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Agrar- und Ernährungswissenschaftlichen Fakultät der  
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**Impact of different types of rubber mats for  
gestating sows on lying and walking comfort and  
their potential of ammonia volatilization**

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***Für***

***Sus scrofa domestica***

***If you can dream it, you can do it.***

*(Walt Disney)*



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## List of Abbreviations

|                                 |                        |
|---------------------------------|------------------------|
| BSC                             | body condition scoring |
| C                               | concrete floor         |
| CA                              | contact area           |
| CH <sub>4</sub> NO <sub>2</sub> | Carbamoyloxonium       |
| cm                              | centimeter             |
| cm <sup>2</sup>                 | square centimeter      |
| CS                              | concrete slats         |
| DE                              | digestible energy      |
| DM                              | dry matter             |
| e.g.                            | exempli gratia         |
| EU                              | European Union         |
| g                               | gramm                  |
| h                               | hour                   |
| HM                              | hard mat               |
| i.e.                            | id est                 |
| kg                              | kilogram               |
| l                               | liter                  |
| m                               | meter                  |
| m <sup>2</sup>                  | square meter           |
| min                             | minutes                |
| MJ                              | megajoule              |
| ml                              | milliliter             |



|      |                      |
|------|----------------------|
| mm   | millimeter           |
| mol  | mole                 |
| N    | newton               |
| Q    | quantile             |
| PF   | peak force           |
| RM   | rough mat            |
| sec  | seconds              |
| SM   | soft mat             |
| SmM  | smooth mat           |
| Tg   | teragramm            |
| VGA  | video graphics array |
| vs.  | versus               |
| VSM  | very soft mat        |
| z.B. | zum Beispiel         |
| %    | percent              |
| °C   | degree Celsius       |



## General Introduction

Sows are accommodated during production cycle in different husbandry systems, such as individual housing (mating station, farrowing pen) or group housing (gestation stall, mating station). In most accommodations only concrete or concrete slats are provided as floors in lying and walking areas. Most of the problems in such accommodations are injuries of claws (heel- und sole necrosis, splits and flaws in the wall of the claw) as well as pressure sore and dermal bruise (Waldmann, 2004). Bonde et al. (2004) investigated lying-down behavior problems, limb disorders and skin lesions of lactating sows housed in farrowing crates in commercial sow herds equipped with different fully or partially slatted hard floors in Denmark. They found that 12 % of the sows showed wounds on the shoulder, 22 % on the hind limbs and 12 % of the sow were lame. Additionally, 41 % of the sows had problems during lying down (e.g. slipping).

Floor properties such as friction, abrasiveness, hardness, surface profile and thermal properties mainly affect animal injuries in livestock buildings (Webb and Nilsson, 1983). Friction determines the condition under which slipping occurs between two specified materials, such as the claw and the floor. Abrasiveness determines the rate of the claw wear. Hardness is one factor determining the maximum stress that tissue will receive. Deforming a floor can reduce the contact pressure on a limb by redistributing the load over a wide area, thus reducing the mechanical stress. Sharp edges induce high stresses in the underlying tissue, which can lead to injuries. Floor temperature can affect posture, behavior and physiology, as has been suggested by Webb and Nilsson (1983). Furthermore, all factors depend on each other, for example a change in surface profile affects both, the frictional and abrasive properties of that surface (McKee and Dumelow, 1995).

The property that mainly affects sow welfare in lying is the hardness of the floor. Zurbrigg (2006) observed shoulder lesions in farrowing sows lying on hard floors in sows. Shoulder lesions affect sow welfare and also consumer attitudes toward swine industry (Zurbrigg, 2006). The presence of injuries are not surprising, because it is known, that 10-20 % pig's total body surface area comes in contact with floor during lying in sternum position, so the entire weight burdens on a very small body area (Arey, 1993; Baxter, 1984).

Straw bedding provides an alternative to concrete floors and improves the physical and thermal comfort of the floor (Barnett et al., 2001; Tuyttens, 2005). Furthermore, straw bedding tends to ease the effects of stress resulting from concrete floors (Warnier and Zayan, 1985). But straw is often not compatible with the liquid manure

system in stables and it results in some challenges, such as potential increases in costs pertaining to purchase the product, additional labor requirements, disease considerations, and current difficulties for the manure handling systems (Day et al., 2002; Tuytens, 2005). That is why straw has not been used extensively in swine production systems in recent liquid manure systems. An alternative to straw, synthetic rubber mats may provide additional floor comfort to pigs (Tuytens, 2005). Rubber mats have become popular in dairy industry, but have been used to a lesser extend in swine industry (Elmore et al., 2010).

Rubber mats for sows were tested mainly for farrowing sows (Boyle et al., 2000; Farmer et al., 2006; Gravås, 1979; Zurbrigg, 2006). When rubber mats were added to farrowing crates, sows spent more time lying on the mats (Gravås, 1979). Furthermore, mats reduced slipping in comparison to metal slats (Boyle et al., 2000). Boyle et al. (2000) observed longer periods of time kneeling for sows on mats in comparison to sows on metal slats. Zurbrigg (2006) assessed a quicker healing time of shoulder lesions for farrowing sows when housed on rubber mats in comparison to sows housed on slatted metal flooring or on a stainless steel plate. For gestating sows until now there are only three studies, which investigated the impact of rubber mats on sow's welfare. Tuytens et al. (2008) observed lying behavior of sows on mats and on solid concrete flooring. They found that sows spent on average 15% more time in lying areas covered with a mat. Moreover, sows on mats significantly lie more often (12 %) in the (semi-) recumbent posture compared to sows lying on concrete and changed lying positions more often in comparison to concrete (Tuytens et al., 2008). Elmore et al. (2010) also observed lying behavior of sows in two different pens. The control pen was composed by four feeding stalls with solid concrete, in the treatment pen feeding stalls were equipped with rubber mats and group area consisted of concrete slats. Elmore et al. (2010) found, that the flooring surface affected pen location used by the sows for lying. So, sows in concrete pens spent significantly more of their resting time in the group area ( $66.20 \pm 4.50$  % of observations) compared to sows with mats in the feeding stalls ( $42.20 \pm 6.09$  % of observations). Additionally, sows on mats spent significantly more of their resting time in the stall area ( $48.70 \pm 6.04$  % of observations), in comparison to sows in concrete pens ( $23.60 \pm 4.5$  %). Díaz and Boyle (2014), investigated the effect of a slatted rubber mat on the behavior and welfare of group housed gestating sows. They covered slatted concrete group areas with the rubber mats and observed that sows in treatment pens spent more time in the group area and lay more there compared with sows in the control pens.

Most studies related to lying behavior of gestating sows on rubber mats have tested only one type of rubber mat in comparison to hard floors like concrete or concrete

slats. Often, no information is given about thickness or hardness of rubber mats used in the investigations. Furthermore, until now pressure loads on different body parts of sows lying in different positions and on rubber mats of different softness are unknown. In the present study pressure distribution of lying sows and during lying down on different types of rubber mats were tested in comparison to concrete. Pressure load were estimated on different body parts and compared between floors to quantify lying comfort.

During walking, mainly two factors may affect injuries in sows. Low friction can cause slips and falls (von Wachenfelt et al., 2008). Abrasiveness floors may cause excessive wear of claws (von Wachenfelt et al., 2008) or could induce pressure injuries on the sole (McKee and Dumelow, 1995). With regard to the requirements for a rubber mat for walking area, only little information exists. It is hypothesized that pigs adapt their gait in response to changes in floor characteristics (Thorup et al., 2007). So pigs' gait can be used as indicator in assessing floor properties (von Wachenfelt et al., 2008). Only few studies have been conducted to study pig gait (Applegate et al., 1988; Thorup et al., 2007; von Wachenfelt et al., 2008; von Wachenfelt et al., 2009b; von Wachenfelt et al., 2009a). Only one study exists about the impact of rubber mats on pig gait (von Wachenfelt et al., 2010). This study investigated friction of rubber mats, while floors were fouled or wetted. But the impact of surface profiles of rubber mats on pig gait was neglected. In the present study two different types of surface profiles (rough vs. smooth) with similar hardness factor were used for kinematic gait analysis and compared to concrete slats.

Floors influence not only sow's welfare, but they also have an important impact on stable climate. So ammonia production from the floor is influenced by roughness and porosity (Braam and Swierstra, 1999). Rough surface profiles may increase rate of ammonia, since in the bigger pores in comparison to smooth surface can cultivate micro-climate that will positively influence urease forming microflora, which is responsible for the production of ammonia. Only very smooth and slippery surfaces achieve a minor ammonia volatilization, however, such surfaces are not appropriate for walking comfort (Leinker, 2007). Moreover, information of possible effects of different surface profiles of rubber mats on ammonia volatilization is still missing. To receive more information about ammonia volatilization on rubber mats for sows, in the present study different types of surface profiles were analyzed for urease activity in a laboratory trial with artificial fouling in comparison to concrete. Furthermore one type of rubber mat were tested for urease activity in comparison to concrete slat under field condition on a swine farm.

In order to evaluate different types of rubber mats regarding lying and walking comfort and their potential to release ammonia from the surface profile, the following subtasks were addressed:

1. Pressure measurements on three different types of rubber mats differing in softness in comparison to concrete for gestating sows lying in sternal and half recumbent position.
2. Pressure measurements on three different types of rubber mats differing in softness in comparison to concrete during lying down in half and full kneeling position for gestating sows.
3. Gait analysis on two different surface profiles of rubber mats in comparison to concrete slats for gestating sows in repeated measurement.
4. Determination of urease activity on four different surface profiles of rubber mats in comparison to concrete in a laboratory trial and on a rubber mat with slope and integrated lying hollows in comparison to concrete slats in a field trial.

The subtasks were described and evaluated in four different chapters of this study.

In chapter one, three different rubber mats differing in softness (penetration depth: hard mat 4.0 mm [HM], soft mat: 14.6 mm [SM], very soft mat: 43.0 mm [VSM]) were tested in comparison to concrete floor on lying sows for pressure load and distribution with a pressure measurement system ("5400 NTL" sensor map system; Tekscan Inc., Boston, MA). It was assumed that with increasing softness pressure load will be reduced by a decrease in peak force and an increase in contact area.

In chapter two, pressure load was measured on carpal joints during lying down on three different rubber mats differing in softness (penetration depth: hard mat 4.0 mm [HM], soft mat: 14.6 mm [SM], very soft mat: 43.0 mm [VSM]). Pressure measurement was also conducted with the "5400 NTL" sensor map system. It was hypothesized, that pressure load on carpal joints in half and full kneeling position decreased with softness of floors. In addition, time for lying down was assessed and compared between floors. It was assumed that sows on hard floors would lie down in a shorter time to avoid high pressure load burdens on the carpal joints in comparison to soft floors.

In chapter three, a kinematic gait analysis was conducted on two different rubber mats with different surface profile (smooth vs. rough) in comparison to concrete slats with gestating sows in repeated measurement on a 0.8 m x 17 m long

walkway. Different stride parameters were recorded per video and analyzed separately for fore and hind limb. It was hypothesized that sows adapt their gait on different floor conditions.

In chapter four, urease activity was analyzed to quantify ammonia volatilization with the static chamber measurement method in a laboratory and a field trial. In laboratory trial four different surface profiles of rubber mats were compared for urease activity with concrete. Specimens of floors were artificially fouled and measured after 16 days of fouling. It was assumed that urease activity would be lower on rubber mats with smooth surface profile compared to rough surface profiles. In field trial a rubber mat with a slope and integrated lying hollows was tested for urease activity in comparison to concrete slats on a sow farm. It was hypothesized that urease activity would be lower on rubber mats compared to concrete slats.

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## **2 Chapter One**

### **Pressure load on specific body areas of gestating sows lying on rubber mats with different softness**

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## Abstract

Rubber mats offer a possibility to increase lying comfort for sows with positive effects on sows lying behavior and health. However, until now there is no information about the relationship between softness of rubber mats and pressure load on certain body areas of sows. We used a total of 68 (40 multiparous, 28 primiparous) German Landrace x German Landrace sows with a body weight within the range of 90 to 330 kg (divided in 3 weight classes) in order to measure peak force and distribution of pressure during lying in sternal and half recumbent position. Measures were done in an experimental pen that was equipped with a pressure sensor map system (5400 NTL; Tekscan Inc., Boston, MA). Three rubber mats differing in softness (penetration depth: hard mat: 4.0 mm [HM], soft mat: 14.6 mm [SM], very soft mat: 43.0 mm [VSM]), were tested and compared to concrete floor (C) as a reference. Pressure load was analyzed in sternal position for body regions sternum, belly and ham, and in half recumbent position additionally for shoulder. For each lying position we determined the body region with the highest pressure load and analyzed the peak force (PF) and the contact area (CA) using a mixed model ANOVA (MIXED Procedure of SAS Enterprise, version 4.3., SAS Institute Inc., Cary, NC) with floor type, weight class of sows and their interaction as fixed factors. Overall, the highest values for PF in sternal position were found on the sternum (median: 1.62 N/cm<sup>2</sup>) and in half recumbent position on the shoulder (median: 2.72 N/cm<sup>2</sup>). In sternal position PF on the sternum was lower on VSM compared to C (P = 0.001). In half recumbent position PF on the shoulder was lower on VSM compared to C (P = 0.013) and compared to HM (P = 0.011). Weight of sows affected PF on the sternum in sternal position with lower values in weight class 1 compared to weight class 2 (P = 0.001) and weight class 3 (P = 0.002). CA under the sternum was larger on SM (P = 0.016) and VSM (P = 0.008) compared to C in sternal position and this was affected by weight class (P = 0.0002). In half recumbent position floor type did not affect CA under the shoulder but CA was larger in weight class 2 and 3 compared to weight class 1 (all P < 0.05). Assuming that a reduced peak force in combination with pressure distributed over a larger area will increase lying comfort, hard rubber mats do not seem to offer a high lying comfort with regard to pressure load on debited body regions such as sternum or shoulder.

