J. Dairy Sci. 88:2381–2387

Freestall Maintenance: Effects on Lying Behavior of Dairy Cattle

M. Drissler, M. Gaworski, C. B. Tucker, and D. M. Weary
Animal Welfare Program, University of British Columbia, Vancouver, Canada V6T 1Z4

ABSTRACT

In a series of 3 experiments, we documented how sand-bedding depth and distribution changed within freestalls after new bedding was added and the effect of these changes on lying behavior. In experiment 1, we measured changes in bedding depth over a 10-d period at 43 points in 24 freestalls. Change in depth of sand was the greatest the day after new sand was added and decreased over time. Over time, the stall surface became concave, and the deepest part of the stall was at the center. Based on the results of experiment 1, we measured changes in lying behavior when groups of cows had access to freestalls with sand bedding that was 0, 3.5, 5.2, or 6.2 cm at the deepest point, below the curb, while other dimensions remained fixed. We found that daily lying time was 1.15 h shorter in stalls with the lowest levels of bedding compared with stalls filled with bedding. Indeed, for every 1-cm decrease in bedding, cows spent 11 min less time lying down during each 24-h period. In a third experiment, we imposed 4 treatments that reflected the variation in sand depth within stalls: 0, 6.2, 9.9, and 13.7 cm below the curb. Again, lying times reduced with decreasing bedding, such that cows using the stalls with the least amount of bedding (13.7 cm below curb) spent 2.33 h less time per day lying down than when housed with access to freestalls filled with sand (0 cm below curb).
(**Key words:** cow comfort, freestall, behavior, sand bedding)

INTRODUCTION

Many factors contribute to the design and comfort of freestalls including dimensions, partition design, and the flooring surface within the stall. Recent studies indicate that dairy cattle show clear preferences for freestall surfaces (Manninen et al., 2002; Tucker et al., 2003), and surfaces play a key role in the incidence of hock and knee injuries (Vokey et al., 2001; Mowbray et al., 2003).

Indeed, there is growing evidence that deep-bedded freestalls provide advantages over other lying surfaces. Dairy cattle prefer heavily bedded concrete stalls to lightly bedded mats (Jensen et al., 1988), and deep-bedded stalls are preferred to stalls with concrete or geotextile mattresses covered with 2 to 3 kg of sawdust (Muller and Botha, 1997; Tucker et al., 2003). Lying times also tend to be longer and standing times shorter for deep-bedded stalls compared with wood-covered stalls (Muller and Botha, 1997) or mattresses (Tucker et al., 2003). In contrast, longer lying times on mattresses than on sand stalls has also been reported (Manninen et al., 2002). In addition to longer lying times in deep-bedded stalls, Cook et al. (2004) found that cows housed on deep-bedded sand were less likely to experience clinical lameness (11%) than those housed on geotextile mattresses (24%). Finally, other studies have shown that deep-bedded surfaces are associated with fewer and less severe hock lesions compared with mattresses with little bedding (Weary and Taszkun, 2000; Vokey et al., 2001; Mowbray et al., 2003).

Amount of bedding used on the stall surface also affects the cow's response. Jensen et al. (1988) found that cows preferred concrete when bedded with 4 to 5 kg of straw, but chose mattresses when little straw bedding remained. Gebremedhin et al. (1985) found that cows were more likely to lie down in concrete stalls when bedding levels were increased. Tucker and Weary (2004) reported higher lying times on heavily bedded geotextile mattresses than on those with little or no bedding.

Practical experience dictates that amount of bedding on the stall surface declines with use by the cows, and that the distribution of bedding within the fixed dimensions of the stall changes. These changes may have profound effects on cow comfort, but to date little has been published that documents when these changes in bedding occur and what effects these changes have on dairy cattle. The objectives of the current study were: 1) to understand how the level of sand bedding in a free stall changes after bedding is added, and 2) to measure how these changes in bedding affect lying behavior of dairy cattle.

MATERIALS AND METHODS

Twenty-four lactating Holstein dairy cattle were used as subjects. Cows were housed in pens with 12 freestalls.

Received January 12, 2005.
Accepted April 5, 2005.
Corresponding author: Cassandra B. Tucker; e-mail: cassandra.tucker@agresearch.co.nz.

