Bedding on Geotextile Mattresses: How Much is Needed to Improve Cow Comfort?

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ABSTRACT

The objective of our study was to evaluate how the amount of sawdust bedding on mattresses affects dairy cattle behavior and preferences. Eleven nonlactating, multiparous cows were housed individually in pens with access to 3 free stalls. Each stall was fitted with a geotextile mattress covered with either 0, 1, or 7.5 kg of kiln-dried sawdust. The experiment began with 7 d of acclimatization to all 3 stalls. Cows were then allowed access to only 1 of the 3 stalls at a time, each for 3 d (restriction phase). At the end of this restriction phase, cows were allowed free access to all 3 stalls for 3 d (free-choice phase). Time spent lying and the number of lying bouts increased significantly with the amount of bedding, from 12.3 ± 0.53 h lying and 8.5 ± 0.62 bouts per 24 h on bare mattresses to 13.8 ± 0.53 h lying and 10.0 ± 0.62 bouts per 24 h on mattresses with 7.5 kg of sawdust. In addition, the animals spent less time standing with only the front hooves in the stalls when more sawdust was present. When allowed free access to all 3 options, all 11 animals spent a majority of their time lying and standing in the 7.5-kg option. In conclusion, cows preferred mattresses bedded with 7.5 kg of sawdust, on which they spent more time lying down and less time standing with only the front hooves in stalls. These results indicate that more sawdust bedding improves cow comfort in stalls with geotextile mattresses. (**Key words:** behavior, free stall, bedding, preference)

INTRODUCTION

Dairy cattle spend approximately 8 to 16 h/d lying down (e.g., Dechamps et al., 1989; Haley et al., 2000; 2001) and between 35 and 175 min/d standing in free stalls (e.g., Stefanowska et al., 2001). Measures of behavior, including time spent lying and standing and behavior before lying down, and measures of preference, such as the amount of time spent in a given option,

have all been used to evaluate how dairy cattle perceive their environment.

Dairy cattle prefer heavily bedded concrete stalls to lightly bedded mats (Jensen et al., 1988; Manninen et al., 2002), 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 are reduced and standing times in stalls are increased when dairy cattle are housed on concrete surfaces (Haley et al., 2000; 2001; O'Connell and Meaney, 1997; Rushen et al., 2001). However, when concrete is covered with bedding, lying times are similar to those seen with soft mats (Wechsler et al., 2000; Manninen et al., 2002). Lying times also tend to be longer and standing times shorter for deep-bedded stalls compared with wood-covered stalls or mattresses (Muller and Botha, 1997; Tucker et al., 2003). Finally, the characteristic head-swinging behavior cattle perform before lying down has been used to evaluate the comfort of lying surfaces. Previous work has shown that cattle spend more time engaged in head-swinging behavior when entering a lying area without bedding than a bedded area (e.g., Müller et al., 1989), and are twice as likely to interrupt the head-swinging behavior when housed in a tie-stall system compared with a deep-bedded system or pasture (e.g., Ladewig and Smidt, 1989; Krohn and Munksgaard, 1993). However, tethering and a low level of bedding are often combined in these experiments, and this makes it difficult to draw conclusions about which feature influences head-swinging behavior before lying down.

Geotextile mattresses are gaining popularity, in part because this surface is marketed as being suitable for use with little or no bedding, thus decreasing labor and other expenses associated with maintaining free stalls. However, given the evidence outlined above, zero or low-bedding management for mattresses may reduce lying times and be less preferred than well-bedded mattresses. Thus, the objective of our study was to evaluate how the amount of bedding on mattresses influences dairy cattle behavior. Specifically, we tested how the quantity of sawdust bedding affected which stall cows chose to lie in (preference) when given access to several options. In addition, we measured how time spent lying

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and standing (stall usage) and head-swinging behavior changed when the animals were restricted to a single option.

