CHAPTER I

INTRODUCTION

Successful animal production requires adequate nutritional and housing management. “Adequate” being a relative term. More specifically, nutrition and housing management should not increase the animal’s risk for becoming diseased. In order to design adequate housing and nutritional programs we have to define normal physiology for specific animal species. The ruminant digestive system is designed to utilize forage as a main source of nutrients and energy. Bovine locomotion system, particularly the foot, is designed for motion on a soft, giving surface. Pasture seems to be a natural habitat for cattle. In the last few decades of cattle production, nutrition and housing have changed. Milk and beef production has become more intensive in order to reduce production costs and increase productivity. Animal housing facilities were adjusted to human working ease and nutrition for the highest possible production. Both housing and nutrition are greatly influenced by economical return. One of the negative results of the industrialization of cattle production is new health disorders. Lameness is one of them, particularly in the dairy industry. The majority of lameness is caused by claw disorders.

Description of claw characteristics under “natural” conditions on pasture and its comparison to adaptation on concrete and a high grain diets may help the understanding of the nature of claw disorders.

Horn growth and abrasion form the shape of the claw. Bovine claw shape can be characterized by dorsal wall length, sole surface area and sole thickness. Differences in shape between lateral and medial claws determine the balance of the foot. The pathogenesis, location, and severity of lameness lesions appear to be dependent on biomechanical interactions of the claw structures and weight distribution within the claw and between the medial and lateral claws.

The objective of this study was to evaluate the effect of feedlot (high grain diet, concrete floor) vs. pasture on claw development in growing beef steers. Claw growth, abrasion, dorsal wall length, sole surface area and sole horn thickness were measured to compare the two different finishing systems. An emphasis was placed on investigation of differences between the lateral and medial claws.

CHAPTER II
LITERATURE REVIEW

Lameness importance, economics and causes

Lameness results in economic losses and welfare problem in cattle populations worldwide (Green et al., 2002; Kossaibati and Esslemont, 1997; Whitaker, 1983). The economical losses are mainly due to the negative impact of lameness on dry matter intake and milk production in dairy cattle (Green et al., 2002). Kossaibati and Esslemont (1997) predicted an overall cost of £246.22 per lameness case (approximately US $446) in the United Kingdom. Lameness resulting from injuries is a significant cause of both feedlot morbidity and mortality. In a review from Nebraska, feedlot lameness was responsible for 16% of health problems and 5% of death losses (Stokka 2001).

Authors in North America, the United Kingdom and Scandinavia have reported a high prevalence of lameness in dairy herds (Wells et al., 1993; Clarkson et al., 1996; Cook, 2003a; Manske et al., 2002; Whay et al., 2002). The majority of lameness lesions in dairy cattle are associated with the lower foot. Based on etiology, herd control and prevention, two groups of disorders causing lameness have been differentiated (Guard, 2001).

- Infectious foot disorders: heel wart (digital, interdigital dermatitis) and foot rot (interdigital necrobacillosis)
- Claw horn lesions: sole, toe and wall ulcers, sole/white line abscesses

Interdigital hyperplasia (corn) does not always relate to lameness and may be caused by both infectious and mechanical causes. Heel erosions, sole or white line hemorrhages, yellow discoloration of the sole horn or double sole do not cause pain and / or lameness but they do have the same pathogenesis as the claw horn lesions and are indicators of past damage of the corium. Infectious foot disorders are often associated with several management characteristics of the herd like barn cleanliness and foot bath management (Holzhauer et al., 2006).

Limited information is published about lameness incidence in beef cattle, especially cow-calf operations (Anderson and Rogers, 2001). The following is a list of common causes of lameness in beef cattle.

- Foot
  - Claw horn lesions: cork screw claw, overgrowth, wall crack, sole/white line abscess, sole, wall and toe ulcer
  - Interdigital tissue: foot rot (interdigital necrobacillosis), interdigital hyperplasia (corn), laceration
- Limb
  - Arthritis (septic, nonseptic)
  - Cranial cruciate ligament tear
  - Flexor tendonitis (septic, nonseptic)
  - Long-bone fractures
- Spine
  - Pelvic fracture, sacroiliac subluxation and luxation
  - Spinal cord trauma
  - Vertebral spondylitis

Several studies have reported the importance of claw horn lesions in dairy herds. Studies can be divided into those that determine the prevalence of lesions in all cows and those that determine lesion prevalence in only lame cows. Using a system of sole scoring, originally developed at the VI Symposium of Diseases of the Ruminant Digit in Liverpool (1990), Smilie et al. (1996) found claw horn lesions in each of 13 free stall herds and in 34.8% of claws of first lactation heifers when examinations were made from 60 d prior and 60 and more d after parturition. Bergsten (1994) reported that sole hemorrhage affected more than 80% of cows in 22 herds in Sweden. In his more recent survey of 101 Swedish dairy herds (predominantly housed in tie stalls) he published that more than a 80% prevalence of sole hemorrhage (Bergsten, 1994). Manske et al. (2002) detected claw horn lesions in 64.7% of claws of 4899 cows across a range of parities. When only lame cows were considered, claw horn lesions were responsible for 35% to 60% of the lameness recorded in two studies on free stall housed herds with summer grazing in the United Kingdom (Murray et al., 1996; Kossaibati and Esslemont, 2000). Warnick et al. (2001) reported claw horn lesions were responsible for lameness events in two US herds housed in free stalls, 23% and 33.1% of the time. In a survey of 1155 lameness treatments on 10 Wisconsin dairy herds involving cattle continuously housed in either tie stall or free stall housing, claw horn lesions were responsible for 36.2% of the treatments (Cook, 2004). These studies suggest that across a wide range of housing conditions, claw horn lesions were responsible for 23% to 60% of lameness in dairy cows.

Topography, etiology and pathogenesis of claw horn lesions with emphasis on the biomechanics of the claw

The determination of characteristics for claw quality is needed to understand claw disorders (Vermunt and Greenough, 1995). Claw quality is the product of horn characteristics, claw shape and the anatomy and physiology of the inner structures of the claw (Politiek, 1986). These authors defined high quality as low susceptibility to claw disorders with a low need for claw care.

Risk factors for claw horn lesions include high grain rations (Livesey and Fleming, 1984; Livesey et al., 2003) and concrete flooring (Bergsten and Frank, 1996; Bergsten and Herlin, 1996; Nordlund, 2004; Webster, 2001).

The pathogenesis of claw horn lesions appears to be dependent on the biomechanical interactions of the claw structures and weight distribution within the claw, and between the medial and lateral claws of a foot. The weight distribution and balance of the foot are determined by the shape of the claws (van der Tol et al., 2004). The shape of the claws of healthy animals is determined by genetic components and by the dynamics of horn growth and abrasion (Vermunt and Greenough, 1995). Alteration of the shape and balance of the foot may contribute to the pathogenesis, location and severity of the lesions (Clarkson et al., 1996; Le Fevre et al., 2001; Murray et al., 1996; Russell et al., 1982; van der Tol et al., 2003). Abnormal claw shape is one of the most significant risk factors in the development of lameness (Anon, 1993). (Russell et al., 1982) assessed the relationship between claw conformation and occurrence of lameness and reported that 42% of claw lesions occurred in abnormally shaped claws.

The lateral claw of the hind limb is the predominant claw on which claw horn lesions occur (Murray et al., 1996). Mechanical (Rusterholz, 1920) and dynamic (Toussaint Raven, 1985) overload of the lateral claw has been proposed as causative factors for lesions to occur in this location. Biomechanical studies of the bovine foot reveal that the lateral and medial claws of the hind limb are loaded unevenly, with greater pressure on the lateral claw (van der Tol et al., 2002). This irregular load on the foot causes irritation of the corium of the lateral claw. Irritation of the corium may cause hypertrophy as well as hyperplasia, resulting in enlargement of the lateral claw. The larger claw will start to bear a greater part of the body weight and, thus a vicious circle is established (Toussaint Raven, 1985). Raven's original theory for the lateral claw carrying more weight is based on dynamic changes of the rear feet during movement of the cow. Raven explains that hips distribute more weight to the lateral claw during side-to-side movement. Secondly, the udder spreads the rear legs and naturally displaces more weight on the lateral claws. Recently, (Nuss and Paulus, 2005)) reported that the lateral claw reaches further distally than the medial claw. They concluded that there might be a difference in length between the medial and lateral digit. Conversely, (Ranft, 1936) demonstrated, that the length of the digit bones was not different and hypothesized that the lateral condyle of the metatarsal bone might be longer than the medial condyle. Consequently, results of the study conducted by (Nacambo, 2004) in calves revealed that the lateral condyles of the metatarsal bones are longer than the medial ones.

When cattle are exposed to hard flooring, like concrete, the negative impact of the physiological imbalance of the foot may be increased. (Vokey et al., 2001) reported that cows on rubber mats had significantly lower lateral claw net growth rates than those on concrete. Concrete was identified as a important contributing factor in pathogenesis of claw horn lesions by several researchers (Wells et al., 1995); (Bergsten and Frank, 1996; Bergsten and Herlin, 1996; Nordlund, 2004; Webster, 2001). Cows in commercial dairy herds tied in stalls equipped with rubber mats were shown to have significantly less severe sole hemorrhages than those tied in concrete stalls (Bergsten, 1994; Wells et al., 1995). (Vermunt and Greenough, 1996) observed that heifers housed on concrete had a greater number and more severe sole hemorrhages than heifers managed in dry lots.

Horn growth, abrasion

Claw horn is in a state of continuous turnover. The rates of formation and loss of horn tissue as well as variation in horn quality become more important in animal production as confinement time increases. Abrasive and hard surfaces such as concrete, increase the rate of horn wear and thus, new horn of high quality must replace the worn horn or animal performance will be affected (Hahn et al., 1986). Hoof horn is produced through a complex process of differentiation (keratinization) of epidermal cells (Tomlinson et al., 2004).

