The Influence of Barn Design on Dairy Cow Hygiene, Lameness and Udder Health

Nigel B. Cook, *BVSc, Cert CHP, DBR, MRCVS*
Clinical Assistant Professor in Food Animal Production Medicine
University of Wisconsin-Madison, School of Veterinary Medicine, Madison, WI 53706

Abstract

A system of hygiene scoring is described which charts the distribution of manure over three areas of the body; udder, lower legs, and upper leg and flank. The practical relevance of quantifying hygiene is described in relation to the prevalence of mastitis and lameness. Aspects of freestall and tiestall design which impact hygiene and lying times are reviewed and the link between cow comfort and lameness is explored.

Introduction

A failure to understand the comfort and spatial requirements of the cow has led to the erection of many dairy barns in North America which compromise cow health and welfare. Few veterinarians have managed to develop the necessary interests and skills to be called upon for housing advice, leaving agricultural engineers to make planning decisions based on cost, ease of manure management and non-health related matters. In Europe, farm assurance programs developed by milk buyers call upon veterinarians to assess the adequacy of dairy herd housing, creating an opportunity for greater involvement in this area. Concerns over food animal welfare are increasing in the US and it is important that the veterinary profession plays a pivotal role in implementing balanced, reasonable and informed changes in management on farms in the future, to improve health and welfare.

Only recently, by working together, have veterinarians, dairy scientists and engineers succeeded in measuring health outcomes derived from environmental factors, thereby improving the quality of advice given to farmers with regard to housing options for dairy cows.

If we are to decrease dairy herd turnover rates and improve cow health and longevity we must ask crucial questions, which impact the survival rate of our dairy cows:

- What kind of bedding is optimal for mastitis prevention?
- Which type of stall design optimizes cow comfort and reduces the prevalence of lameness?
- How can we reduce the prevalence of hock injuries?
- How frequently do we have to scrape alleyways to prevent infectious hoof conditions?

These and many more such questions need to be answered. Therefore, in this paper I would like to review the state of current knowledge on the impact of housing design on hygiene, udder health and lameness.

Hygiene Scoring

Charting the distribution and degree of manure contamination over different areas of the cow's body is not a new idea. Various hygiene scoring systems have been developed over the years to investigate the influence of different kinds of stall base and bedding material on hygiene,[13,14,47] the influence of electric cow trainers,[7] and most recently to examine the effect of tail-docking on manure contamination.[21]

The majority of these systems have failed to be used on farm as a practical tool for monitoring hygiene outside of the research setting. For scoring to be useful to veterinarians and farmers, we must understand the significance of manure contamination on different zones of the body and then be able to compare the degree of contamination with some established benchmark, derived either on the farm itself over time, or from other similar farms.

Figure 1 shows a hygiene scoring system developed and used on Milk Quality Control Investigations for over one year by the author. It charts the degree of manure contamination in three main zones; the udder, the lower leg (rear only) and the upper leg and flank. The chart has evolved over time and a color version can now be downloaded at the web address: www.vetmed.wisc.edu/dms/fapm/forms.htm. Typically, all of the milking cows in a tiestall barn and 25% of the cows in each pen in a freestall barn are scored, along with dry cows and heifers.

Lower leg zone contamination will indicate the amount of manure that the cows have to walk through in alleyways and exercise areas. The upper leg and flank

zone will reflect contamination from lying in manure on the rear of stalls and in wet unhygienic dirt lots. Undocked tails that hang in wet manure filled alleys will also contribute to manure contamination in this zone. The transfer of manure from the lower legs and tail to the udder has been elegantly shown previously,[1] leaving the udder the most important area to score.

Each area is scored 1 = clean, little or no evidence of manure, 2 = clean, only slight manure splashing, 3 = dirty, distinct demarcated plaques of manure, and 4 = filthy, confluent plaques of manure. Any given cow should receive a separate score for each zone, not a single score representative of all zones. When presenting the data, it is uninformative for the farmer to present a mean or a median score for each zone, rather we should be interested in the proportion of scores which are "too dirty". I have arbitrarily designated scores 3 and 4 for each zone as "too dirty". Cows in different environments differ in the zonal pattern of contamination:

- Typically, freestall cows will have high lower leg scores due to poor alleyway hygiene. A few individual cows may have high flank and udder scores if they are lying in alleyways, but this does not usually present as a group problem. Pens where diagonal lying is a problem, especially in heifer groups, may show higher than average flank and upper leg scores.
- In contrast, tiestall cows usually have relatively clean lower legs, as they have less exposure to deep manure in alleys, but they tend to have higher flank and upper leg scores because of lying in manure deposited on the rear of the stall.
- Cows confined to a wet, muddy dirt lot will have the worst hygiene picture of all – their lower legs will be filthy from walking through deep mud and their upper legs and flanks will be covered from having to lie down in the dirt. Post-fresh cows in freestall barns will retain this contamination picture for several weeks.