MATERIALS AND METHODS

Fifteen pregnant and nonlactating Holstein cows were used in this experiment (parity, mean $\pm$ standard deviation: 3.6 ± 1.3). These cows had spent their previous lactation in a barn where 25% of the stalls were fitted with geotextile mattresses covered with sawdust (similar to the 1-kg treatment described below) and the remaining were deep-bedded stalls, with either sand or sawdust over a soil base. During the experiment, each cow was housed alone in a test pen containing a feed trough, a waterer, and 3 free stalls accessible from the alley. All flooring outside the free stall area was concrete. The 3 stalls were either adjacent to each other or separated by a blocked stall between each available stall. Cows had access to only these 3 stalls; access to all others in the facility was blocked (see Tucker et al., 2003 for a layout of the facility). The stalls were 1.2 m wide and 2.7 m long, the neck rail was 1.25 m high, and the brisket board was 10 cm high and 2.25 m from the curb of the stall (see Tucker et al., 2004, for a description of the partition used). The animals were fed grass hay ad libitum. The experiment was carried out between December 2000 and March 2001. The average temperature in the city of Vancouver during this experiment was 8.4°C , with a minimum of -6.2°C and maximum of 12.0°C .

Each stall was fitted with a Pasture Mat geotextile mattress (Promat Ltd., Seaforth, Ontario, Canada), and bedded with 1 of 3 levels of kiln-dried sawdust: 0, 1, and 7.5 kg. The lower 2 levels of bedding (0 and 1 kg) reflected the use of sawdust in common commercial practice. The highest value (7.5 kg) was chosen to provide an extremely well-bedded option, more similar to that found in deep-bedded stalls. The weight of the bedding was used to describe the treatments because the height of the sawdust could not be quantified consistently. In the 1-kg treatment, sawdust covered the entire stall surface, but small sections of the mattresses were visible through the bedding. Bedding was removed and reapplied and pens cleaned twice each day during the morning and afternoon feedings (0800 and 1500 h) to maintain the appropriate amount of bedding on the surface, as there was no bedding retainer.

Three similar test pens were used for the experiment, and trios of animals were tested simultaneously, with one cow in each pen. The location of the bedding treatments was allocated randomly and balanced for each pen, across trials. Five trios (15 animals) were used in the experiment, but information from 4 animals was

lost due to technical malfunction, all from one pen ($n = 11$).

Each test consisted of 3 stages. For the first 7 d (adjustment phase), cows had free access to all 3 stalls. During the next 9 d (restriction phase), cows were allowed access to only a single stall at a time, each for a 3-d period, and the order of access to each treatment was assigned randomly without replacement and balanced across cows. Access to the other stalls was blocked with a wooden barrier hung across the entrance to the stall. During the last 3 d (free-choice phase), cows were again allowed free access to all 3 stalls.

The behavior of the cows was video recorded during the last 48-h period of the free-choice phase and of each restriction period, for a total of 8 d of recording for each cow. Each pen was recorded at 3 frames per second using a Panasonic AG-6720 VHS time-lapse video cassette recorder, a Panasonic WJ-FS 10 digital-frame switcher, and 3 Panasonic WV-BP330 CCTV cameras (Panasonic equipment manufactured in Mississauga, Ontario, Canada). Cameras were located with a view of only the 3 stalls, and a 100-W white light was hung 3 to 6 m above each set of stalls to facilitate recording at night. These recordings were watched continuously to measure 1) time spent lying in the stall, 2) time spent standing with the front hooves in the stall, 3) time spent standing with all 4 hooves in the stall, 4) the number of times the animal lay down in the stall (number of lying bouts), and 5) the number of times the animal entered the stall (number of visits where at least the front hooves were placed in the stall). In addition, in the 1-min period before each lying bout, we recorded the number of times the head swung from one side of the body to the other (crossing the center line) in a continuous motion with the nose oriented toward the stall surface.