The earliest study of claw growth and wear was published in the early 70's by (Prentice, 1973). Numerous studies focusing on the growth and wear of hoof horn followed (Hahn, 1978); (Hahn et al., 1986); (Manson, 1989, 1988); (Tranter and Morris, 1992); (Vermunt and Greenough, 1995) (Table1 and 2).

Table 1: Mean monthly horn growth and wear rates (mm/month) on the dorsal surface of hind lateral claws in various age groups of dairy cattle confined on different surfaces. Adapted from (Vermunt and Greenough, 1995).

Reference	Description	Growth	Wear
Prentice (1973)	Cows on concrete and pasture	3.9	4.1
	Yearlings on straw and pasture	4.4	4.7
	Calves on straw and pasture	4.9	3.2
Clark and Rakes (1982)	Mature cows on concrete	6.0	5.3
Hahn et all. (1986)	Heifers on pasture or dry lot	6.2	5.13
	Heifers on new concrete	7.1	6.9
Murphy and Hannan (1986)	Yearling steers on slats	6.2	5.3
	Yearling steers on straw	5.6	4.1
Schlichting (1987)	Pre-weaned calves on slats	7.5	3.7
	Pre-weaned calves on straw	5.6	1.4
Manson and Leaver (1988)	Dairy cows on concrete		
	- Fed a high-protein diet	5.0	4.1
	- Trimmed and high-protein diet	6.5	3.6
Manson and Leaver (1989)	Dairy cows on concrete		
	- Fed a high-concentrate diet	4.3	4.7
	- Trimmed and high-concentrate diet	5.4	3.8
Vermunt (1990)	Heifers on dry lot	5.6	3.9
	Heifers on concrete /slats	5.9	4.8
Tranter and Morris (1992)	2-years-old cows on pasture	5.9	5.6

Table 2: Rates of net claw growth (growth minus wear) for young dairy cattle confined mainly on concrete (mm/month). Adapted from (Vermunt and Greenough, 1995).

Author	Year	Country	Hind claws	Front claws
Camara and Gravert	1971	West Germany	1.3	-
Dietz and Koch	1972	West Germany	1.4	-
Prentice	1973	United Kingdom	-0.3	0.3
Hahn et all	1978a	United States	0.5	0.4
Hahn et all	1986	United States	0.2	0.1
Vermunt	1990	Canada	1.1	-
Tranter and Morris	1992	New Zealand	0.2	0.3

Based on the published data, a measurement of the claw's dorsal wall was a widely used method to define horn growth and wear in cattle. (Hahn, 1984) described an objective method to measure the claws of dairy cows using the periople line. Prentice (1973) developed an alternative method by tattooing the skin above the coronary band with black ink as a reference point. However, only cattle with unpigmented skin above the coronary band were suitable for this tattooing method. (Tranter and Morris, 1992) measured dorsal wall growth and wear, sole wear and sole concavity in spring calving cows on the pasture over 12 month period. For measurements they used a mark made with soldering iron on the dorsal wall, 10-20 mm below the periople line. They monitored the sole wear by recording the number of weeks it took for 1.5 mm deep groves to disappear from the weight-bearing surface of the hooves. A profile gauge, which is a device used in engineering to reproduce erratic profiles, was used to reproduce the contour of the bearing surface of the hooves at their widest point.

In the normal bovine claw, growth and wear of the horn occur at approximately equal rates. However, certain situations may alter either or both sides of this physiological equation. The major factors that impact the rate of growth and abrasion are age, breed, season, nutrition and type of flooring (Vermunt and Greenough, 1995).

Prentice et al. (1973) reported lower growth rates in claw horn of mature cows when compared to calves and yearlings. (Glicken and Kendrick, 1977) also showed that the growth rate of claw horn is faster in younger cows than in older cows. Hahn et al. (1978) and Tranter and Moris (1992) found higher growth rates in first rather than second lactation cows. (Brinks, 1979) reported hoof horn growth in beef cattle increased from 2-6 years of age and remained relatively constant thereafter. However, (Clark and Rakes, 1982) reported that the rates of hoof horn growth in dairy cattle were not related to age or number of days in lactation. Stage of lactation did not affect the rate of horn growth in Holsteins, but it did in Jerseys (Hahn et al., 1986). However, (Dietz, 1981) reported that horn growth decreased during peak milk production and during the second trimester of pregnancy.

Sex and breed of cattle appeared to have no influence on either growth or wear rates of hoof horn (Schlichtling, 1987; Schneider, 1980). Conversely, Brings et al. (1979) reported differences in horn growth between lines of sires within breeds of cattle and postulated that selection against excessive horn growth or for normal claws should be possible.

Seasonal factors affecting horn growth and wear include nutrition, ambient temperature, photoperiod, moisture and abrasiveness of the surface. (Hahn et al., 1986) reported higher growth rates occurring during warmer parts of the year. Researchers suggested that temperature, management and dietary changes contributed to the cyclic growth patterns of horn tissue. The impact of photoperiod was studied by (Clark and Rakes, 1982), who suggested that greater horn growth in the spring-summer period is due to more light exposure during this time of year. (Wheeler, 1972) concluded that photoperiod did not influence the rate of horn growth but a lower ambient temperature negatively impacted horn growth in sheep. (Tranter and Morris, 1992) in their 12 month-long study reported higher horn growth rates during the summer compared to the winter. They also explained that low horn wear rates occurred during the winter when the cows were on soft pasture. Vermunt (1990) reported little or no horn wear in heifers housed outdoors compared to heifers housed on concrete.

Keratin proteins, which are high in sulphur-containing amino acids like cysteine and methionine (Fraser and Macrae, 1980) are found in the bovine claw. (Manson, 1988) demonstrated higher rates of claw horn growth in dairy cows fed high-protein (19.8%) rations compared to cows fed lower protein (16.1%) diets. Conversely, Greenough et al. (1990) reported decreased growth rates of sole horn in yearling beef cattle with increased dietary protein. (Manson, 1989) reported that horn growth and wear in dairy cows was not increased by high concentrate (11 kg): silage ration compared to a low concentrate (7 kg): silage ration. However, (Greenough, 1990) reported that the growth of sole horn was increased in beef calves fed high-energy rations. Few studies have examined the effect of supplementary methionine or its analogues on horn growth and wear. Hooves of cows fed methionine hydroxy analog grew faster than those of control cows not receiving methionine supplement. Wear rates were not affected significantly by methionine treatment (Clark and Rakes, 1982). However, (Randy, 1985) did not find a significant difference in horn growth in cows supplemented with zinc methionine compared with their controls not supplemented with zinc-methionine. Some minerals have been identified as a key factor in the process of keratinization (horn production). Calcium is needed for activation of epidermal transglutaminase (TG), which is active in cross-linkage of the cell envelope keratin fibers and is involved in the initiation and regulation of the terminal differentiation of the epidermal cells. Insufficient calcium provided to the maturing keratinocyte due to inadequate vascular supply (Nocek, 1997) or calcium availability due to hypocalcemia may lead to depressed TG activity and formation ofdyskeratotic horn (Tomlinson et al., 2004). Zinc has several roles in the keratinization process, such as catalytic, structural and regulatory functions (Rojas et al., 1996). (Baggott et al., 1988)) reported lower concentrations of zinc in claw horn of lame cows compared to cows without a history of lameness. There are no available studies to show a positive effect of zinc supplementation on rate of growth or wear of the claw horn. Thiol oxidase, which is activated by copper plays a role in activation of the thiol oxidase enzyme, which is responsible for formation of disulfide bonds between cysteine residues of keratin filaments (O'Dell, 1990; Toussaint Raven, 1985). (Puls, 1984)) reported increased susceptibility to heel cracks, foot rot and sole abscesses in cattle with subclinical cooper deficiency. Supplementation of the diet with a combination of complexed trace minerals (zinc, cooper, cobalt, and manganese) lead to better claw health and integrity (Nocek et al., 2000). Biotin is a water-soluble B vitamin, deficiency of which leads primarily to changes in epidermal structures such as skin, hair, and claws (Kolb et al., 1999; Mulling et al., 1999). Although biotin deficiency does not occur in ruminants under field conditions, there is mounting evidence from clinical field studies that administration of long term supplemental dietary biotin has a positive influence on hoof and claw quality (Geyer and Schulze, 1994; Schmid, 1995; Josseck et al., 1995; Zenker et al., 1995; Geyer, 1998; Green et al., 2000; (Lischer Ch et al., 2002). Mulling et al. (1999) proposed the analogy of building a "brick wall" to the effect of supplements such as zinc and biotin on hoof keratin formation. Zinc is needed for activation of the enzyme systems needed for formation of sound cellular structure (bricks), whereas biotin is needed for production of the intercellular cementing substance (mortar). Finally vitamin A is needed for normal growth, development, and for maintenance of skeletal and epithelial tissue (NRC, 2001).

An additional factor influencing claw horn growth and wear is the type of housing, particularly the type of flooring. (Peterse, 1986) reported that cows housed in the free stalls with concrete slatted floors had faster horn growth compared to cows housed in tie stalls. Conversely, (Prentice, 1973) found no difference in rates of horn growth of cows kept on concrete or on pasture. (Vermunt, 1990) studied the rates of horn growth and wear on indoor-housed heifers confined to concrete and in heifers housed outdoors in a dry lot (dirt). Horn growth was not different between the two groups of heifers. However, due to reduced wear, the claw length of outdoor-housed heifers was much greater than indoor-housed heifers. As a consequence, claws of outdoor heifers became overgrown. The nature of the surface to which hooves are exposed appears to have a large influence on the rate of hoof wear. Cows housed on abrasive concrete had 35% greater hoof wear than cows on pasture (Hahn et al., 1986). Vermunt (1990) published that heifers housed indoors on slats had 22% more claw horn wear than those housed out of doors. Claw horn wear differs between cows on dry versus wet concrete (Camara and Graved, 1971). In this study claw horn wore twice as fast on wet concrete than on dry concrete. (Vanegas, 2005) reported higher growth and abrasion rates in dairy cows on concrete compared to cows on rubber mats. Manson and Leaver (1988, 1989) demonstrated that horn growth was increased by claw trimming, whereas horn wear decreased. These researchers suggested that some compensatory mechanism stimulated horn growth of trimmed cows. Horn growth typically exceeds the abrasion in lactating dairy cattle compared to beef cattle, which requires trimming on a regular basis. Additionally, the difference in size between the lateral and medial claw is more obvious in dairy cattle compared to beef cattle (author's personal observation).