Table 1 summarizes data collected from 20 Wisconsin dairy farms suggesting benchmarks for the proportion of each zone designated too dirty for freestall and tiestall herds.

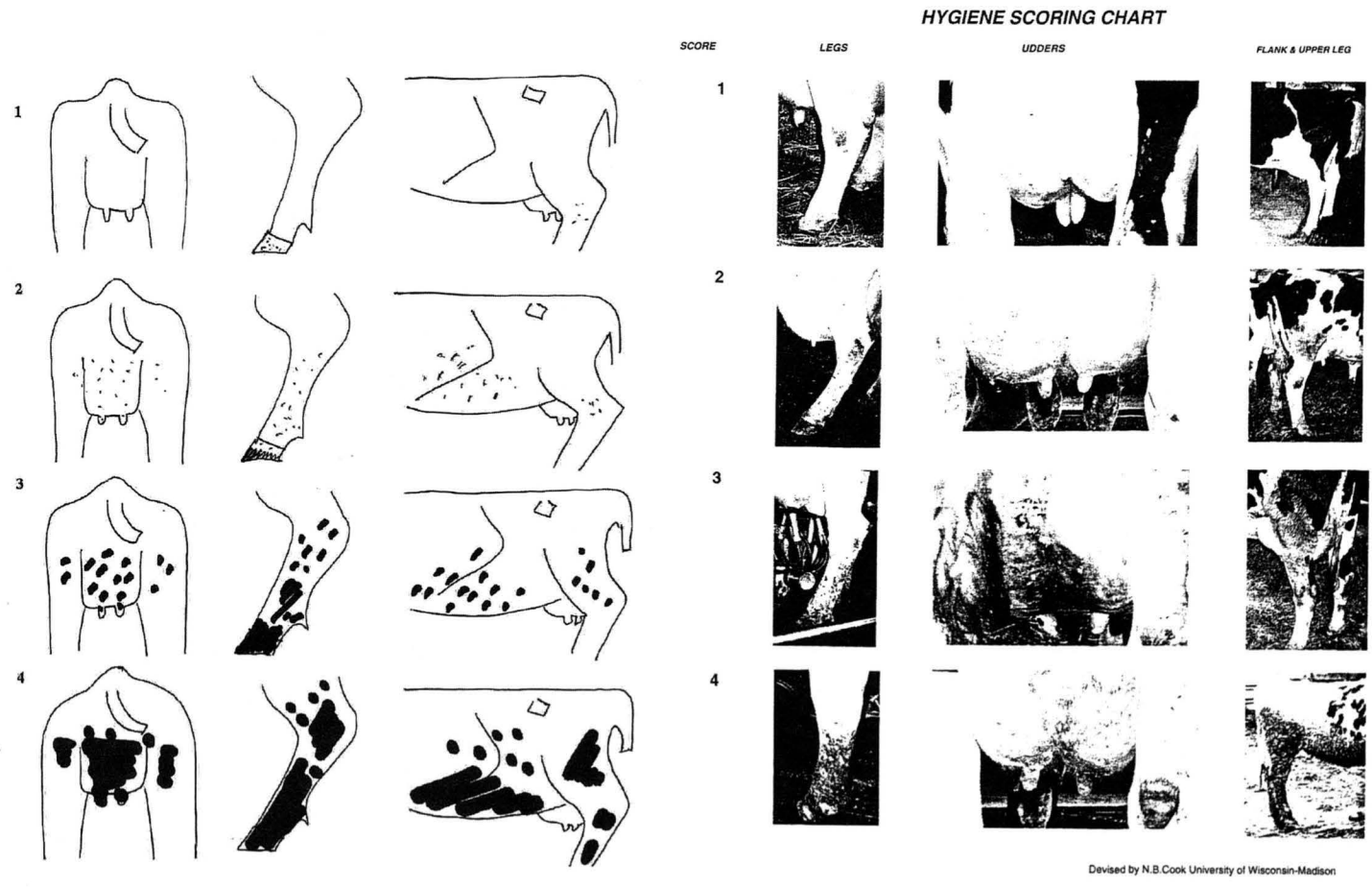

Figure 1. A chart for hygiene scoring cows on a scale of 1 - 4 for three zones of the body; udder, lower leg and upper leg and flank.