Statistical Analysis

All standing behaviors (with front hooves in the stall, 4 hooves in the stall, and total) were log (base 10) transformed to meet the assumption of normality. All standing behaviors, time spent lying, average lying bout length, and the number of lying bouts and visits were analyzed using a mixed model (SAS, 1999). This model included order as a random factor and used a AR(1) covariance structure. The repeated statement included a term for order, and the individual animals were treated as the subject. The linear and quadratic effects of treatment were tested with a contrast statement in this mixed model. The coefficients used in these contrast statements were generated with PROC IML. The quadratic effect was never significant and is not discussed further. All *P* values given in the results section

Figure 1. Scatter plot of mean lying times (h per 24 h) during the restriction phase for 2 levels of sawdust on geotextile mattresses: 0 kg (x-axis) and 7.5 kg (y-axis). One of the 11 animals tested had an extremely low lying time (3 h) on the 0-kg treatment.

are for the linear contrast. The number of head swings performed during the restriction phase was not normally distributed, and transformations did not remedy this. Thus, the nonparametric Page's *L*-test for ordered alternatives was used to test whether the number of head swings changed with the level of bedding. One animal was an extreme outlier (>3 SD from the mean) for both standing and lying times when restricted to a bare mattress (Figure 1). In the case of standing behavior, inclusion of this outlier into the data set altered the conclusions drawn, and this animal was removed from the analysis of all dependent variables in the restriction phase. Preference during the free-choice phase was based on time spent lying or standing in each stall and compared using Friedman's rank test for all 11 animals.

RESULTS

During the restriction phase, lying time increased with amount of sawdust; lying times were lowest on bare mattresses and highest in stalls with 7.5 kg of bedding (Table 1; $P = 0.01$). The number of lying bouts followed the same pattern ($P = 0.04$), and there was no difference in the average duration of lying bouts ($P = 0.37$). The number of visits to the stall was similar across the 3 levels of bedding: 6.8, 6.7, and 6.6 visits/24 h for 0, 1, and 7.5 kg of sawdust, respectively (SE: 0.40, $P = 0.61$). There were large individual differences between cows in the amount of time spent standing in the stalls (range of 21 to 364 min/24 h); cows also differed in whether they stood with only the front or all 4 hooves in the stall. For example, averaging across treatments, one cow spent 93% of her total standing time in the stall with only her front hooves on the stall surface. In contrast, another individual spent 86% of her total standing time with all 4 hooves in the stall. In addition to individual variation in standing times, the quantity of sawdust in the stall influenced the amount of time spent standing with only the front hooves in the stall, and animals spent the most time in this position in the stall with no sawdust (58, 51, and 38 min/24 h for the 0, 1, and 7.5 kg of sawdust, respectively; $P = 0.03$). Total time spent standing in the stall (with either 4 or only the front hooves in the stall) followed a similar pattern to standing with only the front hooves in the stall. In contrast, standing with 4 hooves in the stall was similar across treatments (27, 22, 21 min/24 h; $P = 0.55$). Finally, when animals were housed with access to 7.5 kg of sawdust, they performed, on average, less head-swinging behavior per lying bout than when housed on the 1- and 0-kg treatments (0.63, 0.99, and 1.00 head swings per lying bout for 7.5, 1, and 0 kg of sawdust, respectively; $P < 0.05$).

In the free-choice phase, all 11 animals spent a majority of their time lying and standing in the stall bedded with 7.5 kg of sawdust (Table 2; $P < 0.05$). All 11 cows

Table 1. Stall usage (mean and SE) for 3 levels of sawdust bedding in the restriction phase ($n = 10$; one outlier excluded). Standard errors for standing behavior are unequal because these are back-transformed values. *P*-values are for the linear contrast.

	Amount of sawdust (kg)			<i>P</i> -value
	0	1	7.5	
Lying behavior				
Number of lying bouts (number/24 h)	8.5 ± 0.62	9.3 ± 0.62	10.0 ± 0.62	0.04
Duration of lying bouts (h/bout)	1.5 ± 0.10	1.4 ± 0.10	1.4 ± 0.10	0.37
Lying time(h/24 h)	12.3 ± 0.53	12.5 ± 0.53	13.8 ± 0.53	0.01
Standing behavior				
Front hooves in the stall (min/24 h)	58 +26.6/−17.7	51 +22.8/−15.8	38 +16.9/−11.7	0.03
4 hooves in the stall (min/24 h)	27 +8.4/−6.4	22 +7.1/−5.4	21 +6.6/−5.0	0.55
Total standing in the stall (min/24 h)	106 +30.9/−24.0	85 +24.5/−19.0	70 +19.9/−15.5	0.03

Table 2. Time spent lying (h/24 h) and standing in the stall (min/24 h) for the 3 levels of sawdust bedding during the free-choice phase, shown separately for all 11 animals.

