Improving the Welfare of Dairy Cattle: Implications of Freestall Housing on Behavior and Health

Marina von Keyserlingk and Dan Weary
Animal Welfare Program, University of British Columbia, 2357 Mall, Vancouver, BC, Canada, V6T 1Z4 Email: marina.vonkeyserlingk@ubc.ca Tel: 604 822 4989, Fax: 604 822 2184

Take Home Messages

1) The design and management of the feeding area important. High stocking densities at the feed bunk increase aggressive competition and keep subordinate cows away from feed. Cows who consume less feed are at greater risk for disease.

2) Physical barrier between cows, including head lockers and feed stalls, can help reduce this competition and increase feeding time.

3) Cows like softer surfaces, for both lying down and for standing upon. Deep-bedded stalls work well for cow comfort, but require maintenance.

4) When it comes to the physical structures used to build freestalls, less is more – the hardware we place in the stall is for our benefit and not the cows. The more restrictive we design stalls the less attractive they become for the cow.

5) Access to a dry, comfortable standing area reduces the risk of lameness. A rest period on pasture helps lame cows recover.

Introduction

Poorly designed and managed facilities cause injuries and increase the risk of health problems such as lameness. Producers spend millions of dollars building and renovating their barns with the aim of providing a comfortable environment for their dairy cows, but there has been little work done to scientifically assess cow comfort on commercial farms and to allow producers to evaluate their own facilities. This paper provides an overview of key research findings from our group at The University of British Columbia. This gives us the chance to highlight our own research and what we think are some particularly interesting and promising approaches focusing on the implications of freestall housing on behavior and health for intensively managed dairy cattle.

Cow Comfort

The issue of cow comfort has received considerable interest within the dairy industry, with the bulk of research having focused on the design of free-stalls and the effect of stall design upon stall occupancy and the time spent resting. This research-based knowledge on stall design is now beginning to be implemented in the design of new barns (Le Blanc et al., 2006).

Most research on stall design for cattle has concentrated on two aspects: the surface cows lie down upon, and how the free stall is configured. Cows clearly prefer softer lying surfaces with more bedding, and spend more time lying down in well-bedded dry stalls (Haley et al., 2001, Manninen et al., 2002, Tucker and Weary, 2004; Fregonesi et al. 2007). However, the lying surface can also affect udder health. Use of organic bedding material can increase the risk of some types of mastitis and many studies have now shown the advantages to cows of using sand or other inorganic bedding as a way of reducing the growth of bacteria associated with environmental mastitis (e.g. Zdanowicz et al., 2004). There is some evidence that cows prefer lying down on straw rather than sand (Manninen et al., 2002), but this can be altered with greater experience of sand (Norring et al. 2008). Furthermore, the reduced risk of mastitis or lameness (Cook, 2003; Espejo et al. 2006; Norring et al., 2008) with sand bedding may compensate for the lack of preference.

The configuration of free stalls (for example, size, position of neck rails, etc.,) can also have a major effect upon cow comfort (Tucker et al., 2004, 2005, 2006). In addition to stall width, neck-rail placement is important for managing standing behavior. Both the height of the neck rail and its distance from the curb affect standing (Tucker et al., 2005); more restrictive neck-rail placements (lower and closer to the rear of the stall) prevent cows from standing fully in the stall and this in turn increases the time cows spend on concrete flooring elsewhere in the barn, increasing the risk of lameness as described below.

Stalls should provide a clean, comfortable area for cows to lie down. However, cows often stand in the stalls increasing the risk of feces falling onto the lying area. The common response by barn designers has been to make the stalls more restrictive, forcing cows back into the concrete alley. Keeping cows from using the stalls will keep the stalls clean - both narrow free stalls and the more restrictive neck rail placements reduce the amount of fecal matter that ends up in the stall. However, stall cleanliness alone is a poor measure of stall design. Free stalls that are more comfortable have higher occupancy rates and are therefore most likely to contain feces.