Table 1. Mean proportion of hygiene scores 3 and 4 for udder, lower leg and upper leg and flank zones for 20 Wisconsin dairy farms.

Barn type	Proportion of Hygiene Scores 3 and 4		
	Udder	Lower leg	Upper leg and flank
Mean freestall herds	19	55	19
Best freestall herd	5	26	7
Mean tiestall herds	20	25	30
Best tiestall herd	0	13	5

Why Should We Hygiene Score?

As a veterinarian visiting the farm, it is difficult to tell a farmer that their cows are "too dirty" and that improved cleanliness is required. Use of a quantitative approach, rather than a qualitative opinion, is a more effective means of delivering the message and by scoring in zones we can give more structured advice on how to keep cows cleaner.

For hygiene scoring to be taken seriously, there must be a cost associated with keeping animals dirty. For dairy cows, the cost of poor hygiene is an increased risk of mastitis and lameness.

Hygiene and Mastitis

It has long been known that the rate of new infection increases with the number of bacteria at the teat end.[35] Associations between clean housing, clean cows and lower herd bulk tank somatic cell count have previously been made.[4,5,10] An index of environmental sanitation based on the amount of manure present on the cow and in her environment was a predictor for the occurrence of coliform mastitis in one study.[6] A recent tail-docking study completed at the University of Wisconsin-Madison demonstrated a significant ($P<0.05$) increase in prevalence of environmental mastitis pathogens as udder hygiene score increased.[42] Data from Milk Quality Control Investigations (Figure 2) made by the author, demonstrates a significant ($R^2 = 0.47$, $P=0.004$) relationship between the proportion of udders scoring 3 and 4 on each farm and a six month mean new infection rate derived from monthly SCC analysis using an Excel template called WisGraph®[17]. These data confirm the significance of keeping cows and udders clean and lend support to the system of scoring presented.

It is however, important to realize that the presence of large bacterial numbers at the teat end may not always be obvious. Workers in Minnesota [9] have described a commercially available method of assessing the number of bacteria in bedding samples, and the author has personal experience of several instances where apparently clean bedding harbored many millions of potential udder pathogens which may have contributed to new infections. Hygiene scoring therefore forms only part of a thorough investigation into the source of environmental new infections.

Hygiene and Lameness

Cattle housed in wet, manure contaminated conditions are more likely to suffer infectious diseases of the foot,[8,16,40] such as interdigital necrobacillosis (foot rot), heel horn erosion (HHE) and papillomatous digital dermatitis (heel warts; PDD). A large survey of dairy herds across North America concluded that 43.5% of herds were affected with PDD.[53] The author's experience of 30 typical Wisconsin dairy farms suggests that 90% of the herds are now affected, and PDD is responsible for 52.6% of all lameness treatments.

Foot and Leg Hygiene in Tiestall Barns

Several studies have reported fewer lameness problems in tiestall barns,[23,28] but a recent Wisconsin survey [19] reported no significant difference between tiestall and freestall barns.

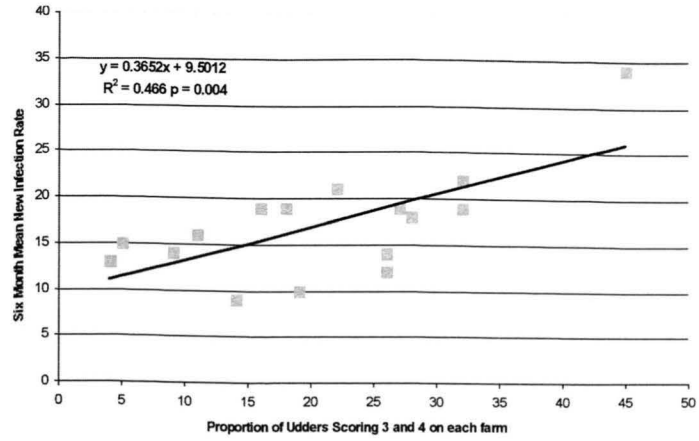

Figure 2. The association between udder hygiene score and intramammary new infection rate on 16 Wisconsin dairy farms.

Moisture level of the rear of the stall was an important determinant of lameness during the summer in a study of 18 midwestern dairy herds[52] that were predominantly tiestall housed. In a study on the use of rubberized slats over the rear of long tiestalls, compared with a solid floor, a lower risk of being dirty and a reduced incidence of PDD, HHE and claw lesions were found.[28] However, it was also noted that cows tended to lay in the adjacent stall more, suggesting a preference for lying on a solid floor. An attempt to improve hygiene may therefore have an adverse effect on cow comfort.