	Amount of bedding (kg)			% Time on option ranked first based on time spent in the stall
Cow	0	1	7.5	
Lying time (h/24h)				
1	0.6	0.0	14.0	96%
2	1.9	0.0	10.5	85%
3	0.0	1.3	11.8	90%
4	0.0	0.0	15.0	100%
5	0.0	0.0	14.3	100%
6	0.0	0.0	13.9	100%
7	0.0	1.2	14.5	92%
8	0.0	0.0	15.1	100%
9	0.0	0.0	11.8	100%
10	0.0	1.0	13.9	93%
11	0.0	0.0	11.1	100%
Standing time (min/24 h)				
1	16	0	134	89%
2	9	12	89	81%
3	0	4	29	88%
4	0	0	39	100%
5	0	0	61	100%
6	0	0	116	100%
7	0	8	68	89%
8	0	2	53	96%
9	0	0	128	100%
10	0	48	66	58%
11	1	1	214	99%

showed a clear preference for lying on the deepest bedding, with 4 of the 11 cows never standing or lying on the other surfaces during this phase of the study.

DISCUSSION

In the following discussion, we argue that preferences for a given level of bedding demonstrate the ability of

dairy cattle to distinguish between the different free stall surfaces. We then argue that changes in lying, standing, and head-sweeping behavior are indicative of the decision to lie down on mattresses with different levels of bedding. Finally, we will discuss the biological relevance of these changes in behavior and other health implications of bedding on geotextile mattresses.

During the free-choice phase, all cows chose the stall with 7.5 kg of bedding, regardless of whether their preference was based on lying or standing time. The preferences were clear, with cows spending 85% or more of their lying time in the heavily bedded stalls. However, the cows used in the current experiment had been previously housed in a barn with both deep-bedded stalls and mattresses covered with some sawdust (similar to the 1 kg/d treatment); hence, limited previous experience with bare mattresses may have influenced the results of both the free-choice and restriction phases. However, as the animals likely had exposure to both deep-bedded sawdust and lightly-bedded mattresses before this experiment, it seems less probable that differences in previous experience can explain the differences in response to the 1- and 7.5-kg treatments. In addition, the clear preferences for the well-bedded option are consistent with other studies that have found that the amount of bedding influences preferences for free stalls (Jensen et al., 1988). Finally, the clear preferences for one level of bedding indicates that dairy cattle have the sensory capacity to distinguish between the various options presented. Although it is unclear which cues the dairy cattle may be using to distinguish between the options, this ability is likely a basis for changes in behavior when the animals have no choice.

Cows spent more time lying down on mattresses with more sawdust bedding. For example, on average, ani-

Table 3. The difference in lying time, number of lying bouts, and duration of lying bouts reported across various experiments. Only experiments that reported a statistically significant difference in lying time were included in this table. Differences were calculated by subtracting the option with the lower lying time from the option with the higher lying time.

Comparisons involving lying surfaces:	Difference in:			Citation
	Lying time (h)	Number of lying bouts	Duration of lying bouts (h)	
Sawdust vs. sand in free stall	3.4*	2.4*	0.1 ¹	Tucker et al., 2003: experiment 1
Sawdust vs. mattress in free stall	1.7*	2.0*	0.0 ¹	Tucker et al., 2003: experiment 2
Straw vs. sand in free stall (summer)	5.4*	5.1*	-1.9	Manninen et al., 2002
Straw vs. sand in free stall (winter)	9.7*	9.1*	-0.4	Manninen et al., 2002
Rubber mats in tie stall vs. slatted floor in pen (4 w)	3.7*	3.1*	NS ²	Munksgaard and Simonsen, 1995
Wood chips vs. concrete in the stand-off area ³	4.9*	2.9*	0.1	Fisher et al., 2003
Concrete in tie stall vs. mattress in pen	4.2*	5.4*	-0.3	Haley et al., 2000
Concrete vs. mattress in tie stall	1.8*	4.1*	-0.3*	Haley et al., 2001

¹Duration of lying bout information analyzed for this table.