The real problem may not be in the design of the stall itself. In most barns the surface for standing outside of the stall is hard, wet concrete. Thus cows use the stall as a refuge from concrete floors -- it provides a dry, softer surface for standing. However, standing in the stall increases the likelihood that cows urinate and defecate on the stall surface, making it less suitable for lying. From this perspective we are stuck with two bad choices: use restrictive stalls that keep the stall surface cleaner but force cows back onto the wet concrete, or use more open designs and increase frequency of stall maintenance. However, there may be a third approach – improving the standing surface elsewhere in the barn.

Improved surfaces for walking and standing. Research on cow comfort has tended to focus on the design of stalls to the exclusion of other important factors. According to popular thinking, when cows are not in the parlor they should be eating or lying down. Unfortunately, no one has explained this to the cows: even when cows have access to well-designed stalls they spend only about 12 h a day lying down. Cows spend the other 12 h a day on their feet, and we need to take this into account in designing suitable housing.

The majority of cows in free-stall housing now spend most of their time standing or walking on concrete floors, and the use of concrete floors has been identified as a risk factor for increased claw lesions and lameness (Somers et al. 2003, 2005, Vanegas et al. 2006). Free-stall barns with concrete floors often have poor drainage, in part because some moisture improves the performance of automatic scraper systems, but when cows stand on wet floors the claws absorb water and become soft, increasing the risk of sole wear (Borderas et al., 2004) and sole lesions (van Amstel et al., 2004). The common use of concrete floors with poor drainage may explain why lameness and claw lesions are more common in free-stall systems, especially where the cows have no access to pasture (Haskell et al., 2006). Recent work has shown that cows prefer to stand on softer flooring (Tucker et al., 2006; Fregonesi et al., 2004). The development of new standing surfaces is an important area for future work.

Even when dry, there are two problems with concrete floors: often they do not provide sufficient traction to allow good cow mobility (van der Tol et al. 2005) and they may be too hard, increasing the pressure on the hooves (Franck and De Belie, 2006). Recently, Rushen and de Passillé (2006) showed that both surface friction and the ability of the floor to absorb shock were important in improving cow mobility, leading to an increase in walking speed and a reduction in the likelihood of the cow slipping. Rubber flooring reduces horn growth and wear (Vanegas et al., 2006), but little is known about alternative flooring surfaces and how these might reduce the risk of lameness and improve cow mobility.

Barn layout. Cow comfort may also be affected by overall layout of the barn. For example, some work has shown that cows rarely use certain stalls in a pen, while seemingly identical stalls are occupied more than 80% of the available time. One study (Gaworski et al., 2003) showed that stalls in the row closest to the feed alley were occupied 41% more frequently than were stalls in more distant rows. In addition, stalls located within the centre of each row were used 12% more often than those stalls located on the periphery of the row (i.e. either near a wall or fence). Natzke et al. (1982) also found that stalls on the periphery were used less than stalls in the interior of the row. These results suggest that certain stalls, particularly those farther from the feed bunk and on the periphery, are less desirable to dairy cattle perhaps because cows need to walk farther, or because of they have to navigate past certain physical (e.g. narrow alleys) or social obstacles (e.g. dominant cows) on their way to the more distant stalls. Indeed, earlier work has indicated that the movements of subordinate animals are prevented by the location of dominant cows (Miller and Wood-Gush, 1991). Such factors may partly explain reduced user satisfaction and lower production in those barn designs consisting of more rows (e.g. 6 and 4 row verses 2 and 3 row barns: Bewley et al., 2001).

Thus large differences in usage can occur even among identically configured stalls within the same barn. The fact that stalls within a pen vary in their popularity suggests that stall availability from the cows' perspective is not the same as from the producer's perspective -- what looks to us as 1:1 cow-to-stall stocking density may seem considerably worse to the cows if some stalls are unacceptable.

Better feeding areas. Despite decades of work focusing on the impact of changes in nutrition on dry matter intake there has been virtually no work addressing other factors that can affect intake, including the design and management of the feeding area. There are several aspects of the feeding environment that affect the cow's ability to access feed, including the amount of available feed bunk space per animal and the physical design of the feeding area. DeVries et al. (2004) showed that doubling feeding space from 0.5 m to 1.0 m per cow reduced by half the number of aggressive interactions while feeding. This reduction in aggressive behavior allowed cows to increase feeding activity by 24% at peak feeding times, an effect that was strongest for subordinate animals.