Electric cow trainers are commonplace in stanchion and tiestall barns throughout the midwest, yet they have been prohibited in Sweden since 1995 for welfare reasons. Trainers were beneficial in terms of improved stall hygiene and claw health and a decreased risk of hock lesions,[2,7] but another study showed an increased risk of silent heats, mastitis, ketosis and culling in 33 herds with trainers, compared with 117 herds without.[38] Many things impact the welfare of our dairy cows, and the authors experience with managing stanchion cows would suggest that "humane" trainers are an integral part of maintaining clean stalls and reducing the rate of clinical mastitis, which is in disagreement with the finding from the latter Swedish survey. A study involving within herd controls is required to shed more light on this area.

Other factors that will influence foot hygiene in tiestall facilities include the frequency of scraping of the manure from the exercise area and whether or not the manure gutter is cleaned before the cows exit the barn, or whether it is covered by a grate.

Foot and Leg Hygiene in Freestall Barns

Foot and leg hygiene in freestall barns is usually worse than in tiestalls (Table 1), largely because of the quantity of manure present in the alleys. Major factors influencing the degree of leg contamination in lactating cow pens are:

- Pen design – two rows or three rows of freestalls
- Frequency of alley scraping
- Stocking density in the pen
- Stall comfort and lying times

Two vs Three Rows

A three row freestall pen with three crossovers, designed to house 100 cows, will have approximately 4070 square feet of alleyway and crossovers. A two row freestall pen, also designed to house 100 cows tail-to-tail, with the same number of crossovers, will have approximately 5004 square feet of alleyway area. That equates to 20% less surface area for the same quantity of manure. Unless we scrape more frequently, the manure level in the pen will be deeper, resulting in dirtier feet and legs and an increased risk of PDD [20].

Frequency of Removal

Frequency and type of alley scraping will have a major impact on manure accumulation. Currently there are four main options:

- Slatted floors
- Flushing
- Manual scraping
- Automatic scrapers

Slatted floors are common in Europe, but they are coming under increased scrutiny due to poor air quality and high ammonia concentration levels in the barn. A recent study suggested that cows have no preference for grooved concrete or a slatted area.[45] However, with the varied climate in the US, slatted barns are unlikely to become commonplace. Flushing and manual scraping are usually performed when the cows are in the collecting yard for milking, normally 2 or 3 times per day. Guidelines for the frequency of removal of manure based on hygiene and health assessments are unavailable. Data from seven dairies in Wisconsin, scraping between 1 and 4 times a day, would suggest that three times a day should be viewed as a minimum frequency for the control of infectious foot disease. Automatic scrapers have the potential to keep freestall cow's lower limbs cleaner, only if they are operated continuously and over a short distance, so that cows do not have to walk through a large wave of manure as it progresses through the pen.

Overstocking

Overstocking will lead to more manure being deposited per square foot of alleyway and exacerbate existing problems, particularly in six row freestall barns, milked and scraped twice daily. It will also impact lying time and potentially increase the risk of laminitis if maintained over a long period.[32]

Lameness and Cow Comfort

Stall Comfort and Lying Times

There is a growing body of evidence that increased lying times have a beneficial effect on lameness prevalence and claw health. Increased time spent lying down in a clean dry comfortable stall will mean less time walking up and down alleyways and lead to cleaner drier feet. However, there are surprisingly few studies that combine documentation of lying times, claw lesions and lameness prevalence.

One Irish study[31] noted that decreased lying times and increased periods spent standing half-in and half-out of stalls with a more restrictive divider style and firmer stall surface were associated with reduced claw health. Another study showed that cows low in the hierarchy spent more than 45% of the time standing in alleys and suffered significantly more sole, interdigital and heel lesions.[24]

Other studies have tended to document stall problems and associations with lameness rather than lying time. Lack of surface cushion, low divider rails (<34cm, 13.5 inches), limited borrowing space and high rear curbs (>16-20cm, 6.5-8 inches) have all been related to an increase in lameness or laminitis.[15,22,31,40] A stall usage index, measured as the proportion of cows in stalls that were standing, either completely in or half-in stalls, one hour before milking, was significantly related to lameness prevalence in a recent Wisconsin lameness survey[19] (Figure 3).