²No values reported, nonsignificant result reported in text.

³Based on 21 h of exposure to each lying surface.

*Indicates $P \leq 0.05$.

mals spent an additional 1.5 h/24 h lying down in stalls when restricted to mattresses covered with 7.5 kg of sawdust, compared with a bare mattress. These results agree with limited evidence from Wander (1976) that greater depth of sawdust is associated with longer lying times. The number of lying bouts followed a pattern similar to lying time, but there was no difference in the average duration of lying bouts for the 3 treatment levels. Similarly, several other authors have reported lower lying times and fewer lying bouts on some lying surfaces (e.g., concrete) compared with other surfaces (e.g., mattresses; reviewed in Table 3). The additional sawdust may improve the comfort of the mattresses for changing positions between lying and standing, as the animals get up and lie down more often in the heavily bedded stall. Indeed, given that the number of visits to the free stall was similar among the 3 levels of sawdust, the additional bedding seems to influence the decision to lie down, but not to enter the stall. Several other authors have also reported changes in lying times associated with the number of lying bouts, but no difference in average duration of lying bouts (all but Haley et al., 2000, in Table 3). Other aspects of free-stall design have been shown to influence the average length of lying bouts (free-stall width: Tucker et al., 2004), and it has been suggested that longer average bout durations may indicate the comfort of the surface while cows are recumbent. Based on this logic, it is possible that the amount of sawdust may not have affected the comfort of the surface while the cow was recumbent but did seem to influence the decision to lie down.

Cows also exhibited fewer head swings before lying down on the heavily bedded option. Indeed, previous work has shown that cattle spend more time examining tie stalls with little bedding than they do examining deep-bedded areas or pasture before lying down (Müller et al., 1989; Krohn and Munksgaard, 1993). In contrast, Haley et al. (2001) reported no differences in head-swinging behavior between cows housed in tie stalls with either concrete or mattresses, but these authors did not specifically sample the time just before lying down, when this behavior is most likely to occur. The current experiment is the first work to demonstrate that the amount of bedding directly influences the performance of head-swinging behavior when the level of confinement is held constant. The function of the head-swinging behavior is not clear, but we speculate that it may be related to the evaluation of the suitability of the lying surface before lying down.

Standing behavior also changed in response to the level of sawdust on geotextile mattresses. Cows spent an additional 20 min/24 h standing with only the front hooves in the stall when provided a bare mattress compared with a stall with 7.5 kg of bedding, but there was

no difference in the amount of time spent standing with all 4 hooves in the stall. Standing with only the front hooves in the stall is not well understood. Galindo et al. (2000) speculated that dairy cattle perform this behavior to avoid dominant cattle within the group; however, this is clearly not the motivation for the animals in this experiment, as the animals were individually housed. Alternatively, Tucker et al. (2003) found that cows spent more total time standing on mattresses covered with 2 to 3 cm of sawdust compared with deep-bedded surfaces and suggested that mattresses may be more comfortable to stand on. However, there are 2 differences between the current experiment and Tucker et al. (2003) that undermine this interpretation. In Tucker et al. (2003), there were differences in total standing time, but these were not always accompanied by differences in lying behavior (time or number of bouts) between mattresses and deep-bedded sawdust. Secondly, in Tucker et al. (2003), the difference in total standing time was driven by differences in standing with 4 hooves in the stall rather than in standing with only the front hooves in the stall (reanalysis of Tucker et al., 2003). In contrast, in the restriction phase of the current experiment, the difference in total standing time seems more influenced by standing with only the front hooves in the stall. In addition, in the free-choice phase of the current experiment, only one cow (number 2, Table 2) stood in a stall that she did not use for lying (1 kg of sawdust). Thus, it appears that animals were not seeking out different surfaces solely to stand on, but that cows were spending more time standing on those surfaces on which they were more reluctant to lie down. In a recent study on stall width (Tucker et al., 2004), we also found that cows spent more time standing in stall designs that were associated with lower lying times.

