

Statistical Analysis

Mean daily rainfall, total rainfall, and wind speed measurements between December 1, 2005, and March 31, 2006 are described. Temperature and relative humidity recordings from each treatment were from January 3 and March 22, 2006.

All other data were analyzed using SAS software (V9.1.3, 1989; SAS Institute Inc., Cary, NC). The animal was considered the experimental unit. Data were tested for normality before analysis by examination of box and normal distribution plots. Sole lesion scores were transformed using a square root transformation. Repeated-measures ANOVA was used (Proc Mixed, SAS Institute, 1989). Lesion scores from the initial inspection and claw hardness were inserted into the model as covariates. Fixed effects were treatment, inspection, breed, lactation number (first, second, third, and fourth or greater), and all relevant interactions. Inspection was the repeated measure, and replicate was considered a random effect. An unstructured covariance structure provided the best model fit. Heel erosion scores approached a normal distribution without transformation, and were analyzed using a mixed model with the same covariates, and fixed and random effects as before.

The Kruskal-Wallis test was used to determine an overall effect of treatment on dermatitis scores. The Wilcoxon Rank test was used to investigate pairwise differences between treatments, between inspections, and between treatments at each inspection. Dermatitis scores are reported as means and interquartile ranges. Fisher's exact test was used to determine differences in incidence (per animal) between treatments. White line disease scores were analyzed using Kruskal-Wallis and Wilcoxon Rank tests as before.

Hoof hardness was analyzed on a per-claw basis, using a similar model to that of hoof pathologies. But recordings from the initial examination were not used as a covariate because multiparous animals had been

on treatment for up to 3 wk before examination, and so recordings were not an accurate representation of hardness before treatment. All hardness scores are reported on the Shore D scale. Correlations between hardness and sole lesion score, heel erosion score, and dermatitis score were tested using Pearson and Spearman correlations.

Locomotion scores were positively skewed, and transformation did not correct for this, so the data were ranked before analysis. A repeated-measures ANOVA was conducted using a mixed model. Fixed effects were as described for lesion scores. Calving date was included as a covariate. Week of lactation was the repeated measure, and replicate was a random effect. Differences in the incidence of clinical lameness detected by the stockpersons over the lactation were analyzed using generalized estimating equations (Proc Genmod, SAS Institute, 1989) due to the binomial nature of the data. The logit of the probability that a cow experienced at least 1 bout of clinical lameness during the experimental period and subsequent lactation was investigated. Treatment, breed, and parity were included in the model as class variables. Significance was based on generalized estimating equation score.

Differences in least squares means in all models were investigated using the *t*-test following Tukey's adjustment for multiple comparisons. Model fit was determined in all analyses by choosing models with the minimum finite-sample corrected Akaike information criteria. Residuals were inspected in all models to confirm normality.

RESULTS

Environmental Measurements

Mean daily rainfall between the start of the experiment and the date the last animal calved were 6.2 mm (interquartile range: 0.0 to 2.3). The maximum recorded daily rainfall was 18.1 mm and this occurred on December 2, 2005. Monthly rainfall, wind speed, and temperature in each treatment are in Table 2.

Hoof Scoring

Treatment had no effect on sole lesion score ($P > 0.01$), but scores increased over time ($P < 0.001$). Sole lesion scores in FS, UP, SP, and CO were 9.3 ± 1.7 , 10.4 ± 1.8 , 9.2 ± 1.8 , and 11.8 ± 1.6 , respectively. The sole lesion scores at calving (5.5 ± 1.3) and 9 wk after calving (10.8 ± 1.3) were both lower than at 14 wk after calving (14.2 ± 1.3 ; $P < 0.01$, $P = 0.01$, respectively). Yet, there was no difference between scores at calving and 9 wk. There was an effect of breed, with Norwegian Red cows having lower sole lesion scores (6.0 ± 1.3) than Holstein-

Table 2. Monthly rainfall, wind speeds (mean $\pm$ SD), and ambient temperatures (mean $\pm$ SD) for each full month during the winter confinement period in free stalls (FS), uncovered out-wintering pads (UP), uncovered out-wintering pads with a self-feed silage pit (SP), and covered out-wintering pads (CO)