Targets for appropriate daily lying time must come from studies of dairy cow behavior in an unencumbered environment. Workers at the University of Liverpool,[44] studying resting time for cows housed in deep straw bedded yards, suggested that 10 hours per day should be considered adequate lying time. More recently, another study found that lying times of cattle on pasture ranged from 10.9 to 11.5 hours per day [41]. A lying time of around 11 hours per day would therefore seem to be an appropriate target.

Tiestalls

Tiestall and stanchion stall lying times will be influenced by the degree of restriction to the rising and lying motion and by surface area and cushion. Several studies have found that, compared to behavior in loose housing, cows restricted in tiestalls were more reluctant to change position from lying to standing, with an increased frequency of interruption of the lying down movement extending the duration of the whole process.[26,30] Lying time increased in tiestalls from 10.4 hours per day on concrete to 12.2 hours per day on a mattress stall base.[27] Cows lay down less frequently, but for longer periods on concrete, suggesting that they were reluctant to perform the actual process of standing and lying. These studies taken together suggest an interaction between

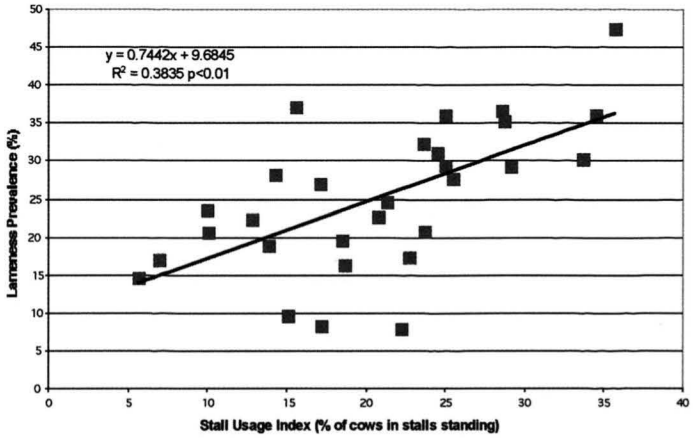

Figure 3. The relationship between Stall Usage Index and lameness prevalence in Wisconsin freestall herds.

lunging inhibition due to stall design, and rising surface. New recommendations have been suggested for extending the length of chains in tiestall barns to 40" long, with the tie rail located 48" above the mattress, in order to give cows greater freedom of movement.[3] However, our own lying time data from the School of Veterinary Medicine stanchion housed dairy herd indicates that we are able to maintain a mean daily lying time of 13 hours with an air mat deep bedded with shavings, even when lunging is severely restricted, suggesting that the stall surface maybe a more important determining factor for lying time than lunge restriction. Modification of stalls with a PVC bedding retainer, so that sand may be used for bedding, has been reported.[36] The success of many of these units may be related to the non-slip nature of the sand surface, rather than the degree of surface cushion *per se*.

Freestalls

Freestall usage is influenced by a number of animal and management factors, such as parity, stage of lactation and stocking rate, but stall design and comfort will always be the final determinant of whether a building is a success or not from the cow's perspective.

First lactation heifers, when first exposed to freestalls in a competitive environment, may lie down for as little as 6.25 hours per day.[43] Another study found that early lactation heifers lay down in the same stalls for only 9 hours per day,[12] compared to 11.4 hours when they were pregnant. Overcrowding has been found to decrease lying times in freestalls.[32,54] Irish workers found that in a group of heifers housed at a stocking density of 200% (2 heifers per stall), lying times were reduced to as little as 5 hours per day, and this was associated with worsening foot lesion scores.[32] Significantly, these authors pointed out that even at this stocking rate, it required several months for lameness to occur, suggesting that many studies on the effect of overstocking are of insufficient length to consider long-term implications to cow health.

A system of evaluating stall usage from the point of view of the cow has been devised[37] Stalls are analyzed on five main determining points:

- Adequacy of surface cushion
- A defined resting area of appropriate size related to the type of animal
- Adequate room for lunging and an unobstructed "bob zone"
- Adequate height below and behind the neck-rail to rise without hindrance
- A curb height no higher than 8 inches

The most important factor determining stall usage is surface cushion. It is the author's opinion that cows will tolerate many inadequacies of stall design to lie on a cushioned surface. Work in Germany[49] elegantly showed daily lying times increase with increasing sur-

face cushion in the same stall. An occupancy choice study demonstrated a cow preference for a deep soil bed over a rubber mat or concrete.[25] In the Wisconsin lameness survey, sand base stall housing achieved a significantly improved Stall Usage Index score and a lower prevalence of lameness [19] (Table 2).

