Foot health in housed cattle: A review

I. du Plessis
Limpopo Province: Department of Agriculture, Mara Research Station, Private Bag X2467, Louis Trichardt 0920, South Africa

Abstract
The aim of this review is to highlight some of the repercussions of locomotive disorders in housed cattle. Some of the reasons for claw injuries are discussed, while the effect of housing and floor type on the claw health and animal welfare/comfort of animals is also conferred. It is argued that the economic implications of poor claw health are a combination of loss of production and the cost incurred in treatment of the injuries. In conclusion some preventative measures are proposed.

Keywords: Animal comfort, claw injuries, housing system, lameness
E-mail: duplessisizak@yahoo.com

Introduction
The intensification of cattle production systems (referring especially to the housing or penning of animals in dairies and feedlots) inevitably led to increased health and welfare problems. These health problems can mostly be ascribed to management practices (Kossaibati & Esslemont, 1997). Although estimates for the prevalence of diseases vary to a large extent, most authors are in agreement that in dairies reproductive disorders, udder health and lameness are regarded as the three main reasons for culling animals (Seegers *et al*., 1998). Insight into the impact of a disease will assist in the understanding of the impact thereof on the economy of the production system (Enting *et al*., 1997).

Lameness broadly refers to a wide range of foot and leg diseases (Ettema & Østergaard, 2006). The proportion of cows culled for locomotive disorders ranged from as low as 2.7% in France (Seegers *et al*., 1998) and 7% in Australia (Harris *et al*., 1988) to from 25% (Whitaker *et al*., 1983) to 34.7% (Enting *et al*., 1997) in the Netherlands. In Kenya the prevalence of clinical lameness was 11.7%, while foot lesions were encountered in 32.9% of all cattle examined (Gitau *et al*., 1996).

The treatment of claw injuries directly impacts negatively on the cost of the production system (Seegers *et al*., 1998) as well as indirectly on the reproduction and production of the animals (Enting *et al*., 1997; Kossaibati & Esslemont, 1997). Depending on the occurrence of claw disorders, the economic impact is regarded as moderate (Seegers *et al*., 1998) to high (Kossaibati & Esslemont, 1997). According to Enting *et al*. (1997) cost calculations vary because different authors include different production factors in their calculations and references containing calculations considering all factors are very rarely found.

Apart from the production and economic implications of diseases for the producer, public awareness of animal health and welfare issues accompanying an intensive production system is ever growing (Kossaibati & Esslemont, 1997; Fregonesi & Leaver, 2001). Loose-housing systems are increasing and are viewed as an enhancement with regards to animal welfare compared to tie-stalls (Fregonesi & Leaver, 2001). In fact, in some European countries (e.g. Switzerland) governments introduced incentive programs to encourage producers to implement more measures to enhance animal health and welfare more than is required by legislation (Regula *et al*., 2004).

Although the simple reasons for claw problems, the economic impact thereof coupled with animal health and welfare issues and production implications will be highlighted in this review, it must be made clear that lameness in cattle is of a complex, multi-factorial nature (Vermunt, 2005).

Reasons/mechanisms for claw injuries
Most claw lesions stem from the claw-floor surface interface (Gitau *et al*., 1996; De Belie & Rombaut, 2003; Laech *et al*., 2005). The hardness/softness, smoothness/roughness and moisture load of the floor contributed significantly to the incidence of lameness. Floor design may contribute to high local pressures (De Belie & Rambaut, 2003) which may in turn lead to trauma of the dermis of the sole (Distl & Mair,

1993). Gitau *et al*. (1996) calculated that the odds of becoming clinically lame were 2.9 times more for cattle in zero-grazing systems than for grazing cattle. Clinical lameness can manifest itself as soon as four months after the animals are housed (Leach *et al*., 2005)