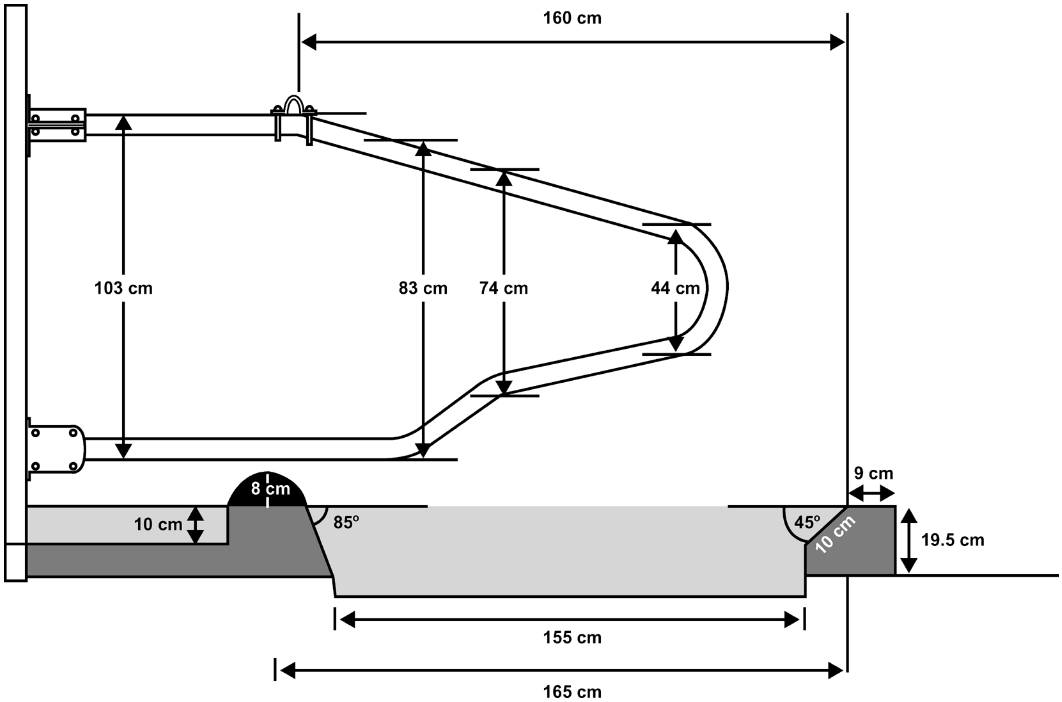

Figure 1. Diagram of freestall partition, brisket area, and curb used in all 3 experiments. When stalls were filled with bedding (to the level of the curb), the neck rail was 129 cm above the bedding, and the partition was 92, 70, and 42.5 cm above the bedding at the 3 locations described in the figure, 44, 74, and 83 cm, respectively.

Each pen contained 3 rows of 4 stalls. The 2 rows facing one another were open at the front (head-to-head) and had a total bed length of 240 cm. The back row of stalls faced a cement wall, and the total bed length of these stalls was 30 cm longer than the head-to-head stalls. In all stalls, the brisket boards were located 165 cm from the curb closest to the alley and were attached to a concrete structure at the front of each stall (Figure 1). This concrete structure and the curb closest to the alley were used as reference points in experiments 1, 2, and 3. Height of the brisket board, neck rail, and dividers above the bedding level varied with treatments, as described below. Stall width measured 120 cm center to center and Artex Y2K dividers (Artex Fabricators Inc., Langley, BC) separated stalls. All stalls were bedded with sand that varied in depth, as described below. Bedding was river sand, sieved over a 2-mm screen, washed with water to remove silt, and stored outside until use.

Cows were fed a TMR to ad libitum intake, with fresh feed provided twice daily at 0530 and 1530 h. Milking occurred at approximately 0700 and 1730 h, and the total time away from the pen for milking varied between 80 to 110 min per 24-h period.

Experiment 1: Estimating Changes in Depth of Sand Bedding

In this experiment, 24 cows were allocated into 2 equal groups of 12, balanced for lactation number (mean ± SD: 1.6 ± 0.2) and DIM (mean ± SD: 123.0 ± 7.6). The 2 groups were housed in 2 neighboring pens.

Behavior was recorded using a single video camera (Panasonic WV-BP330), 8.3 m above each pen, a time-lapse videocassette recorder (Panasonic AG-6540), and a video multiplexer (Panasonic WJ-FS 416; Mississauga, Ontario, Canada). To enable recording during the dark period, 2 red lights (100 W, <5 lx) were suspended above each pen. Each freestall was numbered and each individual cow was identified by markings made with Clairol's Nice and Easy #122, Natural Black, or Clairol's L'Image Maxiblonde, depending on hair color on the back. Video tapes were scored using instantaneous scan sampling every 10 min and the following behaviors were recorded: 1) time spent lying down, 2) time spent standing with all four legs in the stall, and 3) time spent standing with only the front hooves in the stall.

