# Effect of Flooring System on Locomotion Comfort in Dairy Cows:

## Aspects of Gait, Preference and Claw Condition

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# Abstract

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The aim of the thesis was to study influence of different flooring systems on several aspects of locomotion of dairy cows. To assess the gait on different floors, trackway analysis was used. Cows walking on a hard, slippery surface had shorter strides, wider posture and asymmetric steps. A hard, slippery surface resulted in stride shortening, wider posture and asymmetric gait. Using soft rubber mats made gait patterns more similar to those on a natural yielding surface such as sand. When cows with moderate lameness walked on yielding surfaces their gait parameters associated with lameness were less pronounced than on hard concrete surfaces.

Preference studies showed that the majority of cows preferred to walk and stand on soft rubber flooring rather than on concrete flooring. However, lame cows within the group did not show a stronger preference to walk on soft flooring than non-lame cows, presumably due to lower social rank compared to healthy herd mates.

In order to assess the effects of long-term exposure to flooring systems differing in hardness and abrasiveness installed in the walking and standing areas an experimental study was carried out. Claw conformation, claw horn growth and wear rates, as well as static weight and pressure distribution were evaluated. On a rougher flooring (mastic asphalt), exaggerated wear, highest growth rate and a loss of sole concavity was seen, and most weight was exerted to the sole area of the claws. When rubber-equipped feed-stalls were used together with mastic asphalt in alleys cows showed reduced wear, positive net growth and reduced loss of the concavity compared to cows housed on asphalt alley surfaces. In comparison with asphalt flooring, rubber mats on the alleys resulted in lower growth and wear rates, increased net growth, preserved sole concavity and the bulb and wall area of the claw carried the most weight. Rubber mats together with little exposure to an abrasive asphalt surface resulted in claw horn net growth rates similar to that observed on aged, low abrasive concrete slatted floor.

It was concluded that soft flooring provides good locomotion comfort for dairy cows but a moderate abrasion is also required to prevent claw overgrowth.

*Keywords:* dairy cattle, locomotion, claw, preference test, floor, rubber mat, welfare

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*“Cow protection to me is one of the most wonderful phenomena in human evolution. It takes the human being beyond this species. The cow to me means the entire sub-human world. Man through the cow is enjoined to realize his identity with all that lives.”*

*Mahatma Gandhi, Young India, October 6, 1921*

*”Рассуждения о том, что корова есть машина для деланья молока, были ей подозрительны. Ей казалось, что такого рода рассуждения могут только мешать хозяйству”.*

*Лев Толстой, Анна Каренина, 1878*

*(“General principles, as to the cow being a machine for the production of milk, she looked on with suspicion. It seemed to her that such principles could only be a hindrance in farm management”. Leo Tolstoy, Anna Karenina, 1878, translated by Constance Garnett)*

# Contents

# Appendix

## Paper I-IV

The present thesis is based on the following papers, which will be referred to by their Roman numerals:

I. Telezhenko, E., Bergsten, C. 2005. Influence of floor type on the locomotion of dairy cows. *Applied Animal Behaviour Science 93*, 183-197.

II. Telezhenko, E., Lidfors, L., Bergsten, C. 2007. Dairy cows' preferences for soft or hard flooring when standing or walking. *Journal of Dairy Science 90*, 3716-3724.

III. Telezhenko, E., Bergsten, C., Magnusson, M., Nilsson, C. Effect of different flooring systems on claw conformation and claw asymmetry in dairy cows. (In manuscript).

IV. Telezhenko, E., Bergsten, C., Magnusson, M., Ventorp, M., Nilsson, C. Effect of different flooring systems on weight distribution and contact pressure on the claws of dairy cows. (In manuscript)

# Background

The dairy cows´ freedom to express natural behaviour is generally considered to be easier to meet in a loose housing system than in a tie stall system. Cubicle (free stall) systems are becoming increasingly common in high-performing, expanding dairy herds. From an animal well being perspective, the floor design is one of the most critical aspects of loose housing systems because of its direct effect on the cattle's locomotor apparatus. Most walkways in cattle houses are made of concrete because it is fairly durable and resistant to wear, has acceptable hygienic characteristics and is relatively cheap. However, hardness, abrasiveness and slipperiness of concrete floors have been regarded as risk factors contributing to foot and leg lesions resulting in lameness (Webb & Nilsson, 1983; Bergsten & Frank, 1996b; Somers, 2004). Lameness causes substantial cost for dairy production both in terms of extra labour and veterinary treatment costs and also output loss as decreased milk yield, weight loss, impaired fertility and involuntary culling (Bennett *et al.*, 1999). In addition, lameness is a sign of discomfort related to the cow's sensation of pain and is therefore an important welfare issue (Logue, McNulty & Nolan, 1998). Furthermore, lame cows cannot cope with their environment as well as their non-lame herd mates (Galindo & Broom, 2002) and lameness dramatically changes social ranking, feed intake, sexual activity, productive traits and longevity (Hassall *et al.*, 1993; Albright & Arave, 1997). Thus, as their care givers humans must pay more attention to lameness control and prevention measures.

Improved flooring in dairy cow housing systems has received considerable attention but only a few comprehensive studies on the effect of flooring materials, available on the modern market, on the locomotor apparatus in cattle have been published (*e.g.* Vokey *et al.*, 2001; Benz, 2002).

The issue of "locomotion comfort" can be defined as conditions of well-being and contentment in the walking areas. The optimal locomotion comfort implies natural gait and activity of the animals but also good condition of their locomotor apparatus in the long run. In order to be able to design a well functioning loose housing system with best possible locomotion comfort, it is necessary to increase the empirical basis on the effect of the newly introduced flooring types on cow locomotion, behaviour and claw status. Several studies have been carried out at SLU over the last 10 years with the majority being part of an EU-project, "Lame Cow" (QLK5-CT-2002-00969) from 2002 to 2005. The studies presented in this thesis were mainly performed within the "Lame Cow" project.

# Introduction

## Some aspects of evolution of the locomotor apparatus in cattle

Locomotion is an active movement through the environment and that is an important capacity differentiating most members of the kingdom of *Animalia* from members of the other kingdoms of multicellular eukaryotes. The general principle of locomotion is very similar in all animals, where the organism exerts force on the surrounding environment and according to Newton's laws accelerates in the opposite direction (Dickinson *et al.*, 2000). The physical properties of the environment have to a great extent affected the evolution of the locomotor apparatus and the way animals move (Dickinson *et al.*, 2000). Movement on land requires that animals exceed gravity to support and move their bodies to accommodate any changes in the terrain (Biewener, 2003). The evolution of the limb of vertebrates can be traced back to changes in structures observed already in fossils from Ordovician, 463-439 Myr ago (Coates, 1994). Hinchliffe (1991) proposed a theory of "proximal stabilization" according to which the proximal elements of the limb were more conservative, and more evolutionary changes occurred in the distal part of the limb. The dominant theme of evolution of the distal part of the tetrapod limb was a digit reduction, where deviations from the pentadactyl pattern always implied the loss of digits (Shubin *et al.*, 1997). Digit reduction in tetrapods occurred with remarkable constancy with the majority of animals retaining digits III and IV and losing digits I, II and V (Shubin *et al.*, 1997). Cattle as well as other *Artiodactyla* (even-toed ungulates) were no exception having preserved digit III and IV , while the equine hoof provides an example of an extreme digital reduction with only the third digit left (Bragulla & Hirschberg, 2003). Borisevich (1983) classified the digits of hoofed mammals according to the principles of transferring of body generated forces into three groups:

- lateral transferring - the forces are transferred mainly through the hoof wall and suspensory apparatus (*Equine*);
- vertical transferring - the forces are transferred vertically through the footpad (*Camelide*);
- combinational transferring - the forces are transferred both by vertical (foot pad) and lateral (hoof wall) mechanisms (*Ruminantia, Suidae*).

The claw in ungulates is a specialised integumentary accessory organ, where integument is the complex interface between an organism and its environment (Bragulla & Hirschberg, 2003). The form of the distal phalanx and its integumentary structure vary depending on where and how the digits are used (Hamrick, 2001). Thus the light weighted hoof of a horse appeared, in the course of evolution, to enhance the speed of locomotion on a relatively hard ground that was their natural habitat. Camels' hooves were replaced by broad foot pads that were adapted to the very soft, sandy ground and provided more stability during the running pace (Janis *et al.*, 2002). European domestic cattle (*Bos taurus*) descended from the aurochs (*Bos primigenius*), which lived in transitional areas of woodland interspersed with open spaces (Baars *et al.*, 2003). Thus cattle digits evolved under conditions of moderately soft ground found in these environments.

The domestication of cattle started towards the end of the 9$^{th}$ millennium cal BC in the northern part of the Near East (Davis, 2005). One of the most essential reasons for the domestication of wild animals is believed to be an increased human population, where the environment could not provide enough food for the hunter-gatherers society (Davis, 2005; Diamond, 2002). Since that time cattle have been an important part of agriculture not only as providers of food and draught power but also as a source of land fertilisers where grazing played an important role (Baars *et al.,* 2003). Grazing as a main source of food implied also that domesticated cattle performed most of their locomotion activities under conditions of a natural terrain. Only recently, starting at the end of the 19$^{th}$ century, the processes of industrialization of agriculture reduced the role of cattle as an important part of the farm's agrarian cycle (Baars *et al.*, 2003). Artificial fertilizers and developed infrastructure made it possible to decrease the pasture areas and use arable land for cattle food production, zero-grazing systems appeared. In other words the industrialization of agriculture decreased the possibility for cattle to move around in their natural habitat. Therefore, the functionality of the cattle locomotor apparatus (evolved to be used under conditions of grassland) may no longer be adequate in the unnatural environment of the industrial farm. Moreover, the tremendous genetic progress in milk yield achieved during the last 50-60 years has caused harsh challenges to the cow's metabolism, and the function of the locomotor apparatus has thus been dramatically compromised (Bergsten, 2001; Mülling & Greenough, 2006).

## Locomotion in cattle

### *Needs for locomotion*

Locomotion is part of the normal behavioural repertoire of cattle (Albright & Arave, 1997). Cattle move to obtain food, water, to interact with herd mates during social and sexual behaviour and to seek a birth site or shelter. Cattle have an innate motivation for locomotion, which has been found to increase with time of confinement (Loberg *et al.*, 2004). Locomotion maintains adequate blood circulation, develops the muscular system and promotes health (Zeeb, 1983; Gustafson, 1993). It has been shown that walking activity reduces blood concentration of nonesterified fatty acids, which implies a decreased risk of metabolic and digestive disorders (Adewuyi *et al.*, 2006). In their natural environment cattle are able to range over large areas. If cattle travel extremely long distances they will reduce feed intake and milk production (Coulon *et al.*, 1998), but there is a need to walk at least 3–4 km per day to stay in good physical shape (Phillips, 2002). Loose-housing systems aim to provide free-movement of animals but in reality, these confined systems with a daily walking distance of 600-700 m do not give sufficient exercise (Bockisch, 1993). It has been shown that not only cows in tie stalls (Gustafson, 1993) but also animals in loose-housing systems benefit from outdoor exercise (Regula *et al.*, 2004).

## *Some biomechanical aspects of locomotion*

The angulation and arrangement of the limb musculature provide strong evidence that the locomotion apparatus in cattle has mainly been developed for forward motion (Nickel *et al.*, 1986). The function of front and hind limbs in cattle is different. While front limbs support the body during locomotion, the hind limbs have the function of propulsion (Phillips, 2002). The shock absorption is also different between the front and rear limbs. Whereas there is no bony contact between the front limb and the axial skeleton (suspended by the *Serratus ventralis* muscle), the hind limbs are connected to the axial skeleton by the coxofemoral articulation and therefore have a limited ability for shock absorption (Mülling & Greenough, 2006).