De Belie & Rambaut (2003) remarked that the outer hind claws are the most inclined to claw lesions. In fact, Weaver *et al*. (1981) determined that while 88% of all lesions were on the claws, 84% were on the hind claws. This is comparable to the 90.1% and 94% of lesions that Gitau *et al*. (1996) and Galindo *et al*. (2000) calculated respectively for cattle in their studies. Gitau *et al*. (1996), however, found fewer (63.6%) lesions on the hind legs than Weaver *et al*. (1981). De Belie & Rambaut (2003) summarized the physical mechanism for this phenomenon from the work of Toussaint Raven (1977). In conclusion it can be remarked that the outer hind claws are subjected to high fluctuations in their load due to small side way movements, while the load on the inner claws stays much more stable.

Hard surfaces (concrete floors) will increase this effect (De Belie & Rambaut, 2003). These authors indicated that metal floated concrete floors resulted in the largest claw-floor contact areas and the lowest pressures, while washed concrete floors resulted in the smallest claw-floor contact area and the highest pressures.

According to Kossaibati & Esslemont (1997), Manske *et al*. (2002) and Seymore *et al.* (2002) digital disease accounted for 46, 47 and 22% of all lesions, respectively. This infectious disease spreads very readily in a wet, poorly ventilated environment (Ettema & Østergraad, 2006). Digital disease is an infectious condition that affects the skin on the bulbs of the heel or between the digits (Ettema & Østergaard, 2006). It causes inflammation and skin damage (Laven & Proven, 2000).

Interdigital disease accounted for 22% of all lame cases (Kossaibati & Esslemont, 1997). Gitau *et al.* (1996) reported an incidence of 39% of all lame cases for interdigital necrobacillosis followed by severe overgrowth (15.2%).

Sole ulcers seem to be a result of neglected laminitis (a non-infectious inflammation of the soft tissue of the claw), poor horn quality overloading of a limited area of the sole. Ulcers present as defects in the sole horn (Hultgren, 2002) account for 31% of all lame cases (Kossaibati & Esslemont, 1997).

Locomotive ease decreased with increasing age in dairy cows (Gitau *et al*., 1996; Boeling & Pollot, 1998) and should be viewed as being inherent to dairy systems focusing on long-living-high-producing cows (Boeling & Pollot, 1998).

Gitau *et al*. (1996) also theorized that high levels of feeding stimulates hoof growth to an extent where it may exceed the rate of wear, but this phenomenon cannot be described that easily. Leach *et al*. (2005) stated that diet affect claws directly as well as indirectly; directly though the physical effects of nutrition and digestion within the animal and indirectly through factors affecting the behaviour of the animal (e.g. time required for feeding), the physical environment they experience (e.g. properties of the manure they produce) and the interaction between these. The effect of diet seems to be exerted through its effect on the growth pattern and hardness of the hoof horn (Laech *et al*., 2005). Animals on a wet grass silage-based diet had poorer claw health than animals on a barley straw-sugar beet pulp diet. These results confirm that of Webster (2001) and Offer *et al*. (2003) that wet feeding increases claw horn lesions.

Leach *et al*. (2005) argued that diets resulting in wetter, less viscous slurry increased horn wetness by penetrating the horn more easily. This predisposed the hoof horns, especially in the heel region to higher erosion rates.

Although the reasons differ, the results of Galindo & Broom (2000) and Leach *et al*. (2005) correspond. Both studies deduced that the longer housed animals are standing the more prone they are to lameness (through heel erosion); Galindo & Broom (2000) in terms of pecking order and Leach *et al*. (2005) in terms of the time required to consume the daily ration.

There is evidence that animals do not fully recover from lameness suffered at a young age during the raising phase (Leach *et al*., 2005).

Economic implications

Kossaibati & Esslemont (1997) reported that 18.7% of the herd was affected by lameness, but that the total number of cases per 100 cows was 28.1. Approximately $^{1}/_{3}$ of all lame cows were replaced, which equated to 7.6% of all culled cows (Enting *et al*., 1997). Enting *et al*. (1997) remarked that lameness is regarded as the third most important reason for losses from diseases on dairy farms. To comprehend the rationale behind the economic implications, one first has to grasp the effect of lameness on the production of animals.