The physical design of the feeding area can also influence feeding behavior. One of the most obvious features of the feeding area is the physical barrier that separates the cow and the feed, and new research shows that some designs can reduce aggressive interactions at the feed bunk. For example, Endres et al. (2005) compared the effects of a post-and-rail versus a headlock feed line barrier on the feeding and social behavior of dairy cows and found that during periods of peak feeding activity (90 min after fresh feed delivery) subordinate cows had lower feeding times when using the post-and-rail barrier. This difference in feeding times was likely due to positive effects of the headlock barriers in reducing competitive interactions; there were also 21% fewer displacements at the feed bunk when cows accessed feed by the headlock barrier compared to the post-and-rail barrier.

In a second study we retested the effects of these two types of feed bunk barriers, but did so over a range of stocking densities (Huzzey et al., 2006). Cows were tested with the barriers described above but using stocking densities of 0.81, 0.61, 0.41 and 0.21 m/cow (corresponding to 1.33, 1.00, 0.67 and 0.33 headlocks/cow). Daily feeding times were higher and the duration of inactive standing in the feeding area was lower when using a post-and-rail compared to a headlock feed barrier. As well, regardless of barrier type, feeding time decreased and inactive standing increased as stocking density at the feed bunk increased. Cows were displaced more often from the feeding area when the stocking density was increased, and this effect was greater for cows using the post-and-rail feed barrier. Again we found that this effect was greatest for the subordinate cow, particularly at high stocking densities. Clearly, overstocking the feed bunk decreases time spent at the feed bunk and increases competition, resulting in poor feed access.

New work has now shown that providing additional partitions ("feed stalls") between adjacent cows provides additional protection while feeding and allows for improved access to feed (DeVries and von Keyserlingk, 2006). Providing a feed stall resulted in less aggression and fewer competitive displacements, effects that were again greatest for subordinate cows. This reduced aggression allowed cows to increase daily feeding time and reduced the time they spent standing in the feeding area while not feeding. Thus the provision of more bunk space, particularly when combined with feed stalls, improves access to feed and reduces competition at the feed bunk, particularly for subordinate cows. This could help reduce the between-cow variation in the composition of ration consumed by preventing subordinate cows from being forced to access the bunk only after dominant cows have sorted the feed (DeVries et al., 2005). The use of a barrier that provides some physical separation between adjacent cows can reduce competition at the feed bunk. A less aggressive environment at the feed bunk may also have longer-term health benefits; cows engaged in aggressive interactions at the feed bunk are likely at higher risk for hoof health problems (Leonard et al., 1998). A final advantage of such stalls is that they can facilitate the use of alternative flooring surfaces in the feeding area, and access to a softer, drier standing area at the feeder can improve hoof health (Manske et al. 2002).

The "Transition" Cow

The periparturient period or "transition" phase (generally accepted as the period beginning 3 weeks prior to calving and ending 3 weeks following calving) is one of the critical points in dairy production where risks to animal welfare are highest. During the transition period, cows face a number of stressors including diet changes and social regroupings, and the physical, hormonal and physiological changes associated with calving and the onset of lactation. One of the main challenges for transition dairy cows is a sudden increase in nutrient requirements to support the onset of lactation at a time when dry matter intake lags behind (Drackley, 1999).

There are a well-known suite of disorders that afflict cows during transition, including ketosis, fatty liver, displaced abomasums, mastitis, metritis and retained placenta, and milk fever. Susceptibility to certain infectious diseases also peaks at this time (Smith et al., 1985). The high prevalence of infectious disease during transition may also be linked to inadequate nutrition (Goff 2006), as these diseases commonly occur as a secondary illness to primary metabolic disease (Reist et al., 2003). Inadequate nutrition may also contribute to a depression of the immune system during transition (e.g. Mallard et al., 1998; Hammon et al., 2006). Specifically, infectious agents that the body would eliminate under robust immune conditions are more likely to induce clinical infectious disease, especially in vulnerable areas such as the udder and uterus (Cai et al., 1994).