Cattle locomotion is usually fitted within three types of gait: walk, trot and gallop (Phillips, 2002). The walk is probably the most typical and most energy efficient gait, where the force to produce a forward movement is achieved by an exchange between gravitational potential and kinetic energy. At an intermediate walking speed this transfer can reach up to 70% of the total energy and only 30% will be supplied by muscles (Cavagna, *et al.*, 1977). To move faster, cattle use running gaits where kinetic and gravitational potential energy is stored in the muscles, tendons and ligaments when the leg strikes the ground, to recover later at the propulsion stage. No kinetic-gravitational energy transfer occurs when animals are trotting, but when galloping both mechanisms are involved (Cavagna, *et al.*, 1977). During a stride each limb passes two phases: stance (weight-bearing phase) and swing (non-weight-bearing). During the first half of the stance phase, body generated forces result in a decelerating longitudinal ground reaction force, which is directed backwards and brakes the progression. At the mid-stance the deceleration transmits to the propulsion, which propels the body forward. The load exerted to the limb increases to the mid-stance and decreases thereafter. When walking, dairy cows put approximately equal weight on the lateral and medial claws of front limbs, while in the hind limbs most weight is exerted to the lateral claws (van der Tol *et al.*, 2003). It was shown from high speed video of heifers walking on a treadmill, that the distal part of both the fore and hind limb were lifted and protracted with a slight inward rotation and contacted the ground with a slight outward rotation (Meyer *et al.*, 2007).

## *Studying locomotion*

### Subjective methods

Subjective locomotion assessment in cattle is a method commonly used in lameness research to estimate the quality of gait, with the majority of attention devoted to determining the degree of lameness. The most well-known scoring system for cattle locomotion has been published by Manson & Leaver (1988). This system uses a nine-point score from reflecting small changes in locomotion leading to severe lameness. Less detailed scoring systems have also been used to categorize the degree of lameness severity (Tranter & Morris, 1991; Whay *et al.*, 1997). Sprecher *et al.* (1997) developed a system focusing (along with gait scoring) on the back posture, a system that gained much popularity due to its simplicity (Juarez *et al.*, 2003; Amory *et al.*, 2006).

### Objective methods

While subjective lameness scoring can help to evaluate the disorder, it is plagued by observer biases thus there is need for more objective measures of gait. It has been demonstrated that the use of gait analysis with quantitative methods is more precise than results obtained through subjective locomotion scoring (Keegan *et al.*, 1998).

Kinetic and kinematic analyses have been successfully used to study gait in domestic animals, primarily horses (Clayton & Schamhardt, 2001; Barrey, 1999). Kinetics is a science that studies the causes of motion, explaining them by the force applied to the body, its mass distribution and its dimensions. Webb & Clark (1981) and Scott (1987) were among the first researchers studying the dynamics of pressure distribution under cattle claws. Van der Tol *et al.* (2003) used pressure sensors in combination with a force plate, to study ground reaction forces and between-/within-claw pressure distribution in cows walking on a flat surface.

Kinematics describes the geometry of animal movement, studying changes in the position of the body parts during a specified time. The first kinematic animal locomotion study using chronophotography was performed by Muybridge (1887). Since then many kinematic studies of animals have been performed and at present the majority of kinematic studies are carried out with videographic or opto-electronic systems consisting of integrated hardware and software components (Clayton & Schamhardt, 2001). However, only a few published studies have applied quantitative measurements when studying locomotion of cattle. The first and still best comprehensive kinematic study of cattle locomotion was carried out by Herlin & Drevemo (1997). They studied the locomotion of 17 dairy cows using high speed cinematography to determine the influence of different management systems and grazing on locomotion. Phillips & Morris (2000; 2001) studied locomotion in dairy cows on floors with different friction properties and with and without slurry contamination. Recently Flower *et al.,* (2005, 2006, 2007) performed a number of studies, where relationships between claw lesions, milking, flooring and some kinematic variables were established.

## *Concept of gait quality in cattle*

In cattle, no distinction has been made between gait quality and lameness (Manson & Leaver, 1988; Whay & Main, 1999). In sport horses, however, objective measurements of gait quality have been established which are not primarily focused to estimate lameness. Horses with good movements show more retraction in the forelimbs and more protraction in the hind limbs, a prolonged swing phase and ability to achieve a particular speed using a long stride length and a low stride frequency (Clayton, 2001). The assessment of quality of locomotion in cattle, even when it is beyond the detection of lameness (like in some breeding programs) relies on a subjective scoring. The subjective assessment of good movements in cows includes steady head carriage, flexible movements of joints, tracking-up (hind hooves land on or in the front of position of the front hooves) and symmetrical gait (Flower *et al.*, 2006). Impaired locomotion in cows has been described as stride shortening, a “stiff gait” and has also been described in terms of the degree of abduction or adduction of the hind limbs (Whay, 2002; Flower & Weary, 2006).

Recently quantitative methods were introduced to characterize lameness by means of using kinematic (Flower *et al.,* 2005) or kinetic (Rajkondawar *et al.,* 2006) methods. One of the main objectives of these studies was to develop an objective automated lameness detection system. However the existing commercially available lameness detection systems are not as sensitive in determination of painful lesions as visual locomotion scoring performed by a trained veterinarian (Bicalho *et al.,* 2007).

Since the most efforts in biomechanical studies of cattle locomotion have been primarily directed towards describing changes in gait due to lameness, very little information is available on description of "good locomotion" in non-lame cows using quantitative methods.

## The function of the bovine claw

The bovine claw protects the distal phalanx of the limb from harmful environmental factors; provides thermoregulation and transfers body generated forces to the ground (Westerfeld *et al.*, 2004). The epidermis of the claws, as the outmost layer of the integument, produces a cornified superficial layer which due to different keratinisation contains either soft or hard horn. Epidermis which is exposed to high mechanical stress is subjected to hard keratinisation (Bragulla & Hirschberg, 2003).

Different parts of the claw serve the function of force transferring: the digital cushion, the suspensory apparatus of the digit, the claw wall and the coronary cushion (Mülling & Greenough, 2006). The digital cushion plays the main role in shock absorption since the greatest part of it is situated posterior to the navicular bone and therefore does not take part in weight bearing (Räber *et al.,* 2004). The suspensory apparatus consists of a system of dense collagenous fibres extending between the pedal bone and the epidermal lamellae of the hoof wall thereby suspending the distal phalanx within the claw capsule (Westerfeld *et al.*, 2004). The suspensory apparatus is somewhat less extensive at the axial part of the claw capsule and is absent behind the insertion of the deep flexor tendon and in the region of the digital cushion. Consequently, stretching of the suspension apparatus fibres allows a slight displacement and rotation of the pedal bone, which is a part of the shock absorbing mechanism but is also predisposing to sole haemorrhages and sole ulcer (Lischer *et al.*, 2002). However, this part of the corium is usually protected by the natural concavity of the axial part of the sole. Mechanical stress is also transferred to the wall (mainly its abaxial part) and finally to a network of collagen fibres - coronary cushion, which mainly works as a pump but might have a certain biomechanical function (Mülling & Greenough, 2006).

## Disorders of the locomotor apparatus

Lameness in dairy cows belongs to the top of a list of disorders plaguing the economy of modern dairy industry (Bennett *et al.,* 1999). Lameness is a term that generally describes a functional alteration of the locomotion system. The lameness may originate from different causes: congenital defect, infectious or metabolic diseases and or trauma (Greenough, 1997). Most commonly lameness in cattle is a behavioural reaction to pain and is thus a very important welfare issue.

Locomotor disorders in cattle are usually separated into two groups: disorders of the upper limb (proximal limb or leg disorders), and disorders of the distal part of the limb (foot disorders).

Leg disorders usually refer to problems with joints, tendons, bones, etc and have been reported to account for only 12% of clinical lameness caused by leg problems in dairy cows (Russel *et al*., 1982). However, the diagnostics of leg disorders usually requires using complicated and expensive techniques such as ultrasonography, radiology and infra-red thermography which are expensive and difficult to use on farms. Thus the real contribution of leg disorders to clinical lameness is difficult to appreciate. Moreover the cause of lameness may be confounded by disorders of the distal part of the limb, which are very common in dairy cows and easier to detect (Manske *et al*., 2002).

Disorders of the distal part of the limb are usually represented by claw lesions. Claw lesions can basically be divided in two groups: those caused by micro organisms affecting the skin surrounding the claw capsule and bulb horn (often referred to as hygiene related diseases) and those affecting the claw capsule, which are usually associated with laminitis or trauma (Manske, 2002).

Claw lesions are considered to be the major reason for lameness in dairy cows (Murray *et al.*, 1996). However, not all claw lesions do necessarily result in lameness. Kinematic gait analysis did not reveal any difference between locomotion of non lame cows and cows with sole haemorrhages (Flower *et al.,* 2005). Even very painful injuries such as sole ulcer may not be accomplished by lameness (Logue *et al.*, 1994, Manske, 2002). The failure to observe lameness may in part be due to the stoic nature of cows as their innate behaviour is to hide painful conditions as a means of protecting themselves from predators (Weary *et al.*, 2006). Such phenomenon, however, may cause human's to underestimate the herd lameness problem.

In a recent study in the UK the most common lesions were sole ulcer (27%), white line disease (20%) and digital dermatitis (16%) (Amory *et al.*, 2006). In a Swedish study, 60% of 5000 cows examined had sole haemorrhages (the initial stage of sole ulcer and white line disease), 10% had sole ulcers and 5% were lame (Manske *et al.*, 2002). The causes of claw lesions are generally complex, with several metabolic and traumatic components (Mülling, 2007). Their prevalence is also influenced by several management factors (Bergsten, 1994, 2001).

It is well documented, that lesions are most commonly found in the outer rear claws of dairy cows (Murray *et al.*, 1996). The rear claws in dairy cows are often asymmetric and the outer claws usually become larger than the inner claws. It is believed that claw lesions develop from overload of the claw sole causing a compression of the corium between the claw bone and the sole horn (Toussaint Raven, 1973; Blowey, 1993). Compression of the solar corium both causes and may be caused by an inflammation related to laminitis, as explained by Ossent and

Lischer (1998). One aspect of the inflammatory process that follows from compression of the solar corium, is that the cushioning effect of the adipose tissue beneath the pedal bone seems to be lost (Lischer *et al.*, 2002), but the cause-effect relationship is yet to be proven. Ossent *et al.* (1987) used scales and showed how the offload from the outer and inner claws of the rear legs shifted with the cows' movements when standing. They proposed that these changes in weight bearing stimulated the blood circulation and thus the growth of the outer rear claws. However, their hypothesis does not explain the initial asymmetry nor does it take into account the difference in weight distribution between the two claws of one hoof or between sole and white line areas within claws. Before calving, dairy heifers usually have symmetrical claws without significant sole haemorrhages or sole ulcers (Bergsten & Frank, 1996a). During a period of a few weeks around calving, the claws are impaired in their quality and sole lesions appear (Bergsten and Frank, 1996b). The outer rear claws become enlarged and the sole concavity disappears while the initial size and concavity of the inner claws remains (Toussaint Raven *et al.*, 1989; Tranter & Morris, 1992). It is well known that there is a seasonal fluctuation in the prevalence of lesions and also that sole haemorrhages are more common in autumn calving heifers, when newly housed, than in spring calving heifers (Bergsten & Frank, 1996b).

## Floor types and locomotion

### *Different types of walking areas for dairy cows in cubicle houses*

In response to intensification of the dairy industry, cubicle barns have become the dominant type of housing for dairy cows especially in new constructions. Usually there are two choices of floors in the walking areas: solid (with different degree of slope) and draining floors (slatted, with differences in width of slats and slots and in their orientation). Draining floors stay acceptably clean without additional labour for manure removal while solid floors are completely dependent on scraping or flushing at regular intervals. The dominating material used for flooring construction is concrete. Concrete is not a surprising choice as it is durable, strong, easily cleaned and disinfected as well as popular in other forms of construction.