The bovine foot consists of two independent digits. The distal part of the digit is protected by the claw. On the palmar/plantar side of the pastern joint there are two rudimental digits also protected with horn called dewclaws. The claw is a unique structure design to protect the distal part of the digit and has several different segments. Each segment has different function and also different rates of horn growth and abrasion. The rate of horn growth at the abaxial region of the wall is greater than at the dorsal border of the claw (Prentice, 1973). The difference in growth in different regions of the claw was studied by Greenough et al. (1986) and they observed that horn growth of the abaxial wall was greater at the heel than at the toe. Vermunt (1990) found that the horn growth on the abaxial wall of the hind claws was greater than on the toe, but the difference was significant for outdoor-housed heifers only. The information about the difference in growth and abrasion between lateral and medial claws and between front and rear feet is limited. Prentice (1973) reported no difference in horn growth between lateral and medial claws. Tranter and Moris (1992) demonstrated that horn abrasion was greater in lateral claws than medial. Horn growth tended to be greater in lateral claws, but the difference was not significant. Hahn (1979) and Hahn et al. (1986), reported that hind claws grew and wore faster than front claws. Conversely, Prentice (1973) reported that claw horn of front feet claws grew faster than that on hind claws.

Sole thickness

The protective function of the claw capsule is based on adequate sole thickness of approximately 7 mm in the area of the toe (Toussaint Raven, 1989). Thin soles (less than 7 mm) tend to be flexible which can lead to contusion, vascular injury of the corium and subsequent lameness (Greenough, 1987). The ability to assess the sole horn thickness in live animals is technically limited. (Kofler et al., 1999) developed methodology for investigating the sole thickness in cattle using ultrasound. This technique of investigating sole thickness was used in following years by several researchers (Kofler and Kubber, 2000; van Amstel et al., 2003). The effect of claw trimming techniques on sole thickness was studied in dairy cattle (Nuss and Paulus, 2005; van Amstel et al., 2003; van Amstel et al., 2004a; van Amstel et al., 2004b). However, the relationship between sole thickness and various floor conditions was not extensively subjected to investigation. Greenough et al. (1990) investigated claw sole thickness in beef steers after harvest and reported thicker sole horn in beef calves fed high energy diet compared to steers fed high protein diet.

Toe length and sole thickness are associated. (Toussaint Raven, 1989) published that a dorsal wall length of 7.5 cm was associated with sole thickness of 5 to 7 mm. In another study, anatomical measurements of adult bovine cadaver claws with a dorsal wall length of 7.5 cm had an average sole thickness of 8.2 mm (van Amstel et al., 2002). The importance of sole horn growth-abrasion dynamics, sole thickness and relation to claw horn lesions needs to be evaluated.

CHAPTER III

MATERIALS AND METHODS

Animals

Seventy-two yearling Angus crossbreed steers (mean BW 378 ± 6.2 kg) were assigned to two finishing systems in April 2004: feedlot and pasture in 3 replicates of 12 steers each. Steers had completed a trial from December 2003-April 2004. Treatments (n=3) during that period were based on a high forage diets designed to produce 0.23, 0.45, and 0.68 kg average daily gain. The randomization was restricted to have an equal number of steers from each winter ration treatment in each of the two finishing systems. The study began in April 2004 and continued until harvest in September 2004. Forty eight of the steers originated from a single cow/calf operation located at the Virginia Tech Shenandoah Valley Agricultural Research & Extension Center (SVAREC), Steeles Tavern, VA. Steers were born between January and March 2003 and grazed with their dams on pasture until weaning in October 2003. The other 24 steers originated at the West Virginia University Demonstration Farm, Willow Bend, WV. All of the procedures performed on the steers followed the guidelines of Virginia Tech Animal Care Committee.

Diets and feeding management

Steers in the feedlot group were transitioned to an 80 % corn-grain, 20% corn silage (DM basis) diet. On as fed basis, the diet was composed of 30 % corn silage, 65 % corn grain, 4 % soybean meal and 1 % vitamin / mineral premix. The chemical composition of the TMR is in Table 3. Steers were housed in pens with concrete floors at the SVAREC. The steers assigned to pasture were rotationally stocked on cool season mixed grass-legume pastures at the Willow Bend research center, WV. The botanical composition is listed in Table 4 and the nutritive value of the pasture is listed in Table 5.

Table 3: Average chemical composition of the high concentrate diet and diet ingredients fed to steers at Steeles Tavern, VA

Date	Sample	DM %	NDF %	ADF %	CP %
5/31/04-6/7/04	TMR	72.4	19.8	9.3	8.4
	Corn silage	38.1	43.2	24.9	3.3
	Corn grain	86.1	11.4	2.4	7.6
	Soybean meal	92.9	8.1	4.5	47.9
	Premix	94.3	11.2	6.8	31.9
6/16/04-6/21/04	TMR	78.6	18.5	8.0	8.7
	Corn silage	38.6	40.5	23.5	4.1
	Corn grain	85.4	11.7	2.5	7.5
	Soybean meal	91.4	7.6	4.4	46.9
	Premix	94.5	10.3	6.2	34.9
7/12/04-7/26/04	TMR	81.5	17.8	7.7	9.4
	Corn silage	36.4	42.5	24.8	3.5
	Corn grain	88.6	13.4	3.1	7.2
	Soybean meal	91.6	10.4	4.4	47.1
	Premix	94.3	11.5	7.1	34.1
8/2/04-8/9/04	TMR	81.3	19.5	8.3	7.9
	Corn silage	36.8	47.7	27.9	7.9
	Corn grain	88.6	11.9	2.5	7.4
	Soybean meal	91.9	9.1	4.2	47.7
	Premix	93.9	10.1	6.1	31.1
8/16/04-8/23/04	TMR	81.7	17.3	7.2	8.9
	Corn silage	41.2	44.9	26.4	7.5
	Corn grain	87.6	10.7	2.2	6.7
	Soybean meal	91.9	9.9	4.4	49.9
	Premix	93.5	9.6	5.4	35.5
9/6/04-9/13/04	TMR	81.8	17.4	7.5	10.1
	Corn silage	39.6	43.7	25.9	6.8
	Corn grain	88.9	9.9	2.1	6.1
	Soybean meal	92.0	8.3	3.9	47.8

Table 4: Dates and forage types (% of pasture mix) that steers grazed at Willow Bend, WV

Approximate Date	OG	TF	BG	BlG	Other G	Alf	Wh.C	RC	W	D/B
04/21/04	29.5	33.7	21.9	2.0	4.2	0.0	4.9	0.4	0.8	2.6
05/17/04	43.6	20.1	13.0	0.0	15.6	0.0	2.4	2.8	1.9	0.6
06/28/04	32.5	29.5	5.7	0.6	19.6	0.2	2.6	0.5	7.5	1.2
07/25/04	40.8	31.6	4.2	0.0	6.9	0.0	5.0	3.1	8.1	0.3
08/10/04	27.5	3.8	6.9	28.1	3.1	6.4	15.2	0.3	8.4	0.3
09/10/04	29.5	5.9	1.7	16.8	9.3	8.8	17.2	0.1	10.5	0.2

a. OG- orchard grass, TF- tall fescue, BG- brome grass, BlG- bluegrass, other G- other grass, Alf- alfalfa, Wh.C- white clover, RC- red clover, W- weed, D/B- dead / bare

Table 5: Chemical composition of pasture forage samples (DM) at Willow Bend, WV

Date	NDF %	ADF %	TDN %	CP %
April 04	47.4	24.1	77.4	27.6
May 04	59.5	32.8	66.1	17.7
June 04	58.7	33.4	65.1	19.2
July 04	56.8	33.9	64.6	17.7
August 04	61.4	35.3	62.7	16.9
September 04	57.1	33.5	65.1	18.2

Claw measurements: growth and abrasion

Claw measurements were obtained from both medial and lateral claws of the left rear foot on d 0, 56 and 133 of the finishing period. On d 0 steers were restrained in a squeeze chute and a horizontal line was grooved into the dorsal wall 2 cm below the skin-horn junction. Claw length measurements were performed while steers were standing and bearing weight on the measured foot.

A conventional divider was used to determine two distances (Figure 1).

1. Total dorsal wall (toe) length (TL): distance measured on along the junction of the abaxial and axial walls from the skin-horn junction of the toe.