Month	Rain (mm) ¹	Wind (m/s)	Temperature (°C)		
			FS	UP/SP	CO
December 2005	72.3	4.8 $\pm$ 2.25	—	—	—
January 2006	55.2	5.7 $\pm$ 3.07	6.6 $\pm$ 2.95 ²	5.7 $\pm$ 3.17 ²	6.3 $\pm$ 3.05 ²
February 2006	26.3	5.6 $\pm$ 2.41	6.3 $\pm$ 2.21	5.4 $\pm$ 2.42	6.0 $\pm$ 2.24
March 2006	108.1	6.9 $\pm$ 2.49	5.5 $\pm$ 2.96 ³	4.9 $\pm$ 2.99 ³	5.7 $\pm$ 2.97 ³

¹Cumulative total.²Recorded between January 3 and 31, 2006.³Recorded between March 1 and 21, 2006.

Friesian cows (14.3 ± 1.1 ; $P < 0.01$). There was no effect of lactation number.

There were significant effects of treatment ($P = 0.01$) and inspection ($P < 0.001$) on heel erosion scores. Cows in SP had the highest heel erosion score (6.4 ± 0.4 , mean $\pm$ SE), and this was significantly higher than in FS (4.7 ± 0.4 ; $P < 0.05$) and CO (4.7 ± 0.4 ; $P < 0.05$). Cows in the UP treatment were intermediate (5.4 ± 0.4 ; $P > 0.1$) and not different from the other treatments. Heel erosion scores were higher at calving (6.5 ± 0.2) than at either 9 (4.9 ± 0.3 ; $P < 0.001$) or 14 (4.5 ± 0.4 ; $P < 0.001$) wk after calving, with no difference between these later examinations ($P > 0.1$). Heel erosion scores of SP cows were higher at calving than at any other inspection, and higher than scores in FS and CO cows at calving (Table 3). But there was no difference between scores in the SP and the UP treatments at calving ($P > 0.1$). Heel erosion scores were lower 9 wk postpartum in the CO and SP treatments than at calving ($P < 0.05$, $P < 0.001$, respectively). Scores of cows in SP were still lower 14 wk after calving than at calving, but in CO cows, scores were no longer different from the calving score. Furthermore, although the score of SP cows at calving was higher than all other scores, by the 9 wk and 14 wk inspections, heel erosion score was not different compared with scores in any of the other treatments at these inspections. There was no effect of breed on heel erosion score. Nevertheless, there was an effect of lactation number ($P < 0.001$). Cows entering their first lactation had lower heel erosion scores (4.1 ± 0.3) than cows

entering their second (6.8 ± 0.4 ; $P < 0.001$), third (6.9 ± 0.6 ; $P = 0.001$), or fourth or greater lactations (6.1 ± 0.4 ; $P < 0.01$). There were no other differences.

There was an overall effect of treatment on dermatitis score ($P < 0.05$). Cows in FS had the lowest dermatitis score, significantly lower than cows in the SP ($P < 0.01$) and CO ($P < 0.05$; Table 4). At assignment to treatment there was no difference in dermatitis score between treatments ($P > 0.1$). At calving, cows in SP had higher scores than cows in FS ($P < 0.01$) and CO ($P < 0.05$). There were no treatment differences in dermatitis scores 14 wk after calving ($P > 0.05$).

There was no difference in the proportion of animals in each treatment displaying symptoms of dermatitis between any of the treatments at the start of the study ($P > 0.1$). Nonetheless, at calving, there was an effect of treatment on the proportion of animals in each treatment displaying symptoms of dermatitis ($P < 0.05$; Figure 1). In SP there were more animals presenting symptoms than in FS ($P < 0.01$). But at 9 and 14 wk after calving there was no treatment difference in the proportion of animals displaying symptoms of dermatitis ($P > 0.1$; Figure 1).

There was no difference in white line disease scores between treatments, over time, or in the proportion of animals in each treatment that had white line disease ($P > 0.1$, data not shown).