Keywords: pressure load, rubber mat, pigs, lying comfort

## **Introduction**

Lying comfort is important for sow welfare, because sows spend approximately 80 % of their time lying (Buckner et al., 1998). These systems usually have fully or partially slatted concrete flooring for manure removal. However, such manure systems are not compatible with bedding (Scott et al., 2006). Rubber mats have been tested as an alternative floor to improve comfort for farrowing (Gravås, 1979; Boyle et al., 2000; Zurbrigg, 2006; Farmer et al., 2006) and gestating sows (Tuyttens et al., 2008; Elmore et al., 2010). With rubber mats, sows increased lying times (Gravås, 1979; Tuyttens et al., 2008), experienced less slipping and longer kneeling durations (Boyle et al., 2000). Lying in half recumbent position was observed more often on rubber mats than lying in sternal position (Boyle et al., 2000; Elmore et al., 2010). In addition, rubber mats also can reduce shoulder lesions in sows (Zurbrigg, 2006). In all these studies only one type of mat was tested and mat softness was not considered, although the mat softness may likely affect sow lying comfort. It can be assumed that with increasing softness pressure load will be reduced by a decrease in peak force and an increase in contact area in particular under prominent bones like the spina scapulae of the shoulder. Until now pressure loads on different body parts of sows lying in different positions and on rubber mats of different softness are unknown. The aim of our study was to examine (1) under which sow body part pressure load would be highest and (2) which mat softness would reduce the pressure load depending on lying position and sow weight.

## **Material and Methods**

### ***Animals, Housing and Feeding***

The experiment was conducted at the research station of the Friedrich-Loeffler-Institute in Mariensee, Germany. We used a total of 68 (40 multiparous sows with 2 to 8 lactations; 28 primiparous sows) German Landrace x German Landrace sows from the sow herd of the research station. None of the sows was lactating during experiments. At least one day prior to the experiments four sows were moved in an experimental room respectively in which they were kept individually in stalls (1.6 m x 0.6 m) equipped with rubber mats (0.8 m x 1.5 m). All sows were offered water from nipple drinkers (Sueviam Kirchheim/Neckar) and fed once a day with a feeding ration exceeding their nutritional requirements.

**Experimental Design**

The main factors tested in our study were the different floors and the weight of sows. Three different rubber mats and a concrete floor were used. Rubber mats were developed by Kraiburg<sup>®</sup>, Elastik GmbH (Tittmoning, Germany) and these mats differed in softness (hard, soft, very soft) obtained by different textures of the underside of mats. The softness of mats had been measured prior to experiments with a calotte (a hemispheric metal object with a radius of 120 mm) and a penetration force of 200 kg. The very soft rubber mat (VSM) had a height of 6.0 cm and a penetration depth of 43.0 mm, the soft rubber mat (SM) a height of 3.0 cm and a penetration depth of 14.6 mm, and the hard rubber mat (HM) a height of 2.0 cm and a penetration depth of 4.0 mm. All rubber mats measured 1.2 m x 1.8 m. For control we used a concrete floor (C) covered with floor screed (MEM<sup>®</sup> Schnell Estrich, Leer, Germany) resulting in a smooth surface.

The 68 sows from the pool mentioned above had a body weight ranging from 90 to 330 kg. Weights of the sows were immediately assessed before pressure measurement using a digital pig scale (DWI-3006I, DMS-Waagen<sup>®</sup>, Heinsberg, Germany) with a resolution of  $\pm 0.1$  kg. Weights were categorized in three classes (1 to 3). Weight of sows in class 1 ranged from 90 to 170 kg ( $135.7 \pm 19.7$  kg), in class 2 from 171 to 210 kg ( $190.0 \pm 12.0$  kg) and in class 3 from 211 kg to 325 kg ( $254.0 \pm 31.5$  kg). For all sows also body condition scoring (BCS) was performed according to a scoring scheme ranging from 1 (very thin) to 5 (very fat) described by Charette et al. (1996). Furthermore, lameness and claw condition were assessed using a scoring system described by Bonde et al. (2004). Sows showing limb or claw lesions were not included in the experiment.

The different floors were tested in four successive trials starting with HM, followed by SM, C, and VSM. Successive testing of floors was chosen in order to prevent deterioration by permanent retrofitting of the experimental pen (see below). In the HM trial we tested 28 sows, in the SM trial 29 sows, in the C trial 33 sows, and in the VSM trial 28 sows. As these sows were taken from a pool of 68 sows this implicates that in part sows were repeatedly tested on different floors. However, on a particular floor a sow was tested only once. We did not perform the repeated measurements of sows on different floors due to the sows' weight gain between measurements. The number of sows in the weight classes was equally distributed across floors with about eight sows of each weight class per floor type.

## ***Pressure Measurement***

### **Experimental Pen**

Pressure measurements were conducted in an experimental pen (1.8 m x 0.9 m) located in the experimental room. This pen had a frame of steel bars and two doors. The frame on one side was fixed 20 cm above the floor allowing sows to extend their limbs outside of the pen. The floor of the experimental pen was covered with the test floor, the pressure sensor maps (for description see below) and protective foils. Protective foils consisted of two layers lorry tarp (PVC, 0.8 mm, 1.8 x 2.5 m) and one layer of a pool liner (PVC, 1.00 mm, 1.1 x 1.9 m). The test floor was covered with a first layer of lorry tarp on which the pressure sensor maps were laid. The sensor maps were next covered by the pool liner and lorry tarp was overlaid to protect against contamination by feces and urine. This second layer of lorry tarp was stretched resulting in a plane surface which prevents sows from manipulating the experimental floor with their mouth and teeth.

### **Pressure Measurement System**

Pressure was recorded with a "5400 NTL" sensor map system (Tekscan Inc., Boston, MA) including three ultrathin (0.1 mm) flexible sensor maps, each with a measurement surface of 58 x 88 cm and 0.3 sensing points per cm<sup>2</sup> resulting in an area of 2.89 cm<sup>2</sup> for each sensing point. A total measurement surface of 174 x 88 cm was achieved by fitting the three maps in parallel. The measures from the sensing points of the three sensor maps were combined using the tool "5400 NTL" of the Tekscan software. The sensor map system was used with a sensitivity adjusted to the weights of sows. Before a new test floor was measured the sensor maps were pneumatically equilibrated with a hydraulic press (KNF Type, UN 811, KVP Serial No. 1/1242842, Tekscan Inc.) and a vacuum bag (Tekscan Inc.) according to manufacturer's procedure (Tekscan Inc.). This equilibration was used to compensate possible changes in the sensitivity of sensors throughout the measurement period. The raw data were digitally measured in equidistant steps from 0 to 255. Raw digital data were converted into the unit N/cm<sup>2</sup> using a two point linear calibration for each sensor map achieved by two weights of 68 and 133 kg and a basis of 131 x 201 mm. These weights were chosen as we assumed that this would match the weight of sows under different body parts. The two point calibration resulted in a range from 0 to 7 N/cm<sup>2</sup> at a resolution of 0.2 N/cm<sup>2</sup>.

**Data Recording**

One day prior the start of measurements sows were transferred to the experimental room in which they were kept in the four pens described above.

For pressure measurement a single sow from one of the four stalls in the experimental room was moved in the experimental pen where she stayed in maximum 1.5 hours (maximal duration of an experiment). In order not to affect the lying behavior of the test sow, data recording was controlled and documented from an adjacent room by two infrared video cameras (VTC-E220IRP, Sanyo, Video AG, Ahrensburg, Germany) installed 1.50 m above the centre of the experimental pen (camera 1) and on the side of the experimental pen at 0.80 m distance (camera 2). Video recordings were conducted with a customized recording software (FLI Institute Celle, Germany) on an Asus PC (S-Presso Standard) and started as soon as a sow was confined in the experimental pen and ended when the sow left the experimental pen. Simultaneously, pressure load was continuously recorded with the measurement system software (BPMS Research 7.10, Tekscan Inc.) on a Notebook (Acer Extensa 5635). Videos and the pressure data were recorded with a time resolution of 20 frames/sec. Thus, behavioral recordings from video and pressure recordings could be combined for analysis (Figure 1).

If a sow did not lie down after 45 min, recording was terminated and another sow was used. Sows which did not lie down in the first attempt were again tested later on the same or the next day. When all sows of a subgroup were successfully recorded a new subgroup was selected and housed in the experimental room. In total, measurements for each trial lasted about 14 days.

**Analyzing Pressure Data**

Pressure recordings were separately analyzed for sternal and half recumbancy lying position following the descriptions by Ekkel et al. (2003). Due to an insufficient number of recordings it was not possible to analyze the data from full recumbancy lying.

For analysis, from each sow and each lying position a single data set ("screen print") from the continuous recording of pressure data was selected when a sow did not change a given lying position within 15 sec. This criterion was chosen in order to ensure a stable screen print for data analysis. Pressure data from sows lying in sternal position were analyzed for body regions sternum, belly and ham. For lying in half recumbancy position we analyzed the same body regions including the shoulder. Body regions were visually identified according to the sows' anatomy, and, if necessary, controlled by the respective video recording (Figure 1).



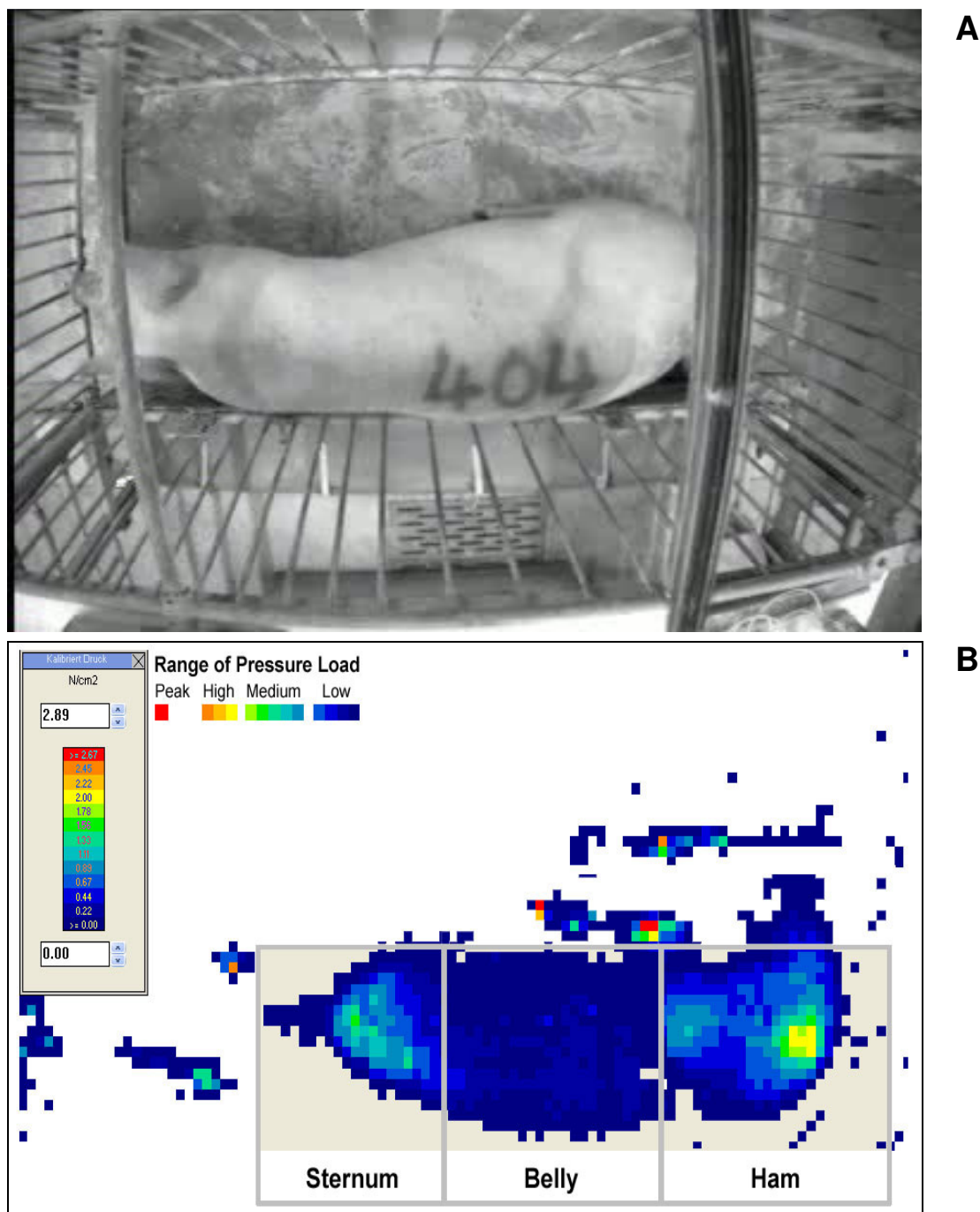


Figure 1: Screen print of a sow lying in sternal position from (A) video recording with infrared video camera and (B) pressure measurement system software.

Pressure data were converted to ASCII data, imported in EXCEL 2007<sup>®</sup> and analyzed with a self-developed macro that calculated pressure parameters as follows. First, sensing points of a value below 10 % of the maximum value were rejected in order to separate signal from noise (Schrader and Hammerschmidt, 1997).

Peak force (PF) in N/cm<sup>2</sup> was determined as the sensing point with the maximum pressure load. The contact area (CA) in cm<sup>2</sup> of the body area with the floor was estimated by counting number of sensing points with values above the noise threshold of 10 % and multiplying with 2.89 cm<sup>2</sup>, i.e. the area covered by a single sensing point.

### ***Statistical Analysis***

In order to determine the body regions with the highest pressure load we calculated the median values of PF for the different body regions for the two lying positions. Subsequently, we analyzed the pressure parameters using a mixed model ANOVA (MIXED procedure of SAS; Enterprise Guide, version 4.3., SAS Institute Inc., Cary, NC). Residuals were tested for normal distribution (Kolmogorov-Smirnov test) and in case of non-normal distribution, log<sub>10</sub>-transformed. Floor type, weight class and their interaction were included as fixed effects. Because not all sows showed both lying positions the actual number of measures included in the analysis is given in the tables.

Body condition scores were not included in the analysis because 88 % of sows had a BCS of 3 (normal), 5 % of 2 (thin), and 7 % of 4 (fat). In addition, BCSs were strongly related to the weight of sows.

## **Results**

### ***Pressure Load in Sternal Position***

The median values of PF in sternal position were 1.62 N/cm<sup>2</sup> (Q1: 1.17 N/cm<sup>2</sup>, Q3: 2.10 N/cm<sup>2</sup>) on the sternum, 0.96 N/cm<sup>2</sup> (Q1: 0.74 N/cm<sup>2</sup>, Q3: 1.19 N/cm<sup>2</sup>) on the belly, and 1.71 N/cm<sup>2</sup> (Q1: 1.33 N/cm<sup>2</sup>, Q3: 2.10 N/cm<sup>2</sup>) on the ham. However, on the sternum PF showed the highest single maximum values ranging up to 8.44 N/cm<sup>2</sup>.