2. Line distance (LD): distance from the skin-horn junction to the line mark on the dorsal wall.

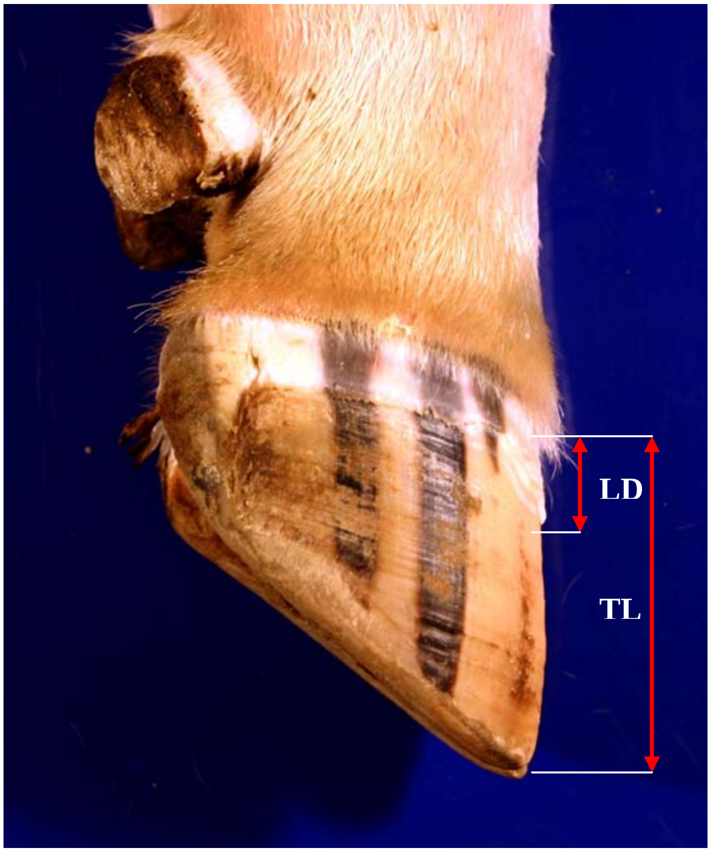


Figure 1. Description of two measured distances: TL- toe length and LD- line distance.

The three measurements token on d 0, 56 and 133 were used to calculate claw growth and abrasion for first period (0-56 d) and for total period (0-133 d).

Growth = line distance (d 56 or d 133) – 2 cm line

Abrasion = (Toe length d 0 + Growth) - Toe length d 56 or d 133

Claw measurements: surface area

The surface area of the lateral and medial claw sole was determined using digital images taken on d 0, 56 and 133. For this procedure steers were restrained in a squeeze chute and the left rear leg was picked up using a rope attached above the tarsal joint. The bottom of the foot was cleaned using a dry towel. The estimated sole surface area was marked using a pen. A ruler (cm scale) was placed at sole level, and was used for calibration during computer evaluation (Figure 2). Surface area of the sole was determined with Image J software (Image J, U.S. National Institutes of Health, Bethesda, Maryland, USA, http://rsb.info.nih.gove/ij/) Sole surface area change was calculated as the difference between measurement on d 0 and 56, and between d 0 and 133.

Figure 2. Digital image used to estimate sole surface area.

Claw measurements: sole horn thickness

At harvest, both front feet were obtained for sole horn thickness evaluation. Lateral and medial claws of the left foot were cut transversally (Figure 3 B). The cut was made across the coronary band perpendicular to the sole surface so that the pedal bone was cut in the middle. Both claws of the right front foot were cut longitudinally (Figure 3 A). The line of the cut was made in the center of the heel bulb and perpendicular to the sole surface. Three measurements were obtained from each claw (Figure 4 and 5). On the transversal section, the measurements of the sole horn were taken from the places that corresponded with the axial and abaxial edge of the pedal bone. The third transversal section measurement was taken from the middle between the axial and abaxial edges. On the longitudinal section, the cranial measurement was taken in a location corresponding to the tip of the pedal bone; caudal measurement with the flexor tubercle and medial measurement in between the cranial and caudal measurements. A total of 12 measurements of sole thickness from both feet were obtained from each steer.

A. B.

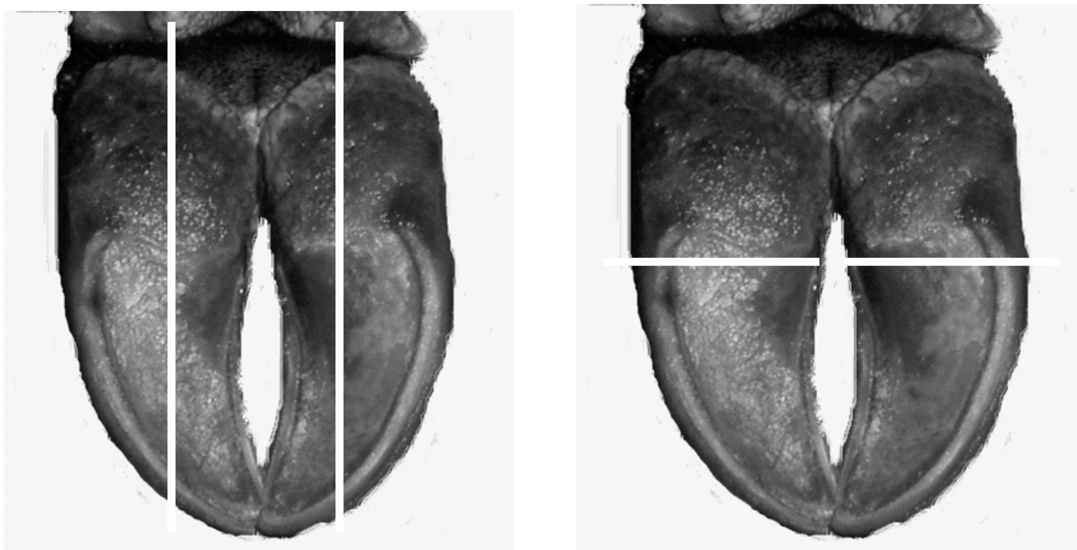


Figure 3. Description of the lines marking longitudinal (A) and the transversal (B) section of the front feet for sole horn thickness measurements.

A. B.

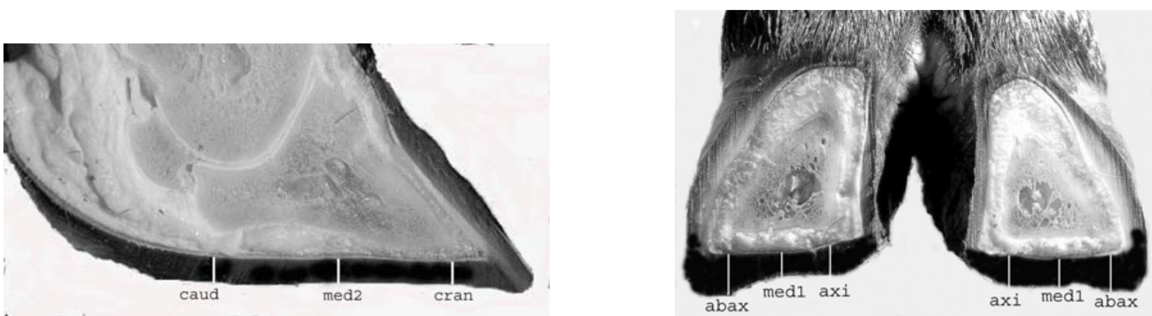


Figure 4. Description of the measured locations on the longitudinal (A) (caudal, medial 2, cranial) and transversal (B) section (abaxial, medial 1, axial).

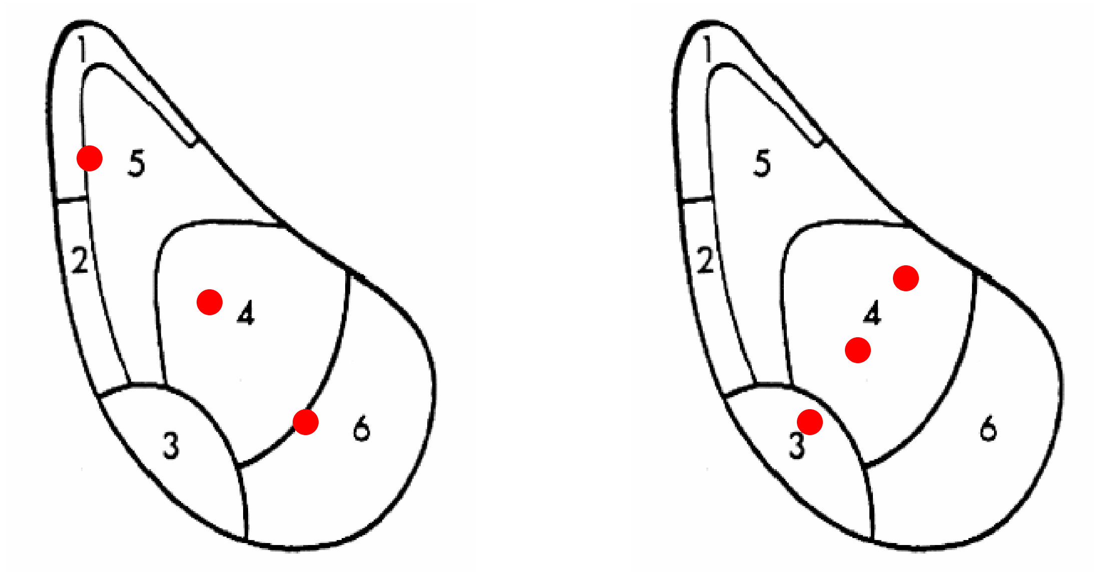


Figure 5. Description of the location where sole thickness measurements were taken in relation to the zoning of the cattle sole. Dots represent location where sole thickness was measured. Zones of the sole amended to conform with recommendations established at the 6th Symposium on Diseases of Ruminant Digit, Liverpool, 1990. Zone 1White zone at the toe, Zone 2 Abaxial white zone, Zone 3 Abaxial wall-bulb junction, Zone 4 Sole-heel junction, Zone 5 Apex of the sole, Zone 6 Heel bulb

Statistical analyses

Response variables analyzed for the left rear foot were dorsal wall growth and abrasion, sole surface area, dorsal wall length and sole thickness for the front feet. Data were analyzed with proc mixed using the MIXED procedure of the SAS system (version 9.12, SAS Institute Inc., Cary, NC). The statistical model was constructed to test main effects of finishing systems (pasture, feed lot), wintering system, and claw (lateral, medial) as well as their interactions. For the analyses, the subject effect was claw (lateral, medial) nested within steer within replicate and within finishing treatment. Growth and abrasion were evaluated for 2 periods: d 0 to 56 and d 0 to 133. Model adequacy was assessed using plots of standardized residuals. Standard errors of the means, means and medians were determined for claw characteristics (growth, abrasion, sole surface area and it change, dorsal wall length and its change and sole thickness). A significant difference was declared for P values less than 0.05 and a trend was declared for P values higher than 0.05 but less than 0.10. Interactions were further evaluated by the SLICE option.