As veterinary examination of post-partum cows is relatively infrequent on most farms (commonly once every two weeks), many cases of transition period disease may go unnoticed. Producers can use urine or milk tests to monitor the health of their animals, but frequent administration of tests on a herd-wide scale can be costly and time-consuming. Moreover, no such tests are available for diagnosing inflammatory uterine disease (metritis or endometritis), one of the most common disorders after calving. Knight et al. (1999) suggested that animals that experience moderate metabolic stress after calving might sacrifice immune function for the sake of maintaining lactation, a considerably more important function at that time. Metabolic resources would not be diverted from lactation until a cow became severely metabolically stressed. Therefore, the common practice of using daily milk yield as a general indicator of animal health is a relatively insensitive method for identifying sick or at-risk animals. For example, milk production responds poorly to mild or subclinical infectious disease. In fact, Rajala-Shultz et al. (1999) found that cows with a fever produced more milk, on average, than did healthy cows. Thus, a more sensitive method of continuously monitoring animal health or risk for disease during the transition period is needed. Recent work (Urton et al. 2005; Huzzey et al. 2007) indicates that changes in feeding behavior and dry matter intake in the weeks prior to calving may be used to identify cows at risk for metritis post partum but more work is required to validate this approach.

Lameness

Lameness is widely regarded as a major welfare problem for dairy cows, affecting milk production and feed intake (Bareille et al., 2003). Lameness can result from infectious disease (such as digital dermatitis and foot rot) or hoof lesions (e.g. ulcers, haemorrhages, white line separation) that are associated with both metabolic challenges and physical injury to the hoof. Nutritional factors such as wet silage can increase risks (Offer et al. 2003), but management factors, such as the use of concrete floors (Somers et al. 2003, 2005; Telezhenko and Bergsten, 2005; Vanegas et al., 2006), zero-grazing (Haskell et al. 2006) and uncomfortable stalls (Cook et al., 2004) are also important.

Unfortunately, producers find it difficult to identify animals at the early stages of lameness (Whay et al., 2003; Espejo et al. 2006), likely because dairy cows remain stoic unless injuries are relatively severe (O'Callaghan, 2002). Current research is developing improved gait scoring system that can be use to identify cows that are becoming lame. Better scoring systems will require improved knowledge of cows' gait, and this can be derived from computer-assisted kinematic techniques that obtain precise measures of gait and how this changes with different types of hoof injuries (Flower et al., 2005). Our group uses a gait scoring system based on several specific gait features (e.g. asymmetric steps, tracking up etc.), and these scores have proven sensitive in identifying cows with sole ulcers (Flower and Weary, 2006), pain reduction following use a non-steroidal anti-inflammatory drug (Flower et al. 2008), and the advantages of softer walking surfaces for lame cows (Flower et al., 2007). Part of the difficulty in identifying lame cows may come from the fact that herd sizes are increasing leaving producers less time to spend watching their animals. This has led to interest in automated means of detecting lameness, such as through changes in how cows distribute the weight among the four limbs either when standing or walking (Rajkondawar et al., 2002; Neveux et al. 2006; Pastell et al., 2007), altered attendance at automated milking systems (Borderas et al., 2008), or automated image analysis (Song et al., 2008).

Conclusion

This review has outlined a few key areas of concern regarding the welfare of dairy cattle housed in freestalls, and has shown how scientific research can help address these concerns. For example, new research has shown how indoor housing systems can be made more comfortable for adult cows and how common diseases like lameness and metritis can be better identified and prevented through improvements in the ways cows are housed and managed.

Acknowledgments

General support for the UBC Animal Welfare Program is provided by Canada's Natural Sciences and Engineering Research Council and by contributions from the Dairy Farmers of Canada, the BC Dairy Foundation, members of the BC Veterinary Medical Association and many others listed at http://www.landfood.ubc.ca/animalwelfare

References

Bareille, N., F. Beaudeau, S. Billon, A. Robert, and P. Faverdin. 2003. Effects of health disorders on feed intake and milk production in dairy cows. Livest. Prod. Sci. 83:53-62

Bewley, J., R. W. Palmer, and D. B. Jackson-Smith. 2001. A comparison of free-stall barns used by modernized Wisconsin dairies. J. Dairy Sci. 84, 528-541.