However, due to properties such as hardness, slipperiness and/or abrasiveness, the concrete floor is not always considered to be animal friendly. Even initially appropriate concrete floors may become too abrasive or too slippery because of concrete degradation with time. The degradation of the concrete occurs due to significant amount of aggressive ions, lactic and acetic acid coming from manure and feed residues together with mechanical wear from animals and from cleaning (De Belie *et al.*, 2000). Excessive slipperiness in cow walking areas is often cited as a greater problem than excessive roughness (Faull *et al.*, 1996). The friction of the floor is a central part in the understanding of slipperiness (Franck *et al.,* 2007). The mechanisms behind friction during cattle locomotion on artificial grounds include an interaction between the claw and a rigid or elastic floor in the presence of manure contamination (lubricant). The friction force is the sum of different components including adhesion (molecular bonds between a claw and floor), hysteresis (periodic deformation at the contact interface) and shape effects, which is particularly important in case of the presence of a lubricant on the floor surface

(Leclercq, 1999). Prevention of accidents due to slipping has also been a human safety concern for a long time (Leclercq, 1999). Research concerning the shoe/floor contact interaction has resulted in a development of safety footwear and floor cleaning techniques (Manning & Jones, 2001). Developing footwear for cows is not practical and thus attention should therefore be directed to the design of the flooring systems. To prevent slipping, different finishing methods of concrete surface are applied as for example grooving, tamping, brushing etc. Besides treatments with epoxy aggregates, acid-resistant asphalt or rubber mats on top of the concrete floor are used (CIGR, 1994).

### *Effect of flooring on cattle locomotion*

The "European Convention for the Protection of Animals Kept for Farming Purposes" states in article 4 that: "1. The freedom of movement appropriate to an animal, having regard to its species and in accordance with established experience and scientific knowledge, shall not be restricted in such a manner as to cause it unnecessary suffering or injury. 2. Where an animal is continuously or regularly tethered or confined, it shall be given the space appropriate to its physiological and ethological needs in accordance with established experience and scientific knowledge" (Council of Europe, 1976). Loose housing systems for dairy cows are therefore strongly recommended to achieve these goals. Although the distance walked by housed cows is considerably reduced compared to when grazed (Zeeb, 1983) there is still a significant amount of locomotion associated with social and other activities (Albright & Arave, 1997). According to Phillips (2002) the most important environmental factors influencing locomotion in cattle are space availability, floor quality and light. However, allocating space for locomotion in dairy houses is costly and is often restricted to a minimum (Anon., 2007) and takes into consideration general management procedures such as cleaning and cow traffic. Consequently, passageways are provided between cubicles and at the feeding areas and very few loafing areas are available apart from the holding pen. Inadequate quality of the floors in the passageways is one explanation for higher prevalence of lameness in cubicle systems than in tied and grazed animals (Faye & Lescourret, 1989; Bergsten & Herlin, 1996; Boelling & Pollott, 1998).

In addition to lameness problems, locomotion of cattle has also received some attention in the scientific literature. Slippery concrete floors may impede different types of natural behaviour in cattle because of reduced activity of the animals (Zeeb, 1983). Herlin & Drevemo (1997) showed that animals kept on slatted concrete floors had a stiffer gait compared to those on pasture. Phillips & Morris (2001) studied cows walking on floors with modified friction obtained using different sized bauxite surface aggregate and showed an improvement of locomotion in response to an increasing floor friction coefficient. However, when the floor was extremely rough, cows showed signs of discomfort by walking slower with decreased time of claw/floor contact. Rushen & de Passillé (2006) showed that cows walking on floors that provided more friction and more compressibility increased their walking speed and showed decreased risk of slipping.

### *Effect of flooring on cattle claws*

The interaction between the claw and the flooring surface has several aspects. The hardness and abrasiveness of concrete floors leads to excessive claw horn wear (Vermunt & Greenough, 1995). If growth is not enough then net growth of the claw will be negative and the thin horn will not protect the underlying soft tissue resulting in tender feet lameness and claw lesions (Van Amstel *et al*., 2004; Bergsten & Frank, 1996b). If an opening of the claw capsule to the corium occurs there is increased risk for secondary bacterial infection and development of a claw abscess. In contrast, lack of claw horn wear results in claw overgrowth which alters the position of the limbs such that the joint-ligament system is stretched and abnormal loading increases the risk of contusion of the corium which may contribute to the development of sole ulcer (Bergsten, 2001). Soft flooring materials decrease the pressure exerted on the claw (Hinterhofer *et al*., 2005) and there are studies which show that rubber mats (Benz, 2002) and straw yards (Somers *et al.*, 2003) decrease the presence of claw lesions. However, there is disagreement in the literature as a recent study (Vanegas *et al*., 2006) failed to find any significant effect in the overall prevalence of claw lesions when comparing the effect of concrete floor and interlocking rubber mats in the alleys. These latter authors did however find that the risk of becoming lame was higher for cows on concrete floors. Low abrasiveness of rubber mats appears to exacerbate the risk of claw overgrowth (Kremer, 2006). However, it has also been shown that rubber alleys results both in decreased wear and growth of the claw horn (Vockey *et al*., 2001; Vanegas *et al*., 2006).

Basing on the earlier studies it is obvious that the flooring surface is an important factor affecting dairy cow locomotion. However more comprehensive research is needed to describe the effect of new flooring products on a number of parameters related to locomotion, including biomechanical, behavioural and anatomical factors. A comprehensive study such as this would provide deeper insights when designing the optimal flooring system that maximizes locomotion comfort in dairy cows. The present thesis is a contribution to this comprehensive understanding of flooring and how it impacts the locomotion apparatus in dairy cows.

# Aim

The aim of the thesis was to assess effects of different flooring systems on dairy cows' locomotion, preference and long term effect on claw conformation and related biomechanical aspects. Special emphasis was placed on the evaluation of indicators of cow locomotion comfort in different flooring systems.

Three main fields of interest were studied and within each the following questions were aimed to be answered:

<u>Locomotion on different floorings.</u>

1. How do different flooring surfaces affect the gait in cows in relation to a natural yielding ground?
2. Does soft flooring affect gait in lame cows differently than in non-lame ones?

<u>Cow preferences for soft and hard flooring.</u>

3. Do cows show a preference for soft flooring when standing or walking in a group?
4. Do lame cows show a greater preference for soft flooring than non-lame cows when tested in a group of cows?

<u>Long-term effect of different flooring systems on claw status.</u>

5. How do flooring systems differing in hardness, abrasiveness and softness affect claw conformation, claw horn growth and wear rates?
6. Does pressure and weight distribution differ between claws exposed to different flooring systems?
7. Do different flooring systems affect the disproportion between the lateral and the medial claw?

# Summary of materials and methods

## Animals and housing

### *Paper I*

Eighteen Swedish Red and White and 18 Swedish Holstein cows were studied. The presence and severity of lameness was scored on a four-point scale, modified from Sprecher *et al.* (1997), according to which, animals with normal gait (n = 25) and mildly (n = 6) and moderately (n = 5) lame cows were identified. No severely lame cows were used in the study. A walkway from the milking parlour to the pasture was used and the walkway included both slatted and solid concrete floors. Twenty mm thick KEN rubber mats (Gummiwerk Kraiburg Elastik GmbH, Tittmoning, Germany) with rubber-studded underside profiles were used on a 10 m section of the slatted and solid walkway. The rubber mats were introduced one month before any cow based measurements were taken. At the exit to the pasture a sand track was prepared using moist sand compacted by a tractor.

### *Paper II*

The study used 150 dairy cows (Swedish Red and White and Swedish Holstein) of a private, commercial, organic dairy farm (280 milking cows). Rubber mats of different quality (Gummiwerk Kraiburg Elastik GmbH, Tittmoning, Germany) were used to modify the existing solid and slatted concrete floors of the different test sections. The soft rubber mats (KEN; 20 mm thick) and extra soft rubber mats (KSL; 30 mm thick) were used in the 120 $m^2$ holding pen to study standing preferences. Slatted rubber mats (KURA-S) and solid rubber mats (KURA-P; both 22 mm thick) were used on the 12 × 3 m walkway from the milking parlour to study walking preferences.

### *Paper III*

One hundred fifteen Swedish Holstein cows participated in Experiment 1 where 23 cows were allotted to each of five flooring systems: 1) solid, acid resistant, mastic asphalt (BINAB, NCC Roads AB, Stockholm Sweden); 2) solid, acid resistant, mastic asphalt with feed-stalls equipped with solid rubber mats (UBO, Barneveld, The Netherlands); 3) continuous, elastic rubber mats (KURA-P, Gummiwerk Kraiburg Elastik GmbH, Tittmoning, Germany); 4) rubber mats KURA-P and feed-stalls (as described for the system 1); 5) slatted concrete. Cows were housed in their respective flooring systems on average 170 days (43-232 range) after claw trimming. Cows kept on the rubber mats passed a 16 m distance of the asphalt floor and a 30 m distance of the slatted concrete floor four times per day on the way to and from the milking parlour.

In Experiment 2, 62 cows were used: 22 in the section with slotted rubber mats (KURA-S, Gummiwerk Kraiburg Elastik GmbH, Tittmoning, Germany) with scrapers, 21 in the section with the slotted rubber mats without scrapers and 19 in the section with concrete slatted floor without scrapers. The measurements were carried out in April to May before claw trimming. The cows were kept in the respective flooring systems on average 174 days (118-213 range). All routines and conditions for including the cows in the study were similar to those in Experiment I except that they were not exposed to any mastic asphalt flooring.

### *Paper IV*

The same facilities were used as described in the Paper III. The first experiment used 77 Swedish Holstein cows housed in different flooring systems: mastic asphalt (n = 16), mastic asphalt with feed-stalls (n = 17); continuous, rubber mats (n = 31); slatted concrete (n = 13). The cows had been accommodated in the respective flooring system on average 189 days (76 - 249 range).

In the second experiment animals from the following flooring systems were used: slatted rubber mats with scrapers (n = 16), slatted rubber mats without scrapers (n = 17) and concrete slatted floor (n = 17). The cows were kept in the respective flooring systems on average 172 days (134 - 213 range).

## Data collection

### *Paper I*

Cow gait was assessed using the trackway measurements on five different surfaces in one sequence; solid concrete without rubber mats, slatted concrete with rubber mats, slatted concrete without rubber mats, solid concrete with rubber mats and wet, compacted sand.

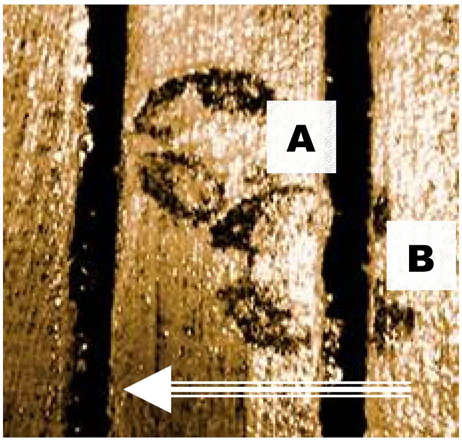


*Fig. 1.* Imprints of the left front (A) and the left rear (B) foot on the slatted concrete floor. The rear imprint is placed behind (negative overlap) and laterally of the front imprint. The arrow indicates the direction of movement. (Photo: E. Telezhenko)

To obtain visible foot imprints (Fig. 1), lime powder ($Ca(OH)_2$) was dispersed over the walkway and mixed with a thin layer of slurry (Fig. 2). The cows walked one by one over the prepared surface at their own chosen speed. In order to make the cows walk continuously, the author of the thesis followed them slowly at a distance of a few metres (Fig. 3). The following elements of trackways were measured: stride length (the distance between two consecutive imprints of the same rear foot); step angle (the angle between the lines connecting the three consecutive imprints of the rear feet); step length (the distance between two consecutive imprints of the left and the right rear foot); step asymmetry (the absolute value of the difference between two consecutive steps); overlap (the lengthwise distance between the front foot imprint and the next imprint of the same side's rear foot).