The PF on the sternum was affected both by floor type ( $P = 0.0132$ ) and weight class ( $P = 0.0012$ ) (Table 1) but not by the interaction between floor type and weight class. Compared to C the PF was lower on VSM ( $P = 0.0012$ ) but did not differ between the other floors. Sows of weight class 1 showed lower peak forces compared to sows of weight class 2 ( $P = 0.0007$ ) and weight class 3 ( $P = 0.0021$ ).

The CA under the sternum differed between floors ( $P = 0.0301$ ), weight classes ( $P < 0.0001$ ) and there was also an interaction between floor type and weight class ( $P = 0.0002$ ). Compared to C the CA was highest on SM ( $P = 0.0156$ ) and VSM ( $P = 0.0080$ ). Regarding weight CA under the sternum was higher for weight class 3 compared to weight class 1 ( $P < 0.0001$ ) and weight class 2 ( $P = 0.0004$ ). Within

weight class 1 the CA was higher on HM ( $P = 0.0028$ ) and on VSM ( $P = 0.0004$ ) in comparison to C and higher on VSM ( $P = 0.0112$ ) compared to SM. In weight class 2 the CA was only higher on SM ( $P = 0.0045$ ) compared to C. Within weight class 3 the CA was higher on C ( $P = 0.0074$ ) and SM ( $P = 0.0173$ ) compared to HM.

### ***Pressure Load in Half Recumbent Position***

The median values of PF across all floors were  $1.29 \text{ N/cm}^2$  (Q1:  $1.04 \text{ N/cm}^2$ , Q3:  $1.91 \text{ N/cm}^2$ ) for the sternum,  $1.14 \text{ N/cm}^2$  (Q1:  $0.92 \text{ N/cm}^2$ , Q3:  $1.37 \text{ N/cm}^2$ ) for the belly,  $1.71 \text{ N/cm}^2$  (Q1:  $1.24 \text{ N/cm}^2$ , Q3:  $2.58 \text{ N/cm}^2$ ) for the ham, and with  $2.72 \text{ N/cm}^2$  (Q1:  $2.09 \text{ N/cm}^2$ , Q3:  $3.81 \text{ N/cm}^2$ ) highest for the shoulder. The PF on the shoulder was affected by floor type ( $P = 0.0388$ ) but not by weight class or the interaction between floor type and weight class. The PF was higher on C ( $P = 0.0128$ ) and HM ( $P = 0.0113$ ) in comparison to VSM but did not differ for SM (Table 2).

The CA under the shoulder was only affected by weight class ( $P = 0.0097$ ), but not by floor type or the interaction between floor type and weight class. In weight class 1 the CA was lowest in comparison to 2 ( $P = 0.0055$ ) and 3 ( $P = 0.0124$ ).

**Table 1: Least squares means (LSM), 95 % confidence interval (CI) of pressure measures on the sternum during lying in sternal position on different floors and for different weight classes**

| Item                    | Floor                                   |   |  |   | Weight class                            |   |   | ANOVA                                 |   |  |
|-------------------------|---|---|--|---|---|---|---|---------------------------------------|---|--|
|                         | C<br>(n = 27)                           | HM<br>(n = 24)                            | SM<br>(n = 21)                           | VSM<br>(n = 23)                         | Weight class 1*<br>(n = 7)              | Weight class 2§<br>(n = 8)              | Weight class 3†<br>(n = 9)              | Floor                                 | Weight class                            | Floor x<br>weight class                |
| PF (N/cm <sup>2</sup> ) | 1.91 <sup>a</sup><br>(1,57; 2,31)       | 1.47 <sup>ab</sup><br>(1,21; 1,80)        | 1.56 <sup>ab</sup><br>(1,26; 1,94)       | 1.17 <sup>b</sup><br>(0,94; 1,45)       | 1.12 <sup>a</sup><br>(0,93; 1,45)       | 1.79 <sup>b</sup><br>(1,50; 2,13)       | 1.70 <sup>b</sup><br>(1,43; 2,01)       | F <sub>3,83</sub> = 3.80<br>P = 0.013 | F <sub>2,83</sub> = 7.30<br>P = 0.001   | NS                                     |
| CA (cm <sup>2</sup> )   | 191.09 <sup>a</sup><br>(171.92; 219.12) | 221.97 <sup>abc</sup><br>(194.95; 252.74) | 244.17 <sup>bc</sup><br>(213.16; 279.70) | 249.29 <sup>c</sup><br>(218.16; 284.16) | 190.77 <sup>a</sup><br>(169.42; 214.81) | 213.06 <sup>a</sup><br>(191.00; 237.67) | 285.10 <sup>b</sup><br>(255.40; 318.26) | F <sub>3,80</sub> = 3.13<br>P = 0.030 | F <sub>2,80</sub> = 12.99<br>P < 0.0001 | F <sub>6,80</sub> = 5.00<br>P = 0.0002 |

PF: Peak force; CA: Contact area

C: Concrete; HM: Hard mat (4.0 mm penetration depth); SM: Soft mat (14.6 mm penetration depth); VSM: Very soft mat (43.0 mm penetration depth)

\* weight range 90 – 170 kg; 135.7 ± 19.7 kg; § weight range 171 – 210 kg; 190.0 ± 12.0 kg; † weight range 211 – 325 kg; 254.0 ± 31.5 kg)

<sup>a-c</sup> Least squares means within a row with different superscripts differ (P < 0.05), NS = not significant

**Table 2: Least squares means (LSM), 95 % confidence interval (CI) of pressure measures on the shoulder during lying in half recumbent position on different floors and for different weight classes**

| Item                    | Floor                             |                                   |                                    |                                   | Weight class                           |   |   | ANOVA                                 |                          |                      |
|-------------------------|-----------------------------------|-----------------------------------|------------------------------------|-----------------------------------|--|---|---|---------------------------------------|--------------------------|----------------------|
|                         | concrete<br>(n = 25)              | hard mat<br>(n = 20)              | soft mat<br>(n = 21)               | very soft mat<br>(n = 22)         | Weight class 1<br>(n = 7)              | Weight class 2<br>(n = 7)               | Weight class 3<br>(n = 8)               | Floor                                 | Weight class             | Floor x weight class |
| PF (N/cm <sup>2</sup> ) | 3.35 <sup>a</sup><br>(2.85; 3.87) | 3.43 <sup>a</sup><br>(2.86; 3.99) | 3.07 <sup>ab</sup><br>(2.51; 3.62) | 2.39 <sup>b</sup><br>(1.84; 2.93) | 3.25<br>(2.85; 3.87)                   | 3.04<br>(2.56; 3.51)                    | 2.89<br>(2.43; 3.36)                    | F <sub>3,76</sub> = 2.93<br>P = 0.039 | NS                       | NS                   |
| CA (cm <sup>2</sup> )   | 171.06<br>(130.09; 211.97)        | 141.29<br>(95.89; 186.69)         | 205.04<br>(160.54; 249.54)         | 223.61<br>(179.83; 267.39)        | 135.92 <sup>a</sup><br>(98.05; 173.79) | 214.38 <sup>b</sup><br>(176.11; 252.65) | 205.45 <sup>b</sup><br>(173.97; 236.93) | NS<br>P = 0.010                       | F <sub>2,76</sub> = 4.93 | NS                   |

PF: Peak force; CA: Contact area

C: Concrete; HM: Hard mat (4.0 mm penetration depth); SM: Soft mat (14.6 mm penetration depth); VSM: Very soft mat (43.0 mm penetration depth)

\* weight range 90 – 170 kg; 135.7 ± 19.7 kg; § weight range 171 – 210 kg; 190.0 ± 12.0 kg; † weight range 211 – 325 kg; 254.0 ± 31.5 kg)

<sup>a-b</sup> Last means squares within a row with different superscripts differ (P < 0.05), NS = not significant

## Discussion

For the first time this study analyzes the pressure load on different body regions in sows lying in different positions. We assumed that a minimum peak force in combination with a maximum area of pressure distribution offers maximum lying comfort for sows. This was confirmed by our results showing that the softest mat reduced the pressure load strongest when sows are lying in sternal and in half recumbent position. In addition, pressure load was affected by the weight of sows. Thus, our results yield important information about the design of floors for comfortable lying for sows.

When sows lie in sternal position, a high peak force was measured particularly under the sternum. Baxter (1984) and Arey (1993) assumed, that in sternum position only 10-20 % of pig's total body surface area comes in contact with floor, i.e. that the entire weight burdens on this comparable small body area. The sternum is a bony part of the thorax and in comparison to the belly and the ham which have a proportion of 20-40 % fat and 40-60 % muscle content (Monziols et al. 2006) it is likely to be less protected against pressure load. Despite this different protection by muscle and fat tissue, peak force on the sternum was as high as on the ham. Although there are no studies about possible damages or injuries of the sternum due to pressure load, the high peak force on the sternum is likely to result in an impaired resting comfort.

Only the very soft mat with a penetration depth of 43 mm lead to a significant decrease of pressure load on the sternum and with increasing weight class peak force on the sternum increased irrespective from floor type. Thus, only a very soft mat seems to be able to reduce peak force on the sternum while lying in sternal position. However, the area under the sternum with contact to the floor was higher for the soft mat and for the very soft mat in comparison to concrete floor which was most pronounced in weight class 1. As contact area also is suggested as a parameter for lying comfort (Hänel et al., 1997), already the soft rubber mat seems to result in an improved lying comfort. The highest contact area in sows of the heaviest weight class was expected due to their larger body size which is related to body weight.

In half recumbent position the highest peak force was on the shoulder and here the peak force was nearly twice as high as on the sternum in sternal position. Comparable to the sternum the large tuber on the spine of pigs scapulae is sparsely covered with fat and muscle tissue (Monziols et al., 2006) and less protected against pressure load. Moreover, the shoulder blade is characterized by a tongue-shaped bony prominence, the tuber spina scapulae, and it is likely that

pressure load is concentrated on this bone. Shoulder lesions such as decubital ulcers are most often seen near the tuber of the scapular spine (Jensen, 2009). The peak force on the shoulder could be reduced on the very soft mat compared to the hard mat and the concrete floor and it is well known that rubber mats support the healing of shoulder ulcerations (Zurbrigg, 2006). Furthermore, in a study by Tuytens et al. (2008) gestating sows lied up to 20 % more often in half recumbent position and up to 25 % less in sternal position when compared to concrete floor. As lying in half recumbence is suggested as more comfortable than lying in sternal position this may indicate that an increased lying comfort can be accompanied by benefits for the health of sows.

Surprisingly, peak force on the shoulder was not affected by weight of sows. In addition, we also did not find an effect of floor type on the size of contact area under the shoulder. These findings possibly results from the high pressure load concentrated on the small-scaled structure of the tuber spina scapulae which does not enable an effective distribution of pressure load over a larger area. However, contact area under the shoulder was lowest in the light weighing sows probably due to the smaller size of the spina scapulae in the lighter and younger sows.

Although our results point out that only the softest mat used in our study might be able to significantly reduce the pressure load it has to be taken into account that the protective foils which have to be used to protect the sensitive sensor maps might have masked any minor differences in softness of the harder mats. The very soft mat in our study had a penetration depth of 43 mm and penetration depth of the other mats were distinctly lower (4.0 and 14.6 mm). Thus, using mats with a penetration depth between a range of 14 to 40 mm might also reduce pressure load. In addition, measurements of the pressure load should be combined with behavioral observations such as in preference tests in order to get information about the assessment of the comfort by the sows.

In conclusion, pressure measurements can add important information to behavioral studies by identifying body regions with highest pressure loads during lying. Our results show that the pressure load on lying sows depends on the respective floor type and can differ between lying positions and the weight of sows. The most affected body parts are the sternum in sternal lying position and the shoulder in half recumbent lying position. Hard rubber mats do not seem to offer a high lying comfort with regard to pressure load.

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### **3 Chapter Two**

**Pressure load and duration in half and full kneeling position while gestating sows lie down on rubber mats with different softness**

## Abstract

The lying behavior of sows depends on floor type and rubber mats are also likely to provide more comfort for sows while lying down. Until now, no information has been published on the pressure load on carpal joints of sows while lying down. A total of 68 (40 multiparous, 28 primiparous) German Landrace x German Landrace sows within the weight range of 90 to 330 kg were used to measure peak force of pressure in half and full kneeling position while lying down. Measurements were conducted in an experimental pen with a pressure sensor map system (5400 NTL, Tekscan Inc., Boston, MA). As floors, three rubber mats with different softness (penetration depth: hard mat 4.0 mm [HM], soft mat: 14.6 mm [SM], very soft mat: 43.0 mm [VSM]) were tested in comparison to concrete floor (C). Peak Force (PF) was measured in half and full kneeling position on carpal joints with contact to floor. In full kneeling position the median values of PF from both carpal joints were analyzed. In addition, the duration of time sows spend in half and full kneeling position while lying down was measured and analyzed using video recordings. All data was analyzed using one-way nonparametric ANOVA (NPAR1WAY Procedure of SAS Enterprise, version 4.3., SAS Institute Inc., Cary, NC). PF on rubber mats was significantly higher ( $P = 0.0020$ ) in both half and full kneeling position compared to C. Time sows spent in half or full kneeling position did not differ between floors ( $P > 0.05$ ). A subsequent analysis of pressure data revealed that most likely the system produced artifacts probably due to traction and shearing forces and the appearance of dynamic pressure in pressure measurements of animals in motion. Thus, it is concluded that for further investigations a pressure measurement system with a higher spatial resolution should be used in order to obtain valid results regarding the pressure load on carpal joints of sows while lying down in half and full kneeling position.

Keywords: pressure load, pig, lying down, rubber mats, lying comfort

## Introduction

Lying down behavior of sows has been investigated mostly for farrowing sows in relation to piglet crushing. Bonde et al. (2004) suggested that apart from any discomfort and frustration caused by restricted space provided in farrowing crates, the physical environment may lead to welfare problems as crate structures and flooring can injure the animal. Boyle et al. (2002) observed, that sows needed several attempts before succeeding in lying down on hard surfaces during the first days in farrowing crates which was associated with carpal lesions. Bonde et al. (2004) found associations between lying down behavior and clinical indicators such as skin lesions on the limbs (e.g. carpus) due to abnormal lying behavior. Smith (1988) also suggested that traumatic damage to the limb might cause lameness in sows. So the lying down behavior seems to be influenced by the floor's condition.