Borderas, T. F., B. Pawluczuk, A. M. de Passille, and J. Rushen. 2004. Claw hardness of dairy cows: Relationship to water content and claw lesions. J. Dairy Sci. 87:2085-8093.

Cai, T. Q., P. G. Weston, L. A. Lund, B. Brodie, D. J. McKenna, and W.C. Wagner. 1994. Association between neutrophil functions and periparturient disorders in cows. Am. J. Vet. Research. 55:934-943.

Cook, N. B. 2003. Prevalence of lameness among dairy cattle in Wisconsin as a function of housing type and stall surface. J. Am. Vet. Med. Assoc. 223:1324–1328

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.

DeVries, T. J., and M. A. G. von Keyserlingk. 2006. Effects of feeder design on the social and feeding behaviour of lactating dairy cows. J. Dairy Sci. 89: 3522-3531.

DeVries, T. J., M. A. G. von Keyserlingk, and D. M. Weary. 2004. Effect of feeding space on the inter-cow distance, aggression, and feeding behavior of free-stall housed lactating dairy cows. J. Dairy Sci. 87:1432-1438.

DeVries, T. J., M. A. G. von Keyserlingk, and K. A. Beauchemin. 2005. Frequency of feed delivery affects the behavior of lactating dairy cows. J. Dairy Sci. 88:3553-3562.

Drackley, J. K. 1999. Biology of dairy cows during the transition period: the final frontier? J. Dairy Sci. 82:2259-2273.

Endres, M. I., T. J. DeVries, M. A. G. von Keyserlingk, and D. M. Weary. 2005. Effect of feed barrier design on the behavior of loose-housed lactating dairy cows. J. Dairy Sci. 88:2377-2380.

Espejo, L. A., M. I. Endres, and J. A. Salfer. 2006. Prevalence of lameness in high-producing Holstein cows housed in freestall barns in Minnesota. J. Dairy Sci. 89:3052-3058.

Flower, F.C., M. Sedlbauer, E. Carter, M. A. G. von Keyserlingk, D. J. Sanderson, and D. M. Weary. 2008. Analgesics Improve the Gait of Lame Dairy Cattle. J Dairy Sci 2008 91: 3010-3014.

Flower, F. C., D. J. Sanderson, D. J. and D. M. Weary. 2005. Hoof pathologies influence kinematic measures of dairy cow gait. J. Dairy Sci. 88:3166-3173.

Flower, F. C., A. M. de Passillé, D. M. Weary, D. J., Sanderson, and J. Rushen. 2007. Softer, higher friction flooring improves gait of cows with and without sole ulcers. J. Dairy Sci. 90: 1235-1242.

Flower, F. C. and D. M. Weary. 2006. Effect of hoof pathologies on subjective assessments of dairy cow gait. J. Dairy Sci. 89:139-146.

Franck, A., and N. De Belie. 2006. Concrete Floor–Bovine Claw Contact Pressures Related to Floor Roughness and Deformation of the Claw. J Dairy Sci. 89: 2952-2964.

Fregonesi, J. A., C. B. Tucker, D. M. Weary, F. C. Flower, and T. Vittie. 2004. Effect of rubber flooring in front of the feed bunk on the time budgets of dairy cattle. J. Dairy Sci. 87:1203-1207.

Fregonesi, J. A., D. M. Veira, M. A. G. von Keyserlingk, and D. M. Weary. 2007. Effects of Bedding Quality on Lying Behavior of Dairy Cows. J Dairy Sci 2007 90: 5468-5472.

Gaworski, M. A., Tucker, C.B., and Weary, D.M. 2003. Effects of two free-stall designs on dairy cattle behavior. Pages 139-146 in Proc. of the Fifth International Dairy Housing Conference, American Society of Agricultural Engineers, St. Joseph, MI.

Goff, J.P. 2006. Major advances in our understanding of nutritional influences on bovine health. J. Dairy Sci. 89:1292-1301.