The amount of sawdust on geotextile mattresses influences lying, head-swinging, and standing behavior, but the biological relevance of these changes in behavior is unclear. Lying time is thought to be important to dairy cattle for several reasons. Cows spend a large portion of their time lying; even a 3-h deprivation of lying is sufficient to cause cows to forego eating in order to lie down (Metz, 1985). In addition, cows housed on concrete for 21 h/d will spend more time lying down during 3 h of pasture access, compared with animals housed on woodchips 21 h/d (Fisher et al., 2003). Several physiological changes are associated with reduced lying time; these include a decrease in circulating levels of growth hormone (Munksgaard and Lvendahl, 1993), a short-term increase in plasma cortisol levels (e.g., Fisher et al., 2002) and an increased incidence of lameness (Singh et al., 1993; Leonard et al., 1994). The time spent standing with the front hooves in the stall has

also been associated with physical consequences including an increased number of claw horn lesions (Colam-Ainsworth et al., 1989; Galindo and Broom, 2000; Flower and Weary, 2002). However, little is known about the nature of the relationship between time spent standing and lying and these deleterious consequences. For example, are the average lying times seen with the bare mattresses (12.3 h/d) enough to cause some problems, or do these only occur with extremely short lying times, such as the 3 h/d shown by the one outlier cow? The average lying time on the bare mattress falls well within the range of lying times reported in previous studies, including those in which cattle were housed on pasture (e.g., Dechamps et al., 1989; Krohn and Munksgaard, 1993; Singh et al., 1993). Indeed, we lack the information to interpret the biological importance of relatively small changes in behavior, such as differences in lying, standing, and head-swinging, between the 3 treatments tested in the current experiment. A more comprehensive understanding of how lying and standing times relate to health is needed, and future research should focus on this issue.

Previous work has shown that mattresses with little bedding are associated with a higher incidence and more severe hock lesions compared with deep-bedded surfaces (Weary and Taszkun, 2000; Mowbray et al., 2003). Indeed, Nilsson (1992) found that hock injuries were more common when cattle were housed on surfaces with less penetration (or harder surfaces). By covering mattresses with a thick layer of bedding (as in 7.5 kg of sawdust treatment), the surface will be softer and is likely to reduce the incidence of injury. More work is needed to understand the importance of various physical properties of stall surfaces (e.g., thermal conductance, visual appearance, coefficient of friction) to dairy cattle. Claw health may also relate to lying surface: Increased amounts of bedding reduce problems with hoof health (Colam-Ainsworth et al., 1989).

The number of lying bouts, time spent standing with only the front hooves in the stall, and the number of head swings all changed in response to the amount of sawdust on the geotextile mattress. Based on these changes, increased amounts of sawdust bedding appear to increase the suitability of the surface in terms of the decision to lie down. Indeed, all cows could clearly distinguish between the 3 treatments and showed clear preferences for lying and standing in stalls with more sawdust. Thus, to promote comfort, geotextile mattresses are best managed with copious bedding.