The impact of rubber mats as an alternative floor to improve comfort was tested in different investigations for farrowing (Boyle et al., 2000; Farmer et al., 2006; Gravås, 1979; Zurbrigg, 2006) and gestating sows (de Carvalho et al., 2009; Elmore et al., 2010; Tuytens et al., 2008). De Carvalho et al. (2009) found positive effects on rubber mats even when sows were walking or standing due to a larger area of contact between the claw and the floor, which reduces the impact load on joints and claws. In an investigation from Boyle et al. (2000), sows on mats spent longer periods of time kneeling compared to sows on metal slats (40.2 vs. 21.7 sec). The authors assume, that rubber mats offer more comfort by adding a cushioning effect to the knees when lying down. In contrary, on slippery concrete floors time to lie down may take longer as sows try to avoid slipping (Marchant and Broom (1996). Fraser (1975) found that sows were reluctant to lie down when bedding was not provided, which may have been due to decreased floor comfort (Arey 1993).

Citing Baxter and Schwaller (1983), Damm et al. (2005) divide the lying down sequence into five stages: "(1) One foot is lifted and placed onto the floor so that the sow drops into a half kneeling position, the second is then lifted, placed on to the floor, and the sow drops into a full kneel, (2) the sow may pause before movement continues, (3) the sow slides one knee forward along the floor and rotates the upper part of her body to bring a shoulder and side of the head to rest on to the floor, (4) again, the sow may pause before movement continues, and finally (5) the sow lowers her hindquarters and rotates slightly causing the rear legs to slide sideways". Although O'Connell et al. (1996) remarked that during lying down there might be considerable pressure on the knees probably resulting in

discomfort for sows, until now the pressure load during lying down on different floors is unknown.

It is hypothesized, that highest pressure while lying down sequence will be measured on knees, when whole body weight burdens on the carpal joints. So, in the present study maximal pressure load was examined separately on the carpal joints in half and full kneeling position as characterized in stage 1 of the lying down sequence described above. Maximal pressure load was measured on three different mats with different softness in comparison to concrete floor. It was hypothesized, that pressure load on carpal joints in half and full kneeling position decreased with softness of floors. Additionally, duration of time sows spent in half and full kneeling position was determined on different floors while lying down. It was assumed that sows on hard floors would lie down in a shorter time to avoid high pressure load burdens on the carpal joints in comparison to soft floors.

## **Material and Methods**

Pressure measurements during lying down were included in measurements for lying sows as described in chapter one. Thus, different floor types (hard mat [HM], soft mat [SM], very soft mat [VSM], concrete floor [C]), number of sows, their weights, usage of pressure measurement system, experimental pen and video recordings were the same as described in chapter one and will not separately repeated here. As in chapter one described video recordings started as soon as a sow was confined in the experimental pen. Because of the continuously video recordings with entrance of the sow in the experimental pen, not only different lying positions of the sow were recorded, but also her lying down sequence. For video analysis, sequence of lying down was cut from the remaining videos containing different lying positions and analyzed as described below.

### ***Analyzing Pressure Data***

The video recordings were examined and lying down behavior was categorized into normal and abnormal lying down behavior following the description of Bonde et al. (2004). In recordings with normal lying down behavior the stage (1) of lying down behavior as defined by Baxter and Schwaller (1983) (described in Damm et al., (2005), p. 15) was selected for further analysis: "One foot is lifted and placed onto the floor so that the sow drops into a half kneeling position, the second is then lifted, placed onto the floor, and the sow drops into a full kneel". In the respective video recordings the start and end time of stage (1) was noted and paralleled in time with the recordings of pressure measurements. Then pressure recordings were corrected with calibration data and pressure load for each sow analyzed in half and full kneeling position on the different test floors. Pressure analysis based

on single picture screen prints, whereby a first picture was taken when the sow lied down on one carpal joint, while the second fore limb's claw was lifted from surface (half kneeling position, see Figure 1). A second picture was taken when the sow lied down on both carpal joints, while one of the hind limb's claw was lifted from the surface (full kneeling position, see Figure 2).

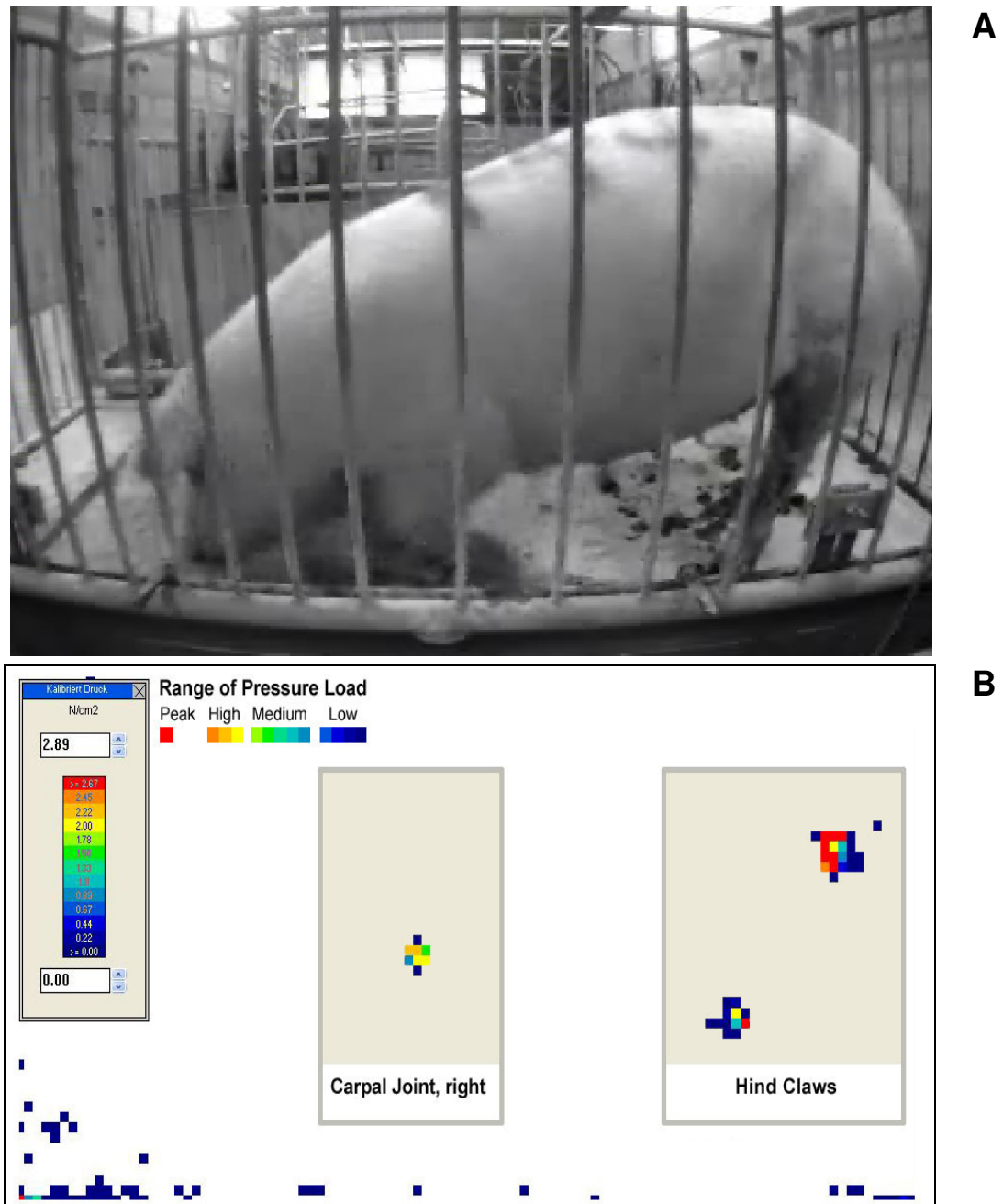


Figure 1: Screen prints of a sow in half kneeling position from (A) video recording with infrared video camera and (B) pressure measurement system software with graphical editing

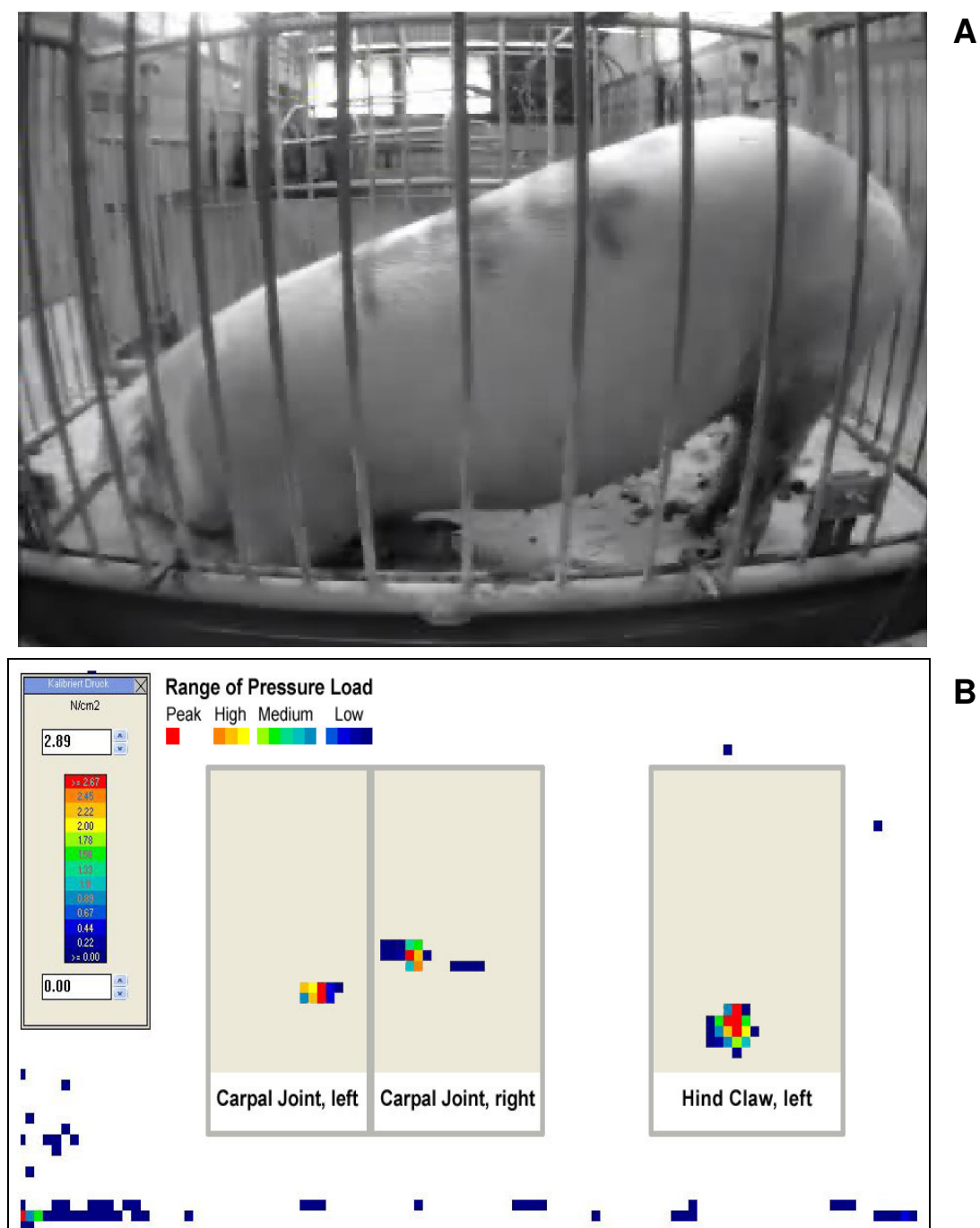


Figure 2: Screen prints of a sow in full kneeling position from (A) video recording with infrared video camera and (B) pressure measurement system software with graphical editing

Both screen prints were converted in TEKSCAN® Software to ASCII data and imported into EXCEL 2007® for further analysis with a customized macro that automatically calculated pressure parameters as described in Chapter One. For analysis of pressure load during lying down, only peak force (PF) was analyzed.

In addition to analysis of pressure data, the duration of time sows spent in half and full kneeling position was calculated by subtracting start and end frame number provided from the pressure video for the duration of each position. The difference of frames was subsequently multiplied with 0.05 sec. The amount of seconds was calculated from the frame speed of 20 frames per second. Thus, each single frame in the video sequence lasted 0.05 sec.

### ***Statistical Analysis***

Differences of the PF and duration of kneeling positions between the different floors were analyzed using one-way nonparametric ANOVA (NPAR1WAY Procedure of SAS Enterprise, version 4.3., SAS Institute Inc., Cary, NC). Residuals were tested for normal distribution with Kolmogorov Smirnov test. Due to the assumption that artifacts were measured, the distribution of PF data was subsequently analyzed with Chi-square test ( $\chi^2$ -test). The variance of the median was expressed with quartile 1 (Q1) and 3 (Q3).

## **Results**

### ***Pressure Load in Half and Full Kneeling Position***

In half kneeling position PF was affected ( $P = 0.0020$ ) by floor. In half kneeling position the median of the PF on C was  $3.18 \text{ N/cm}^2$  (Q1:  $1.82 \text{ N/cm}^2$ , Q3:  $3.81 \text{ N/cm}^2$ ), on HM  $3.81 \text{ N/cm}^2$  (Q1:  $3.81 \text{ N/cm}^2$ , Q3:  $3.81 \text{ N/cm}^2$ ), on SM  $3.81 \text{ N/cm}^2$  (Q1:  $3.81 \text{ N/cm}^2$ , Q3:  $3.81 \text{ N/cm}^2$ ) and on VSM  $3.81 \text{ N/cm}^2$  (Q1:  $3.81 \text{ N/cm}^2$ , Q3:  $6.98 \text{ N/cm}^2$ ). PF was affected by floor ( $P = 0.0020$ ) and was significantly different between C and all mats. C differed significantly to HM with  $P = 0.0085$ , to SM with  $P = 0.0011$  and to VSM with  $P = 0.0070$ .

The subsequent analysis of the distribution of pressure data showed a high amount of the value of  $3.81 \text{ N/cm}^2$  at all floors in half kneeling position. The value of  $3.81 \text{ N/cm}^2$  was also the median for all mats. The value of  $3.81 \text{ N/cm}^2$  was measured on C for 31.0 %, HM for 61.3 %, SM for 69.0 % and on VSM at 48.2 %. The distribution of measured values in half kneeling position did not differ between the floors ( $P = 0.2238$ ).