CHAPTER IV

RESULTS

Dorsal wall growth

Dorsal wall growth (Table 7) in the first 56 d of the finishing period tended to be influenced by finishing system ($P=0.055$). Dorsal wall growth of feedlot steers tended to be greater than growth of pasture steers. Within feedlot steers the lateral claw grew faster than the medial claw ($P<0.05$), while growth of the lateral and medial claw did not differ in the pasture steers.

Dorsal wall growth during the 133 d finishing period was influenced by finishing system ($P<0.01$), claw ($P<0.01$) and there was a finishing system x claw interaction ($P<0.01$). Dorsal wall growth of feedlot steers was greater than growth of pasture steers (Table 6). Within feedlot steers the lateral claw grew faster than the medial claw ($P<0.001$), while growth of the lateral and medial claw did not differ in the pasture steers (Table 7). Winter treatment, average daily gain or replicates within finishing systems did not have an impact on dorsal wall growth during both periods.

Dorsal wall abrasion

Dorsal wall abrasion (Table 7) in the first 56 d of the finishing period was influenced by finishing system ($P<0.001$) and finishing system x claw interaction ($P<0.01$), while claw had no effect on abrasion. Abrasion was greater for feedlot steers when compared to pasture steers. Abrasion for the lateral claw within feedlot steers was greater than the medial claw ($P<0.01$) but did not differ in the steers on pasture.

Dorsal wall abrasion during the 133 d finishing period was influenced by finishing system ($P<0.001$) and finishing system x claw interaction ($P<0.001$), while claw tended to have an effect ($P=0.056$). Abrasion was greater for feedlot steers when compared to pasture steers (Table 6). Abrasion for the lateral claw within feedlot steers was greater than the medial claw ($P<0.01$) but did not differ in the steers on pasture.

Winter treatment or replicates within finishing systems did not have an impact on dorsal wall abrasion for either period.

Table 6: Growth and abrasion in the feedlot and pasture and growth and abrasion of the lateral and medial claws (means ± SE) in the first part of the finishing period (56 d) and throughout the whole finishing period (133 d)

Growth (mm/period [a, b])	Feed lot (n=36)	Pasture (n=36)	P- value
d 0 to 56	12.5±0.6	8.9±0.6	0.055
d 0 to 133	29.5±0.8	21.3±0.8	0.008
	Lateral claw	Medial claw	P- value
d 0 to 56	11.2±0.5	10.2±0.5	0.01
d 0 to 133	26.1±0.6	24.7±0.6	0.002
Abrasion (mm/period [a, b])	Feed lot (n=36)	Pasture (n=36)	P- value
d 0 to 56	11.7±0.7	1.2±0.7	<.0001
d 0 to 33	24.5±0.9	9.3±0.9	<.0001
	Lateral claw	Medial claw	P- value
d 0 to 56	6.9±0.6	5.9±0.6	0.091
d 0 to 133	17.5±0.7	16.3±0.7	0.056

[a] Period = 56d

[b] Period=133d

Table 7: Growth and abrasion of the medial and lateral claws (means ± SE) in feedlot and pasture steers in the first part of the finishing period (56 d) and throughout the whole finishing period (133 d)

	d 0 to 56			d 0 to 133		
Growth (mm/period [a, b])	Medial claw	Lateral claw	P-value	Medial claw	Lateral claw	P-value
Feed lot (n=36)	11.8±0.7	13.1±0.7	0.019	28.2±0.9	30.8±0.8	<0.001
Pasture (n=36)	8.5±0.7	9.2±0.7	0.191	21.4±0.9	21.2±0.9	0.701
Abrasion (mm/period [a, b])						
Feed lot (n=36)	10.3±0.8	13.1±0.8	0.001	22.8±1.0	26.3±1.0	<0.001
Pasture (n=36)	1.6±0.8	0.8±0.84	0.372	9.81±1.1	8.84±1.1	0.299

[a] Period = 56 d

[b] Period=133 d

Sole surface area

Sole surface area (Table 8, Figure 6) increased in the first 56 d of the finishing period. The change was influenced by finishing system ($P<0.005$), claw ($P<0.001$) but was not influenced by finishing system x claw interaction.

Sole surface area likewise increased during the 133 d finishing period (133 d). The change was influenced by finishing system ($P<0.05$) and claw ($P<0.001$) and by finishing system x claw interaction ($P<0.05$).

Winter treatment or replicates within finishing systems did not have impact on sole surface area change in either period.

At the beginning of the finishing period the average sole surface area did not differ between finishing systems. On d 56 and at the end of the 133 day period, the steers on pasture presented larger ($P<0.05$) sole surface area than steers in the feedlot.

Average sole surface area of the lateral claw was larger than the medial claw at the beginning ($P<0.001$), on d 56 ($P<0.001$) and at the end ($P<0.001$) of the finishing period in both finishing systems (Figure 6 and Table 8).

Winter treatment or replicates within finishing systems did not have an impact on sole surface area on d 0, 56 and 133.

Table 8: Sole surface area ($mm^2 \pm$ SE) on d 0, 56 and 133 of the finishing period for lateral and medial claws.

Sole surface area (mm^2)	Medial claw	Lateral claw	P- value
	d 0		
Feed lot (n=36)	2480.6±62.9	2688.2±62.9	<0.001
Pasture (n=36)	2340.4±63.4	2721.9±63.4	<0.001
	Day 56		
Feed lot (n=36)	2357.2±66.4	2848.5±66.4	<0.001
Pasture (n=36)	2849.8±68.4	3144.1±68.4	<0.001
	d 133		
Feed lot (n=36)	2867.0±76.1	3475.4±76.1	<0.001
Pasture (n=36)	3113.0±78.5	3662.9±78.5	<0.001

P-values for finishing system x claw interaction

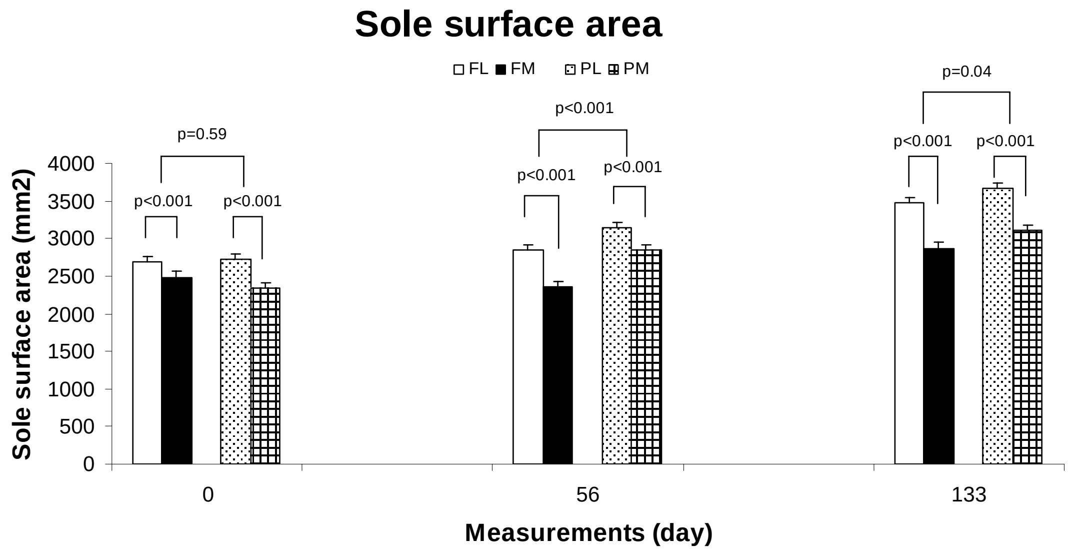


Figure 6. Sole surface area (mm^2) of the lateral (FL) and medial (FM) claws in feed lot steers and of the lateral (PL) and medial (PM) claws in the pasture steers at the beginning (d 0), middle (d 56) and the end (d 133) of the finishing period.

P values represent differences between claws within finishing systems and difference between finishing systems.

Dorsal wall length

The dorsal wall length (Table 9, Figure 7) increased during the first 56 d. The change was not influenced by finishing system but by claw (P<0.05). The finishing system x claw interaction was not significant.

Dorsal wall length increased during the total finishing period (133 d). The total change was influenced by finishing system (P<0.05), claw (P<0.05) and by finishing system x claw interaction (P<0.05). In the feedlot steers the medial claw length increased more than the lateral claw length (P<0.001), where as in the pasture steers no difference in length change between claws was observed.

The winter treatment influenced the change in the dorsal wall length in the first 56 d (P<0.001) but had no effect during the whole finishing period (133 d).

At the beginning of the finishing period (d 0) the average dorsal wall length did not differ between finishing systems but did differ between claws. The medial claws of pasture and feedlot steers had longer dorsal walls compared to the lateral claws (P<0.01) (Figure 7 and Table 9). At the d 56 of the finishing period the average dorsal wall length differed between finishing systems (P<0.05) and also between the claws (P<0.001). The medial claws of feedlot steers had longer dorsal walls compared to the lateral claws (P<0.001). Medial and lateral claws did not differ in dorsal wall length on pasture (Figure 7 and Table 9). At the end of the finishing period (d 133), the steers on pasture had longer dorsal walls (P<0.05) than the feedlot steers. However, there was no difference in length of the dorsal walls between medial and lateral claws for pasture steers but feedlot steers had longer dorsal walls on medial claws as compared to lateral claws (P<0.001) (Figure 7 and Table 9).