Haley, D. B., J. Rushen, and A. M. de Passille. 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.

Hammon, D.S., I. M. Evjen, T. R. Dhiman, J. P. Goff and J. L. Walters. 2006. Neutrophil function and energy status in Holstein cows with uterine health disorders. Vet. Immun. Immunopath. 113:21 29.

Haskell, M. J., L. J. Rennie, V. A. Bowell, M. J. Bell, and A. B. Lawrence. 2006. Housing system, milk production, and zero-grazing effects on lameness and leg injury in dairy cows. J. Dairy Sci. 89:4259-4266.

Huzzey, J. M., T. J. DeVries, P. Valois, and M. A. G. von Keyserlingk. 2006. Stocking density and feed barrier design affect the feeding and social behavior of dairy cattle. J. Dairy Sci. 89:126-133.

Huzzey, J.A., D.M. Veira, D.M. Weary, M.A.G. von Keyserlingk. 2007. Behavior and intake measures can identify cows at risk for metritis. J. Dairy Sci. 90:3320-3233.

Knight C. H., D. E. Beever, and A. Sorensen. 1999 Metabolic loads to be expected from different genotypes under different systems. British Society of Animal Science Occasional Publication 24:27 35

LeBlanc, S. J., K. D. Lissemore, D. F. Kelton, T. F. Duffield, and K. E. Leslie. 2006. Major advances in disease prevention in dairy cattle. J. Dairy Sci. 89:1267-1279.

Leonard, F. C., I. Stienezen, and K. J. O'Farrell. 1998. Overcrowding at the feeding area and effects on behavior and claw health in Friesian heifers. Pages 40-41 in Proc. 10th Int. Symp. Lameness in Ruminants, Lucerne, Switzerland.

Mallard, B. A., J. C. Dekkers, M. J. Ireland, K. E. Leslie, S. Sharif, C. Lacey Vankampen, L. Wagter, and B. N. Wilkie. 1998. Alteration in immune responsiveness during the peripartum period and is ramification on dairy cow and calf health. J. Dairy Sci. 81:585-595.

Manske, T., J. Hultgren, and C. Bergsten. 2002. Prevalence and interrelationships of hoof lesions and lamenss in Swedish dairy cows. Prev. Vet. Med. 54:247-263.

Mayntz, M. and R. Costa. 1998. Effect of pharmacologically induced changes in milk ejection on suckling in *Bos taurus*. Physiol. Behav. 65:151-156.

Miller K. and D. G. M. Wood-Gush. 1991. Some effects of housing on the social-behavior of dairy cows. Anim. Prod. 53:271-278.

Natzke, R. P., D. R. Bray, and R. W. Everett. 1982. Cow preference for free stall surface material Rubber mats, carpeting, and a layered mat. J. Dairy Sci. 25:146-153.

Neveux, S., D. M. Weary, J. Rushen, M. A. G. von Keyserlingk, and A. M. de Passillé. 2006. Hoof discomfort changes how dairy cattle distribute their body weight. J. Dairy Sci. 89:2503-2509.

Norring, M., E. Manninen, A. M. de Passillé, J. Rushen, L. Munksgaard, and H. Saloniemi. 2008. Effects of Sand and Straw Bedding on the Lying Behavior, Cleanliness, and Hoof and Hock Injuries of Dairy Cows. J Dairy Sci 2008 91: 570-576.

Offer, J.E., K.A. Leach, S. Brocklehurst, and D.N. Logue. 2003. Effect if forage type on claw horn lesion development in dairy heifers. Vet. Rec. 165:221-227.

O'Callaghan, K. A. 2002. Lameness and associated pain in cattle – challenging traditional perceptions. In. Pract. 24:212-219.

Pastell, M. E. and M. Kujala 2007. A Probabilistic Neural Network Model for Lameness Detection. J Dairy Sci 90: 2283-2292

Rajala-Schultz, P. J., Y. T. Grohn, and C. E. McCulloch. 1999. Effects of milk fever, ketosis, and lameness on milk yield in dairy cows. J. Dairy. Sci. 82:288-294.