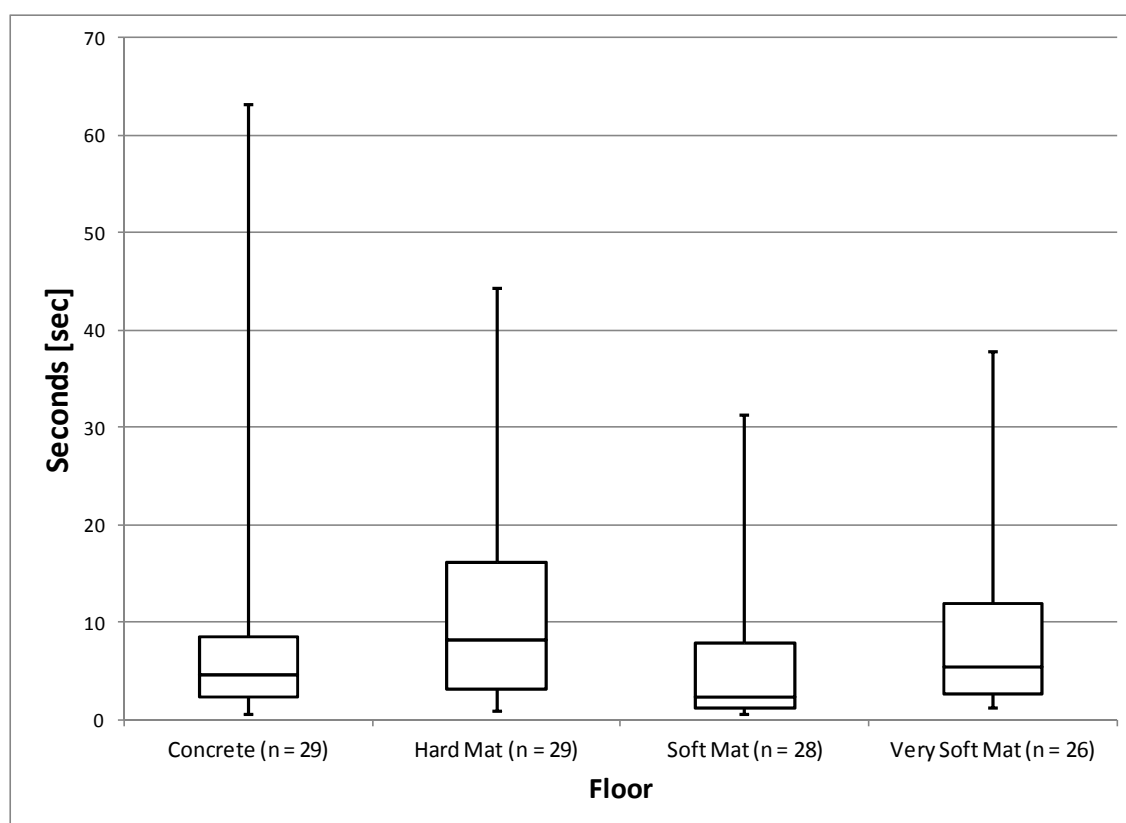
In full kneeling position, PF also was affected by the floor ( $P = 0.0020$ ). As in half kneeling position, the PF significantly differed between C and all mats. C differed significantly to HM with  $P = 0.0095$  to SM with  $P = 0.0089$  and to VSM with  $P = 0.0017$ . In median, the PF was  $2.83 \text{ N/cm}^2$  (Q1:  $2.32 \text{ N/cm}^2$ , Q3:  $3.37 \text{ N/cm}^2$ ) on C,  $3.81 \text{ N/cm}^2$  (Q1:  $2.91 \text{ N/cm}^2$ , Q3:  $3.81 \text{ N/cm}^2$ ) on HM,  $3.29 \text{ N/cm}^2$  (Q1:  $2.86 \text{ N/cm}^2$ , Q3:  $3.81 \text{ N/cm}^2$ ) on SM, and  $3.81 \text{ N/cm}^2$  (Q1:  $3.01 \text{ N/cm}^2$ , Q3:  $5.11 \text{ N/cm}^2$ ) on VSM.



In full kneeling position, there was also a high amount of the value of 3.81 N/cm<sup>2</sup> for PF, although lower compared to half kneeling as the subsequent analysis of the data resulted in. Sows showed on HM for 30 %, on SM for 24.1 % and on VSM for 16 % a PF for 3.81 N/cm<sup>2</sup>. On C, no amount of the value of 3.81 N/cm<sup>2</sup> was observed. However, the amount of PF values did not differ significantly between floors ( $P = 0.2171$ ).

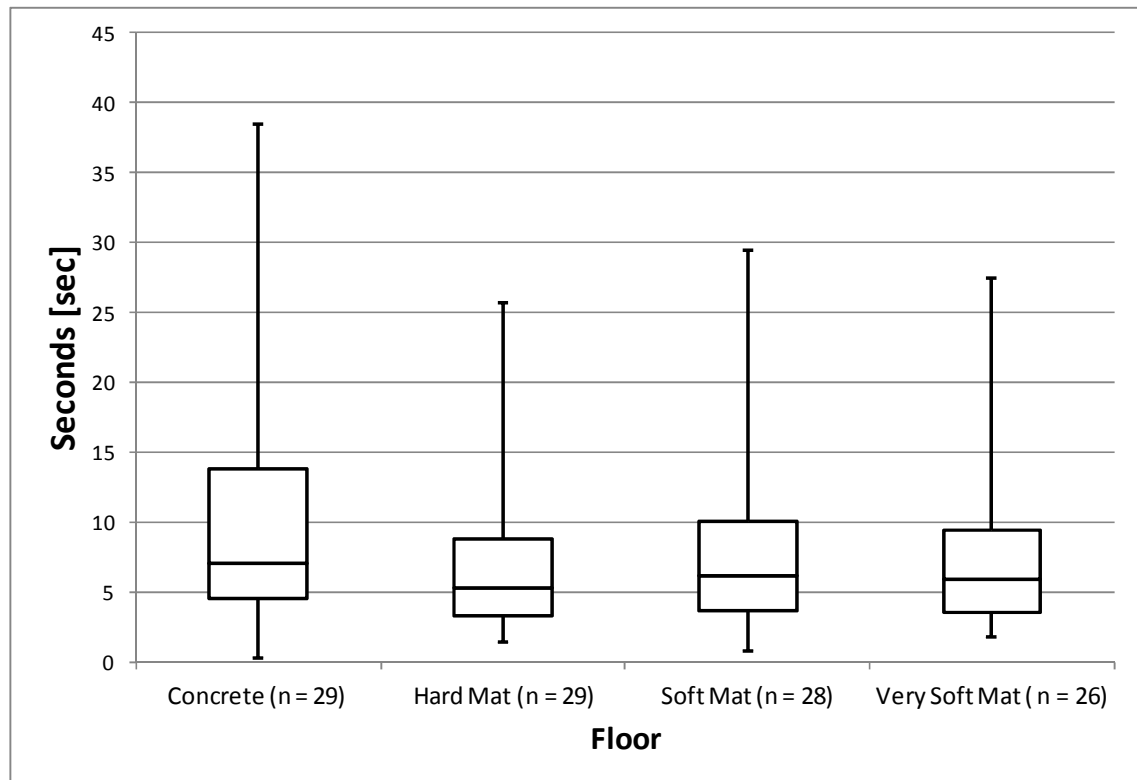
### ***Duration of Lying in Half and Full Kneeling Position***

Sows spent in median 4.6 sec on C, 8.2 sec on HM, 2.3 sec on SM and 5.4 sec on VSM in half kneeling position (see Figure 3). Maximum durations in half kneeling position were observed on C with 63.1 sec, followed by HM with 44.3 sec and SM with 44.3 sec, and on VSM with 37.9 sec. However, the durations in half kneeling position did not differ between floors ( $P = 0.0940$ ).



**Figure 3: The duration of time sows spent in half kneeling position during lying down on different floors**

In full kneeling position sows spent in median 7.0 sec on C, 5.4 sec on HM, 6.1 on SM and 5.6 sec on VSM (see Figure 4). Maximum duration in full kneeling position was observed on C with 38.5 sec, on HM with 25.8 sec, on VSM with 27.5 sec and on SM with 29.5 sec. The duration sows spent lying on full kneeling position did not differ between floors ( $P = 0.6774$ ).



**Figure 4: The duration of time sows spent in full kneeling position during lying down on different floors**

## Discussion

The aim of the present study was to measure the peak pressure on the carpal joints of sows when lying down on floors differing in softness. It was hypothesized that pressure load would be higher on hard floors and therefore the duration of kneeling would be shorter on hard floors in order to avoid an uncomfortable lying position. The hypothesis was not confirmed by the study. However, in contrast to this hypothesis, PF on C was lower compared to softer mats and duration of kneeling did not differ between floors. It was rather remarkable that the majority of data for PF showed a value of 3.81 N/cm<sup>2</sup>. In half kneeling position the value of 3.81 N/cm<sup>2</sup> was observed in mean with 60 % over all mats. On C the value was measured only to 31.0 % in half kneeling position. In full kneeling position the value was measured only to 23 % in mean on all mats and on C no amount of a PF of 3.81 N/cm<sup>2</sup> was observed. It is inexplicable, why even 3.81 N/cm<sup>2</sup> was the most frequent value measured on mats in comparison to C, but it has to be considered, that an artifact was measured. Pressure measurement system used, was originally developed for measurement of human beings, e.g. to measure pressure distribution on mattresses (5400 NTL) or on car seats (5400 N), thus, for measuring pressure under comparable large body areas.

On pressure measurement system a carpal joint was pictured by nine sensor points in mean. Each sensor point had a size of 2.89 cm<sup>2</sup>. So one carpal joint sized in mean 26 cm<sup>2</sup>. From this area it can be calculated that a carpal joint would have had a diameter of 5 cm. This was a very small area for pressure impact. It is assumed that on mats more traction and shearing force arises on measurement foils due to selective impact of pressure from carpal joints. In comparison, on concrete as hard floor no traction or shearing force could have been influenced the measurement system. This could explain the high amount (83 %) of the value 3.81 N/cm<sup>2</sup> for both lying down positions over all mats in comparison to concrete, where only 31.0 % of the values amounted 3.81 N/cm<sup>2</sup>.

Furthermore, pressure load consists of static and dynamic intervals. Dynamic pressure is measured for an animal in motion, whereas static pressure is measured then the animal is not in motion. Due to the high change of movements of the sow within lying down process, a high amount of dynamic pressure was measured. Different motions during dynamic intervals of pressure load could be resulted in peak loads that influenced pressure load measurements as artifacts.

Nevertheless, it seems that the pressure measurement system reached its limitations in measuring small areas like the carpal joints on soft floors. Thus, a pressure measurement hardware system with higher spatial resolution possibly would have been more adequate (e.g. 1.4 sensors per cm<sup>2</sup>; Sensor Model 3150 HL; TEKSCAN<sup>®</sup>). However, pressure sensors with a higher spatial resolution cover a much smaller area. The named pressure measurement system has a matrix wide of 43.6 cm and length of 36.7 cm. With the size of 26 cm<sup>2</sup> of one carpal joint, it would be possible to cover this area on the matrix. McGlone et al. (2004) investigated the physical size of gestating sows, while they measured depth of three different genotypes of sows up to a known body weight of 240 kg in order to estimate sow width while lying down. Due to their investigations, shoulder width amounted to 43.5 ± 0.4 cm in maximum. Thus, the matrix wide of 43.6 cm of the sensor model 3150 HL could be sufficient to record pressure load on carpal joints in half and fully kneeling positions for sows up to a body weight of 240 kg. However, the limitation of the sensor model in length could be a disadvantage, because it could be difficult to direct sows to lie down on a limited matrix area.

Because of probable artifact in measurement no valid statement is possible, whether rubber mats may reduce pressure load on carpal joints and increase comfort during lying down. Whereby pressure measurements does not produced valid results in the present study, from other investigation positive effects of rubber mats during lying down are noted. Boyle et al. (2000), who examined the effect of

mats on the welfare of sows and piglets in the farrowing house, observed that mats were more comfortable for sows to kneel on. Fraser (1975) noted, that in the absence of bedding sows appear to be reluctant to lie down due to a lack of physical comfort. This observation support the hypothesis that pressure load on hard floors has to be higher than on soft floors. However, in neither of these studies the actual pressure was measured.

In the present study, no significant difference of duration sows spent in half or full kneeling position was found between floors. This confirms previous research conducted by Boyle et al. (2000) who also found no significant differences in lying down duration in kneeling position between rubber mats and full slatted metal slats, although sows on mats tended to spent longer time in kneeling position on mats. Also Leonard et al. (1997) found no significant differences in time duration of lying down between different floors. They observed lying behavior in farrowing crates on half slatted metal and plastic floor and they focused on the entire lying down sequence. Both research groups observed sows and their piglets from farrowing to weaning, so it can be assumed that a longer observation time in the current study would have been resulted in no other results.

Whereas research on the impact of rubber mats on animal lying behavior is investigated sparsely for pigs, it has been primarily conducted in cows. These studies have focused on the relationship between lying behavior and leg injuries in dairy cows kept in cubicle systems with straw bedding or soft lying mats (Wechsler et al., 2000), softer flooring in tie stalls on resting behavior (Rushen et al., 2006) and on concrete on comparison to rubber mats (Haley et al., 2001), to name just a few. Typically, the duration of lying time was investigated on different floors. Wechsler et al. (2000) observed additionally the total duration of lying down and found out that duration did not differ significantly between cows kept in cubicle systems with straw bedding and cows kept in cubicle systems with soft lying mats. The other authors gave no information about duration of lying down sequence. It has to be assumed that the flooring doesn't have an impact on duration of lying down, neither in pigs nor in cows.

## **Conclusion**

The pressure measurement system 5400 NTL was not capable to measure peak force validly while lying down in half and full kneeling position. Artifacts were probable measured due to shearing and traction forces on sensor foils while sows were kneeling on different rubber mats.

Peak load during dynamic pressure intervals in comparison to static pressure can overlap pressure load. Thus, it should be calculated once to which amount dynamic pressure arises during pressure measurements with sows in motion.

Furthermore, resolution of the pressure measurement system of 0.3 sensors per  $\text{cm}^2$  was too low to measure body parts like carpal joints, that size  $26 \text{ cm}^2$  in mean.

For further investigation a pressure measurement system with a resolution of 1.4 sensing points per  $\text{cm}^2$  should be used to record pressure load on carpal joints due to the small size of carpal joints. A capable pressure measurement system could be the sensor Model 3150 HL presented by the firm TEKSCAN<sup>®</sup> to measure pressure load in half und full kneeling position for sows with a body weight up to 240 kg.

Time sows spent in half and full kneeling position was not different between different floor types. Thus, rubber mats with different softness does not influence duration of lying down in comparison the concrete slats.