In support of these data, a nine-month cow preference study at the University of Wisconsin demonstrated the best Stall Usage Index and proportion of time lying was achieved using sand freestalls, compared to a selection of mattresses, a water bed and a rubber mat.[39] Managing sand bedded stalls is not without its problems, but benefits from improved foot health alone more than compensate for its purchase and removal.[18] To date, there are no studies quantifying daily lying times for sand bedded freestalls. In contrast, there are a plethora of studies documenting improved lying times on mattresses compared with rubber mats and concrete surfaces.[11,12,27] Mattresses have a distinct disadvantage over sand because they carry a much greater risk of hock damage. In one study, 91% of cows on mattresses and only 24% of cows on sand had evidence of hock abrasion.[50]

The interaction between lameness, lying times, hygiene and the type of surface that the cow's foot is exposed to when she is standing is a complex one. Current theories on the pathogenesis of laminitis clearly demonstrate an interaction between events around parturition, diet and the environment.[33,51] In the authors opinion, excessive time spent weight bearing may facilitate the breakdown of the dermal-epidermal lamellar connection, initially triggered by the activation of metalloproteinases and other similar enzymes from either hormonal events around calving time[46] or from the action of *Streptococcus bovis* exotoxin[34] released during an acidotic event. Increased duration of weight bearing may facilitate the transport of the exotoxin to the capillary beds of the dermal tissues, and also stress the connections between the dermis and epidermis, facilitating sinking of the pedal bone within the horn capsule, subsequently producing clinical signs of laminitis at the sole surface.

Rough walking surfaces have been shown to increase lameness prevalence[23] and excessive exposure to concrete may result in excessive wear of the claws. However, the benefits of installing rubberized walking surfaces in the feed alleys of freestall barns have yet to be proven. One recent study[48] found no overall significant effect of rubber alleys on claw lesions and lameness, but did highlight the many complex interactions between stall base type and walking surface.

Conclusion

The environment in which we keep our dairy cows has a dramatic effect on their health and welfare. Designing clean comfortable housing, even if it is not the lowest cost or cheapest to maintain, is key in determining the health and longevity of the dairy cow on the farm. More research is required to determine the long-term health consequences of our housing decisions.

References

1. Abe N: The deeper the "mud", the dirtier the udder. *Hoard's Dairyman* 144: 439, 1999.
2. Alban L, Agger JF, Lawson LG: Lameness in tied Danish dairy cattle: the possible influence of housing systems, management, milk yield, and prior incidents of lameness. *Prev Vet Med* 29:135-149, 1996.
3. Anderson N: Observations on cow comfort using 24 hour time lapse video. *Proc 12th Int Symp Lameness in Ruminants*, Orlando, pp 27-34, 2002.
4. Barkema HW, Schukken YH, Lam TJGM, Beiboer ML, Benedictus G, Brand A: Management practices associated with low, medium and high somatic cell count in bulk milk. *J Dairy Sci* 81: 1917-1927, 1998.
5. Barkema HW, Van der Ploeg JD, Schukken YH, Lam TJGM, Benedictus G, Brand A: Management style and its association with bulk milk somatic cell count and incidence rate of clinical mastitis. *J Dairy Sci* 82:1655-1663, 1999.
6. Bartlett PC, Miller GY, Lanc SE, Heider LE: Managerial determinants of intramammary coliform and environmental Streptococci infections in Ohio dairy herds. *J Dairy Sci* 75:1241-1252, 1992.
7. Bergsten C and Pettersson B: The cleanliness of cows tied in stalls and the health of their hooves as influenced by the use of electric trainers. *Prev Vet Med* 13: 229-238, 1992.
8. Bergsten C: Infectious diseases of the digits. In *Lameness in Cattle, ed 3*. WB Saunders Co, Philadelphia, 1997, pp 89-100.
9. Bey RF, Reneau JK, Farnsworth RJ: The role of bedding management in udder health, 45 – 55 In *41st Annual Meeting Proceed-*

Table 2. The effect of stall base on lameness prevalence, Stall Usage Index and the proportion of cows with hock abrasions on 30 Wisconsin dairy farms.