Hoof hardness scores were highest (Shore D scale) at assignment to treatment (43.9 ± 0.6), and lowest at calving (40.0 ± 0.6 ; $P < 0.001$). By 9 wk after calving,

Table 3. Least squares means ($\pm$ SEM) of heel erosion score in each treatment at each inspection¹

Inspection time	Free stall	Uncovered pad	Covered pad	Self-feed pad
Calving	5.2 $\pm$ 0.46 ^a	6.4 $\pm$ 0.49 ^{ab}	6.0 $\pm$ 0.48 ^{a,A}	8.3 $\pm$ 0.50 ^{b,B}
Week 9	4.7 $\pm$ 0.48	5.5 $\pm$ 0.52	3.9 $\pm$ 0.49 ^B	5.5 $\pm$ 0.51 ^A
Week 14	4.0 $\pm$ 0.68	4.2 $\pm$ 0.76	4.2 $\pm$ 0.70 ^A	5.5 $\pm$ 0.73 ^A

^{a,b}Means within rows with different lowercase superscripts indicate significant differences.^{A,B}Means within columns with different uppercase superscripts indicate significant differences.¹Cows were managed at pasture at the wk 9 and wk 14 inspections.

Table 4. Arithmetic means and interquartile ranges of dermatitis scores for each treatment at each inspection date¹

Inspection time	Free stall	Uncovered pad	Covered pad	Self-feed pad
Assignment to treatment	0.79 (0–1)	0.95 (0–2)	0.83 (0–1)	1.00 (0–2)
Calving	0.33 (0–0) ^a	0.76 (0–2) ^{ab}	0.43 (0–1) ^a	1.42 (0–2) ^b
Week 9	0.52 (0–0)	1.00 (0–1)	1.04 (0–2)	1.30 (0–2.5)
Week 14	0.39 (0–0)	0.67 (0–1)	0.78 (0–1)	0.85 (0–0)
Overall	0.51 (0–0) ^a	0.85 (0–2) ^{ab}	0.77 (0–1) ^b	1.14 (0–2) ^b

^{a,b}Means within rows with different superscripts indicate significant differences.

¹Cows were managed at pasture at the wk 9 and wk 14 inspections.

hoof hardness score was higher than at calving (42.6 ± 0.7 ; $P < 0.001$), but lower than at the beginning of the experiment ($P < 0.05$). At the 14-wk examination, hoof hardness scores were similar to those at the beginning of the experiment (43.0 ± 0.6 ; $P > 0.1$). Cows on CO had harder claws (43.3 ± 0.7) than cows on either UP (41.7 ± 0.7 ; $P < 0.01$) or SP treatments (41.7 ± 0.7 ; $P < 0.01$); FS animals had similar hardness scores (42.8 ± 0.7 ; $P = 0.1$) to the latter 2 treatments. There was a significant interaction between treatment and inspection time. There was no difference in hardness score between left and right medial claws (43.8 ± 0.7 and 43.7 ± 0.7 , respectively, $P > 0.1$), or between left and right lateral claws (40.5 ± 0.7 and 41.4 ± 0.7 , respectively, $P > 0.1$). Nonetheless, other comparisons indicated that medial claws were significantly harder than lateral claws ($P < 0.001$). Furthermore, cows of the Norwegian Red breed had lower hardness scores (42.0 ± 0.6) than Holstein-Friesian cows (42.7 ± 0.6 ; $P = 0.05$).

There was no correlation between hardness and dermatitis scores ($P > 0.1$), and low correlations with sole

lesion scores ($P < 0.001$; Pearson correlation, $\rho = -0.226$) and heel erosion scores ($P < 0.05$; $\rho = -0.075$).