To understand how both the shape and the average depth of sand bedding changed over time and with different amounts of usage, we monitored all 24 freestalls over a 10-d period. At the beginning of this period, the freestalls were filled with sand during the afternoon milking, such that the bedding was level with the curb. During each of the 10 successive afternoon milkings, a grid was used to measure the distance between the sand and 43 different points on the grid. The grid measured 120 × 160 cm and had 10-cm long legs that rested on the concrete structure at the front of the stall and the

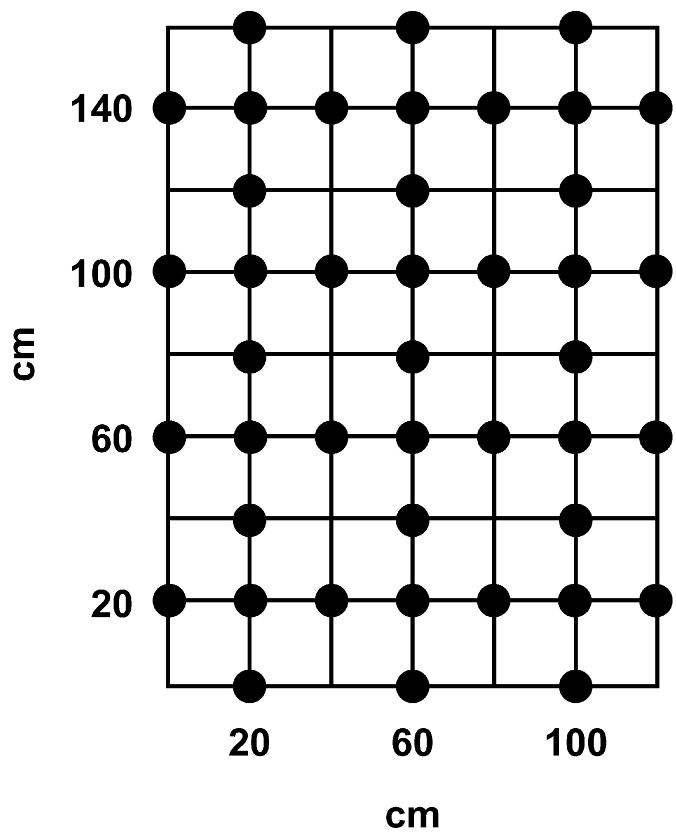

Figure 2. Diagram of grid used to measure bedding depth. The grid measured 120 × 160 cm and had 10-cm legs that rested on the concrete structure at the front of the stall and the curb. Black circles represent locations where measurements were taken.

curb (Figure 2). This extra height was necessary because sand was occasionally higher than the curb.

On the first day after the stalls were filled, measurements were only collected for 12 of the 43 points (at the intersections of the 4 rows and 3 columns in the grid). Data from these 12 points, however, were well correlated with the estimates based on 43 points ($r_{Pearson}$ correlation coefficient = 0.96).

To estimate the average depth of the sand bedding, we took an average of the distances between the grid and the sand bedding for each stall, after subtracting the height of the legs (10 cm). The statistical analysis of these data was descriptive. We plotted the mean and SD of these values against time measured in days. In addition, we examined correlations between the average of bedding depth on d 10 with the total number of hours the stall was occupied during the 10-d period. To estimate the shape of the stall, we generated plots based on the average depth of sand at each of the 43 points (n = 24 freestalls).

Experiments 2 and 3: Effects of Sand Depth on Lying Behavior in Stalls with Fixed Dimensions

In both experiments, the 24 cows were allocated into 4 groups balanced for lactation number (experiments 2 and 3: mean ± SD, 1.6 ± 0.2) and DIM (experiment 2: 172.8 ± 10.7, experiment 3: 197.8 ± 10.7). Cows were housed in 4 neighboring pens. To accommodate storage of sand for the various treatments, the 2 peripheral stalls in each row were blocked off with chains 0.7 m above the curb, resulting in a total of 6 stalls per 6 cows.