	Sand stall base herds (n=8)	Other**stall base herds (n=22)
Mean (SE) lameness prevalence		
Summer	13.6 (3.2)*	24.2 (2.0)*
Winter	16.9 (4.0)*	27.2 (2.3)*
Freestall Stall Usage Index (%)	15.0*	25.0*
Proportion of cows with hock abrasion (%)	5.4*	38.8*

* Denotes statistical significance across rows at $P<0.05$, one way ANOVA
** Other refers to stall bases made of bedded concrete, rubber mats and rubber filled mattresses

ings of National Mastitis Council, Inc. February 3-6, Orlando, Florida, 2002.
10. Bodoh GW, Battista WJ, Schultz LH: Variation in somatic cell counts in Dairy Herd Improvement milk samples. *J Dairy Sci* 59:1119-1123, 1976.
11. Cermac J: Cow comfort and lameness – Design of cubicles. *Bov Pract 23:* 79-83, 1988.
12. Chaplin SJ, Tennent HE, Offer JE, Logue DN, Knight CH: A comparison of hoof lesions and behaviour in pregnant and early lactation heifers at housing. *Vet J* 159: 147-153, 2000.
13. Chaplin SJ, Tierney G, Stockwell C, Logue DN, Kelly M: An evaluation of mattress and mats in two dairy units. *App Ani Behaviour Sci* 66: 263-272, 2000.
14. Chiappini U, Zappavigna P, Frrari P, Rossi P: Straw flow litter for dairy cows: Experimental tests with different slopes and different quantities of straw. *Third International Dairy Housing Conference; Dairy Systems for the 21st Century*, Orlando, Florida, Published by ASAE, Michigan, USA, 1994, pp 138-144.
15. Colam-Ainsworth P, Lunn GA, Thomas RC, Eddy RG: Behaviour of cows in cubicles and its possible relationship with laminitis in replacement dairy heifers. *Vet Rec* 125: 573-576, 1989.
16. Cook NB, Cutler KL: Treatment and outcome of a severe form of foul-in-the-foot. *Vet Rec* 136: 19-20, 1995.
17. Cook NB, Nordlund K, Bennett T, Emery K: Quantifying the contribution of non-lactating cow udder infection to the overall incidence of new intra-mammary infections on farm. *2nd International Mastitis and Milk Quality Symposium*, Vancouver, Canada, September13 – 15, 2001, pp 121-125..
18. Cook NB: How good is sand bedding for your cows? *Hoard's Dairyman,* October 25th, 2001.
19. Cook NB: Lameness prevalence and the effect of housing on 30 Wisconsin dairy herds. *Proc 12th Int Symp Lameness in Ruminants*, Orlando, 2002, pp 325-327.
20. Cook NB: Two row barns or three-row – that is the question! *UK Vet* 7: 1-3, 2002.
21. Eicher SD, Morrow-Tesch JL, Albright JL, Williams RE: Tail docking alters fly numbers, fly avoidance behaviours and cleanliness, but not physiological measures. *J Dairy Sci* 84: 1822-1828, 2001.
22. Faull WB, Hughes JW, Clarkson MJ, Downham DY, Manson FJ Merritt, JB, Murray RD, Russell WB, Sutherst JE, Ward WR: Epidemiology of lameness in dairy cattle: the influence of cubicles and indoor and outdoor walking surfaces. *Vet Rec* 139: 130-136, 1996.
23. Faye B, Lescourret F: Environmental factors associated with lameness in dairy cattle. *Prev Vet Med* 7: 267-287, 1989.
24. Galindo F Broom DM: The relationships between social behaviour of dairy cows and the occurrence of lameness in three herds. *Res Vet Sci* 69: 75-79, 2000.
25. Gebremedhin KG, Cramer CO, Larsen HJ: Preference of dairy cattle for stall options in freestall housing. *Transactions of ASAE* 28: 1637-1640, 1985.
26. Haley DB, Rushen J, de Passille AM: Behavioural indicators of cow comfort: activity and resting behaviour of dairy cows in two types of housing. *Can J Anim Sci* 80: 257-263, 2000.
27. Haley DB, de Passille AM, Rushen J: Assessing cow comfort: effect of two types and two tie stall designs on the behaviour of lactating dairy cows. *Appl Anim Behav Sci* 71: 105-117, 2001.
28. Hultgren J: Observational and experimental studies of the influence of housing factors on the behaviour and health of dairy cows. *Doctoral thesis*. Uppsala, Sweden, 2001.
29. Keown McDaniel, 1979. Referenced in Vokey FJ, Guard CL, Erb HN, Galton DM: Effects of alley and stall surfaces on indices of claw and leg health in dairy cattle housed in a freestall barn. *J Dairy Sci* 84: 2686-2699, 2002.