The winter treatment influenced the dorsal wall length at d 0, 56 and 133 (P<0.05 for all three sampling dates).

Table 9: The dorsal wall length (mm± SE) on d 0, 56 and 133 of the finishing period for lateral and medial claws.

Dorsal wall length (mm)	Medial claw	Lateral claw	P- value
	d 0		
Feed lot (n=36)	65.0±0.84	63.9±0.84	0.005
Pasture (n=36)	62.2±0.85	60.8±0.85	0.001
	Day 56		
Feed lot (n=36)	66.6±0.9	63.9±0.9	<0.001
Pasture (n=36)	69.4±0.9	69.4±0.9	0.945
	d 133		
Feed lot (n=36)	70.6±0.66	68.5±0.66	<0.001
Pasture (n=36)	73.8±0.68	73.5±0.68	0.528

P-values for finishing system x claw interaction

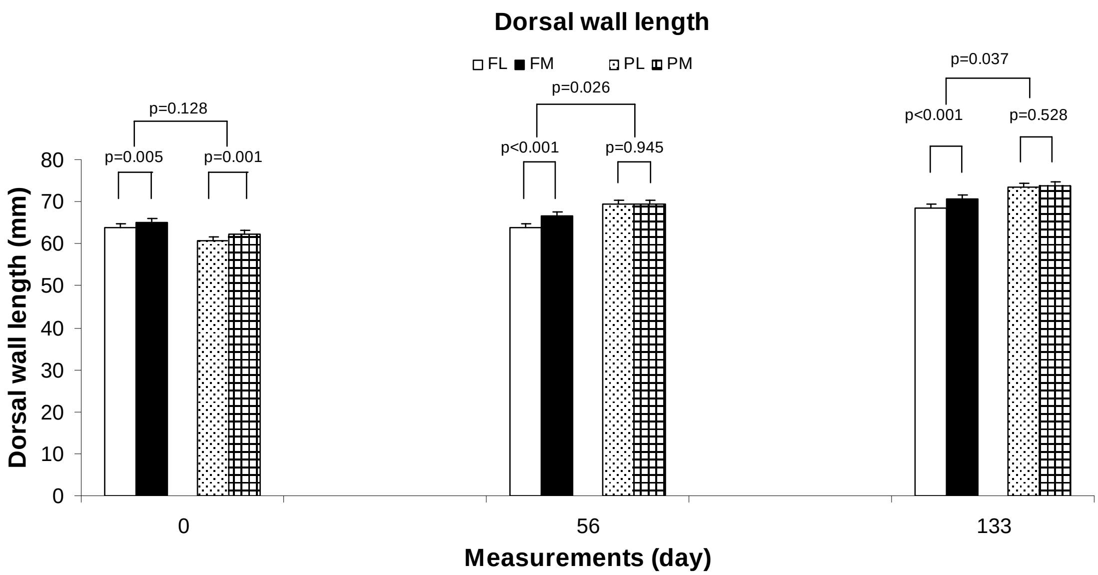


Figure 7. Dorsal wall length (mm) of the lateral (FL) and medial claw (FM) of the feed lot steers and lateral (PL) and medial claw (PM) of the steers on pasture at the beginning (d 0), middle (d 56) and at the end (d 133) of the finishing period.

P values represent differences between claws within finishing systems and difference between finishing systems.

Sole horn thickness: evaluation of the transversal section

Sole in all measured locations was significantly thicker in the feedlot steers when compared with pasture steers, except for the abaxial measurement (zone 3) (Figure 8 and 9). The average sole thickness did not differ between the lateral and medial claws in all measured locations, except the abaxial locations (zone 3 and 5) for both finishing systems. In the abaxial location there was a difference between lateral and medial claw thickness, ($P<0.001$).

Sole thickness varied within the claw (Table 10). The thinnest location of the claw on the transversal section was the middle of the claws. This was observed in both finishing systems. Claws of the steers from pasture exhibited the thickest soles, on the transversal section, in the abaxial side of the claws (8.4±0.6 mm). Conversely, the thickest part of the sole horn in feedlot steers was the axial side of the claws (10.7±0.5 mm) (Figure 8).

Sole horn thickness: evaluation of the longitudinal section

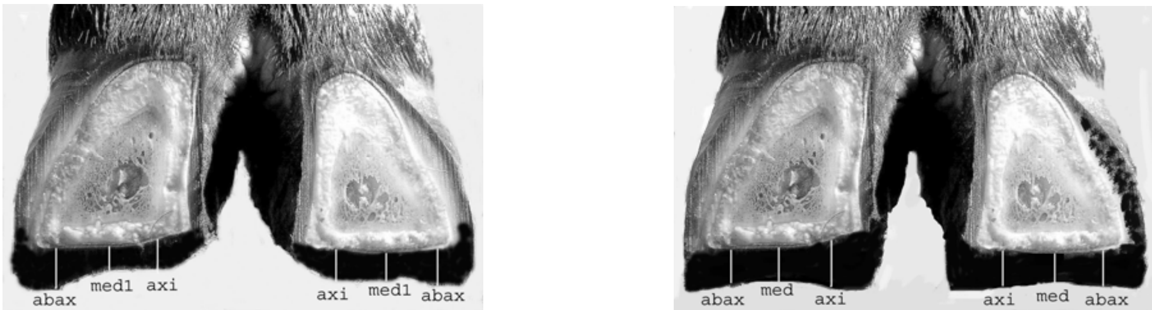
The thinnest part of the sole on the longitudinal section, for the steers on pasture, was the middle measurement (5.9±0.3mm). The thickest place in both environments on the longitudinal section was the caudal measurement (12.0±0.5 mm) for feedlot steers and (8.13±0.5mm) for the pasture steers (Figure 9).

Replicate within environments, winter treatments and weight gain did not have any significant impact on all the measured parameters.

Table 10: Average (mm± SE) sole thickness at harvest of the front feet in six different locations of the sole of steers from feedlot and from the pasture.

	Transversal section			Longitudinal Section		
Sole horn thickness (mm)	Axial	Middle 1	Abaxial	Caudal	Middle 2	Cranial
Feed lot (n=36)	10.7±0.5	7.7±0.4	9.2±0.7	12.0±0.5	8.9±0.4	8.8±0.4
Pasture (n=36)	6.7±0.5	5.7±0.4	8.4±0.6	8.1±0.5	5.9±0.3	7.0±0.4
P value	0.003	0.016	0.378	0.006	<0.001	0.002

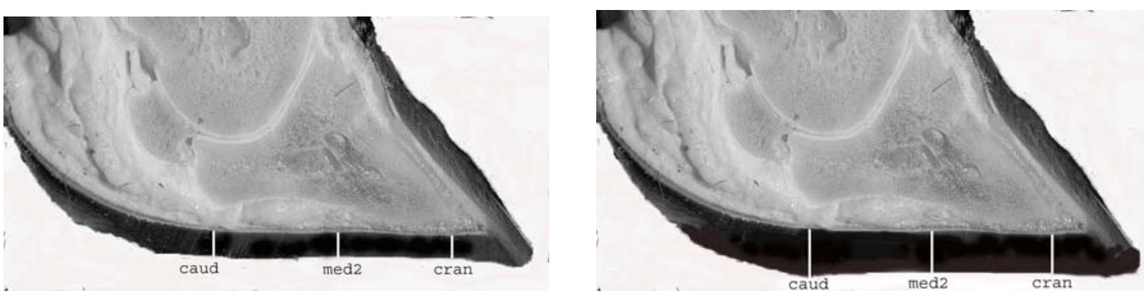
Figure 8



Pasture Feed lot

Figure 8. Created example picture of average sole horn thickness on the transversal section of the left front feet, lateral and medial claws from steers on pasture (4a) and feed lot (5b). Three locations (1. abaxial (abax): abaxial edge of the pedal bone, 2. medial1 (med1): center between abaxial and axial, 3. axial (axi): axial edge of the pedal bone).

Figure 9



Pasture Feed lot

Figure 9. Created example picture of average sole horn thickness on the longitudinal section of the right front feet, average of lateral and medial claws from steers on pasture (a) and feet lot (b). Three locations (1. caudal (caud): flexor tubercle of the pedal bone, 2. medial 2 (med2): center between caudal and cranial, 3. cranial (cran): tip of the pedal bone).

CHAPTER V

DISCUSSION

Hoof wall growth and wear

Based on published data, a measurement of the claw's dorsal wall is a widely used method to define horn growth and wear in cattle (Hahn, 1984). The movement of a mark away from the periople segment has been traditionally used. The periople segment can be divided into two structures used as upper reference points in performed studies. Meyer et al. (1968) used skin-horn junction as the upper limit to measure wall length in hooves from slaughtered animals. Hahn et al. (1984) recommended using the periople line as an upper limit for hoof length measurements in live animals. Prentice (1973) tattooed the skin above the coronary band with black ink as a proximal reference point. However, only animals with unpigmented skin above the coronary band were suitable for this tattooing method. In our study we used the skin-horn junction as an upper limit for hoof measurements. This method was convenient because the periople line was hardly visible and skin-horn junction was easy to palpate and recognize on restrained, standing steers.

Steers in confinement on concrete floors and offered a high energy diet had faster horn growth and wear rates than steers grazing pasture.

Horn growth (6.65 mm/month) and abrasion (5.54 mm/month) rates in feedlot steers are similar to results from other cattle studies (Hahn et al., 1986; Murphy, 1986). The growth (4.80 mm/month) and abrasion (2.11 mm/month) rates of pasture steers in the present study appear to be lower (15% and 55%, respectively) than those reported by other authors (Murphy, 1986; Tranter and Morris, 1992). The difference could be because of softer underfoot conditions which did not promote higher horn growth and abrasion. Hoof growth rates in pasture steers was lower compared with feedlot steers, however on pasture, growth exceeded abrasion by 56.1% while in feedlot steers by only 16.7%. As a consequence, claws of pasture steers became longer than claws of steers in the feedlot. The net growth of feedlot steers was 1.1 mm/month and was 2.69 mm/month of pasture steers. These results are in agreement with (Vermunt, 1990) who studied the rates of horn growth and wear in indoor-housed heifers confined to concrete and in heifers housed outdoors in a dry lot (dirt). Horn growth was not different between the two groups of heifers. However, due to 22% lower wear, the claw length of outdoor-housed heifers was much greater than in indoor-housed heifers.