Gemini Tiny-Tag data loggers (Gemini Dataloggers Ltd., Chichester, UK) were used to measure lying time, the number of lying bouts, and the duration of each lying bout for each animal. During preliminary testing, 7 cows were fitted with data loggers and observed via continuous video during 48 h. Data loggers were set to record position every 11 s or every 30 s. Compared with the records from video, data loggers (at both sample rates) produced identical estimates for lying time (r = 1.0) and near-identical estimates of number of lying bouts (r = 0.99; C. Winckler, unpublished data, 2005). In this experiment, the loggers were attached to the outer side of the hind legs (metatarsus) of the animals using vet wrap and were set to record the cows' position every 30 s. Halfway through each experiment, the loggers were switched to the opposite hind leg to minimize the chance of hair loss. In experiment 2, the cows were away from their pens during 120 to 150 min on the first day of each treatment. This was slightly longer than on other days (80 to 110 min) because data loggers took longer to attach than the regular milking time. Due to improved procedure, no extra time was required to attach data loggers in experiment 3.

We applied 4 treatments in experiments 2 and 3. Treatments were assigned to the 4 groups in each experiment using a Latin square.

Experiment 2: Treatments

Based on results from experiment 1, we applied 4 treatments that were equivalent to the average values for bedding depth and shape on d 0, 3, 6, and 9 after stalls were filled (0.0, 3.5, 5.2, or 6.2 cm at the deepest point, relative to the curb). For the 0-cm treatment, the stalls were filled level with the curb (see Table 1 for a summary of treatment descriptions). For the other treatment levels, the stalls were given a concave shape using 2 plywood boards attached perpendicularly, such that the lower board could be rotated. To create the concave shape, the upper board was placed on the curb and the concrete at the front of the stall, and the lower board was rotated to displace sand away from the center. The upper board measured 170 cm in length, and the lower board measured 120 cm, having a rounded bottom

Table 1. Descriptions of treatments applied to the sand bedding in experiments 2 and 3.

Description of treatment	Experiment 2				Experiment 3			
Mean depth, cm	0	3.5	5.2	6.2	0	6.2	9.9	13.7
Depth at center of stall, cm	0	6.3	8.0	9.9	. . .	. . .	. . .	. . .
Depth at 60 cm from center, cm	0	5.0	6.4	7.7	. . .	. . .	. . .	. . .
Shape imposed, yes or no	No	Yes	Yes	Yes	No	No	No	No

that tapered from the widest point at the center to the narrowest point at the edge. Boards used to create the 3 treatment conditions measured 6.3, 8.0, and 9.9 cm at the widest point and 5.0, 6.4, and 7.7 cm at the narrowest. Treatments were applied for a total of 2 d per treatment and bedding was measured and reshaped twice daily during milking times.

Experiment 3: Treatments

Many producers level the bedding as part of their daily stall maintenance. Thus, even though bedding levels drop, the cows still have access to a relatively even surface. In addition, the results from experiment 1 demonstrated that some stalls showed more dramatic bedding loss than we observed on average. The aims of experiment 3 were: 1) to determine if changes in depth still affected cows when sand was leveled, and 2) to explore the effects of a wider range of bedding depths. We retested the range of values from experiment 2 (i.e., 0 and 6.2 cm) and added a treatment level equal to the maximum depth observed on d 4 (13.7 cm; below this value, sand was often wet and hard) and an intermediate value (9.9 cm). These treatments were imposed by raking the sand level. Bedding was measured and re-leveled twice daily during milking, and treatment levels were imposed during 2 consecutive days.

Statistical Analyses

Failure of data loggers resulted in the loss of data for 1 cow in 3 different groups in experiment 3. Therefore, statistical analysis was based on 5 cows for each of these 3 groups in experiment 3. The group of cows was treated as the experimental unit (n = 4) in both experiments 2 and 3. Values from the two 24-h periods at each treatment level were averaged before analysis.

Pearson correlations were used to assess the relationship between bedding depth on d 10 and total stall usage during the 10-d period in experiment 1. In experiments 2 and 3, time spent lying, the number of lying bouts, and the mean duration of lying bouts were analyzed using the GLM procedure in SAS (SAS Institute, 1999). This model included a term for group (3 df), order of exposure to each treatment (3 df), and the effects of treatment (3 df) against the residual error (6 df). Linear, quadratic, and cubic effects of treatment (1 df each) were tested with a contrast statement in the GLM. The coefficients used in these contrast statements were generated with PROC IML (SAS Institute, 1999). The quadratic and cubic effects were never found to be significant and are not discussed further. All P values given in the Results section are for the linear contrast.