*Fig. 2.* Preparing the walkway with lime powder and slurry (Photo: M. Magnusson)

*Fig. 3.* Obtaining the trackway and measuring the speed (Photo: M. Magnusson)

The measurements were taken from four consecutive strides using a folding rule and an angle meter (Fig. 4). The walking speed of each cow was measured with a stopwatch. All measurements were made by the author of the thesis.

*Fig. 4.* Measuring the trackway (Photo: M. Magnusson)

### *Paper II*

Floor preference for standing was tested in the holding pen before the cows entered the milking parlour. The holding pen was divided length wise into two sections and the following floor materials were tested: extra soft rubber mats versus soft rubber mats, soft rubber mats versus solid concrete, and extra soft rubber mats versus solid concrete. Prior to the comparison of different flooring materials, control observations were performed, using concrete in both sections. Every alternative was tested for four days on each side of the holding pen in association with the afternoon milking. All observations of cow distribution in the sections were made from video recordings, captured by a video camera positioned 3.5 m above the holding pen. The distribution of cows between sections was observed for the entire herd; however, only observations with more than 3.2 $m^2$ free space available per cow within the holding pen were used for the analysis. The average proportions over multiple observations per day and management group were calculated and used for the subsequent analysis.

To test walking preference the walkway was divided lengthwise into two identical parts. Slatted and solid rubber mats were tested against each other and against slatted concrete. Each floor type was tested over four days on the left side and four days on the right side of the walkway in association with the afternoon milking. Concrete flooring on both sides of the sections was tested as a control method before the comparisons of different materials were made. All observations of the distribution of cows were made continuously from the video recordings. Lame cows were identified at each observation, and their floor choice was recorded separately. Only cows with moderate and severe lameness (clear visible gait asymmetry) were judged as lame.

### *Paper III*

Measurements of the lateral and medial left, hind claws were assessed before and after the first (autumn) trimming and before the second (spring) trimming. Toe length was measured along the dorsal border from the tip of the toe to the proximal end of the claw capsule at the coronary band. Toe angle was measured at the tip of the toe. Sole concavity of the claw of the left foot was measured with a commercially available profile gauge. To characterise the depth of the concavity of the sole, measurements were obtained at 15 mm, 25 mm, 35 mm and 45 mm from the abaxial claw margin of each claw along the horizontal line crossing contour at 10 mm perpendicular to the abaxial margin. From the sole profile contour also the width of the lateral and medial claw and the height difference of the sole measured at the two outmost distal points of the medial and lateral soles were obtained.

Claw growth and wear were measured over a four-month period by measuring the distal displacement of a mark which had been burnt into the dorsal wall of the outer and inner hind claw at the start of the observation period.

### *Paper IV*

Measurements of weight and pressure distribution of the claw soles were performed with I-Scan™ system and analysed with F-scan™ system (Tecscan Inc, Boston, MA, USA). During the measurements the sensor was placed on a stainless steel plate (1.5 mm thick) and was covered with a 1 mm thick rubber cloth. Three measurements were made per cow, under which a total of 1,500 frames per cow were recorded with a frequency of 100 frames per second. Each measurement (500 frames) was averaged to a single frame. Each claw sole (lateral and medial) was divided into three zones: zone of bulb, zone of claw wall and zone of claw sole. To define the zone on the colour-coded outputs from the pressure measurement, digital photos of the corresponding claw sole of each cow were individually matched to the pressure picture. The vertical ground reaction force (GRF), contact area, and average contact pressure were determined within the defined zones.

## Statistical analysis

### *Paper I*

The speed and individual trackway means, obtained from measurements of four consecutive strides on each floor, were calculated with analysis of variance (ANOVA, JMP v. 5; SAS Institute, Inc., Cary USA, 2002) with the between- and the within-subject design. Two different statistical models were used to describe the data. The first model included floor as within-subject effect and lameness degree as between-subject effect. In the second model only cows without signs of lameness were included in the analysis. In this model breed and parity were included as between-subject effects, and floor as the within-subject effect. The cow effect was considered random and other effects were considered fixed in both models. Multiple comparisons were performed using Tukey's Honestly Significantly Different (HSD) test.

### *Paper II*

A repeated measures Analysis of Variance with a mixed linear model (SAS 8.02; SAS Inst., Cary USA, 2003) with the first order autoregressive correlation structure, for the management group within a tested floor-combination and side, was used to analyze the effect of flooring on the choice of cows on a group level.

The model for analysis of preferences for standing included the effect of floor combination, the effect of side of the holding pen, the effect of the number of contacts with a floor on the same side of the holding pen and the effect of the management group (defined as a subject in the model). Because the proportion of cows standing on a particular side might be based on different numbers of observations within each group and day, the data were weighted by the number of observations for each day and group.

Due to a significant interaction between floor and contact number with the floor in Experiment 2, the effect of floor was built as ten categories: control observations and interaction term between floor combination and the contact number with a particular floor. Other effects in the model were: the side of the walkway, cows walking alone or together with other animals, and the management group (defined as a subject in the model). The proportions of cows walking on a particular side were weighted by the number of observed animals for each group and day. Due to a weak negative correlation between the distributions of lame and non-lame cows, these two subgroups were analyzed separately using the same model.

Multiple comparisons of the least squares means for “floor combination” (holding pen) and “floor combination × contact number” (walkway) with the control observations were performed using Dunnett adjustment (Dunnett’s 2-tailed t-test).

### *Paper III*

The statistical analyses were performed using statistical package JMP 5 (SAS Inst., 2002).

In Experiment 1, solid rubber flooring with and without feed-stalls and in Experiment 2 slatted rubber floorings with and without scrapers were treated as one flooring system respectively and data were analysed with separate but similar models.

The final model for data on claw conformation and claw horn growth/wear rates included the following factors: flooring system, month when cow entered the flooring system, parity (*1, 2, 3 or more*), lactation stage and interaction between flooring system and lactation number. In addition, the model for analysis of conformational traits included a covariance of a measurement after the first claw trimming as a correction for a baseline.

Least square means were processed from the models and multiple comparisons were performed with Tukey-Kramer adjustment. The paired t-test was used to compare outer and inner claw measurements within a flooring system.

### *Paper IV*

The statistical analysis was made using Analysis of Variance with a mixed linear model (PROC MIXED procedure in SAS 8.02, SAS Inst., Cary, 2003). The preliminary analysis found no differences between cows in the sections with rubber mats with or without feed-stalls and with or without scrapers. Therefore all animals in sections with rubber mats within each experiment were combined into one group (rubber mats) for the statistical analysis. The final model was similar for both experiments and included for the force and pressure data the following effects: flooring system, lactation number and categorized days in the study as fixed effects, cow as repeated and random effect nested within the flooring system, lactation number, and days in study. The vertical force was analyzed as percentage of the total force applied to the foot. To describe contact area and contact pressure, a covariate of total weight applied to the foot was used in the models. A compound-symmetry correlation structure was used for repeated measurements. Least square means was processed from the models and multiple comparisons were performed with Tukey-Kramer adjustment.

A 5% ($P < 0.05$) significance level was used throughout all the papers.

# Summary of results

## Locomotion on different floors (Paper I)

According to measurements of coefficient of friction, the slatted concrete floor was the most slippery surface, the solid concrete floor was the least slippery and the rubber mats were intermediate.

The gait pattern deviations from the sand surface (value obtained on the sand minus corresponding value on an artificial floor) are presented in Fig. 5. Strides and steps were considerably shortened and the rear foot imprints were placed at a greater distance behind the front ones (larger negative overlap) on the slippery slatted concrete floor in comparison with all the other flooring surfaces. Although cows walking on the solid concrete floor took shorter strides and step than on the sand surface, they did not differ in walking speed. Length of strides and steps increased on solid and slatted elastic rubber mats compared with the corresponding concrete floors.

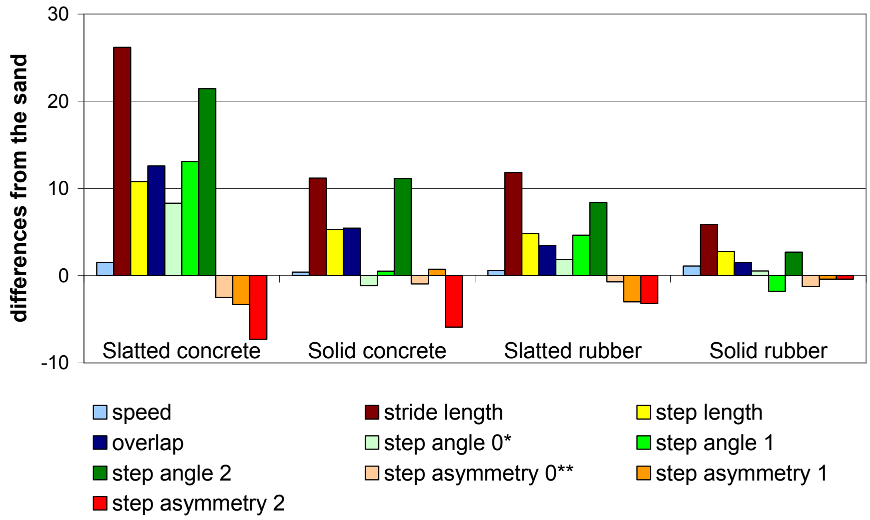


*Fig. 5.* Differences of parameters of gait measured on the compacted sand and on the artificial floorings. The larger the deviation from the X axis the larger the difference from the natural surface was.
*, ** due to significant interaction between lameness and flooring the step angle and step asymmetry presented separately for lameness scoring 0 (non-lame), 1 (mildly lame) and 2 (moderately lame).

In moderately lame animals speed was lower and the stride and step lengths were shorter compared to non-lame and mildly lame cows. Analyses within each lameness degree revealed that the moderately lame cows walked with a significantly wider posture on solid and slatted concrete than on the yielding surfaces. Comparisons of cows with different lameness scores within a floor type showed that the moderately lame cows had a smaller step angle on the concrete flooring compared with the non-lame ones while there were no significant differences between lame and non-lame animals when walking on yielding surfaces. In cows with moderate lameness the step asymmetry was less pronounced on the sand and on the floor with solid rubber covering.

## Preferences for different floors (Paper II)

The proportion of cows standing on the side of the holding pen with rubber mats of both types was significantly higher than during control observations when only concrete floor was available. There was no interaction between day of contact and the particular floor combination in the holding pen.

During preference testing on the walkway the proportion of cows walking exclusively on the rubber mats increased gradually during the four days of testing on the same side. In non-lame cows, the application of slatted rubber mats and solid rubber mats resulted in a 25% and a 30% increase at the 4$^{th}$ day, respectively. A slightly higher preference was observed for walking on solid rather than on slatted rubber mats. The preference of lame cows for soft surface was not as distinct as in non-lame cows (19% and 12% of increase on the 4$^{th}$ day for the slatted rubber and solid rubber mats, respectively). The proportion of solitary non-lame cows walking on the side with rubber mats was greater and the proportion of solitary lame cows walking on the rubber tended to be higher than the proportion of cows walking together with other animals.

*Fig. 6.* Cows showing preference for the rubber mats on the left side of the walkway (Photo: E. Telezhenko).

## Claw conformation in different flooring systems (Paper III)

On the more abrasive asphalt floors, cows had shorter toes and steeper claw angles. The concavity of claw soles was reduced on abrasive floorings, especially in the lateral claws. Rubber equipped feed-stalls reduced the loss of sole concavity caused by asphalt floors. Asphalt floors caused greater wear of the rear claws, which responded with a more rapid horn growth rate (Fig.7). Rubber mats on walking areas and feed places reduced both wear and growth. When cows were kept on rubber mats and had a limited access to the asphalt floor on the way to the milking parlour (Experiment 1), the wear rate was not different from cows housed on the aged concrete floor. Without any access to asphalt flooring (Experiment 2), animals on rubber flooring had lower wear rate and greater net growth than cows housed on concrete floors. The combined results of wear and growth rates of lateral claw in the both experiments are presented in Fig. 7. In all the flooring systems, the wear of the toe was greater in medial claws than in the lateral claws. Measurements of asymmetry between lateral and medial claw did not differ across the flooring systems and associations between different traits of asymmetry were generally low.