Effect of lameness on production parameters

From their own and previous studies Enting *et al*. (1997) deduced that there are five main factors (accounting for 93.5% of total losses) that affect the losses due to lameness, namely: losses in milk, fat and protein production, loss of future income, cost associated with premature culling, prolonged calving intervals, cost of labour and treatments by producer.

Lameness affects the reproduction rate and milk production negatively, most probably through a reduction in intake (Ettema & Østergraad, 2006) coupled with resulting metabolic disorders (Enting *et al*., 1997). Apart from a reduction in total milk production (11.3%), the fat (14.1%) and protein (16.4%) production were also reduced (Enting *et al*., 1997). The estimated reduction in total milk production varies to a great extent between different studies and was calculated to be 360 kg, 120 kg and 70 kg on average by Ettema & Østergraad (2006), Kossaibati & Esslemont (1997) and Enting *et al*. (1997), respectively.

Kossaibati & Esslemont (1997) stated that more than half of the total cost for the treatment of lameness stemmed from reduced fertility and a higher culling rate. They also concluded that mastitis and lameness are the most expensive disorders.

Effect of lameness on costs

The cost involved in the treatment of lameness can be divided into two classes namely: direct costs and indirect costs (Kossaibati & Esslemont, 1997). Direct costs include veterinarian costs and medicine costs, while indirect costs include lower milk production, lower reproduction rates and other subsequent diseases (Borsberry & Dobson, 1989; Oltenacu *et al*., 1990; Mellado & Reyes, 1994).

Losses due to lameness are usually expressed in terms of the total loss per lame cow and the total loss per cow present in the herd. Calculated losses from claw diseases are tabulated in Table 1.

Table 1 Average losses made for cows with claw diseases

Source	Currency	Losses per lame cow per year	Losses per average cow in herd
Whitaker *et al*. (1983)			
Lameness	£	47.00	11.75
Harris *et al*. (1988)			
Clinical lameness	AUS$	42.90	3.20
Enting *et al*. (1997)			
Digital disease	NLG	229.79 (€ 104)	48.76
Koissabati & Esslemont (1997)			
Digital dermatitis	£	240.24	
Interdigital disease	£	131.12	
Sole ulcer	£	424.92	
Ettema & Østergaard (2006)			
Lameness	NLG	192	

Enting *et al*. (1997) also compared the cost of clinical digital disease of herds with the lowest incidence of lameness to that of herds with the highest incidence. The losses per lame cow in herds with the highest incidence (NLG 172.08) were approximately half of that of the herds with the lowest incidence (NLG 389.86). However, if the total loss per average cow in the herd was calculated, the losses in herds with the lowest incidence were approximately half of that of herds with the highest incidence (NLG 24.32 *vs*. NLG 57.86).

Using a footbath to reduce the prevalence of digital dermatitis, Ettema & Østergraad (2006) indicated that when digital dermatitis accounted for 25% of lame cases, the margin per cow-year was increased by € 8.00 and only € 4.20 when the incidence was 13%.

As the milk production of cows is much lower on small-scale, rural farms (~ 5 kg/cow/day) than on commercial farms, the economic impact is expected to be much less for small-scale dairies than for commercial dairies (Gitau *et al*., 1996).

Effect of housing on animal health and animal welfare/comfort

In Europe with its extremely cold winters, animals are usually kept indoors during the winter (Hultgren, 2002). Either tie-stalls or loose housing systems (strawyards and cubicles, according to Fregonesi & Leaver, 2001 and Hultgren, 2002) are used. Tie-stalls are usually older facilities, while loose-housing systems are more recently erected facilities aimed at the improvement of animal welfare and comfort (Fregonesi & Leaver, 2001; Hultgren, 2002; Regula *et al*., 2004).