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REFERENCES

- Colam-Ainsworth, P., G. A. Lunn, R. C. Thomas, and R. G. Eddy. 1989. Behavior of cows in cubicles and its possible relationship with laminitis in replacement dairy heifers. *Vet. Rec.* 125:573–575.
- Dechamps, P., B. Nicks, B. Canart, M. Gielen, and L. Istasse. 1989. A note on resting behaviour of cows before and after calving in two different housing systems. *Appl. Anim. Behav. Sci.* 23:99–105.
- Fisher, A. D., M. Stewart, G. A. Verkerk, C. J. Morrow, and L. R. Matthews. 2003. The effects of surface type on lying behaviour and stress responses of dairy cows during periodic weather-induced removal from pasture. *Appl. Anim. Behav. Sci.* 81:1–11.
- 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.
- Flower, F., and D. M. Weary. 2002. Testing measures of lameness: Using behaviour to predict presence and severity of hoof lesions in dairy cattle. *J. Dairy Sci.* 85(Suppl. 1):247. (Abstr.)
- Galindo, F., and D. M. Broom. 2000. The relationships between social behaviour of dairy cows and the occurrence of lameness in three herds. *Res. Vet. Sci.* 69:75–79.
- Galindo, F., D. M. Broom, and P. G. G. Jackson. 2000. A note on possible link between behaviour and the occurrence of lameness in dairy cows. *Appl. Anim. Behav. Sci.* 67:335–341.
- Haley, D. B., A. M. de Passillé, and J. Rushen. 2001. Assessing cow comfort: Effects of two floor types and two tie stall designs on the behaviour of lactating dairy cows. *Appl. Anim. Behav. Sci.* 71:105–117.
- 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.
- Jensen, P., B. Recén, and I. Ekesbo. 1988. Preference of loose housed dairy cows for two different cubicle floor coverings. *Swed. J. Agric. Res.* 18:141–146.
- Krohn, C. C., and L. Munksgaard. 1993. Behaviour of dairy cows kept in extensive (loose housing/pasture) or intensive (tie stall) environments II. Lying and lying-down behaviour. *Appl. Anim. Behav. Sci.* 37:1–16.
- Ladewig, J., and D. Smidt. 1989. Behavior, episodic secretion of cortisol, and adrenocortical reactivity in bulls subjected to tethering. *Horm. Behav.* 23:344–360.
- Leonard, F. C., J. O'Connell, and K. O'Farrell. 1994. Effect of different housing conditions on behaviour and foot lesions in Friesian heifers. *Vet. Rec.* 134:490–494.
- Manninen, E., A. M. de Passillé, J. Rushen, M. Norring, and H. Saloniemi. 2002. Preferences of dairy cows kept in unheated buildings for different kind 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 *Proceedings of the 5th International Dairy Housing Conference*. American Society of Agricultural Engineers, St. Joseph, MI.
- Müller, C., J. Ladewig, H. H. Thielscher, and D. Smidt. 1989. Behavior and heart rate of heifers housed in tether stanchions without straw. *Physiol. Behav.* 46:751–754.
- Muller, C. J. C., and J. A. Botha. 1997. Cow behaviour in relation to different freestall surfaces during winter temperate climate. Pages 1069–1076 in *Livestock Environment 5 Vol. 2*. American Society of Agricultural Engineers. 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.
- Nilsson, C. 1992. Walking and lying surfaces in livestock houses. Pages 93–110 in *Farm Animals and the Environment*. C. Phillips and D. Piggins, ed. CAB International, Wallingford, UK.
- O'Connell, J. M., and W. J. Meaney. 1997. Comparison of shredded newspaper and sawdust as bedding for dairy cows: Behavioural, clinical and economic parameters. *Irish Vet. J.* 50:167–170.
- Rushen, J., A. M. de Passillé, D. Haley, E. Manninen, and H. Saloniemi. 2001. Using behavioral indicators and injury scores to assess the effect of stall flooring on cow comfort. Pages 716–723 in *Livestock Environment 6*. Vol. 2. R. Stowell, R. Bucklin, and R. W. Bottcher, ed. American Society of Agricultural Engineers. St. Joseph, MI.
- SAS User's Guide: Statistics, Version 8 Edition. 1999. SAS Inst., Inc., Cary, NC.
- Singh, S. S., W. R. Ward, K. Lautenbach, J. W. Hughes, and R. D. Murray. 1993. Behaviour of first lactation and adult dairy cows while housed and at pasture and its relationship with sole lesions. *Vet. Rec.* 133:469–474.
- Stefanowska, J., D. Swierstra, C. R. Braam, and M. M. W. B. Hendriks. 2001. Cow behaviour on a new grooved floor in comparison with a slatted floor, taking claw health and floor properties into account. *Appl. Anim. Behav. Sci.* 71:87–103.
- 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. 2004. Freestall dimensions: Effects on preference and stall usage. *J. Dairy Sci.* 87:1208–1216.
- Wander, J. F. 1976. *Haltungs- und verfahrenstechnisch orientierte verhaltensforschung*. *Züchtungskunde* 48:447–459.
- Weary, D. M., and I. Taszkun. 2000. Hock lesions and free-stall design. *J. Dairy Sci.* 83:697–702.
- Wechsler, B., J. Schaub, K. Friedli, and R. Hauser. 2000. Behaviour and leg injuries in dairy cows kept in cubicle systems with straw bedding or soft lying mats. *Appl. Anim. Behav. Sci.* 69:189–197.