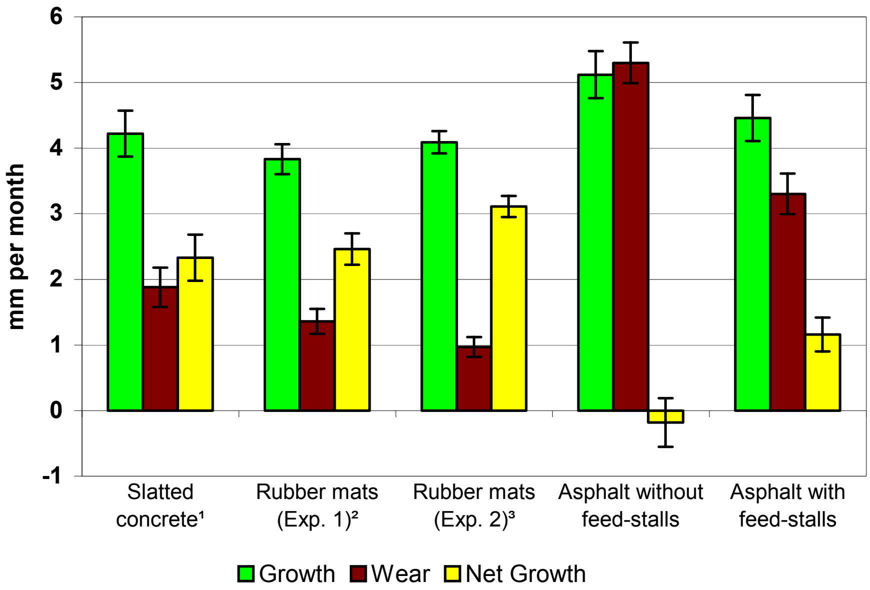


*Fig. 7.* Growth and wear rates of dorsal border of lateral claws (during 4 months after calving) in cows from different flooring systems (mean ± SE).

[1] Average value for experiments 1 and 2.

[2] Rubber mats, experiment 1 – solid rubber floor (KURA-P) with short access to asphalt floor.

[3] Rubber mats, experiment 2 – slatted rubber mats (KURA-S) without contact with asphalt floor.

## Weight and pressure distribution as a result of exposure of different flooring systems (Paper IV)

Generally, the animals exerted about 1500 N of load on their rear left limb. Analysis of the distribution of vertical GRF (weight) revealed a significant difference within claw weight distribution across different flooring systems.

The results of colour-coded output of I-scan system (Tecscan Inc, Boston, MA, USA) matched with claw sole images in cows kept in the different flooring systems are presented in Fig. 8.

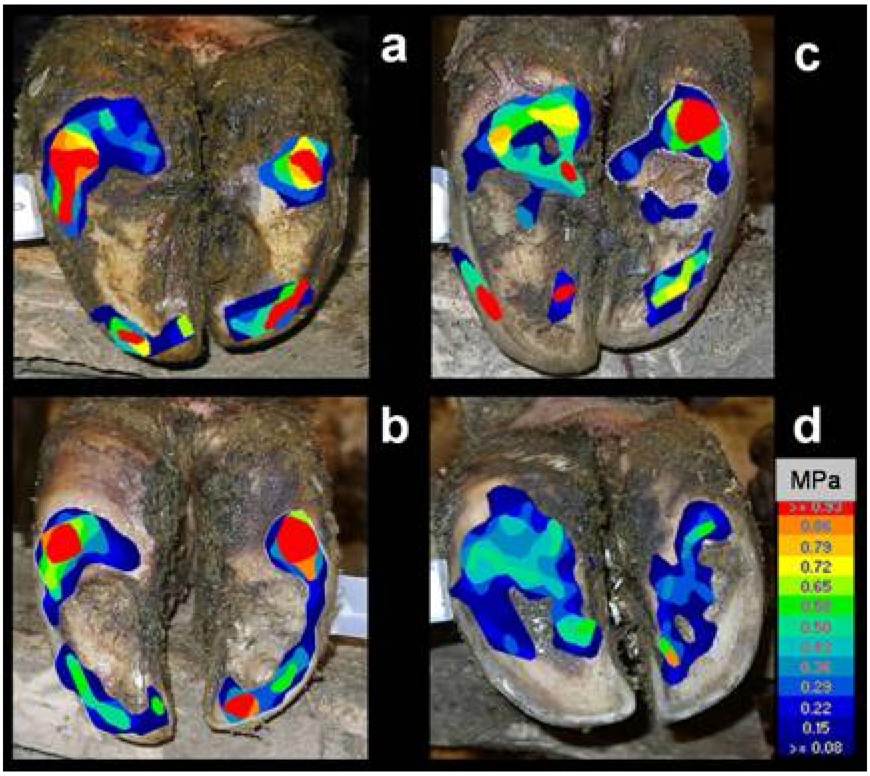


*Fig. 8*. Pressure distribution between and within claws of Swedish Holstein cows, a) low abrasive concrete slatted floor; b) rubber mats (KURA-P ™) without access to the asphalt floor (Experiment 2); c) mastic asphalt floor with feed-stalls; d) mastic asphalt floor without feed-stalls.

Most of the weight was carried by the "bulb" and the "wall" zone when cows were exposed to low abrasive concrete floors. With a short daily contact to asphalt flooring (Experiment 1), the measured parameters of claws exposed to rubber mats did not differ from those on less abrasive slatted concrete floors. However, when cows were prevented any access to the asphalt (Experiment 2) the weight bearing of the "sole" zone in cows kept on rubber mats was smaller compared to that in cows housed on the slatted concrete. At the same time the cows housed on the rubber mats in Experiment 2 had significantly greater proportion of weight exerted to the lateral bulb.

In cows on asphalt flooring without feed-stalls most weight was exerted to the "sole" zone, they had the largest total contact area and as a consequence the lowest average pressure. Feed-stalls in combination with asphalt floors resulted in a decreased total contact area in comparison with claws exposed to asphalt without feed-stalls and apparently a higher pressure was exerted to the "sole" zone compared to the other flooring systems. The cows confined on slatted concrete floors had significantly higher average contact pressure exerted to the lateral claw than animals in all other flooring systems. None of the flooring systems differed significantly in relative weight distribution on the whole medial or lateral claw. In general the proportion of the vertical force (weight) applied to the lateral and medial claw can be described as 60% and 40%, respectively.

# General discussion

## Methodological considerations

### *Paper I*

Measuring the space between footprints is a simple way to obtain information about animal locomotion even when direct observations are impossible, as in the case of extinct animals. The first intensive study of fossil tracks was carried out by Hitchcock (1836). Data obtained from footprints are used in human biomechanics as a simple and inexpensive method to quantify important aspects of gait (Wilkinson *et al.*, 1995).

The study described in Paper I was to the author's knowledge the first systematically implemented use of trackway measurements for locomotion analysis in dairy cows. In addition, the paper was the first published work objectively assessing the effect of different flooring surfaces on locomotion of lame cows.

Measurement of trackways is a method for obtaining several spatial kinematic variables. In addition, the method is inexpensive, easy to apply and interferes minimally with the movement of cows in their "home" environment. However, it should be noted that, the information obtained from trackways is not as precise and as complete as that obtained by a sophisticated computer based motion analysis system. The measurements of trackways lack some important kinematic parameters such as angulations and trajectories of joints as well as important temporal stride characteristics. The only temporal parameter used in the present study was speed, calculated as the time used for passing the tested walkways. By measuring the time with a stopwatch, certain measurement errors are inherent.

It has been shown that the presence of slurry may overcome the slip resistant properties of the floor (Rushen & de Passilé, 2006). A recent biomechanical study of pig locomotion revealed a significant effect of contamination of the floor on the animal gait (Thorup *et al.*, 2007).Yet, the presence of the thin film of slurry in the present study did simulate real farm conditions.

### *Paper II*

Preference studies for different floorings were carried out under normal conditions of a commercial dairy farm and on a group level which has its *pros* and *cons* described below. Several types of free-choice tests have been used in applied ethology to answer questions about what animals prefer. The majority of the studies used social animals, which both were housed and tested individually (Fraser & Matthews, 1997). It has been shown that the presence or absence of companion animals may have a significant effect on the animals' motivation for resources, and this effect is resource dependent (Sherwin, 2003). Therefore the preference of group housed animals, tested without the social context, might have limited external validity. In addition, choices made under specially designed test conditions may differ from choices made under conditions of real-life (Lawrence

& Illius, 1997). On the other hand, the complexity of relations between different members within a group of cows makes it difficult to correctly analyze and interpret the results (Bouissou *et al*., 2001). To avoid dealing with complex relationships between members of size-fluctuating groups, data in Paper II were analysed on a group level and the management group was considered as the subject for the analysis.

Certainly it would be interesting to investigate social interactions in a controlled experiment using small groups, where all are individually marked. However the behaviour of individual cows was not the primary objective of study as it is dependant on many factors e.g. social interactions. Rather, the main ambition of the study was to assess the preferences of cows at the group level, under similar conditions present in commercial herds. A controlled experiment, e.g. separating cows of different ages or physical characteristics, or using focal animal observations, would limit our ability to understand the preferences of the group. For instance, a focal animal could behave quite differently depending on which other cows happened to be in the holding pen or in the walkway at the same time.

### *Paper III*

The measurements of toe length and toe angle along with wear and growth rates of claw horn were carried out according to standardized methods on both lateral and medial claws of a hind foot. In addition the claw sole profile was measured using the technique initially used by Tranter *&* Morris (1992). It would be quite logical to propose that the conformation of the weight bearing surface is one of the most important conformational traits in relation to claw function. However, surprisingly few research groups have investigated the conformation of the plantar/palmar surface (sole concavity) of the claw. The profile gauge, which was used for reproducing the sole contour, was also useful for measuring sole width and difference in height between lateral and medial claw. All the measurements were carried out by the author of the thesis, thus the error source “due to operator” was minimized. However the measurements of horn growth were presumably at a greater risk of the error “due to measurement” because the proximal end of the claw capsule is less firm than tip of the toe and it is more difficult to establish consistent reference points there.

To control the effect of physiological factors, horn growth and wear were measured at the same lactation stage (approximately 120 days in milk). However, the introduction of animals into the experiment over a four month period may have introduced some bias as horn growth has been shown to be influenced by season and related length of the day (Vermunt, 1990). Therefore, the effect of month at the start of the study was used in the statistical model.

The higher wear rates on asphalt floors in comparison with slatted concrete may be explained not only by higher abrasiveness of the asphalt surface but may also be a consequence of higher humidity on the solid floors. The solid asphalt floor provided a presumably more humid environment (despite frequent scraping) than on the concrete slats, and higher moisture content might contribute to higher wearing rate (Bonser, *et al.*, 2003).

### *Paper IV*

The results obtained in Paper IV provide insight into the functional conformation of the claw and the relative effect of different flooring systems. However, the method in which the vertical GRF and pressure distributions were captured puts certain limitations on a wider extrapolation of the obtained results. Unfortunately, none of the tested flooring systems could be fully represented by the smooth, rather hard and solid surface of the pressure plate.

Since it was difficult to control how much of the cow's weight is applied to the foot and because a standing cow will likely shift weight from one leg to the other (Neveux *et al*., 2006) the relative values of the vertical GRF were chosen for the analysis. The contact area and pressure are dependent on the loading applied (De Belie & Rombaut, 2003), therefore, the contact area and pressure were corrected for the total weight exerted to the foot.