RESULTS

Experiment 1

Over time, the stall surface took on a concave shape, and bedding depth was lowest at the center of the stall and highest at the edges (Figure 3). The loss of bedding was greatest after new bedding was added, and sand levels continued to decline during the entire 10-d period (Figure 4). In addition, some stalls had more sand removed than others; the maximum depths observed on any given day tended to be 3 times the average depth. A trend ($r_{Pearson} = 0.29$; $P \geq 0.16$) occurred for stalls with higher occupancy times to have the greatest loss in sand depth after 10 d.

Experiments 2 and 3

Lying times were lower in both experiments 2 ($P \leq 0.03$) and 3 ($P \leq 0.01$) in freestalls having less sand (Table 2). In experiment 2, the mean lying time was 1.15 h less in stalls when an average of 6.2 cm of sand was removed compared with those that were filled to the height of the curb. For every 1-cm decrease in bedding, cows spent approximately 11 min less lying during each 24-h period. In experiment 3, animals spent 2.33 h less lying down per day in the stalls having 13.7 cm of sand removed compared with stalls that were filled to the height of the curb. In this experiment, cows lay down about 10 min less per 24-h period with every 1-cm decrease in sand.

Mean duration of lying bouts was shorter ($P \leq 0.01$) when the stalls contained less sand in experiment 3 and a similar tendency ($P \leq 0.11$) occurred in experiment 2. The pattern of longer lying bouts in well-bedded stalls, however, was not as consistent as the pattern of higher lying times observed in these stalls. For example, in experiment 2, 17 of the 24 cows had shorter lying bouts in the 6.2-cm treatment compared with the 0-cm treatment,

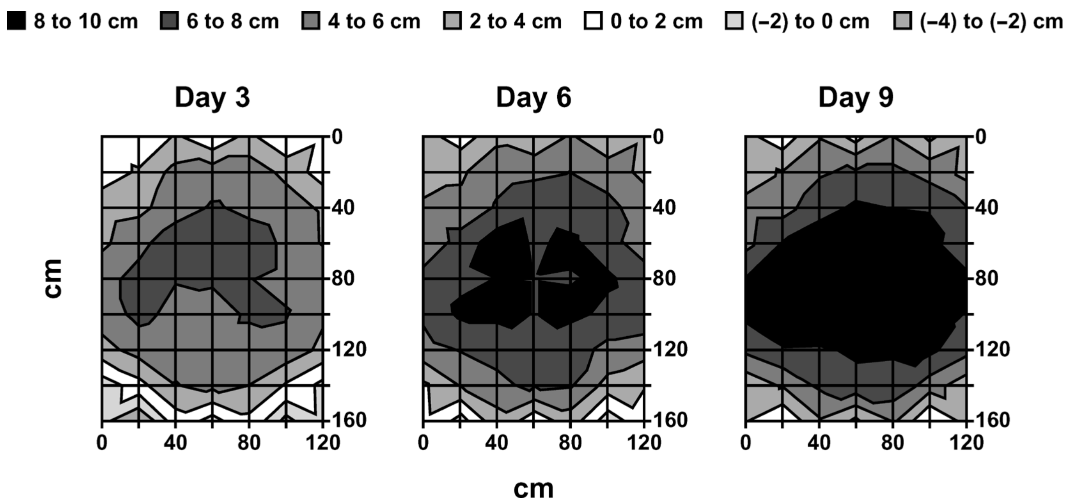

Figure 3. Distribution of sand on d 3, 6, and 9 after bedding was added to the stalls, as measured in experiment 1. Values represent depth of sand below the curb. Negative values refer to conditions in which sand was above the curb.

but 20 of 24 cows had shorter lying times. In experiment 3, 15 of the 21 cows had shorter lying bouts in the 13.7 cm treatment than in the 0-cm treatment, but 20 of the 21 cows had shorted lying times. The mean number of lying bouts in a 24-h period was 11.4 ± 0.6 in experiment 2 and 11.1 ± 0.5 in experiment 3. The number of lying bouts did not differ among treatments in either experiment.