Prentice (1973) reported a lack of difference in horn growth or abrasion between lateral and medial claws in dairy cattle. Conversely, Tranter and Morris (1992) demonstrated that horn abrasion was greater in lateral claws in dairy cattle on pasture. Also horn growth tended to be greater in lateral claws, but the difference was not significant.

Murphy (1986) and Hahn et al. (1986) measured rates of horn growth and wear in beef cattle housed either on slats or on straw. Increased rate of horn growth in steers on slatted floors was observed on the front medial and hind lateral claws. Similarly, our study revealed a significant difference of horn growth and abrasion between lateral and medial claws of rear limbs in the feedlot steers. In pasture steers no difference was observed for growth or abrasion between claws. It seems like higher turnover of the claw horn may potentially lead to lose of balance of the foot. Further research needs to be done to explain the different response of the lateral and medial claw under hard versus soft underfoot conditions and on high grain versus forage based diets.

Sole surface area

Sole surface area, also referred to, as ground surface area, was studied particularly in context to claw conformation, its heritability and association with lameness (Distl, 1984). Methods to estimate the sole area include the use of claw imprints or tracing the claw on paper. The area can be calculated by multiplying claw length with claw width. van der Tol et al. (2002) was the first to use a force plate to measure weight distribution under the bovine foot. The outcome of the weight distribution measurement is in kg/mm^2. This method enables reliable measurements of the sole weight bearing area. Trained cattle can be used with this technique only. In this project, we used digital pictures for the estimation of the sole surface area. This method was found as a possible alternative to force plate measurements in feedlot and pasture cattle settings.

At the beginning of this study, all steers had larger sole surface area of the lateral compared to medial claws and maintained this difference throughout the study in both environments. Interestingly, the steers on pasture developed larger sole surface areas of both claws compared to steers in the feed lot. The larger sole surface area of the steers on pasture is likely a consequence of the higher claw horn net growth due to a lower wear rate. The size difference between the lateral and medial claws has been observed before (Toussaint Raven, 1989). Additionally, in dairy cows, the incidence of lesions is higher in hind lateral claws compared to other claws (Murray et al., 1996). Controversial theories were developed to explain the enlargement and susceptibility to lesions of the hind lateral claws (Rusterholz, 1920). The present study revealed that feedlot steers with higher horn turnover increased the size difference between lateral and medial claws compared to steers finished on pasture.

Sole thickness

The conditions at the harvest facility did not allow us to obtain the rear feet and thus perform sole thickness measurements on the same foot that we used for all other measurements, as previously described. There is limited information published about sole horn growth and wear since these are difficult to measure as compared to the wall measurements. Greenough (1990) calculated net growth rates for sole horn by comparing sole horn thickness of hooves in groups of beef steers after slaughter. In the present study, steers in the feed lot finished with significantly thicker soles on the front feet than steers on the pasture. Additionally, sole thickness varied within the location of the claw. In steers from the feed lot, the thickest part of the sole was axial and caudal; whereas in the steers on pasture the thickest part of the sole was abaxial and caudal. These sole horn thickness measurements can be explained by the presence of the concavity of the soles in the pasture steers whereas steers from the feed lot finished with more flat shaped soles.

The possible explanation of the difference in the sole horn shape is the claw's ability to adapt to hard, not giving surface. It seems like the physiological shape of the sole in cattle on concrete is flat (site to site parallel) and in cattle on pasture is the concave shape. Tranter and Morris (1992) developed a method to determine sole horn wear by measuring the disappearance of grooves made in the sole horn. Using a profile gauge the concavity of the sole was measured on live animals. It was found that sole abrasion is a dynamic process modeling the sole concavity. In present study, significant impact of the two finishing systems on the difference of the sole thickness between the lateral and medial claws in front feet was not observed.

CHAPTER VI

IMPLICATIONS

Better understanding of the bovine hoof biology may help in prevention of lameness on farms with total confinement. This study revealed various biomechanical responses of a bovine foot in two different environments. High energy ration and hard concrete surface resulted in loss of foot balance and thicker sole horn in finishing steers. The design of appropriate management and preventive programs to minimize lameness and promote cattle well-being depends on prediction of claw horn turnover dynamics relative to the ration and environment. However, the study was not design to differentiate the effect of nutrition and housing. Therefore, further studies should be performed to recognize the impact of nutrition and flooring type on claw characteristics.

LITERATURE CITED

Anderson, D. E., and G. M. Rogers. 2001. Prevention of lameness in cow-calf operations. Vet Clin North Am Food Anim Pract 17: 209-223, viii.

Anon. 1993. Cutting the cost of lameness in cattle. Vet. Rec. 133: 128.

Baggott, D. G., K. J. Bunch, and K. R. Gill. 1988. Variations in some inorganic components and physical properties of claw keratin associated with claw disease in the british friesian cow. Br. Vet. J. 144: 534-542.

Bergsten, C. 1994. Haemorrhages of the sole horn of dairy cows as a retrospective indicator of laminitis: An epidemiological study. Acta Vet. Scand. 35: 55-66.

Bergsten, C., and B. Frank. 1996. Sole haemorrhages in tied heifers in early gestation as an indicator of laminitis: Effects of diet and flooring. Acta Vet. Scand. 37: 375-381.

Bergsten, C., and A. H. Herlin. 1996. Sole haemorrhages and heel horn erosion in dairy cows: The influence of housing system on their prevalence and severity. Acta Vet. Scand. 37: 395-408.

Brinks, J. S., Davis, M.E., Mangus,W.L.and Denham, A. H. 1979. Genetic aspects aspects of hoof growth in beef cattle. J. Anim. Sci. 49: 152-153.

Camara, S and Gravert, H.Q. 1971. Investigations on hoof abrasion in cattle. Züchtungskunde 43: 111-26.

Clark, A. K., and A. H. Rakes 1982. Effect of methionine hydroxy analog supplementation on dairy cattle hoof growth and composition. J. Dairy Sci. 65: 1493-1502.

Clarkson, M. J., D. Y. Downham, W. B. Faull, J. W. Hughes, F. J. Manson, J. B. R. D. Murray, W. B. Russell, J. E. Sutherst, W. R. Ward 1996. Incidence and prevalence of lameness in dairy cattle. Vet. Rec. 138: 563-567.

Dietz, O. P. and G. Prietz 1981. Quality and status of cattle hoof horn. Monatshefte fur Veterinarmedicin 36: 419-422.

Distl, O., M. Huber, F. Graf and H. Krausslich. 1984. Claw measurements of young bulls at performance testing stations in Bavaria. Livest. Prod. Sci. 11: 587-598.

Fraser, R. D., and T. P. Macrae. 1980. Molecular structure and mechanical properties of keratins. Symp Soc Exp Biol 34: 211-246.

Glicken, A., and J. W. Kendrick. 1977. Hoof overgrowth in holstein--friesian dairy cattle. J Hered 68: 386-390.

Green, L. E., V. J. Hedges, Y. H. Schukken, R. W. Blowey, and A. J. Packington. 2002. The impact of clinical lameness on the milk yield of dairy cows. J Dairy Sci 85: 2250-2256.

Greenough, P. R. 1987. Pododermatitis Circumscripta (ulceration of the sole) in cattle. Agri-Pract.: 17-22.

Greenough, P. R., J. J. Vermunt, J. J. Mckinnon, F. A. Fathy, P.A. Berg and R. D. H. Cohen 1990. Laminitis -like changes in the claws of feelot cattle. Can. Vet. J. 31: 202-208.

Guard, C. 2001. Investigating herds with lameness problems. Vet Clin North Am Food Anim Pract 17: 175-187, vii.

Hahn, M. V., B. T. McDaniel, and J. C. Wilk 1986 Rates of hoof growth and wear in holstein cattle. J Dairy Sci 69: 2148-2156.

Hahn, M. V., B. T. McDaniel and J. C. Wilk 1984 Description and evaluation of objective hoof measurements of dairy cattle. J. Dairy Sci. 67: 229-236.

Hahn, M. V., B. T. McDoniel and J. C. Wilk 1978. Hoof growth and wear rates of holstein cows confined to a new flushed concrete surface. J. Dairy Sci. 61: 84.

Holzhauer, M., C. Hardenberg, C. J. Bartels, and K. Frankena. 2006. Herd- and cow-level prevalence of digital dermatitis in the netherlands and associated risk factors. J Dairy Sci 89: 580-588.

Kofler, J., and P. Kubber. 2000. [ultrasonographic measurement of the sole horn thickness in bovine claw]. Berl Munch Tierarztl Wochenschr 113: 81-87.

Kofler, J., P. Kubber, and W. Henninger. 1999. Ultrasonographic imaging and thickness measurement of the sole horn and the underlying soft tissue layer in bovine claws. Vet J 157: 322-331.

Kossaibati, M. A., and R. J. Esslemont. 1997. The costs of production diseases in dairy herds in england. Vet J 154: 41-51.

Le Fevre, A. M., D. N. Logue, J. E. Offer, I. McKendrick, and G. Gettinby. 2001. Correlations of measurements of subclinical claw horn lesions in dairy cattle. Vet Rec 148: 135-138.

Ch. J. Lischer, U. Koler, H. Geyer, Ch. Mülling, J. Schulze, P. Ossent 2002. Effect of therapeutic dietary biotin on the healing of uncomplicated sole ulcers in dairy cattle--a double blinded controlled study. Vet J 163: 51-60.