The defined claw sole zones only partly corresponded to the anatomical segments of the weight bearing surface of soft bulb ("bulb zone"), abaxial and axial wall and white line ("wall zone"), hard bulb and sole ("sole zone"). A better definition of the claw zones was limited by the technical abilities of the F-scan system and restricted ability to completely recognize all the reference points of the colour-coded output. However, solely using the color-coded contact image for division on different zones might lead to misjudgement on the different reference points of the claw (Van der Tol *et al*., 2002). Thus, we used scaled digital photos of the corresponding claw, which made it possible to establish adequate reference points. As this manual incorporation of the claw picture into sensor images is labour intensive we encourage future research to find ways of computerizing this process. Other possible sources of error may occur due to an unusual posture of the limb. In the present study attempts were made to place all limbs in a standard position, which may not have been a natural position for certain cows and therefore may not have been representative of her normal loading.

## Synthesis of Papers I-IV

### *Perception of floors*

Reducing slipperiness of the walking areas in cubicle barns have been a major issue of floor improvement for a long time. The coefficient of friction (ratio between frictional and normal force, $F_{\mu}/F_N$) was regarded as the most informative technical parameter of slip resistance (Chang *et al.*, 2001). It should be noted that the coefficient of friction (COF) is not a fixed value but a function depending on a number of factors including weight, sliding speed, characteristic of the interacting materials, and character of lubricant (Grönqvist *et al*., 2001). To increase the mechanical interlocking between the claws and floor there are two basic approaches: when the floor protrudes into the claw horn (hard floor option) and when the claw sinks into the surface (soft floor option). While walking on the surfaces with higher friction properties cows increased their stride and step length

(Paper I) which is in agreement with results by Phillips & Morris (2000, 2001). As the rubber flooring resulted in a less constrained walking than did the hard floor with a higher COF (Paper I), it can be presumed that a technical test of a surface has limited ability to model the interaction between the animal claw and the floor during locomotion. The results obtained for locomotion on soft rubber mats in Paper I were recently confirmed by a study where computer-aided kinematic techniques were used for analysis of cattle locomotion (Flower *et al.,* 2007). In that study cows walking on rubber mats had longer strides, greater overlapping and shorter periods of triple support than cows walking on concrete. Walking with shorter strides on a slippery floor is an adaptive mechanism for preventing slipping, in which the COF required for walking is kept below the available COF (Van der Tol *et al.*, 2005). Besides shortened strides, slippery floors force cows to modify their posture i.e. step angle was considerably diminished (Paper I). With a small step angle the centre of mass is placed centrally within a cow's base of support and a more balanced position is provided. In contrast, a large angle (narrow walking posture) is characteristic of a more efficient gait due to minimal lateral displacement of the centre of gravity (Alexander, 1985). Alterations of the gait adopted on a slippery surface may remain even when a cow walks on a floor with acceptable friction (Herlin & Drevemo, 1997).

Cows could discriminate flooring surfaces with low and high friction but they did not show a particular preference for a certain COF value (Phillips & Morris, 2002). In the present study cows did, however, prefer soft floorings when they had a choice (Paper II). Therefore we may conclude that the softness of the flooring played a more important role than friction when cows chose soft rubber mats over concrete surfaces. Some scientists have questioned whether the choices animals make under artificial conditions always lead to increased welfare (Houston, 1997). Since the long-term consequences of the instant choice for the softer floor fall outside the cows' cognitive capacities, it was necessary to analyze the long-term effects of the flooring particularly on the claws (the part of the locomotor apparatus in direct contact with the flooring).

### *Effect of floor on claw conformation and claw functionality*

Claw measurements were long ago suggested as indirect markers of claw health and susceptibility to lameness (Smit *et al.,* 1986). The term "Claw Quality" was established as a general expression for horn characteristics, claw conformation, anatomical and physiological parameters of the inner structure of the claw (Politiek, *et al.*, 1986). It is however still a subject for discussion whether the claw shape is a predisposing factor or a result of the lesion.

In a number of investigations the associations between claw shape and lameness were established. It was shown e.g. that cows with long toes and shallow toe angles are more probable to have impaired claw health (Distl *et al.*, 1990). However the association is not so simple. The claw conformation in Paper III was affected by floor abrasiveness, which is in agreement with other studies (Vermunt & Greenough, 1996; Vokey *et al.,* 2001) Abrasive floors in general resulted in shorter claws and steeper claw angle, but did not automatically result in better claw health. Instead, exposure to the abrasive asphalt floor causes the loss of sole concavity (Paper III) and the lack of concavity was associated with lameness (Tranter *et al.*, 1993). The lack of sole concavity resulted in a decreased weight bearing role of the claw wall (Paper IV). The exclusion of the claw wall from the weight bearing indicated that the function of the suspensory apparatus was reduced. Thus claw sole and digital cushion (the prime function of which is shock absorption) became the main components in transferring body generated forces.

It was shown that older cows had reduced strength of the suspensory apparatus (Maierl *et al.*, 2007), which could be a result of a general, physiological, aging. But it might also be explained that the claw walls in older cows are less involved in the weight bearing due to abrasive floors and/or improper claw trimming. Since the suspensory apparatus was not properly exercised its strength could be reduced resulting in a higher risk for sole ulcer. Moreover, the most intensive exposure to the abrasive flooring (mastic asphalt without feed-stalls, Paper III) resulted in a convex shape of the sole of the lateral claw. The most protruding part of the convex claw, observed on the hanging limb, was at the axial portion of the sole. Sole overloading may cause bruising of the corium and be one of the predisposing factors of sole ulcer (Vermunt & Greenough, 1995).

The reason for developing a convex shape on hard abrasive floors could possibly be explained as follows: during weight bearing the claws are separated resulting in stretching of the distal interdigital ligament which is attached to the axial aspect of the distal phalanges (Greenough, 1997). During stretching the elastic energy may be stored in the ligaments and when it recovers a tension directed to the abaxial edge of the claw will take place. This tension would contribute in loading the more robust abaxial edge of the claw even if the sole is flat but on an abrasive floor it will contribute to the wear of the abaxial wall. Besides, the claw horn of the wall is hardest but maybe not as resistant to wear as the elastic horn of the solear portion of the claw. To support the latter statement future research is required on the abrasion resisting properties of different parts of the claw capsule.

The convex shape did not, however, result in weight bearing solely by the axial segment of the sole, rather the contact area included a large portion of the sole and even some part of the abaxial wall (Paper IV). This suggests a supination of the claws (especially lateral ones) under load. Serious supination would cause a stretching the interdigital space and possibly make it more susceptible to infectious agents. On the other hand, the large contact area of the sole obtained when cows walked on the abrasive floor, resulted in low pressure, which compensated for the hard floor impact (Paper IV). The feed-stalls caused less wear of the sole horn, but did not prevent the wall from wearing on the asphalt floor, resulting in a smaller contact area and higher pressure exerted on the sole (Paper IV). The claw health data obtained Experiment 1 in Paper IV also revealed no effect of the flooring system on the risk of claw lesions with the exception of the feed-stalls, which resulted in higher risk of sole haemorrhages (Hultgren *et al.,* 2007). In cows housed on the rubber mats without daily access to the abrasive flooring (Experiment 2 in Papers III and IV) considerable amount of weight was carried by the lateral bulb. The shift of the weight bearing towards posterior part of the claw on the hard surface presumably was caused by claw horn overgrowth due to low wear rates on the rubber mats (Paper III). While the loading pattern may be different on the soft floor, on the hard surface (*e.g.* when the cows walked to the milking parlour) the overburdening of the rear part of the claw may cause the contusion of the corium (Bergsten, 2001).

Since flooring affected posture during locomotion (Paper I) the weight-distribution between claws may have been different on different floors. It is believed that a greater load on the lateral claw stimulates claw growth and results in progressing claw asymmetry (Bergsten, 2001). Yet, the conformational study revealed that development of asymmetrical claws could not be attributed solely to a certain flooring system (Paper III). Neither was it found that floors with different slipperiness affect the disproportion in weight distribution between lateral and medial claws (Paper IV). The larger size of the lateral claw is usually associated with its rapid growth (Vokey, et al., 2001), but the results of Paper III suggest that a greater net growth was determined by the less effective wear of the lateral claw. In addition, the hypothesis that greater pressure causes more rapid growth of the claw horn seems to not be confirmed. Indeed greater pressure on the claw wall in cows kept on concrete slatted floor did not result in such rapid growth as on the asphalt flooring (where pressure on the wall was actually lower). On the other hand, the high contact pressure registered at the wall area did not imply high pressure that would be transferred to the dermis. The pressure exerted on the distal part of the wall will spread on the large area of lamellae resulting in lower average pressure. Therefore the high pressure on the wall may be even lower when it reaches the dermis than the pressure exerted on the sole where pressure would be applied directly to the underlying structures.

### *Lameness and floor quality*

In Paper I it was described that the stride length was significantly decreased in moderately lame cows, and non-lame as well as lame cows increased their stride length on the yielding surfaces. The stride shortening during lameness is characterised by shortened swing durations and longer stance durations, which is an important method of reducing the peak loads on the lame limbs (Buchner, 2001). On the hard concrete surfaces lame cows walked with a significantly smaller step angle compared with non-lame cows, while on the soft surfaces the step angles of lame cows were no different from those of non-lame cows (Paper I). The difference in step angle between lame and non-lame animals could be explained by more hind limb abduction in the lame cows. Another important parameter influenced by lameness was step asymmetry. Step asymmetry arises primarily from shortening of one step, but varied step abduction can contribute to greater step asymmetry as well. Lame cows showed exaggerated step asymmetry on all the hard floors, while non-lame cows increased the asymmetry only on the slippery floor (Paper I). The findings in Paper I were recently confirmed by a study by Flower *et al.* (2007), where rubber mats significantly improved locomotion in cows with sole ulcer. The reaction on the rubber mats was similar to that observed by Weary & Flower (2006) where lame cows decreased in subjectively assessed step asymmetry in response to ketoprofen treatment. This finding suggests that soft flooring decrease the discomfort due to pain, which is important to take into account while comparing lameness scores between different flooring systems. Although soft floors appear to give some pain relief and reduce the expression of lameness it is not a complete solution of the problem of pain management of lame cows.

Despite the improved locomotion parameters observed in cows walking on the soft flooring, lame cows, being part of the group, would not always take advantage of the opportunity to walk on the surface providing greater comfort (Paper II). The fact that lame cows did not always choose the soft floor may be explained by a number of factors. Firstly, competition from other higher-ranked non-lame cows may have prevented the lame cows from accessing the softer walking area. Further, the continuous threat of competition may have resulted in the lame cows learning to use the less comfortable walking surface even when no competitors around. The first hypothesis has been confirmed by a recent study by Platz *et al.* (2007). These authors showed that high ranking cows occupied the rubber flooring (covering 45% of the total floor area) significantly longer time than low ranking animals did. Secondly some type of lameness my not result in pain relief when moving on a soft surface. In horses, for example, lameness deriving from soft tissue injuries tends to be worse on a soft ground (Ross, 2003).

Although the effect of the different flooring systems on lameness was beyond the scope of the thesis, analysis of lameness scoring data obtained from Experiment 1 (Paper III and IV) revealed that rubber mats resulted in a lower risk for lameness in older cows (Hultgren *et al.,* 2007).

## Concept of a flooring system for the best locomotion comfort

The term locomotion comfort refers broadly to how well an animal copes with the environment in which it moves. The essence of locomotion comfort fits well with the concept of “Five freedoms” (Webster, 2001) especially concerning the freedom from discomfort, from pain and freedom to express normal behaviour. For a long time the concept of cow comfort has referred exclusively to the technical properties of the stall. Moreover, the measurements of time spent lying has been considered as a valid measure of cow comfort (Cook *et al.*, 2005). Yet, the attempts to reduce the time a cow spends outside the stall may ignore the animal’s need to express natural behaviour.