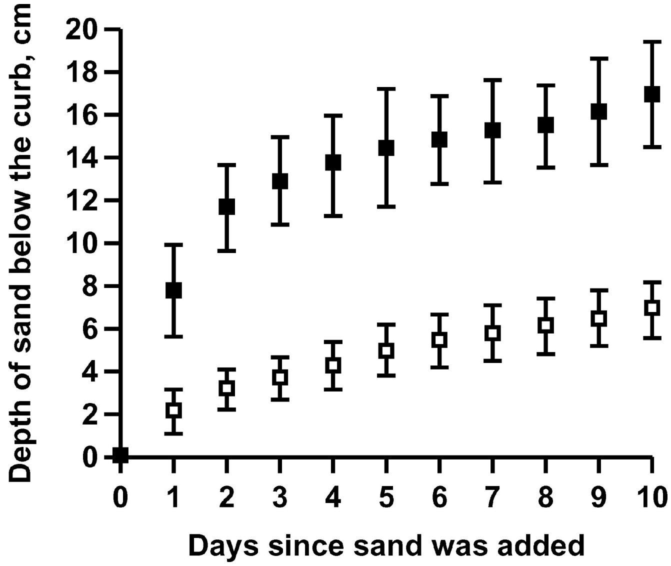

Figure 4. Effect of time since sand was added (from d 0) on the mean (open squares) and maximum (filled squares) depth of sand below the rear curb in 24 freestalls, as measured in experiment 1. Means are presented with brackets representing standard deviations.

DISCUSSION

This study provides the first illustration of how bedding in stalls changes over time and quantifies the effect of such changes on the lying behavior of dairy cattle. Results from experiment 1 showed that the change in depth of sand was greatest on the day after new sand was added and decreased during a 10-d period. Over time, the stall surface became concave, and sand depth was lowest at the center and highest at the edges of the stall. Stalls with higher occupancy times tended to have the greatest decrease in sand level after 10 d. Sand may be removed by the cows digging or by dragging sand out when they exit the stalls. Further research is required to understand how sand is leaving the stall.

Changes in bedding depth in stalls with fixed dimensions may correspond with changes in the bacterial populations in the sand. In experiment 1, we found that the greatest change in maximum sand depth occurred by the second day after bedding had been added. Bacterial counts in deep-bedded sand increased after the freestalls were filled and generally reached their maximum 1 or 2 d after bedding was added (Zdanowicz et al., 2004). Similar time trends have been reported for bacterial growth in sawdust bedding (Hogan and Smith, 1997; Hogan et al., 1999; Zdanowicz et al., 2004). Increased manure contamination and, therefore, availability of nutrients, may explain these changes in bacterial growth. Alternatively, in deep-bedded freestalls, bacterial contamination of fresh bedding may be linked to exposure to bacteria present in the older bedding in the stall. As the depth of sand changes, new sand is mixed with older bedding that already may be contaminated.

Table 2. Effect of depth of sand bedding on lying behavior (lying time, number of lying bouts, and average bout duration) in experiments 2 and 3.

	Depth of sand bedding, cm				SE	$P^1 \leq$
Experiment 2	0	3.5	5.2	6.2		
Lying time, h/24 h	13.20	12.82	12.51	12.05	0.28	0.03
Number of lying bouts, no./24 h	11.00	11.52	11.92	11.33	0.55	0.45
Average bout duration, h/bout	1.25	1.22	1.15	1.14	0.05	0.11
Experiment 3	0	6.2	9.9	13.7		
Lying time, h/24 h	13.70	12.42	11.74	11.37	0.32	0.01
Number of lying bouts, no./24 h	11.34	10.85	10.67	11.43	0.47	0.94
Average bout duration, h/bout	1.33	1.24	1.18	1.11	0.04	0.01

[1]*P* values presented are for the linear contrast only.

Our study provides the first experimental evidence that the depth and shape of sand bedding in freestalls influences the lying behavior of cattle. In experiment 2, cows spent less time lying down in stalls with less bedding and a more pronounced concave shape. On average, cows reduced their lying times by about 11 min for every 1-cm decrease in sand depth. In experiment 3, cows showed a similar rate of decline in lying times when bedding was leveled and sand depth dropped below the curb. These findings are consistent with other work that reported longer lying times on well-bedded mattresses compared with bare or lightly bedded mattresses (Tucker and Weary, 2004). Cows are more likely to spend time lying down in concrete stalls with more bedding (Gebremedhin et al., 1985). However, in experiment 2 and 3, no change was detected in the number of lying bouts. As reviewed in Tucker and Weary (2004), when cows have difficulty lying down or standing up, they change this specific behavior by either standing up or lying down less often (fewer lying bouts). We speculate that the number of lying bouts is an indicator of the ease with which the cow stands up or lies down, and this response did not differ among treatments tested.