Animal welfare and comfort is usually assessed by a combination of assessment methods. These methods include behavioural observations, evaluation of skin alterations indicative of poor 'cow comfort', clinical examination and health records (Regula *et al*., 2004).

Although contradictory results exist (Hultgren, 2002), loose-housing is widely deemed to improve animal welfare and comfort compared to tie-stalls (Regula *et al*., 2004). This is probably due to an increased level of exercise as Regula *et al*. (2004) reported that the introduction of regular exercise in tie-stalls also improved animal welfare and comfort, most probably through improved claw health (Krohn & Munksgaard, 1993; 1994; Weary & Taszkun, 2000). Gustafson, (1993) and Gustafson & Lund-Magnussen (1995) also found that regular exercise increased claw health. In a loose-housing system access to an outside area and pastures usually forms part of the housing system.

Behavioural studies found that animal welfare and comfort differed between strawyards and cubicles. In one experiment, cows in strawyards spent more time lying down ($P < 0.01$), ruminating ($P < 0.001$) occupying the bed area ($P < 0.001$), while no significant differences could be detected in a second experiment (Fregonesi & Leaver, 2001). This indicates that animals in cubicles are not necessarily uncomfortable. No significant differences in agonistic behaviour were found between the two housing systems (Fregonesi & Leaver, 2001).

Pecking order (ranking) influenced the behaviour of cows. Low ranking cows spent less time lying and more time standing still than medium and high ranking cows (Galindo & Broom, 2000). However, eating times did not differ between the high, medium and low ranking groups. As the time standing increased, the number of interdigital and heel lesions increased (Galindo & Broom, 2000). Low ranking cows also had a higher incidence of lameness compared to medium and high ranking cows.

The effect of pecking order can be compounded by animal density in loose-housing systems. Fisher *et al*. (1997) mentioned that at higher animal densities live weight gain is reduced either due to reduced food intake, reduced feed conversion ratio and/or a combination thereof. Growth rates dropped from ~ 0.70 kg per day to 0.52 kg per day when the space allowance per animal (beef heifers) was decreased from between 2.0 and 3.0 m^2 to 1.5 m^2 (Fisher *et al*., 1997). At 2.0, 2.5 and 3.0 m^2 no significant differences in growth rate were observed. The reduction in the efficiency in feed conversion is ascribed to the fact that at 1.5 m^2 heifers were standing for longer periods and lying down less than when more space was allowed.

Although the two loose-housing systems used by Fregonesi & Leaver (2001) appear to have very little effect on milk production, body condition and calving to conception intervals, studies indicating the contrary are cited by them.

In stawyards cows seem to be dirtier than in cubicles which may lead to a higher incidence of mastitis and somatic cell count in strawyards (Albright & Alliston, 1971; Bakken, 1981; Fregonesi & Leaver, 2001).

As cows in both strawyards and cubicles have access to concrete areas and as a result thereof hoof wear is similar for both housing systems (Fregonesi & Leaver, 2001). Therefore no differences in locomotive disorders were found between these two housing systems.

Effect of floor type on claw health and animal welfare/comfort

There are indications that floor type and construction has a high impact on walking and lying comfort of animals (De Belie, 1997). The effect seems to be exerted through a two-way mechanism; the effect of the floor roughness and the presence of moisture (urine and faeces), as summarized by De Belie & Rombaut (2003) and Laech *et al*. (2005). According to Chaplin *et al*. (2000) floor material should improve cow comfort when lying down and yet provide enough support for cows to rise and lie down without slipping.

Rubber-slatted floors improved cleanliness and thereby also animal health and comfort (Hultgren & Bersten, 2001). The incidence of udder diseases and infectious claw diseases were reduced on rubber-slatted floors compared to matted floors (Hultgren & Bergsten, 2001). There was no significant difference in claw horn growth and wear between rubber-slatted and rubber-mat floors (Hultgren & Bergsten, 2001).