Poor locomotion is not only an issue of animal welfare but also an important aspect of a well-functioning milk production in loose housing systems. The slipperiness of the walking areas has been the main concern of the appropriate design of indoor walking areas (Faull *et al.,* 1996). The two most common solutions to control slipperiness were discussed extensively in the thesis, namely using hard flooring having a consistent rough surface (acid resistant mastic asphalt) or using yielding materials (elastic rubber mats). Yet, it was stated that hard floors fail to provide sufficient friction for normal cow movement including turning, accelerating and stopping without being too abrasive for claws (van der Tol *et al.*, 2005). The excessive wearing of claw horn and loss of a natural, functional claw shape on a hard floor with good friction properties was confirmed in the present thesis (Paper III, IV). A yielding surface would provide good footing and therefore decrease slipping risk without deterioration of functional claw shape. It seems that soft flooring not only provides safe footing, but also might decrease discomfort due to lameness and increase general locomotion comfort in cubicle systems (Paper I-II).

It should be noted that to achieve good locomotion, rubber mats should be soft enough to provide a good grip especially in the presence of a lubricant (slurry) and at the same time they must provide steady support when fully loaded. Extremely soft mats do not assist in effective propulsion and may cause muscle fatigue (King, 2002). It has also been reported that the energy cost of walking increased when cattle walked through 300 mm deep mud in comparison with a hard surface (Dijkman & Lawrence, 1997).

Although health parameters are important justifications of locomotion comfort, the effect of flooring systems on health status of the locomotion system was beyond the scope of this thesis. In spite of several reports indicating improved health and locomotion in cows housed on rubber flooring (Benz, 2002; Vokey *et al*., 2001; Vanegas *et al*., 2006) we still can not state for certain that soft rubber flooring improves the clinical condition of the locomotion apparatus of cattle. In reviewing the literature it is apparent that the idea that soft flooring may promote health is based on the following statements:

- soft flooring results in lower contact pressure (Hinterhofer *et al.,* 2005) which should result in lower risk for bruising the corium (Manske, 2002, Bergsten, 1994);
- better grip on a yielding floor reduce the slipping risk and therefore prevent injuries related to traumas (Rushen & de Passillé, 2006);
- soft flooring results in increased locomotion activity (Benz, 2002) which facilitates cow health (Gustafson, 1993) and might even solve some metabolic problems (Adewuyi *et al.,* 2006);
- when standing on an ergonomic yielding floor the body naturally and imperceptibly sway which encourages subtle movements which stimulate blood circulation (King, 2002). It has been shown that standing on soft flooring decreased muscle fatigue in working personnel (Rys & Konz, 1994).

The last statement is interesting as it may have some application to the control of laminitis without providing long distance motion.

Since none of the flooring materials available on the market today totally satisfies the requirements for the best possible locomotion comfort there are attempts to combine different floorings into one flooring system. For example the problem with higher net growth of the claws exposed to the rubber flooring may be solved by short exposure to abrasive surface (Paper III). Providing soft surface only at feeding sites (feed-stalls) might have a less desirable effect when the animals exposed to the highly abrasive floor in the walking areas, since the excessive abrasion of the wall on asphalt floors was not fully prevented by the use of feed-stalls (Papers III-IV). It appears that corrective claw trimming based on the principals of optimal function of the claw continues to be an important component of the locomotion comfort management of dairy cows housed indoors.

Locomotion apparatus and particularly the distal part of the limb in cattle evolved under conditions of yielding ground surface. We should, however, realise that even a floor design, which has been optimally approximated to the "natural" ground, will not solve all locomotion problems observed in modern high-producing dairy cows. For many generations cows have been bred for production traits which dramatically altered their functionality. A modern high-producing dairy cow is not a very "functional" animal and thus we can not expect from her "a natural" locomotion even if she moves on a natural ground. Therefore, the flooring and management should be adjusted to the existing welfare needs of today's high producing dairy cow, in order to promote the best achievable locomotion comfort.

# Conclusions

From the results obtained in the present thesis the following conclusions can be drawn:

1. Elastic rubber mats improved the gait of both lame and non-lame cows especially in comparison with gait on the slippery concrete slatted floor.
2. Lame cows showed reduced discomfort related patterns (such as step asymmetry) while walking on soft floorings.
3. When provided with a choice, cows preferred to stand and to walk on a softer flooring. However, lame animals within a herd did not express higher preference for soft flooring compared to non-lame cows. This finding may be attributed to competition with high ranked cows.
4. Abrasiveness of the flooring surface was the most important property in its influence on claw conformation and rates of claw horn wear and growth. The most intensive exposure to the abrasive flooring resulted in exaggerated wear and growth rate (but very low net growth) of claw horn; furthermore, concavity of the sole was lost.
5. Cows housed with the least exposure to the abrasive floorings preserved the concave form of the claw sole, had low rates of claw horn growth and wear but had largest net growth of the claw horn.
6. Changed conformation on the abrasive floors resulted in altered weight and pressure distribution within the claws, where the weight was directed mainly on the sole segment of the claw and weight bearing role of the claw wall was diminished.
7. No significant effect of any flooring system was found on functional and conformational disproportion between lateral and medial claws.

# Practical recommendations

The results in this thesis provide some practical recommendations regarding flooring design of dairy houses. Slip resistance should be provided by the softness of the floor. Hard, abrasive surfaces should be used only to control claw overgrowth and should not be used as a solution to reduce slipperiness or to substitute regular claw trimming. The optimal solution for flooring at the walking areas therefore seems to be a soft flooring (to improve comfort and slip resistance) with moderate abrasion (to control claw overgrowth and provide normal function of the claw). Since available rubber floorings do not provide the required degree of abrasion, short exposure to abrasive floors may be a viable alternative. Cow traffic should be organized in such a way that all the cows in the herd are equally exposed to the abrasive flooring. The degree of abrasiveness and intensity to exposure for different floorings should be explored through future research. Floor claw interaction that simulates the natural conditions present on grassland should provide the onset of claw horn growth and wear and decrease the need (or amount of work) for functional claw trimming.

# Summaries in other languages

## Svensk sammanfattning

Mjölkkors rörelsefrihet är en viktig del av deras naturliga beteende och tillfredställs av naturliga skäl bättre i lösdriftssystem än i uppbundna system. Även om kor i lösdriftstall har större möjlighet till fria rörelser och sociala kontakter än uppbundna kor, kan lösdrift å andra sidan innebära en större påfrestning på rörelseapparaten, varför utformningen av gångytorna är av största betydelse. Djurens rörelseapparat har utvecklats i nära samspel med deras naturliga miljöer. De europeiska mjökkoraserna härstammar från uroxar, som levde i ett omväxlande landskap med skog och betesmark. Kornas klövar anpassades därför till rörelser på ett relativt mjukt och i normalfallet hygieniskt underlag. Större exponering för en undermålig miljö i form av snävt tilltagna rörelseytor, dålig hygien och hårda och halkiga golv kan bidra till en större risk för och en högre förekomst av skador på framförallt klövar och ben, med rörelsestörningar och hälta som följd. Vid utformningen av ett väl fungerande lösdriftsstall krävs ett golvsystem som ger optimal rörelsekomfort, dvs möjlighet till och stimulans av fria naturliga rörelser med liten halkrisk samt förutsättningar för en god ben- och klövhälsa.

Syftet med denna avhandling var att studera effekten av olika golvsystem på mjölkkors rörelsemönster, preferens för olika golvtyper och dess långsiktiga effekter på klövform och belastningsförhållanden mellan och inom klövarna.

För att undersöka olika golvsystems effekt på rörelsemönstret användes fotspårsanalys, dvs. mätning av avstånd och vinklar mellan kornas fotavtryck då de fick gå ca 10 meter på ett plant underlag. I rörelsestudien användes både halta och icke halta kor. Rörelsemönstret hos varje ko undersöktes på fem olika underlag: betongspaltgolv och helt betonggolv med och utan mjuka, 20 mm tjocka gummimattor (Kraiburg Gummiverk GmbH) samt på ett naturligt, eftergivligt underlag i form av fuktig, packad sand. Rörelsestudien visade på tydliga skillnader mellan olika underlag. Det rörelsemönster som mest avvek från naturligt underlag var halkigt betongspaltgolv där korna, i jämförelse med de andra underlagen, gick med förkortade steg, bred benställning och bakklövens avtryck placerat långt bakom framklövens avtryck. Rörelsemönstret på mjuka gummimattor karakteriserades av friare rörelser än på betonggolv och närmade sig därmed det på naturligt sandunderlag. Mjukt underlag resulterade också i minskat uttryck för hältrelaterade gångparametrar såsom stegasymmetri hos kor med hälta, vilket tydde på att de hade mindre ont på mjukt underlag.

För att kunna rådfråga korna själva om vilket golv de skulle föredra, gjordes preferensstudier. Studierna genomfördes i en mjölkbesättning med ca 280 kor i ekologisk drift. Först testades preferensen för att stå på mjuka respektive extra mjuka gummimattor (Kraiburg Gummiverk GmbH) eller betong i samlingsfållan. Ett år senare testades preferensen för att gå på hela gummimattor, spaltgummimattor eller betongspaltgolv på gången från mjölkgropen till stallet. Varje underlag testades mot ett annat underlag under fyra dagar på varje sida av samlingsfållan eller gången. Djurens fördelning jämfördes med kontrollobservationer under fyra dagar i samlingsfållan eller gången innan gummimattorna introducerades.

Andelen kor som stod på den sida av fållan som täckts med gummimattor, oavsett typ, var signifikant högre än vid kontrollobservationerna med betonggolv. Det fanns en svag preferens för extra mjuka gummimattor jämfört med mjuka gummimattor, men denna skillnad var inte statistiskt säkerställd från kontrollen. Vid preferenstestet på gången från mjölkgropen ökade andelen kor som enbart gick på sidan med gummimatta, oavsett typ, gradvis under de fyra dagar försöket pågick. Hos icke-halta kor ökade preferensen för gummispalt respektive hel gummimatta med 25 respektive 30 % fram till den fjärde observationsdagen. Preferensen för hel gummimatta var något starkare än för gummispalt. Preferensen för mjuka golv ökade mindre hos halta kor än icke halta (12 respektive 19 % ökning fram till dag fyra för gummispalt respektive hela gummimattor).

Slutsatsen var att majoriteten av korna föredrog att stå och gå på gummimatta jämfört med betonggolv, men att halta kor visade lägre preferens förmodligen på grund av konkurrens från högre rankade, icke halta, kor.

Klövform och klövens tryckfördelning mellan och inom klövar studeras i en långtidsstudie där olika golvsystem jämfördes under två stallsäsonger i fem, förutom golven, likvärdiga stallavdelningar om vardera 20 liggbås. Första stallsäsongen jämfördes betongspaltgolv, med hela golv med gummimatta eller gjutasfalt, samt med eller utan gummimatteförsedda ätbås. Andra stallsäsongen studerades gummispaltmatta med och utan skrapor på spalten, samt betongspaltgolv utan skrapor.

Vid en jämförelse av klövväggens slitage och tillväxt visade sig både tillväxten och slitaget vara störst på gjutasfaltgolv i stallar utan ätbås. Klövslitaget på gjutasfalt utan ätbås översteg något tillväxten, vilket resulterade i en negativ nettotillväxt av tålängden. Med gummimatteförsedda ätbås minskade klövslitaget i gruppen på asfalt och både tillväxt och slitage minskade för kor som gick på gummimattor med eller utan ätbås. Under första stallsäsongen passerade korna från gruppen med gummimattor avdelningen med gjutasfalt på väg till mjölkningen och då skiljde sig inte deras klövtillväxt och slitage från dem inhysta på betongspaltgolv. Under andra stallsäsongen hade korna på gummimattor inte kontakt med gjutasfalt och då minskade deras klövslitage, vilket resulterade i högre nettotillväxt än på betongspaltgolv.