Shorter lying times are clearly associated with less comfortable housing systems (Haley et al., 2000) and higher lying times may provide other benefits to dairy cattle. Researchers have found that cattle deprived of the opportunity to lie down have greater acute increase in cortisol concentrations, reduced responses to ACTH challenges, and reduced concentrations of circulating growth hormone compared with free-lying counterparts (Munksgaard and Løvendahl, 1993; Fisher et al., 2002). Cattle were more motivated to lie down than to eat after being deprived of both resources for 3 h (Metz, 1985). Indeed, others have tested the level of motivation for lying and found that heifers will work to spend 12 to 13 h lying down per day (Jensen et al., 2005). Cattle that spend less time lying also may have poorer claw health, because standing on concrete flooring is thought to predispose dairy cattle to lameness and claw lesions (Bergsten and Frank, 1996). Lying times reported in this study, however, are still within a range considered by many to be normal for dairy cattle in freestalls (Tucker et al., 2004b). It is unclear whether the changes in sand depth and shape tested in these experiments would result in changes in other traits such as claw health.

In experiment 3, lower lying times corresponded with shorter lying bouts. We speculate that shorter lying bouts indicate some discomfort while recumbent. As sand levels decreased, the rear curb and concrete at the front of the stall became more exposed and the effective lying area became smaller. Increased contact with the concrete features may have been responsible for shorter lying bouts. Other factors, such as the size or the favored lying position of the cow, may have affected the amount of discomfort. Such individual differences may explain some of the variation found in lying-bout duration in response to decreasing sand levels.

Other studies also reported shorter lying bouts in response to potential discomfort while recumbent. Shorter lying bouts and overall daily lying time for cows housed in narrower stalls were reported (Tucker et al., 2004a). As a result, the authors proposed that contact with stall partitions might reduce comfort while recumbent. Similarly, Österman and Redbo (2001) found that cows milked twice daily had shorter average lying bouts and daily lying times than those milked 3 times daily, possibly because cows milked less frequently experienced more discomfort associated with udder fill.

In experiment 2, lower lying times also corresponded with shorter lying bouts, but this trend was not statistically significant. A possible explanation for this difference between experiments 2 and 3 is that both the shape and the amount of sand were manipulated in experiment 2. When the concave shape was imposed, sand was displaced toward the edges of the stall, and this may have buffered exposure to the concrete features of the stall. Alternatively, the sample size in experiment 2 may have been insufficient to detect the smaller difference between treatments (0.11-h difference in duration of lying bouts between 0- and 6.2-cm treatments in experiment 2 vs. a 0.22-h difference between 0- and 13.7-cm treatments in experiment 3).

In addition to shorter lying bouts, injury may result from contact with exposed concrete curbs. Hock lesions of dairy cattle housed in either deep-bedded sand stalls or stalls with a geotextile mattresses recessed 5 cm below the curb and covered with sand were studied (Mowbray et al., 2003). Those housed in the deep-bedded stalls had more hair loss on the tuber calcis (point of the hock) than those housed in the recessed-mattress system, likely due to increased risk of contact with the cement curb in the deep-bedded stalls.

In conclusion, depth of sand in deep-bedded freestalls declines during the days following addition of bedding. Dairy cattle respond to these reduced bedding levels by lying down for fewer hours per day and for shorter intervals, indicating compromised comfort in poorly bedded stalls. We recommend that the lying surfaces in deep-bedded stalls be maintained to the level of the curb.

ACKNOWLEDGMENTS

We thank members of the UBC Animal Welfare program and the staff of the UBC Dairy Research and Education Centre for their help throughout the study. We are especially grateful to Kyle Pidcock, Katie Martinolich, Marcia Endres, Sabine Dippel, and Christoph Winckler for their contributions to the project. This research was funded by grants from the Dairy Farmers of Canada and the Natural Sciences Engineering Research Council of Canada and through the NSERC Industrial Research Chair in Animal Welfare, supported by the BC Dairy Foundation, the BC SPCA, members of the BC Veterinary Medical Association, and many other donors listed on our web site at www.agsci.ubc.ca/animalwelfare.

REFERENCES

Bergsten, C., and B. Frank. 1996. Sole hemorrhages in tied heifers in early gestation as an indicator of laminitis: Effect of diet and flooring. Acta Vet. Scand. 37:375–382.

Cook, N. B., T. B. Bennett, and K. V. Nordlund. 2004. Effect of free stall surface on daily activity patterns in dairy cows with relevance to lameness prevalence. J. Dairy Sci. 87:2912–2922.