Animals react very differently if rubber flooring is compared to concrete flooring. Haley *et al.* (2001) found that cows on mattress flooring lay down for 1.8 hours per day more (51.0 *vs.* 43.4%) than cows on concrete floors, while cows also lay down for longer times on mattress flooring (68 *vs.* 62 minutes). Floor type did not influence the time spent eating.

Rubber mattresses consist of multiple cells filled with uniformly sized rubber crumbs (Haley *et al.*, 2001). Chaplin *et al.* (2000) compared the comfort of cows housed on mattresses to that of cows housed on rubber mats. They observed no differences in terms of milk production, feed intake, weight change or the prevalence of lameness between the two types of flooring. Cows on mattresses did, however, seem to adapt quicker to housing than those on mats. Cows on mattresses spent more time eating, lying down and ruminating than cows on mats, suggesting that they were more comfortable on mattresses than on mats.

Tuytens (2005) remarked that rubber flooring can provide equal floor-comfort to cows than straw bedding. Disadvantages of straw include cost, labour, hygiene and incompatability with manure drainage system (Tuytens, 2005).

On a grooved concrete floor, the scraper posed more of a problem to the cows than slipping (Stefanowska *et al.*, 2001). Although minor differences were observed in the behaviour of the cows, the study was done over too a short period (six weeks in total) to make any meaningful conclusion as to the effect on claw health.

Possible control or prevention strategies for claw diseases

Reducing the prevalence of lameness will reduce the total cost involved in the treatment of the disease (Ettema & Østergaard, 2006). Several preventative measures exist that can be included in the management strategy to reduce the incidence of lameness and will be discussed briefly.

Footbaths

Although Laven & Proven (2000) reported that footbaths reduced the risk of lameness due to digital dermatitis, Ettema & Østergaard (2006) assumed that it does not have an influence on the severity of other forms of lesions. The effectiveness of footbaths also varied depending on the prevalence of digital dermatitis in the herd. With an incidence of 25% of all lameness cases, footbaths increased the margin per cow-year by € 9.40, while it was only increased with € 6.60 when the incidence was 13% (Ettema & Østergaard, 2006).

Biotin supplementation

Biotin is a B vitamin and a nutrient involved in keratin synthesis and deposition (Lisher *et al.*, 2002). Biotin supplementation seems to reduce the risk of lameness due to white line disease by half (Hedges *et al.*, 2001). Supplementing biotin increased the margin per cow-year by € 3.00 (P = 0.01; Ettema & Østergaard, 2006). Lisher *et al.* (2002) cited various studies indicating that the effect of biotin is not through a faster horn growth rate, but rather due to improved horn quality.

Preventative trimming

Preventative trimming restores/maintains the symmetry between claws and the correct shape of the claws (Manske *et al.*, 2002). Nuss & Paulus (2006) suggested that the sole of the medial (inner) claw should be left 3 mm thicker than the lateral (outer) claw in order for the sole of the lateral claw to remain thick enough to protect the corium and the claw to retain a normal shape.

Rubber flooring

Ettema & Østergaard (2006) quoted Benz (2002) regarding the effect of rubber flooring on foot lameness. She concluded that elastic, yielding flooring improved claw health (reduced incidence of sole ulcers, white line diseases and bruises) and slip resistance significantly compared to hard concrete and slatted flooring. Rubber flooring reduced the incidence of lameness significantly more in zero grazing systems than in grazing systems (Ettema & Østergraad, 2006).

Although rubber flooring increased the margin per cow-year, the cost of for instance extra trimming should be considered together with the cost of installation (Ettema & Østergaard, 2006). This is necessary as these authors indicated that the net growth of the claws of cows on rubber flooring was significantly higher compared to that of cows on concrete floors (0.74 *vs*. 0.34 cm in 100 days). These authors calculated that coupled with preventative trimming twice per year, installing rubber flooring increased the margin per cow-year with € 14.20.