Livesey, C. T., and F. L. Fleming. 1984. Nutritional influences on laminitis, sole ulcer and bruised sole in friesian cows. Vet Rec 114: 510-512.

Livesey, C. T., J. A. Metcalf, and R. A. Laven. 2003. Effect of concentrate composition and cubicle bedding on the development of hoof haemorrhages in holstein heifers after calving. Vet Rec 152: 735-739.

Manson, F. J. and J. D. Leaver 1988. The influance of dietary protein intake and of hoof trimming on lameness in dairy cattle. Anim. Prod. 47: 191-199.

Manson, F. J. and J. D. Leaver 1989. The effect of concentrate : Silage ration and hoof trimming on lameness in dairy cattle. Anim. Prod. 49: 15-22.

Murphy, P. A. and J. Hannan 1986. Effects of slatted flooring on claw shape in intensively housed fattering beef cattle. Proc. Vth International Symposium of the Ruminant Digit, Dublin:2-7.

Murray, R. D., D. Y. Downham, M. J. Clarkson, W. B. Faull, J. W. Hughes, F. J. Manson, J. B. Merritt, W. B. Russell, J. E. Sutherst, W. R. Ward 1996. Epidemiology of lameness in dairy cattle: Description and analysis of foot lesions. Vet. Rec. 138: 586-591.

Nacambo, S., Hassig, M., Lischer,C., Nuss, and K. 2004. Difference in length of the metacarpal and metatarsal condyles in calves and the correlation to claw size. Proc. 13th International Symposium and 5th Comference on Lameness in Ruminants, Maribor, Slovenia: 104-106.

Nocek, J. E. 1997. Bovine acidosis: Implications on laminitis. J. Dairy Sci. 80: 1005-1028.

Nocek, J. E., A. B. Johnson, and M. T. Socha. 2000. Digital characteristics in commercial dairy herds fed metal-specific amino acid complexes. J. Dairy Sci. 83: 1553-1572.

Nordlund, K. V. 2004. Investigation strategies for laminitis problem herds. J. Dairy Sci. 87: E27-E35.

NRC. 2001. Pages 162-164 in Nutrient Requirements of Dairy Cattle. 7th rev. ed. Natl. Acad. Press, Washington, DC.

Nuss, K., and N. Paulus 2005. Measurements of claw dimensions in cows before and after functional trimming: A post-mortem study. Vet J: article in press.

O'Dell, B. 1990. Copper. Proc. Present Knowlidge in Nutrition. 6th ed. M.L. Brown, ed.ILSI Press, Washington, DC: 261-267.

Peterse, D. 1986. Claw measurements as parameters for claw quality in dairy cattle. Proc. of the Vth International Symposium on Disorders of the Ruminant Digit, Dublin: 87-91.

Politiek, R. 1986. Importance of claw quality in cattle: Review and recomendations to achive genetic improvement. Livest. Prod. Sci. 15: 133-152.

Prentice, D. E. 1973. Growth and wear rates of hoof horn in Ayrshire cattle. Res Vet Sci 14: 285-290.

Puls, R. 1984. Mineral levels in animal health. Diagnostic data. 2nd Ed. Sherpa International, Clearbrook, BC, Canada.

Randy, H., C. J. Sniffen, J. E. Nocek, E. E. Wildman and H. William 1985. Effect of zinc methionine supplementation on milk yield, lameness and hoof growth in lactating dairy cows. J. Dairy Sci. 68, (suppl.1).

Ranft, W. H. 1936. Die feineren anatomischen merkmakmale der zehenknochen, speziell der klauenbeine, des rindes. Morfologische Jahrbuch 78: 733-420.

Rojas, L. X., L. R. McDowell, R. J. Cousins, F. G. Martin, N. S. Wilkinson, A. B. Johnson, J. B. Velasquez 1996. Interaction of different organic and inorganic zinc and copper sources fed to rats. J Trace Elem Med Biol 10: 139-144.

Russell, A. M., G. J. Rowlands, S. R. Shaw, and A. D. Weaver. 1982. Survey of lameness in british dairy cattle. Vet Rec 111: 155-160.

Rusterholz, A. 1920. Das spezifisch-traumatische klauensohlengeschwur des rindes. Sweizer Archiv fur Tierheilkunde 62: 505-525.

Schlichtling, M. 1987. Adaptation of cattle to different floor types. In: Cattle Housing Systems, Lameness and Behaviour, pp 87-97. Ed. H.K. Wierenga and D.J. Peterse.

Schneider, P. 1980. Einfluss des vaters auf gliedmassenstellung und klauenformen sowie abriebfestigkeit und wassergehalt des klauenhornes der nachkommen. Ph.D. Diss., Lidwig-Maximilians-Universitat, Munchen.

Stokka, G. L., K. Lechtenberg, T. Edwards, S. Macgregor, K. Voss, D. Griffin, D. M. Grotelueschen, R. A. Smith and L. J. Perino 2001. Lameness in Feedlot Cattle. Vet. Clin. North Am. Food Anim. Pract. 17: 1

Tomlinson, D. J., C. H. Mulling, and T. M. Fakler. 2004. Invited review: Formation of keratins in the bovine claw: Roles of hormones, minerals, and vitamins in functional claw integrity. J Dairy Sci 87: 797-809.

Toussaint Raven, E. 1985. The principles of claw trimming. Veterinary Clinics of North America: Food Anim. Prac. 1: 93-107.

Toussaint Raven, E. 1989. Structure and function of the claw. Page 13 in Cattle footcare and claw trimming. Farming press books, Ipswich.

Tranter, W. P., and R. S. Morris. 1992. Hoof growth and wear in pasture-fed dairy cattle. N Z Vet J 40: 89-96.

van Amstel, S. R., F.L. Palin, J. K. Shearer, R. A. Robinson. 2002. Anatomical Measurement of Sole Thickness in Cattle following Application of Two Different Trimming Techniques. The Bovine Practitioner 36: 136-140.

van Amstel, S. R., F. L. Palin, B. W. Rorhbach, and J. K. Shearer. 2003. Ultrasound measurement of sole horn thickness in trimmed claws of dairy cows. J Am Vet Med Assoc 223: 492-494.

van Amstel, S. R., F. L. Palin, and J. K. Shearer. 2004a. Measurement of the thickness of the corium and subcutaneous tissue of the hind claws of dairy cattle by ultrasound. Vet Rec 155: 630-633.

van Amstel, S. R., J. K. Shearer, and F. L. Palin. 2004b. Moisture content, thickness, and lesions of sole horn associated with thin soles in dairy cattle. J Dairy Sci 87: 757-763.

van der Tol, P. P., J. H. Metz, E. N. Noordhuizen-Stassen, W. Back, C. R. Braam, W. A. Weijs 2002. The pressure distribution under the bovine claw during square standing on a flat substrate. J Dairy Sci 85: 1476-1481.

van der Tol, P. P., J. H. Metz, E. N. Noordhuizen-Stassen, W. Back, C. R. Braam, W. A. Weijs 2003. The vertical ground reaction force and the pressure distribution on the claws of dairy cows while walking on a flat substrate. J Dairy Sci 86: 2875-2883.

van der Tol, P. P., J. H. Metz, E. N. Noordhuizen-Stassen, W. Back, C. R. Braam, W. A. Weijs 2004. The effect of preventive trimming on weight bearing and force balance on the claws of dairy cattle. J Dairy Sci 87: 1732-1738.

Vanegas, J. 2005. Effect of rubber flooring on claw health of lactating dairy cows housed in freestall barns. In; Proceedings, 38th annual conference of the AABP, Salt Lake City, Utah: 203-204.

Vermunt, J. J. 1990. Lesions and structural characteristics of the claw of dairy heifers in two management systems. MSc Theses, University of Saskatchewan, Saskatoon.

Vermunt, J. J., and P. R. Greenough. 1995. Structural characteristics of the bovine claw: Horn growth and wear, horn hardness and claw conformation. Br Vet J 151: 157-180.

Vermunt, J. J., and P. R. Greenough. 1996. Sole haemorrhages in dairy heifers managed under different underfoot and environmental conditions. Br Vet J 152: 57-73.

Vokey, F. J., C. L. Guard, H. N. Erb, and D. M. Galton. 2001. Effects of alley and stall surfaces on indices of claw and leg health in dairy cattle housed in a free-stall barn. J Dairy Sci 84: 2686-2699.

Webster, A. J. 2001. Effects of housing and two forage diets on the development of claw horn lesions in dairy cows at first calving and in first lactation. Vet J 162: 56-65.

Wells, S. J., A. M. Trent, W. E. Marsh, N. B. Williamson, and R. A. Robinson. 1995. Some risk factors associated with clinical lameness in dairy herds in Minnesota and Wisconsin. Vet. Rec. 136: 537-540.

Wheeler, J. B., J. W. Benet and J. C. D. Hutchison 1972. Effect of ambient temperature and day length on hoof growth in sheep. J. Agric. Sci. (Cambridge) 79: 91-97.

Whitaker, D. K. and J.M. Smith, E.J. 1983. Incidence of lameness in dairy cows. Vet. Rec. 113: 60.

VITA

Ondrej Becvar was born on November 20, 1973 in Prague, Czech Republic. In June 1999, he graduated from the Veterinary and Pharmaceutical University (VFU) Brno, Czech Republic. From September 1999 till May 2003 he worked at the Surgery and Orthopedics Department of the Clinic of Ruminant Diseases at VFU Brno as a postgraduate student and clinical instructor. In June 2003 he started internship at the Production Management Medicine at, Blacksburg, VA which he finished in June 2004. In July of that year, Ondrej began Residency/Master’s program at VA-MD Regional College of Veterinary Medicine. His interest is preventive bovine medicine and his research is in the area of lameness in cattle.