Fisher, A. D., G. A. Verkerk, C. J. Morrow, and L. R. Matthews. 2002. The effects of feed restriction and lying deprivation on pituitary-adrenal axis regulation in lactating cows. Livest. Prod. Sci. 73:255–263.

Gebremedhin, K. G., C. O. Cramer, and H. J. Larsen. 1985. Preference of dairy cattle for stall options in free stall housing. Trans. ASAE 28:1637–1640.

Haley, D. B., J. Rushen, and A. M. de Passillé. 2000. Behavioural indicators of cow comfort: Activity and resting behaviour of dairy cows in two types of housing. Can. J. Anim. Sci 80:257–263.

Hogan, J. S., V. L. Bogacz, L. M. Thompson, S. Romig, P. S. Schoenberger, W. P. Weiss, and K. L. Smith. 1999. Bacterial counts associated with sawdust and recycled manure bedding treated with commercial conditioners. J. Dairy Sci. 82:1690–1695.

Hogan, J. S., and K. L. Smith. 1997. Bacteria counts in sawdust bedding. J. Dairy Sci. 80:1600–1605.

Jensen, M. B., L. J. Pedersen, and L. Munksgaard. 2005. The effect of reward duration on demand functions for rest in dairy heifers and lying requirements as measured by demand functions. Appl. Anim. Behav. Sci. 90:207–217.

Jensen, P., B. Recen, and I. Ekesbo. 1988. Preference of loose housed dairy cows for two different cubicle floor coverings. Swed. J. Agric. Res. 18:141–146.

Manninen, E., A. M. de Passillé, J. Rushen, M. Norring, and H. Saloniemi. 2002. Preferences of dairy cows kept in unheated buildings for different kinds of cubicle flooring. Appl. Anim. Behav. Sci. 75:281–292.

Metz, J. H. M. 1985. The reaction of cows to a short-term deprivation of lying. Appl. Anim. Behav. Sci. 13:301–307.

Mowbray, L., T. Vittie, and D. M. Weary. 2003. Hock lesions and free-stall design: Effects of stall surface. Pages 288–295 in Proc. 5th Int. Dairy Housing Conf. ASAE, St. Joseph, MI.

Muller, C. J. C., and J. A. Botha. 1997. Cow behaviour in relation to different freestall surfaces in winter temperate climate. Pages 1069–1076 in Livestock Environment 5, Vol. 2. ASAE, St. Joseph, MI.

Munksgaard, L., and P. Løvendahl. 1993. Effects of social and physical stressors on growth hormone levels in dairy cows. Can. J. Anim. Sci. 73:847–853.

Österman, S., and I. Redbo. 2001. Effects of milking frequency on lying down and getting up behaviour in dairy cows. Appl. Anim. Behav. Sci. 70:167–176.

SAS Institute. 1999. SAS User's Guide. Statistics, Version 8 ed. SAS Inst., Inc., Cary, NC.

Tucker, C. B., and D. M. Weary. 2004. Sawdust bedding on geotextile mattresses: How much is needed to improve cow comfort? J. Dairy Sci. 87:2889–2895.

Tucker, C. B., D. M. Weary, and D. Fraser. 2003. Effects of three types of free-stall surfaces on preferences and stall usage by dairy cows. J. Dairy Sci. 86:521–529.

Tucker, C. B., D. M. Weary, and D. Fraser. 2004a. Free-stall dimensions: Effects on preference and stall usage. J. Dairy Sci. 87:1208–1216.

Tucker, C. B., D. M. Weary, J. Rushen, and A. M. de Passillé. 2004b. Designing better environments for dairy cattle to rest. Pages 75–89 in Advances in Dairy Technology, Vol. 16 (Proceedings of the 2004 West. Can. Dairy Seminar). J. Kennelly, ed. University of Alberta, Edmonton, Canada.

Vokey, F. J., C. L. Guard, H. N. Erb, and D. M. Galton. 2001. Effects of alley and stall surface on indices of claw and leg health in dairy cattle housed in a free-stall barn. J. Dairy Sci. 84:2686–2699.

Weary, D. M., and I. Taszkun. 2000. Hock lesions and free-stall design. J. Dairy Sci. 83:697–702.

Zdanowicz, M., J. A. Shelford, C. B. Tucker, D. M. Weary, and M. A. G. von Keyserlingk. 2004. Bacterial populations on teat ends of dairy cows housed in free stalls and bedded with either sand or sawdust. J. Dairy Sci. 87:1694–1701.