Vid analys av tryckfördelningen mellan och inom klövar hos kor efter ca 6 månaders inhysning i de ovan nämnda golvsystemen, visade det sig att på asfaltgolv hade klövarna mycket större kontaktyta än på betongspaltgolv och gummimattor. Större kontaktyta på asfaltgolv resulterade i lägre tryck. Hos dessa djur var emellertid den största belastningen koncentrerad till klövsulan. Klövarna hos kor inhysta på gummimatta hade mindre kontaktyta och en stor del av lasten var fördelad på klövväggen, att jämföra med asfaltgolv där belastningen på klövväggen var obetydlig. Analys av klövsuleprofiler bekräftade att sulkonkaviteten, som skapades vid verkning vid försöksstart, kvarstod på mjuka gummimattor och slitet betonggolv men försvann på det grövre asfaltgolvet.

Studierna visade inte att olika golvsystem påverkar asymmetri i klövform eller viktfördelning mellan ytter- och innerklöv.

Slutsatsen från långtidsstudien var att, golvets ytstruktur hade störst effekt på klövkapselns form och relaterad lastfördelande funktion. Ett hårt slitande golv resulterade i en klövform där klövväggens viktbärande funktion minimerades med en överbelastning av klövsulan som följd och därmed ökad potentiell risk för klövskador. Ökad nettotillväxt på golv med för lågt slitage skulle kunna resultera i överbelastning av ballar och felaktiga benaxlar och riskera att ge andra typer av skador.

Resultaten av avhandlingen tyder på att mjuka gummimattor gynnar naturliga rörelsemönster, komfort och djurens välbefinnande. Ett hårt slitande golv ger bra friktion som minskar halkrisken men ändrar klövformen så att viktiga funktionella egenskaper förloras. Optimala golvsystem måste vara mjuka för att ge god komfort och vara mindre halkiga men samtidigt ge visst slitage på klövarna för att behålla klövens normala form och funktion. På grund av att gummimattor inte ger tillräcklig slitage på klövarna kan viss exponering för ytor som ger ett visst slitage rekommenderas. Med avseende på djurpreferenser för olika golv måste kotrafiken utformas och utrymme medges så att alla djur ges möjlighet att exponeras i likartad utsträckning för olika golvtyper i stallet. Om kor med rörelsestörningar, på grund av trånga utrymmen och konkurrens från andra djur, inte ges tillgång till den bästa miljön utsätts djuren för onödigt lidande och skadorna kan förvärras. Halta djur bör därför avskiljas tills skadorna har behandlats och avläkt.

# Резюме

Передвижение в пространстве или локомоция является неотъемлемой частью нормального поведенческого репертуара крупного рогатого скота. Кроме того, локомоция необходима для общего здоровья продуктивных животных, их нормального роста и развития, плодовитости и увеличения продуктивности. Беспривязная система содержания молочного скота, которая становится все более распространенной, призвана обеспечивать возможность свободного круглосуточного передвижения животных.

Эволюция двигательной функции животных осуществлялась в тесном контакте с окружающей средой, которая являлась предопределяющим фактором развития способа локомоции, а также функциональных особенностей конечностей. Опорно-двигательный аппарат предка европейского крупного рогатого скота (*Bos Primigenius*) эволюционировал в условиях лесостепи, а следовательно в условиях умеренно деформирующегося грунта. В силу определенных объективных обстоятельств, полы в помещениях для беспривязно-боксового содержания крупного рогатого скота, в подавляющем большинстве, представлены железобетонными конструкциями. Железобетонные полы с их твердой и зачастую чрезмерно скользкой поверхностью не соответствуют функциональным и анатомическим особенностям локомоторного аппарата крупного рогатого скота. Поэтому проблема заболеваний конечностей при беспривязно-боксовой системе содержания стоит черезвычайно остро. Целью данной работы было комплексное исследование эффекта различных половых покрытий на локомоцию, поведение, а также на морфо-функциональные особенности копытец крупного рогатого скота.

Для анализа влияния полового покрытия на локомоцию был разработан метод измерения следовых дорожек. В течение эксперимента были изучены следовые дорожки 36 коров голштинской и шведской красной пород, с различным статусом опорно-двигательного аппарата. Локомоция каждого животного изучалась на пяти покрытиях: сплошной и щелевой бетонный пол с применением и без применения мягкого резинового покрытия толщиной 20 мм, и прессованный влажный песок (как образец натурального, природного покрытия). Для лучшей дискриминации отпечатков копытец на всей поверхности (за исключением песка) наносился водный раствор гидроксида кальция ($Ca(OH)_2$).

По результатам технических тестов наименьший коэффициент трения был зафиксирован на щелевом бетонном полу, наибольший на сплошном бетонном полу; резиновое покрытие характеризовалось промежуточным значением коэффициента трения. Результаты анализа следовых дорожек выявили достоверное влияние пола на локомоцию коров. Параметры локомоции наиболее отклоняющиеся от локомоции по натуральному покрытию (песок) были зафиксированны на скользкой поверхности щелевого бетонного пола, где животные передвигались со значительно укороченным шагом, широкой постановкой конечностей и при этом

отпечаток задней конечности располагался далеко позади отпечатка передней конечности. Локомоция на мягком резиновом покрытии приближалась по своим характеристикам к локомоции на модели естественного мягкого покрытия. У животных с нарушениями локомоции асимметрия шага была выражена в меньшей степени при передвижении по песку и мягким резиновым покрытиям. Кроме того, животные с нарушениями локомоции передвигались с более широкой постановкой конечностей по бетонным полам, чем по мягким поверхностям.

Было заключено, что качество локомоции молочных коров было улучшено на полах, усовершенствованных резиновым покрытием. В том числе, было показано повышение комфорта передвижения у животных с заболеваниями конечностей по мягким покрытиям по сравнению с традиционными бетонными полами.

Предпочтение животных различным поверхностям, предназначенных для стояния и передвижения, было изучено в условиях коммерческой молочной фермы (280 молочных коров голштинской и шведской красной пород) с беспривязным содержанием. Контроль свободного выбора коров между различными половыми покрытиями осуществлялся в доильном зале, в период ожидания перед заходом в доильную установку, а также в проходе, после окончания дойки. Следующие материалы использовались на половине доильного зала для определения препочтения: мягкие сплошные резиновые маты (KEN, Kraiburg Gummiverk GmbH), резиновые маты повышенной мягкости (KSL, Kraiburg Gummiverk GmbH) и сплошной бетонный пол. При проверке предпочтения в проходе использовались щелевые резиновые маты (KURA-S, Kraiburg Gummiverk GmbH), сплошные резиновые маты (KURA-P, Kraiburg Gummiverk GmbH) и щелевой бетонный пол. Каждая комбинация полов была испытана в течение четырех дней на правой и левой стороне доильного зала и прохода. Распределение животных фиксировалось на видео и в дальнейшем сравнивалось с контрольным распределением (распределение животных в доильном зале и проходе при однородном половом покрытии).

Результаты эксперимента показали, что при условии свободного выбора между бетонным полом и полом, покрытым резиновыми матами, более значительная пропорция стада предпочитала стоять и передвигаться по резиновым покрытиям. Сравнительно большее предпочтение было отдано более эластичному покрытию, а также сплошному покрытию по сравнению с щелевым. Коровы с клиническими нарушениями опорно-двигательного аппарата, находясь в группе с другими животными, показали невысокое предпочтение мягкому покрытию по сравнению со здоровыми животными. Причиной последнего могла быть конкуренция между животными, где здоровые животные с более высоким социальным рангом вынуждали больных животных с низким социальным рангом занимать менее выгодные позиции.

Для анализа влияния различных полов на морфо-функциональные характеристики копытец молочных коров был проведен полномасштабный эксперимент в течение двух стойловых периодов (протяженность каждого периода была около 6 мес.) в условиях экспериментальной фермы Шведского Аграрного Университета (Альнарп). В экспериментальном помещении были выделены секции на 20 голов с идентичными условиями кормления и содержания, за исключением конструкции полов на аллеях и в местах кормления. В течение первого стойлового периода сравнивались следующие системы полов: щелевой бетонный пол, асфальтовый пол с кормобоксами (имеющими резиновое покрытие пола), асфальтовый пол без кормобоксов, а также сплошные резиновые маты (KURA-P, Kraiburg Gummiverk GmbH). В течение второго стойлового периода щелевой бетонный пол сравнивался с щелевыми резиновыми покрытиями (KURA-P, Kraiburg Gummiverk GmbH) со скрейперами и без них.

В течение эксперимента определялись морфологические показатели латерального и медиального копытец левой задней конечности, скорость стирания и роста копытного рога. Кроме того, с помощью сенсора давления (Tekscan Inc., Boston, MA, USA) определялось контактное давление и распределение опорно-силовой нагрузки между латеральным и медиальным копытцами, а также в пределах каждого копытца.

При сравнении темпов роста и стирания рога копытной стенки выяснилось, что как стирание, так и рост были наибольшими при содержании на асфальтовых полах без кормобоксов. При этом стирание копытной стенки в небольшой степени превзошло ее рост, что отразилось в негативном абсолютном росте копытного рога. При совместном использовании асфальтовых полов и кормобоксов с резиновыми полами, стирание копытного рога уменьшилось. Использование резинового покрытия на аллеях уменьшило как стирание, так и рост копытного рога по сравнению с асфальтовым покрытием. Во время первого стойлового периода животные, содержащиеся на резиновых матах, прогонялись через асфальт по пути в доильный зал, и это сказалось на отсутсвии различий в темпах роста копытного рога при сравнении с изношенным щелевым бетонным полом. Во время второго сезона контакт с асфальтом отсутствовал, что привело к уменьшенному стиранию копытного рога и, в результате, к большей длине копытец на резиновом покрытии в сравнении с бетонным полом.

Результаты, полученные при помощи сенсора давления, показали значительное влияние характера полов на распределение опорно-силовой нагрузки копытец. Под влиянием абразивного асфальтового покрытия опорно-силовое взаимодействие копытец с полом было опосредованно главным образом подошвенным отделом копытец. С другой стороны, в результате большего износа копытного рога на асфальте, подошвенный отдел приобрел большую площадь контакта с полом, что отразилось в сравнительно небольшом давлении на подошву копытца. В копытцах животных, содержащихся на резиновых полах, основную роль в опоре играли мякиши и стенки копытец. Морфологический анализ профиля опорной поверхности копытец подтвердил уменьшение, а зачастую и исчезновение, нормальной, вогнутой формы подошвы копытец, подвергнутых влиянию абразивных полов. В то же время не было обнаружено влияние различных полов на диспропорцию морфологии и распределение опорно-силовой нагрузки между латеральным (внешним) и медиальным (внутренним) копытцами.

Таким образом, полномасштабный эксперимент позволил установить, что абразивность является основным свойством полов, влияющим на морфо-функциональные показатели копытец молочных коров. При содержании животных на твердом и абразивном покрытии роль копытцевых стенок в опоре уменьшается, а значит, увеличивается потенциальный риск наминок в области подошвы. С другой стороны, при содержании на полах с низкой абразивностью, чрезмерное отрастание копытцевого рога может привести к чрезмерному смещению нагрузки в область мякиша и нарушению статической функции копытец.

Результаты исследований показали, что мягкое резиновое покрытие способствует естественной локомоции и комфорту молочных коров. Абразивное покрытие уменьшает риск падения, но в результате продолжительного воздействия таких полов утрачиваются важные функциональные механизмы копытец. Следовательно, оптимальным полом для коров является мягкая поверхность, обеспечивающая нормальное движение и комфорт, при этом обеспечивающее некоторое стирание копытного рога для поддержания нормальной формы и функции копытец. Так как резиновые покрытия могут не обеспечивать необходимое стирание копытного рога, может быть рекомендован кратковременный контакт с умеренно абразивной поверхностью. Принимая во внимание предпочтения животных различным половым покрытиям, необходимо создать такие условия для движения животных, чтобы все члены стада экспонировались на различных полах в равной степени. Животные с заболеваниями конечностей должны быть обеспечены большим комфортом, что позволит улучшить результаты лечения и темпы выздоровления.

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