Locomotion Scoring

Locomotion scores for each treatment were: FS = 8.7 ± 0.4 , UP = 9.4 ± 0.5 , SP = 8.8 ± 0.4 , and CO = 8.8 ± 0.4 . One cow was affected by a severe growth in the interdigital space of her right hind hoof for the duration of the experiment. This cow had consistently high locomotion scores during the recording period. When this cow was removed from the data set, the mean of cows in UP was 8.8 ± 0.3 , with other treatments unchanged. However, there was no effect of treatment or interaction between treatment and week of lactation on locomotion scores when analyzing either data set ($P > 0.1$). In subsequent analysis the complete data set was used. There was an effect of week of lactation ($P < 0.05$), and locomotion scores generally increased until a peak score at 12 wk of lactation (9.3 ± 0.3 ; Figure 2). During the winter accommodation period, 2 cows were clinically lame,

Figure 1. The percentage animals in each treatment at each inspection date that displayed symptoms of dermatitis, where FS = indoor freestalls, UP = uncovered out-wintering pad (OWP), SP = self-feed OWP, CO = covered OWP. Cows were managed at pasture at the wk 9 and 14 inspections.

Figure 2. Mean weekly locomotion score from calving to 14 wk. Cows were managed at pasture during this period. The 6 aspects of locomotion that were recorded (scale of 1 to 5) were added to give a total locomotion score for each cow on each recording occasion. Therefore, the minimum possible score was 6 and the maximum was 30.

both in the UP treatment. However, both were chronically lame before the start of the experiment. The number of clinical cases of lameness recorded by the stockpersons during the subsequent lactation was low: 1, 2, 1, and 1 in UP, FS, SP, and CO, respectively.

DISCUSSION

As expected, more severe heel erosion was found in the self-fed animals at calving than in any of the other treatments. This is in accordance with results for beef cattle confined on OWP without a concrete feed apron (Hickey et al., 2002). Cows feed for up to 8 h/d (O'Driscoll et al., 2007a) and defecate 16 times per day, in particular while feeding (Aland et al., 2002). Thus, if the feed area was not cleaned regularly, a thick layer of manure accumulated rapidly. The corrosive nature of cattle manure is one of the primary elements in the development of heel horn erosion (Manske et al., 2002), explaining the high heel erosion scores in this treatment at calving. Cows in this treatment were exposed to silage effluent, because the silage pit was constructed directly on the woodchip. Nonetheless, Gregory et al. (2006) found that silage effluent did not have a sole-softening effect, whereas slurry, urine, and rainwater did. Therefore, it is likely that the buildup of slurry and exposure to moisture was the primary reason for the development of heel erosion. Heel erosion scores subsequently decreased once the animals went to pasture, and by 9 wk after calving, heel erosion scores were similar to other treatments. This illustrates the speed with which the heel bulb can recover. Similarly, although there were higher dermatitis scores at calving in the SP cows, scores quickly decreased similar to that

of the other treatments once the cows went to pasture. These results show that although hoof health may be compromised during the dry period in cows that self-feed on OWP, there do not appear to be significant carryover effects into lactation.

Lower sole lesion scores in the Norwegian Red breed were expected, because this breed has had functional traits (i.e., traits that increase profitability by reducing costs) included in the Norwegian total merit index since the 1960s (Heringstad et al., 2001). Although these traits were not specifically related to lesion development, it is likely that cows that have good leg conformation have good foot health. Body weight is distributed more appropriately on the hoof so the horn can develop and grow in a healthy fashion. Furthermore, good claw shape possibly indicates healthy horn, and cows that had poor claw conformation may not have been selected for breeding. It is surprising that the Holstein-Friesian breed had harder hoof horn recordings than the Norwegian Red, because the opposite may have been expected. This is an indication that other factors besides the hardness of the sole were involved in the development of sole lesions.

Hoof hardness scores were in agreement with reports in the literature. Bergsten et al. (2003) described Shore units of hardness between 41 and 46 at a similar position on the sole in lateral claws. Borderas et al. (2004) reported scores of between 41 and 50 at zone 5 of the sole. Thus, this method of recording hoof hardness provides reliable results. We expected that there would be no difference in hoof hardness between left and right lateral claws or left and right medial claws, and the results confirmed this. Indeed, the lateral claw was more likely to develop lesions than the medial claw

(Vanegas et al., 2006), which may be a result of a softer sole, as reported in this study.