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## **4 Chapter Three**

**Gait analysis of gestating sows on rubber mats with different surface profiles in comparison to concrete slats**



## **Abstract**

Poor floor quality in sow housing can lead to problems with the skeletal and locomotor system such as lameness, claw lesions or even fractures. In the present study, two different slatted rubber mats with different surface profiles (rough [RM] vs. smooth [SmM]) were tested in comparison to concrete slats (CS). A total of 15 German Landrace x German Landrace sows (mean weight  $196 \pm 72$  kg) were analysed for gait in a repeated measurement design. Gait analysis was performed in an experimental room ( $18.5 \times 4.7$  m<sup>2</sup>) in which floors were tested in the order CS, SmM, RM, CS. Floors were installed as a walkway ( $17.0 \times 0.8$  m). At a 3 m long test section in the middle of the walkway sow gait was recorded in front of an equidistant measuring tape by a video camera. Gently driven by the experimenter each sow passed the walkway five times and from the mean values of the last three passages the following parameters were analysed using VirtualDub® 1.9.11: walking speed, stride length, swing time and stance time. All parameters were analyzed separately for fore and hind limb. Data were tested for normal distribution with PROC UNIVARIAT in SAS (Enterprise Guide, version 4.3., SAS Institute Inc., Cary NC) and differences between test repetitions were tested with PROC MIXED for repeated measurements. Walking speed of sows significantly differed between test repetition ( $P = 0.0049$ ). This was not affected by experimenter's walking speed ( $P > 0.05$ ). However, differences in sows' walking speed resulted from a habituation of sows to the repeated test walks rather than from effects of floor type. Except swing time ( $P = 0.0058$ ) the others stride parameters did not differ among test repetitions. Further investigations of sow gait floors shall be designed in a random order for better controlling habituation effects.

Keywords: rubber mats, gait analysis, sow, surface profile

## Introduction

Leg problems in sows may occur for several reasons. One of the major environmental factors is the pen floor (Thorup et al., 2007). In the EU pigs are predominantly kept in fully or partly slatted housing systems (von Wachenfelt et al., 2008). Heinonen et al. (2006) showed that sows housed on slatted floors were twice as much lame than sows housed on solid floor. Lameness is a very common problem among sows and one of the most common reasons for culling them, although it is not considered among the main reasons for mortality of sows (Chagnon et al., 1991). Following Webb and Nilsson (1983), even floor properties such as friction, abrasiveness, hardness and surface profile affect animal injuries in livestock buildings. But these four factors are not independent from each another as, for example, a change in surface profile can affect both the frictional and abrasive properties of the surface (McKee and Dumelow, 1995).

Low friction can cause slips and falls (von Wachenfelt et al., 2008). Floors with too low friction may cause slips damaging the joints due to overexertion and falls which may cause injuries and ultimately can result in fractures of legs (Thorup et al., 2007). On the contrary, floors with a very high abrasive effect can result in an excessive wear of claws (von Wachenfelt et al., 2008) or can induce pressure injuries on the sole (McKee and Dumelow, 1995).

Applegate et al. (1988) mentioned, referring to Webb and Nilsson (1983) and Baxter and Mitchell (1977), that an ideal floor should minimize animal discomfort, injury and disease and should not become deformed, deteriorate or require extraordinary maintenance. It is hypothesized that pigs modify their gait in response to changes in the floor condition (Thorup et al., 2007). Moreover, pig gait can be used as an indicator for assessing floor properties and lameness (von Wachenfelt et al., 2008). Von Wachenfelt et al. (2008) found that a body in motion can be studied by kinetic and kinematic analysis. Kinetic measurements focus on locomotor forces, while kinematic analysis studies the changes in body segment position during a specific time (von Wachenfelt et al., 2008). Kinematic studies offer a noninvasive technique since gait can be analyzed with a digital video camera without repercussions on the subject as the measurements are made based on the images. After Barrey (1999) various kinematic parameters can be obtained, such as stride length, stride speed, swing and stance phase. The respective subject can be used as an indicator for normal and abnormal gait as well as for analysis of an overloading or slipping motion (von Wachenfelt et al., 2008). In kinetic studies external forces are measured using electronic force sensors that record the ground reaction forces when the foot is in contact with the ground. The sensor can be

installed either on the ground in a force plate or in a force shoe device, attached under the hoof (e.g by horses) (Barrey, 1999).

Until now, only few studies have been conducted on pig gait (Applegate et al., 1988; Thorup et al., 2007; von Wachenfelt et al., 2010; von Wachenfelt et al., 2008; von Wachenfelt et al., 2009a; von Wachenfelt et al., 2009b). Applegate et al. (1988) and von Wachenfelt et al. (2008) investigated pig gait kinematic, whereas Thorup et al. (2007) and von Wachenfelt et al. (2009b) observed pig gait kinetic. Von Wachenfelt et al. (2009a) conducted pig gait analysis with kinetic and kinematic measurements. In all investigations pigs' gait was studied mainly on concrete floors, whereby surface characteristics were changed by fouling or wetting. From investigations about lying comfort in sows the impact of rubber mats is discussed as alternative flooring to prevent injuries from lying on hard floors as concrete or concrete slats (Boyle et al., 2000; Elmore et al., 2010; Tuyttens et al., 2008). Also design of surface profile may influence friction and abrasiveness and can prevent claw overgrowing and injuries from slipping. Until now, only one study exists about the impact of rubber mats on pigs' gait (von Wachenfelt et al., 2010). Von Wachenfelt et al. 2010 tested two floor conditions, clean and artificially fouled by pig feces for the same rubber flooring material. One result of their investigation was that pigs walked faster on clean condition than on fouled rubber mats (1.18 vs. 1.06 m/sec).

In the present study, two different slatted rubber mats with different surface profiles (rough vs. smooth) were tested in comparison to concrete slats with kinematic gait analysis with 15 sows in a repeated measurement design. It was hypothesized that sows adapt their gait in response to changes in the floor condition. It was assumed that walking speed and stride parameters will be differ for different floors, while on rough mat the highest walking speed was expected due to a high friction in comparison to concrete slats and smooth mat.

## **Material and Methods**

### ***Animals, Housing and Feeding***

The experiment was conducted at the research station of the Institute of Farm Animal Genetics Friedrich-Loeffler-Institute in Mariensee, Germany, from September to October 2012. In the mating area sows were individually housed in crates. Crates had a frame constructed of steel bars (2.10 m x 0.78 m), solid concrete flooring (0.8 m<sup>2</sup>) and cast iron slats at the rear (0.8 m<sup>2</sup>). During gestation sows were housed in a room (18.2 m x 8.8 m) with six group pens. Per pen four to five sows were housed together with a space allowance of 4.6 m<sup>2</sup> per sow. Each pen included a feeding area (ø 7.3 m<sup>2</sup>) with concrete floor (ø 4.0 m<sup>2</sup>) and cast iron

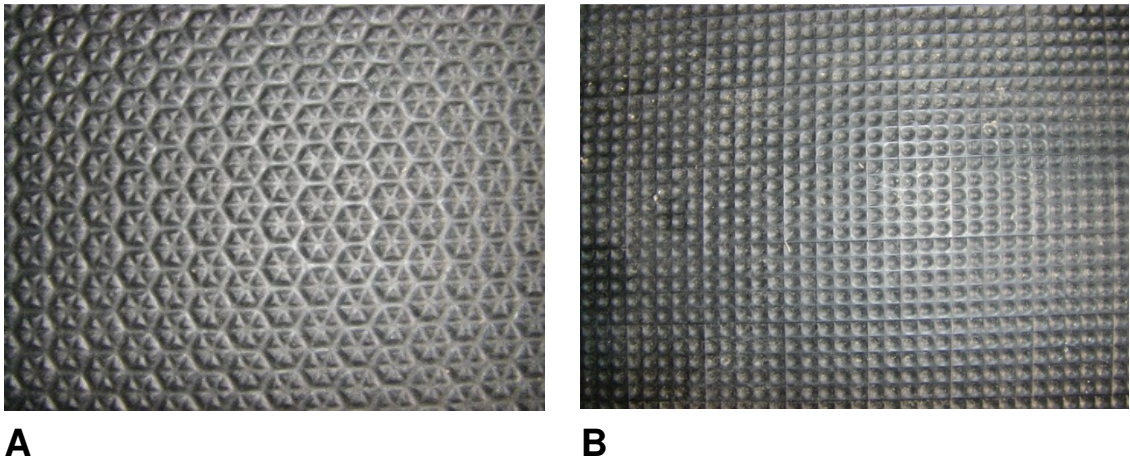
slats ( $\varnothing$  3.3 m<sup>2</sup>). Lying area ( $\varnothing$  12.5 m<sup>2</sup>) was separated from feeding area by a step and had solid concrete flooring. Farrowing accommodation consisted of four rooms with eight pens per room. Pens (2.3 m x 1.8 m) were fitted with angled farrowing crates (1.6 m x 0.6 m). Each pen was half slatted (2.2 m<sup>2</sup>) with cast iron slats at the rear. At the front pens had concrete flooring (2.0 m<sup>2</sup>). A rubber mat for the piglets (1 m<sup>2</sup>) was located on either side of the farrowing crate.

In the mating accommodation sows were fed once a day 2.6 kg dry matter (DM) a diet consisting of 154 g protein, 45 g fiber, 36 g fat and 17.0 MJ digestible energy (DE)/kg DM. During gestation sows received the same diet, whereby sows from day 84 of gestation were fed 3.2 kg DM. In addition, about 100 g straw was given to each sow once a day as manipulative substrate during pregnancy. In farrowing pens sows received a diet consisting of 206 g protein, 48 g fiber, 35 g fat and 17.0 MJ DE/kg DM. Farrowing sows were fed 3.0 kg DM twice a day. All sows had continuous access to water from a nipple drinker (Suevia, Kirchheim/Neckar, Germany) in mating and farrowing accommodation. During gestation a cup drinker (Suevia, Kirchheim/Neckar, Germany) provided *ad libitum* water.

For gait analysis a total of 15 German Landrace sows were selected from mating and gestating pens. Sows were screened visually in mating and gestation pens for body weight within a range of 100 and 300 kg and weighed immediately before gait analysis on a digital pig scale (DWI-3006I, DMS-Waagen®, Heinsberg, Germany). Furthermore sows were assessed for lameness with a technique described by Karlen et al. (2007). Front and hind limb were evaluated with a technique described by Baumann et al. (2012). Sows with scores higher than two, were excluded from gait analysis. Finally, body condition scoring (BCS) were performed according to the technique described by Charette et al. (1996).

### **Test Floors**

Test floors were concrete slats (CS) (1.4 m x 0.4 m; Thyke-Lokenberg®, Betonwerk GmbH, Neuenkirchen, Germany) and two slatted rubber mats, with different surface profiles, developed by Kraiburg®, Elastik GmbH, Tittmoning, Germany. Mat 1 (RM; 1.4 x 0.8 m), was 24 mm thick. The surface consisted of 10 mm diameter hexagons inquiries per cm<sup>2</sup> with incorporated abrasive corundum to produce a rough surface and to support claw abrasion. Mat 2 (SmM; 1.4 x 0.8 m) was 20 mm thick and consisted of a smooth surface with four 4 mm diameter circular slots per cm<sup>2</sup> (see Figure 1).

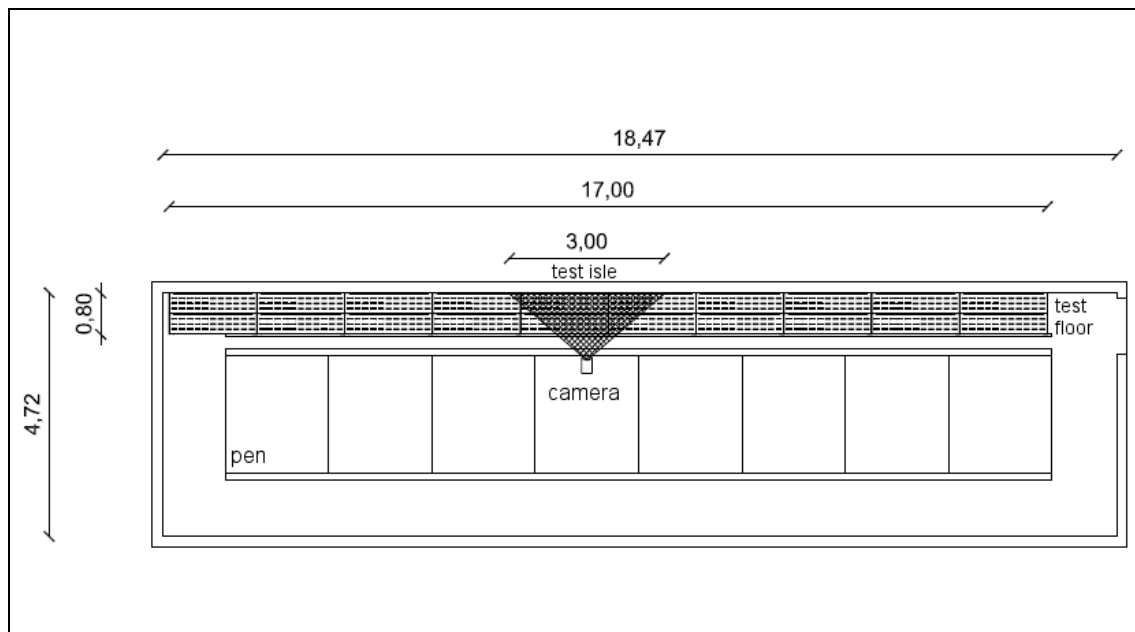


**Figure 1: Surface profile of A) rough mat (RM) and B) smooth mat (SmM)**

### ***Experimental Set-up***

Gait analysis was performed in an experimental room (18.5 x 4.7 m) with eight pens centered in the middle. Each pen (2.0 x 2.4 m) was fitted with angled farrowing crates (1.6 x 0.6 m) and half slatted (2.4 m<sup>2</sup>) with cast iron slats at the rear. Front side persisted of concrete flooring (2.4 m<sup>2</sup>). At one side wall a walkway (17 x 0.8 m) was build up for gait analysis (see Figure 2).

Walkway was covered with replaceable concrete slats. For gait analysis on rubber mats, mats were screwed on slats. Test floors were analyzed in the following order: CS, SmM, RM and CS. Floors were measured in a successive order due to time-consuming modification of experimental set-up. For experimental set-up, 4 days were needed in mean while gait analysis per floor lasted about 6 days. On a 3 m long test isle in the middle of the walkway sow's gait was recorded in front of an equidistant measuring tape by a video color camera (Santec®, VTC-E220IRP, Ahrensburg, Germany), that was installed at a perpendicular distance of 1.25 m above the walkway. Two 5 m long level staffs (Meincke Baulaser & Funktechnik®, Ludwigslust, Germany) were placed at each side of the test isle and were used for calibrating the camera. Video recording was performed with a time resolution of 20 frames per second and VGA quality with 768 x 576 pixels.