30. Krohn CC, Munksgaard L: Behaviour of dairy cows kept in extensive or intensive environments II: Lying and lying down behaviour. *Appl Animal Behav Sci* 37: 1-16, 1993.
31. Leonard FC, O'Connell JM, O'Farrell KJ: Effect of different housing conditions on behaviour and foot lesions in friesian heifers. *Vet Rec* 134: 490-494, 1994.
32. Leonard FC, O'Connell JM, O'Farrell KJ: Effect of overcrowding on claw health in first-calved friesian heifers. *Br Vet J* 152: 459-472,1996.
33. Livesey CT, Harrington T, Johnston AM, May SA, Metcalf JA: The effect of diet and housing on the development of sole haemorrhage, white line haemorrhage and heel horn erosion in Holstein heifers. *Anim Sci* 67: 9-16, 1998.
34. Mungall BA, Kyaw-Tanner M, Pollitt CC: In vitro evidence for a bacterial pathogenesis of equine laminitis. *Vet Microbiol*. 79:209-223.
35. Neave FK, Dodd FH, Kingwill RG: A method on controlling udder disease. *Vet Rec* 78:521-725, 1966.
36. Niles DN: Sand bedding in tiestall operations. *Third International Dairy Housing Conference; Dairy Systems for the 21st Century*, Orlando, Florida. Published by ASAE, Michigan, USA, 1994, pp 173-176.
37. Nordlund K, Cook NB: A flowchart for evaluating dairy cow freestalls. *Comp Cont Ed Pract Vet* (Submitted for publication), 2002.
38. Oltenacu PA, Hultgren J, Algers B: Associations between use of electric cow-trainers and clinical diseases, reproductive performance and culling in Swedish dairy cattle. *Prev Vet Med* 37: 77-90, 1998.
39. Palmer R: *Personal Communication*, 2002.
40. Philipot JM, Pluvinage P, Cimarosti I, Sulpice P, Bugnard F: Risk factors of dairy cow lameness associated with housing conditions. *Vet Res* 25:244-248, 1994.
41. Phillips CJC, Rind MI: The effects on production and behaviour of mixing uniparous and multiparous cows. *J Dairy Sci* 84: 2424-2429, 2001.
42. Ruegg P: *Personal Communication*, 2002.
43. Singh SS, Ward WR, Lautenbach K, Hughes JW, Murray RD: Behaviour of first lactation and adult dairy cows while housed and at pasture and its relationship with sole lesions. *Vet Rec* 133: 469-474, 1993.
44. Singh SS, Ward WR, Hughes JW, Lautenbach K, Murray RD: Behaviour of dairy cows in a straw yard in relation to lameness. *Vet Rec* 135: 251-253, 1994.
45. Stefanowska J, Swierstra D, Van den Berg JV, Metz JHM: Do cows prefer a barn compartment with a grooved or slotted floor? *J Dairy Sci* 85:79-88, 2002.
46. Tarlton JF, Webster AJF: A biochemical and biomechanical basis for the pathogenesis of claw horn lesions. *Proc 12th Int Symp Lameness in Ruminants*, Orlando, 2002, pp 395-398.
47. Visser RQ: A comparison of bedding material for dairy cows – a case study. *Third International Dairy Housing Conference; Dairy Systems for the 21st Century*, Orlando, Florida. Published by ASAE, Michigan, USA, 1994, pp 186-191.
48. Vokey FJ, Guard CL, Erb HN, Galton DM: Effects of alley and stall surfaces on indices of claw and leg health in dairy cattle housed in a freestall barn. *J Dairy Sci* 84: 2686-2699, 2002.
49. Wandel H, Jungbluth T, Benz B: Cow comfort in loose house systems. *Proc 12th Int Symp Lameness in Ruminants*, Orlando, 2002, p 313.
50. Weary DM, Taszkun I: Hock lesions and freestall design. *J Dairy Sci* 83: 697-702, 2000.
51. Webster AJF: Effects of housing and two forage diets on the development of claw horn lesions in dairy cows at first calving and in first lactation. *Vet J* 162: 56-65, 2001.
52. Wells SJ, Trent AM, Marsh WE, Williamson NB, Robinson RA: Some risk factors associated with clinical lameness in dairy herds in Minnesota and Wisconsin. *Vet Rec*136: 537-540, 1995.
53. Wells SJ, Garber LP, Wagner BA: Papillomatous digital dermatitis and associated risk factors in US dairy herds. *Prev Vet Med* 38:11-24, 1999.
54. Wierenga HK, Hopster H: The significance of cubicles for the behaviour of dairy cows. *Appl Anim Behav Sci* 26: 309-337, 1990.