Decreasing the length of time spent indoors

According to the reasoning of Ettema & Østergaard (2006) cows are less likely to become lame during the time of the year that they spend foraging on pastures. Thus if the duration of the housing period is shortened, the cows are at a lower risk of becoming lame for a longer period. Increasing the time that cows grazing time at pasture with 56 days resulted in a € 3.90 ($P < 0.01$) increase in the margin per cow-year (Ettema & Østergaard, 2006).

References

Albright, J.L. & Alliston, C.W., 1971. Effects of varying the environment upon the performance of dairy cattle. J. Anim. Sci. 32, 556-577.

Bakken, G., 1981. Environment and bovine udder diseases in the loose housing systems for dairy cows with reference to relevant data from the cow house system. Acta Agric. Scandinavia 31, 445-451.

Benz, B., 2002. Cited by Ettema & Østergaard, 2006.

Boelling, D. & Pollott, G.E., 1998. Locomotion, lameness, hoof and leg traits in cattle I. Phenotypic influences and relationships. Livest. Prod. Sci. 54, 193-203.

Borsberry, S. & Dobson, H., 1989. Periparturient diseases and their effect on reproductive performance in five dairy herds. Vet. Rec. 124, 217-219.

Chaplin, S.J., Tierney, G., Stockwell, C., Logue, D.N. & Kelly, M., 2000. An evaluation of mattresses and mats in two dairy units. Appl. Anim. Behav. Sci. 66, 263-272.

De Belie, N., 1997. On-farm trial to determine the resistance of different concrete slats for fattening pigs. J. Agric. Eng. Res. 68, 311-316.

De Belie, N. & Rombaut, E., 2003. Characterization of claw-floor contact pressures for standing cattle and the dependency on concrete roughness. Biosystems Engineering 85, 339-346.

Distl, O. & Mair, A., 1993. Computerized analysis of pedobarometric forces in cattle at the ground surface/floor interface. Computers and Electronics in Agriculture 8, 237-250.

Enting, H., Kooij, D., Dijkhuizen, A.A., Huirne, R.B.M. & Noordhuizen-Stassen, E.N., 1997. Economic losses due to clinical lameness in dairy cattle. Livest. Prod. Sci. 49, 259-267.

Ettema, J.F. & Østergaard, S., 2006. Economic decision making on prevention and control of clinical lameness in Danish dairy herds. Livest. Sci. 102, 92-106.

Fisher, A.D., Crowe, M.A., Kiely, P.O. & Enright, W.J., 1997. Growth, behaviour, adrenal and immune responses of finished beef heifers housed on slatted floors at 1.5, 2.0, 2.5 or 3.0 m^2 space allowance. Livest. Prod. Sci. 51, 245-254.

Fregonesi, J.A. & Leaver, J.D., 2001. Behaviour, performance and health indicators of welfare for dairy cows housed in strawyard or cubicle systems. Livest. Prod. Sci. 68, 205-216.

Galindo, F. & Broom, D.M., 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., Broom, D.M. & Jackson, P.G.G., 2000. A note on possible link between behaviour and the occurrence of lameness in dairy cows. Appl. Anim. Behav. Sci. 67, 335-341.

Gitau, T., McDermott, J.J. & Mbiuki, S.M., 1996. Prevalence, incidence, and risk factors for lameness in dairy cattle in small-scale farms in Kikuyu Division, Kenya. Prevent. Vet. Med. 28, 101-115.

Gustafson, G.M., 1993. Effects of daily exercise on the health of tied dairy cows. Prevent. Vet. Med. 17, 209-223.

Gustafson, G.M. & Lund-Magnussen, E., 1995. Effect of daily exercise on the getting up and lying sown behaviour of tied dairy cows. Prevent. Vet. Med. 25, 27-36.

Haley, D.B., Passillé, A.M. & Rushen, J., 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.