**Figure 2: Experimental room and experimental set-up for gait analysis**

### ***Data Recording***

Sows were tested in subgroups of four (except for the last group with only three sows). All sows of each subgroup were fixed in farrowing crates of the experimental room with free access to water over measurement period after morning feeding in their conventional accommodation. Gait analysis was conducted for each subgroup between 1000 and 1400 h. Sows of each subgroup were successively measured. A single sow was guided along the test walkway from the front by the experimenter with noodles with 2 m distance to prevent disturbing individually chosen speed of the sow. All sows were guided in one and the same direction. A total of five passages for each sow was conducted, whereby the last three passages were used for data analysis. A successful passage was defined as a sow's walking at a steady pace without stopping on the 3 m long test isle. After finishing the test for a subgroup, all sows were returned to their conventional accommodation.

### ***Analysis of Gait***

Video analyzing was done with VirtualDub® 1.9.11. To analyze sow's gait, the test isle was calibrated with yardsticks during data recording. Afterwards, a self-made grid, consisting of vertical lines lined up with 2.5 cm units according to the calibration of yardsticks used in the test isle, was taped on the PC screen for video analyzing. The calibration with the yardsticks on the test isle and the used self-made grid used for video analysis are shown in Figure 3.



**Figure 3: Screen print of the test isle calibrated with yardsticks with the self-made grid (blue, red and green lines) taped on the PC screen for video analysis**

Sows walking speed was calculated from nose tip to nose tip. In addition, experimenter's walking speed from food tip and food end of one and the same leg from the first and last line of the grid was calculated. Claw tip positions were used to measure stride length, stride time, swing time and stance time for fore and hind limb (see Table 1).

**Table 1: Parameters for analyzing sows gait as described in von Wachenfelt et al. (2009a)**

|               |  |
|---------------|--|
| Walking speed | Defined distance divided by time the animal covered defined distance in m/sec                          |
| Stride length | Horizontal displacement between two consecutive foot strikes of the same foot in m                     |
| Stride time   | Time interval between two consecutive foot strikes of the same foot in m/sec                           |
| Swing time    | Time the foot is not in contact with the ground (interval between toe-off and following toe-on) in sec |
| Stance time   | Time the foot is in contact with the ground (interval between toe-on and following toe-off) in sec     |

At a horizontally distance of 2.2 m sows gait could be observed exactly per video, so this distance was used for analyzing walking speed for sow and experimenter. Virtual Dub offered the possibility to show frame numbers of a video which was used for time analysis. Stride, swing and stance time was calculated by subtracting end and start frame number referring to parameter description. Due to known recording frequency of 20 frames per seconds, difference was multiplied with 0.05. Stride length was estimated with the help of the calibrated grip. Each stride parameter was analyzed for fore and hind limb for the left side of the sow's because left body side was faced to the observer on monitor. Stride parameter of fore and hind limb and for all three passages were averaged for each sow.

### ***Statistical Analysis***

Data were tested for normal distribution with PROC UNIVARIAT in SAS (Enterprise Guide, version 4.3, SAS Institute Inc., Cary, NC) with Kolmogorov-Smirnov Test. As data were normally distributed further analysis was done with PROC MIXED as repeated measurement with measurement order as fixed effect and sow number as repeated effect with compound symmetry as covariance structure. In case of statistical significances within stride parameters, inter group effects were tested with PROC TTEST. All stride parameter were analyzed separately for fore and hind limb. The variance of the mean was expressed as standard deviation (PROC TTEST) or of the least squares means with standard error (PROC MIXED).

## **Results**

### ***Animals Weight, BCS and Claw Condition***

Sows' mean weight over all measurements was 196.9 kg  $\pm$  52.7 kg. Over all measurements sow weight increased for about 13 kg. The lightest sow weighted 108.0 kg in measurement 1 and 118.0 kg in measurement 4. The heaviest sow weighted in measurement 1 (278.0 kg) and 310.0 kg in measurement 4.

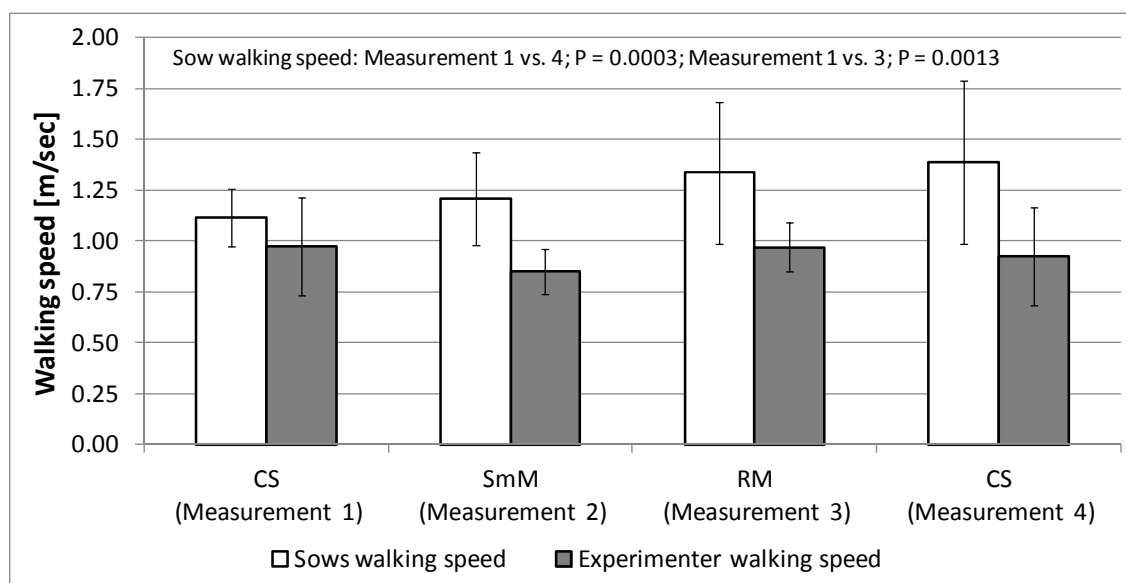
Body condition of sows over all floors was in mean at score 2.5 (1.7 %), at score 3.0 (41.7 %), at score 3.5 (36.7 %) and at score 4 (1.7 %). So the majority of the sows were in a good body condition.

Over all sow measurements counted 37.4 % lameness score 1, that was described as sow's ability to stand and move unaffected with symmetrical limb movements. 61.7 % of the sows had the lameness score 2, that indicate a moderately lameness in that sow's ability to stand was obviously reduced. The condition of claw on fore limb had to 63.3 % the score 1 and to 35.0 % the score 2. On hind limb only 58.4 % showed the score 1, but 41.7 % the score 2. Score 3 were not recorded for any sow.



### ***Sows and Experimenter Walking Speed***

Sows' walking speed increased with measurement order and was in mean  $1.27 \pm 0.28$  m/sec over all floors and was significantly affected by test repetition ( $P = 0.0049$ ). Second measurement of CS was significantly different in comparison to first measurement on CS ( $P = 0.0003$ ). Within different floor types, there was a significant difference between CS in measurement 1 and RM ( $P = 0.0013$ ). In contrary, experimenter walking speed was  $0.92 \pm 0.18$  m/sec over all floors without significant differences between floors ( $P = 0.1607$ ) (see Figure 4).

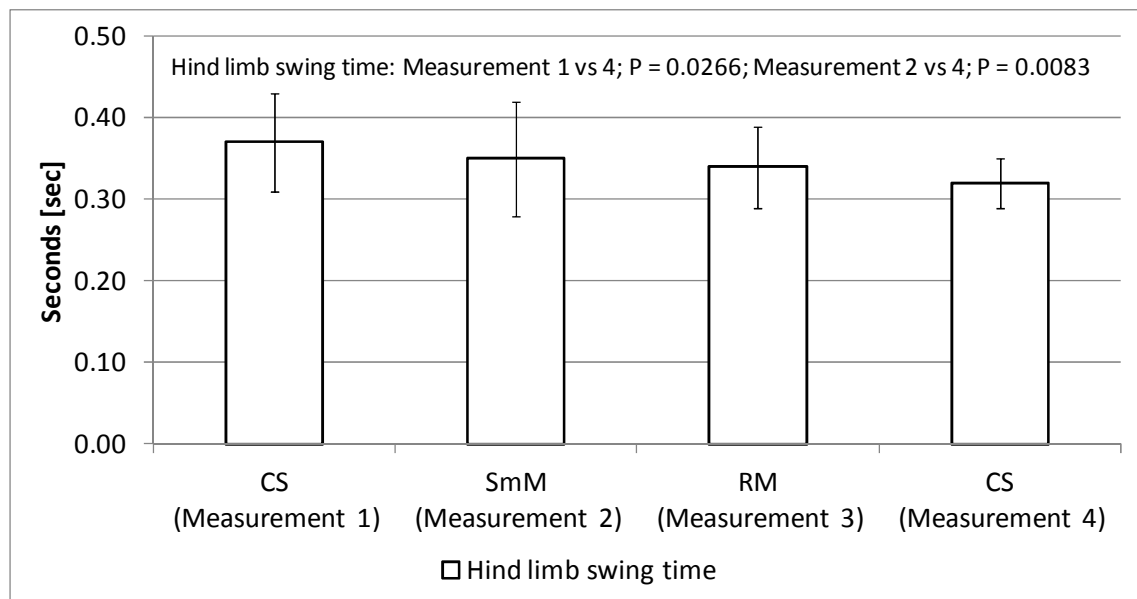


CS = Concrete slats, SmM = Smooth Mat, RM = Rough Mat

**Figure 4: Sow and experimenter walking speed over all test floors**

### ***Stride Parameters***

There were no significant differences in stride parameters in fore or hind limb between floors except for swing time on hind limb ( $P = 0.0058$ ). Swing time on hind limb was in mean  $0.35 \pm 0.05$  sec and decreased with increasing number of measurements. A significant difference ( $P = 0.0266$ ) was found between CS of measurement 1 and CS of measurement 4. Furthermore, swing time on hind limb was significant different between SmM and RM ( $P = 0.0083$ ). The significant differences within different floors are shown in Figure 5.



CS = Concrete slats, SM = Smooth Mat, RM = Rough Mat

**Figure 5: Hind limb swing time over all test floors**

The other stride parameters and their results are listed in Table 2. Stance time on fore limb was in mean over all floors  $0.63 \pm 0.14$  sec and on hind limb also  $0.63 \pm 0.13$  sec. Stride lengths on forelimb was in mean  $0.95 \pm 0.08$  sec and on hind limb stride length was  $0.94 \pm 0.08$  sec. Mean stride time on fore limb was  $0.98 \pm 0.16$  sec and on hind limb  $0.98 \pm 0.16$  sec. Swing time on fore limb was  $0.35 \pm 0.12$  sec and on hind limb  $0.35 \pm 0.05$  sec over all floors in mean.

**Table 2: Least Square Means (LSM) and Standard Error (SE) for different stride parameters on different floors**

|                   | CS<br>Measurement 1<br>(n = 15) | SmM<br>Measurement 2<br>(n = 15) | RM<br>Measurement 3<br>(n = 15) | CS<br>Measurement 4<br>(n = 15) |
|-------------------|---------------------------------|----------------------------------|---------------------------------|---------------------------------|
| <b>Fore limb</b>  |                                 |                                  |                                 |                                 |
| Stance time [sec] | $0.66 \pm 0.02$                 | $0.62 \pm 0.05$                  | $0.63 \pm 0.04$                 | $0.61 \pm 0.04$                 |
| Stride length [m] | $0.92 \pm 0.02$                 | $0.93 \pm 0.03$                  | $0.96 \pm 0.02$                 | $0.97 \pm 0.02$                 |
| Stride time [sec] | $1.00 \pm 0.04$                 | $1.00 \pm 0.03$                  | $0.97 \pm 0.05$                 | $0.93 \pm 0.05$                 |
| Swing time [sec]  | $0.34 \pm 0.01$                 | $0.38 \pm 0.03$                  | $0.34 \pm 0.01$                 | $0.32 \pm 0.01$                 |

| Hind limb         |                          |                          |                           |                           |
|-------------------|--------------------------|--------------------------|---------------------------|---------------------------|
| Stance time [sec] | 0.63 ± 0.03              | 0.64 ± 0.03              | 0.65 ± 0.04               | 0.60 ± 0.04               |
| Stride length [m] | 0.91 ± 0.02              | 0.96 ± 0.02              | 0.94 ± 0.02               | 0.96 ± 0.03               |
| Stride time [sec] | 1.00 ± 0.04              | 1.00 ± 0.04              | 0.98 ± 0.05               | 0.92 ± 0.04               |
| Swing time [sec]  | 0.37 ± 0.02 <sup>a</sup> | 0.35 ± 0.02 <sup>a</sup> | 0.34 ± 0.02 <sup>ab</sup> | 0.32 ± 0.008 <sup>b</sup> |

<sup>a-b</sup> Least Square Means within a row with different superscripts differ  $P < 0.05$

CS = Concrete slats, SmM = Smooth Mat, RM = Rough Mat

## Discussion

In the present study, walking speed differed significantly between floors but also between repetitions of CS 1 and CS 2. So, no impact of floors on walking speed could have been measured, but an effect of measurement order. Furthermore, all floors were tested in a repeated measurement design and concrete slats were measured twice, at the start and the end of the trials. Von Wachenfelt et al. (2008, 2009a, 2009b and 2010) and Thorup et al. (2007) selected pigs randomly for each trial. By von Wachenfelt et al. (2008, 2009a, 2009b and 2010) a trial consisted of 10 passes by an individual pig in each trial of floor conditions. Two replicates were conducted for each type of floor. Applegate et al. (1988) randomly had chosen order of trials, whereby eight pigs were used in repeated measurement with two replications per floor. In the present study, two alternatives for a successive testing of the different floors might be implemented. First, the order of floors could have been systematically altered for each subset of sows, i.e. 5 sows could have been tested in the order CS, SmM, RM; another 5 sows in the order SmM, RM, CS; and 5 sows in the order RM, CS, SmM. However, retrofitting of the walkway was time consuming and, thus, this option was discarded. A second option would have been to install three walkways with the three different floors in the experimental room. In such a design the sows could have been tested in a random order for the different floors. However, this would have required a much larger room. As a consequence, the design with successive testing of floors was chosen. It was not expected that the sows would habituate to the treatment over a total timespan of seven weeks and intervals of almost one week between trials. In order to test for possible habituation the floor CS was tested both at the beginning at the end of trials.