Rajkondawar, P. G., U. Tasch, A. M. Lefcourt, B. Erez, R. M. Dyer, and M. A. Varner. 2002. A system for identifying lameness in dairy cattle. Appl. Eng. Agric. 18:87-96.

Reist, M., D. Erdin, D. von Euw, K. Tschuemperlin, H. Leuenberger, Y. Chilliard, H. M. Hammon, C. Morel, C. Philipona, Y. Zbinden, N. Kuenzi, and J. W. Blum. 2003. Estimation of Energy Balance at the Individual and Herd Level Using Blood and Milk Traits in High-Yielding Dairy Cows J. Dairy Sci. 85: 3314-3327.

Rushen J., and A. M. de Passillé. 2006. Effects of roughness and compressibility of flooring on cow locomotion. J. Dairy Sci. 89:2965-2972.

Smith, K.L., D.A. Todhunter, and P.S. Schoenberger. 1985. Environmental mastitis: cause, prevalence, prevention. J. Dairy Sci. 68:1531-1553.

Somers, J. G. C. J., K. Frankena, E. N. Noordhuizen-Stassen, and J. H. M. Metz. 2003. Prevalence of claw disorders in Dutch dairy cows exposed to several floor systems. J. Dairy Sci. 86:2082-2093.

Somers, J. G. C. J., W. G. P. Schouten, K. Frankena, E. N. Noordhuizen-Stassen, and J. H. M. Metz. 2005. Development of claw traits and claw lesions in dairy cows kept on different floor systems. J. Dairy Sci. 88:110-120.

Song, X., Leroy, T., Vranken, E., Maertens, W., Sonck, B., and Berckmans, D. 2008. Automatic detection of lameness in dairy cattle-Vision-based trackway analysis in cow's locomotion. Comp. Electr. Agric. 64:39-44

Telezhenko, E., and C. Bergsten. 2005. Influence of floor type on the locomotion of dairy cows. Appl. Anim. Behav. Sci. 93:183-197.

Tucker, C. B., D. Fraser, and D. M. Weary. 2001. Tail docking dairy cattle: effects on cow cleanliness and udder health. J. Dairy Sci. 84:84-87.

Tucker, C. B., and D. M. Weary. 2004. 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. 2004. Freestall dimensions: effects of preferences and stall usage. J. Dairy Sci. 87:1208-1216.

Tucker, C. B., D. M. Weary, and D. Fraser. 2005. Neck-rail placement: effect on freestall preference, usage, and cleanliness. J. Dairy Sci. 88:2730-2737.

Tucker, C. B., M. Zdanowicz, D. M. Weary. 2006. Brisket boards reduce freestall use. J. Dairy Sci. 89:2603-2607.

Urton, G., M. A. G. von Keyserlingk, A. P. Viera, and D. M. Weary. 2005. Feeding behavior identifies dairy cows at risk for metritis. J. Dairy Sci. 88:2843-2849.

van Amstel, S. R., J. K. Shearer, and F. L. Palin. 2004. Moisture Content, Thickness, and Lesions of Sole Horn Associated with Thin Soles in Dairy Cattle. J Dairy Sci. 87: 757-763.

van der Tol, P. P. J., J. H. M. Metz, E. N. Noordhuizen-Stassen, W. Back, C. R. Braam, W. A. Weijs. 2005. Frictional forces required for unrestrained locomotion in dairy cattle. J. Dairy Sci. 88:615-624.

Vanegas, J., M. Overton, S. L. Berry, and W. M. Sischo. 2006. Effect of Rubber Flooring on Claw Health in Lactating Dairy Cows Housed in Free-Stall Barns. J Dairy Sci. 89: 4251-4258.

Whay, H. R., D. C. J. Main, L. E. Green, and A. J. F. Webster. 2003. Assessment of the welfare of dairy cattle using animal-based measurements: direct observations and investigation of farm records. Vet. Rec. 153:197-202.

Zdanowicz, M., J. A. Shelford, C. B. Tucker, D. M. Weary, and M. A. G. von Keyserlingk. 2004. Sand and sawdust bedding affect bacterial populations on teat ends of dairy cows housed in freestalls. J. Dairy Sci. 87:1694-1701.