A reduction in hoof hardness scores from the beginning of the experiment to calving was recorded in all treatments. This is probably due to physiological changes associated with parturition (Nocek, 1997) due to hormonal changes that may cause increased vascular permeability, and increase the risk of edema and ischemia in the hoof. This could have contributed to the softening of the hoof horn observed in the current experiment. Therefore, the reduction in hoof hardness observed at calving could be a risk factor for injury to the sole of the hoof depending on underfoot conditions. Indeed, hoof hardness was poorly correlated with sole lesion scores, implying that hardness played a part in lesion development, although other factors could be involved.

As expected, animals in CO had harder hooves during the experiment compared with animals without shelter. However, the hooves of animals in the CO, and not those in the FS, were the hardest. The woodchip area in the CO treatment was protected from precipitation and was much drier than on the other OWP (O'Driscoll et al., 2007b). Although the floors in the FS were scraped regularly, the concrete remained moist, probably because the nonabsorbent nature of concrete meant that even after scraping, a wet layer remained on the surface. Thus, the surface in the CO was probably drier than that in the cubicle house. Animals in SP and UP had nowhere dry to stand or lie particularly during periods of wet weather.

Disorders of the hoof are the primary cause of lameness in cattle. On the other hand, although significant differences in both heel erosion and dermatitis scores were found, these were not reflected in differences in locomotion score. It is possible that the disorders were not severe enough to be biologically meaningful; that is, increasing increment levels in the scoring system may not correspond with increasing levels of pain or discomfort. Furthermore, with regard to dermatitis, the higher scores at calving in the SP cows were due to a greater number of animals displaying symptoms, not increased severity within individual animals. An alternative explanation is that even though the pain associated with the lesions may have increased, it was not severe enough to result in any behavioral changes. Previous studies showed that locomotion scores do not change until lesions are severe (Flower and Weary, 2006). They found no difference between the gait of healthy cows and cows with sole hemorrhages, but cows that had sole ulcers had higher (worse) locomotion scores than either of the former 2 groups. Thus, the results from our study confirm that the presence of mild lesions has little to do with locomotion score, and that

these lesions can occur at a prepathological level without affecting cow gait.

The lack of a difference in locomotion scores between all treatments is important when considering the welfare implications of confining animals on OWP. Impaired locomotion or lameness may be caused by upper limb trauma such as lesions to the hocks or knees (Weary and Taszkun, 2000), or stress on a separate body system; for example, cows that are milked once daily display impaired locomotion at peak lactation (Gleeson et al., 2007). Furthermore, cows in FS have a greater number of and more-severe lesions on their limbs than animals on OWP (Boyle, 2005). The 4 treatments in this experiment comprised various combinations of features that could affect locomotion score and lameness incidence, either due to hoof or limb traumas; for example, concrete or woodchip flooring, hard bedding or soft bedding (woodchip), and flooring that was either unsheltered or sheltered from environmental moisture. The finding that locomotion scores did not differ between treatments indicated that in the short-term, none of these accommodation systems causes a greater level of damage or discomfort with regard to locomotion than any other. It is important to emphasize that locomotion was scored during the period when cows were accommodated at pasture. Therefore, it is possible that the negative effects of any of the confinement systems may not have been detectable, because the environment at pasture may have facilitated recovery.

Locomotion scores peaked between 10 and 12 wk postpartum, which coincides with peak lactation in a spring-calving pasture herd (Cavestany et al., 2005). High udder firmness scores are associated with increased locomotion scores (Gleeson et al., 2007). In addition, because cows were at pasture, the discomfort of a full udder coincided with an increase in the amount of time spent walking to and from the milking parlor.

Overall, the results from this experiment indicate that the use of OWP as a winter confinement system for dairy cows in late pregnancy does not pose a significant threat to hoof health when managed at a stocking density of 12 m²/head. The CO group had harder hooves, which may be important in reducing the development of sole lesions after calving. Furthermore, an OWP with a feeding area that cannot be cleaned needs to be carefully managed. This is to ensure that animals are not exposed to excessive amounts of moisture and manure, which have negative implications for dermatitis and heel erosion. Finally, it is important to note that even though animals in this experiment were turned out to pasture immediately after calving, sole lesion scores from all OWP treatments increased thereafter. Therefore, even when accustomed to soft underfoot conditions

before calving, cows are susceptible to sole lesions in early lactation.

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