Harris, D.J., Hibburt, C.D., Anderson, G.A., Younis, P.J., Fitspatrick, D.H., Dunn, A.C., Parsons, I.W. & McBeath, N.R., 1988. The incidence, cost and factors associated with foot lameness in dairy cattle in south-western. Victoria. Aust. Vet. J. 65, 171-176.

Hedges, J., Blowey, R.W., Packington, A.J., O'Callaghan, C.J. & Green, L.E., 2001. A longitudinal field trail of the effect of biotin on lameness in dairy cows. J. Dairy Sci. 84, 1969-1975.

Hultgren, J., 2002. Foot/leg and udder health in relation to housing changes in Swedish dairy herds. Prevent. Vet. Med. 53, 167-189.

Hultgren, J. & Bergsten, C., 2001. Effects of a rubber-slatted flooring system on cleanliness and foot health in tied dairy cattle. Prevent. Vet. Med. 52, 75-89.

Kossaibati, M.A. & Esslemont, R.J., 1997. The cost of production diseases in dairy herds in England. Vet. J. 154, 41-51.

Krohn, C.C. & Munksgaard, L., 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.

Krohn, C.C. & Munksgaard, L., 1994. Behaviour of dairy cows kept in extensive (loose housing/ pasture) or intensive (tie small) environments. III. Grooming, exploration and abnormal behaviour. Appl. Anim. Behav. Sci. 42, 73-86.

Laven, R.A. & Proven, M.J., 2000. Use of an antibiotic footbath in the treatment of bovine digital dermatitis. Vet. Rec. 147, 503-506.

Leach, K.A., Offer, J.E., Svoboda, I. & Logue, D.N., 2005. Effects of type of forage fed to dairy heifers: Associations between claw characteristics, clinical lameness, environment and behaviour. Vet. J. 169, 427-436.

Manske, T., Hultgren, J. & Bergsten, C., 2002. The effect of claw trimming on the hoof health of Swedish dairy cattle. Prevent. Vet. Med. 54, 113-129.

Mellado, M. & Reyes, C., 1994. Associations between periparturient disorders and reproductive efficiency in Holstein cows in Northern Mexico. Prevent. Vet. Med. 19, 203-212.

Nuss, K. & Paulus, P., 2006. Measurements of claw dimensions in cows before and after functional trimming: A post-mortem study. Vet. J. 172, 284-292.

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

Oltenacu, P.A., Frick, A. & Lindhe, B., 1990. Epidemiological study of several clinical diseases, reproductive performance and culling in primiparous Swedish cattle. Prevent. Vet. Med. 9, 59-74.

Regula, G., Danuser, J., Spycher, B. & Wechsler, B., 2004. Health and welfare of dairy cows in different husbandry systems in Switzerland. Prevent. Vet. Med. 66, 247-264.

Seegers, H., Beaudeau, F., Fourichon, C. & Bareille, N., 1998. Reasons for culling in French Holstein cows. Prevent. Vet. Med. 36, 257-271.

Stefanowska, J., Swierstra, D., Braam, C.R. & Hendriks, M.M.W.B., 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.

Toussaint Raven, E., 1977. Cited by De Belie & Rombaut, 2003.

Tuyttens, F.A.M., 2005. The importance of straw for pig and cattle welfare: A review. Appl. Anim. Behav. Sci. 92, 261-282.

Vermunt, J.J., 2005. The multifactorial nature of cattle lameness: A few more pieces of the jigsaw. Vet. J. 169, 317-318.

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

Weaver, A.D., Anderson, L., De Laistre Banting, A., Knezevic., P.F., Peterse, S.J. & Sankovic, F., 1981. Review of disorders of the ruminant digit with proposals for anatomical and pathological terminology and recording. Vet. Rec. 106, 117-120.

Webster, A.J.F., 2001. 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.

Whitaker, D.A., Kelly, J.M. & Smith, E.J., 1983. Incidence of lameness in dairy cows. Vet. Rec. 113, 60-62.