As defined at Barrey (1999), a gait can be defined as a complex and strictly coordinated rhythmic and automatic movement of the limbs and the entire body of the animal which result in the production of progressive movements. Furthermore, stride is defined as a full cycle of limb motion, whereby a complete limb cycle

includes a stance phase and a swing phase (Barrey, 1999). In this regard, walking speed is indirectly influenced by stride parameters and reverse. Due to adaption of sows on measurement condition walking speed increased in mean over all floors with measurement order independent from floor type, whereas stride and swing time decreased over all measurements for fore and hind limb.

Walking speed on concrete slats in measurement 4 was higher than in measurement 1 at the beginning of experiment. It was observed that sows adjusted on measurements condition, but not on different floors. Due to hypotheses that pigs adapt their gait to floor condition, the highest walking speed was expected for rough mat characterized by a higher friction in comparison to concrete slat and smooth mat. Von Wachenfelt et al. (2008) observed a lower walking speed (20 %), a shorter stride length (16 %) and an increased stance time (16 %) in fouled floors conditions compared with clean floor condition. Thorup et al. (2007) also measured a lower walking speed by 16 % and stride length by 7 % on a greasy concrete surface compared with a dry surface. Even fouled floors are known for its lower friction and its potential to cause slips and falls (von Wachenfelt et al., 2009a). Furthermore, in the present study brand-new floors were used and differences in friction of floor surface were too low to estimate differences in stride parameters. But Applegate et al. (1988) and von Wachenfelt et al. (2008, 2009a, 2009b and 2010) also used brand-new floors and they found significant differences in floors. Thorup et al. (2007) only mentioned the usage of solid concrete as test floor, without any declaration whether the floor was brand-new or used in stable, already. So it can be assumed that effect of fouling seem to be higher in comparison to usage of brand-new floors. For the present study, unfortunately with adaptation of sows to the measurement condition, no valid statements are possible to the impact of floor surface on pig gait.

In the present study gait analysis was conducted by one person. The experimenter tempted sows with noodles from the front through the trial for gait analysis. This was done to receive a steady speed of sows for gait analysis. Guiding from the back of the sows appeared not expedient and was characterized by many stops in front of the test area, where the video was automatically recorded. It was suggested that walking speed of experimenter might be influence walking speed of sows, but whereas walking speed of sows significantly increased with measurement, experimenter's walking speed remained constant. This strategy was new in comparison to the gait analysis made with pigs until now. Applegate et al. (1988) conducted gait analysis with three persons. One, who operated the camera, another released pigs onto test pad one at a time a third followed the pig across the

test pad. In von Wachenfelt et al. (2008) and Thorup et al. (2007) no information was found how animals were guided through test trials.

The mean walking speed over all floor types was lower in comparison to data reported von Wachenfelt et al. (2008), but higher in comparison to Thorup et al. (2007). Stride length was higher in the present study in comparison to von Wachenfelt et al. (2008) and Applegate et al. (1988). The weights of pigs used in the different studies for gait analysis ranged from 31.6-40.8 kg (Applegate et al., 1988), 72.4-75.0 kg (Thorup et al., 2007) and 113 kg in mean (von Wachenfelt et al., 2008). In the present study, sows weighted 196.9 kg in mean. Indeed, elder and taller pigs were used in comparison to other studies. The differences in stride parameters are attributed to different age groups used in the mentioned studies.

In the present study, no differences in stride parameter between fore limb and hind limb were found. Thorup et al. (2007) mentioned significant differences between fore and hind limb for swing/stance phase ratio and stance phase duration. They measured 8 % shorter stance time in hind limbs, whereas swing/stance phase ratio was 12 % lower on fore limb. Applegate et al. (1988) also reported 14 % shorter stance time in hind limbs. Von Wachenfelt et al. (2008) also reported 10 % shorter stance time for the hind limb than that of the fore limbs. Von Wachenfelt et al. (2008) mentioned, that Applegate et al. (1988) noted that stride length, walking speed, time and phase were influenced slightly and inconsistently by differences between wetted test surfaces, even though the range in surface friction was wide relative to commercial practice. Thorup et al. (2007) found that stride length was shortened and stance phase prolonged only in greasy floor conditions and not in wet. In this present study no wet floors were investigated, so this could be the reason why no differences in stride parameter between fore and hind limbs were found.

## **Conclusion**

In the present study, no valid differences between different floors in sow's gait could be measured due to habituation of sows to the treatment. This habituation was obvious although there had been intervals of almost one week between trials. For further investigation on pig gait, it is recommended using a design in which floor effects are tested in a random order or in which the order is systematically varied.

Fouling or wetting of floors could give additional information about pig's gait on brand-new floor condition as mentioned in recent studies about pig gait. Different levels of abrasiveness or friction measuring on dry floors may be too low to estimate differences of floors.

To conduct gait analysis with only one experimenter is possible without affecting walking speed of sows, when animals are tempted from the front with steady pace ( $0.92 \pm 0.18$  m/sec). Moreover, gait analysis with more than one person to minimize effort and increase animal control is recommended for further analysis.

Stride parameters as walking speed and stride length are dependent from weight and age of pigs. This coherence should be considered when results from own investigations are to be compared with other studies.

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## **5 Chapter Four**

### **Urease activity on rubber mats for sows compared to concrete and concrete slats - a pilot study**

## Abstract

Rubber mats can have positive effects on sow welfare but may negatively influence volatilization of ammonia depending on the roughness of surface profiles. In this pilot study it was tested in a laboratory trial whether artificially induced urease activity would differ on rubber mats with varying surface profiles in comparison to concrete floor. In an additional field trial done on farm in two waiting pens for gestating sows urease activity on lying areas equipped with rubber mats was compared with urease activity on concrete slats. In both trials urease activity was measured using a static chamber. In the laboratory trial, a high variation of urease activity ( $65.65 \text{ mg NH}_4^+\text{-N m}^{-2} \text{ h}^{-1}$ ; Q1:  $-72.60 \text{ mg NH}_4^+\text{-N m}^{-2} \text{ h}^{-1}$ , Q3:  $264.16 \text{ mg NH}_4^+\text{-N m}^{-2} \text{ h}^{-1}$ ) within measures of each floor was found. However, the sample sizes ( $n = 3$ ) were too small for statistical analysis. In the field trial, no significant differences in urease activity were found between rubber mats and concrete slats ( $P = 0.84$ ). Using a static chamber for measuring urease activity is a practicable method. However, due to the very high variation in the resulting data, large samples are necessary to achieve valid data. Furthermore, measuring urease activity directly in a field trial seems to result into more valid data compared to laboratory trials with artificial fouling.

Keywords: ammonia, urease activity, rubber mats, surface profile, concrete slats

## Introduction

Ammonia (NH<sub>3</sub>) is an important pollutant that plays a crucial role in the acidification and the eutrophication of ecosystems (Krupa, 2003). Besides China and the United States, the European Union is one of the largest emitters with 3.7 Tg NH<sub>3</sub> per year (European Environment Agency, 2010). Referring to the European Environment Agency (2010), pig production accounts for 25 % of the livestock emissions in Europe. The main source is ammonia releases from the stables. In stables ambient temperature and relative humidity, ventilation, seasonal variations as well as floor type influence ammonia emission (Philippe et al., 2011). Braam and Swierstra (1999) wrote that ammonia emitted from floors is produced by the breakdown of nitrogen in the urine of the animals. Thereby urine is excreted as urea and catalyzed by the enzyme urease. Urease is present in the feces and mainly formed in a persistent, solid layer on the floor surface. The rate of urea breakdown is defined as urease activity and can be indirectly measured as increased ammonium-nitrogen content of the liquid layer.

Due to Braam and Swierstra (1999) NH<sub>3</sub> production from the floor is influenced by its' roughness and porosity with lower NH<sub>3</sub> emissions from smooth surfaces. However, according to von Wachenfelt et al. (2008), low friction can cause slips and falls. On the contrary, surfaces with high roughness provide slip resistance and abrasiveness (McKee and Dumelow, 1995; von Wachenfelt et al., 2008; Webb and Nilsson, 1983), whereby over-abrasive floors cause an excessive wear of claws and too little abrasiveness leads to overgrown claws (McKee and Dumelow, 1995). Thus, floors do not only have influence on NH<sub>3</sub> emission, but also on the animal welfare.

The usually flooring systems for pigs are concrete slats with a slurry pit underneath. The slats provide a good drainage of manure through the floor and limit fouled areas which are significant sources of NH<sub>3</sub> (Svennerstedt, 1999). Rubber mats are an alternative floor for farrowing and gestating sows that contributes to an improved lying comfort and thus a higher animal welfare (Boyle et al., 2000; Elmore et al., 2010; Gravås, 1979; Tuytens et al., 2008; Zurbrigg, 2006). Besides their positive impact on the animal welfare, the influence of rubber mats on the ammonia emissions or urease activity have not been studied for pigs so far.

Due to the potential of rubber mats to influence stable climate this pilot study measured the urease activity on different surface profiles of rubber mats in comparison to concrete in (1) a laboratory trial and on a single type of rubber mat in comparison to concrete slats in (2) a field trial.

Urease activity or ammonia emission can be measured with a dynamic or static chamber. In the dynamic chamber ammonia volatilisation will be measured in channelled air as the difference of the ammonia amount of the in-going and out-going air. With the static chamber, a closed chamber is put over a defined area, wherein the increase of concentration through emitted ammonia is measured (Berg et al., 2001). Both methods have advantages and disadvantages. While the effort of using a dynamic chamber is higher than for the static chamber, the dynamic chamber can be used for continuous measurements over a certain period of time. In contrast, static chamber have a high practicability. However, the very small measurement area (< 1 m<sup>2</sup>) and the short measurement time (< 1 h) are a disadvantage and require certain frequency of measurements (Berg et al., 2001).


In this pilot study, the static chamber was chosen for measuring urease activity due to its practicability and simple application in field trials. Until now there are no data on urease activity measures in sow housing by static chambers. Thus, the results of a pilot study is used to calculate, whether the chosen sample size is large enough for a valid measurement. If the chosen sample size is not sufficient due to high variance of measures with the static chamber the obtained data can be used to calculate the required sample size and the number a repetitions necessary for further sound investigations on urease activity on different floors for sows.

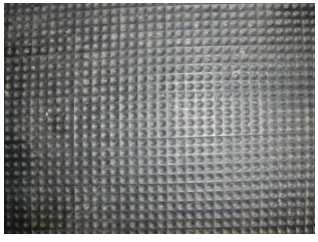

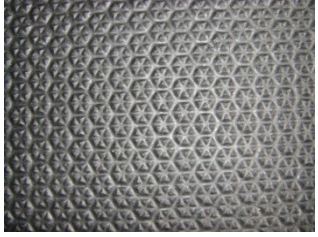
## Material and Methods

### *Laboratory Trial*

The laboratory trial was conducted in April 2013 at the research station of the Friedrich-Loeffler-Institute in Mariensee, Germany. Four rubber mats with different surfaces were analyzed in comparison to concrete. The characteristics of rubber mats' surfaces are shown in Table 1.

**Table 1: Characteristics of rubber mats' surfaces profiles**

| Surface profiles  | Description of surface profiles   |
|---|---|
|  | <p><b><i>Rubber mat 1</i></b></p> <p>Elevation: 11-16 mm edge length with 3 mm wide spaces and 1 mm depth, asymmetric order, smooth surface</p> |

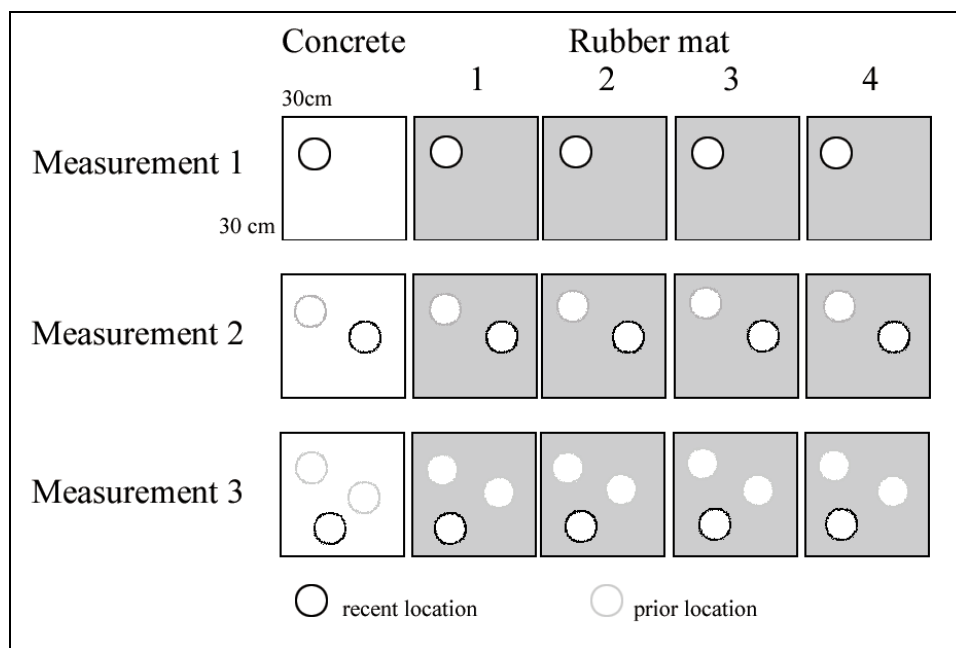
|   |  |
|---|--|
|  | <p><b>Rubber mat 2</b></p> <p>Deepening: Circles with 3 mm diameter, symmetric order, 7.5 circles per cm<sup>2</sup>, semi-rough surface</p>           |
|  | <p><b>Rubber mat 3</b></p> <p>Elevation: Quadrates with 11-12 mm edge length with 1-2 mm depth, symmetric order, semi-rough surface</p>                |
|  | <p><b>Rubber mat 4</b></p> <p>Elevations: Hexagons with radial stamping and 6 mm edge length and 1 mm depth spaces, symmetric order, rough surface</p> |

From each floor a specimen with a size of 30 x 30 cm was used and placed horizontally in a laboratory room with  $21.6 \pm 0.5$  °C and  $59.4 \pm 4.2$  % air humidity in mean. All specimens were fouled artificially according to the description of Braam and Swierstra (1999) and Leinker (2007) with pig feces and synthetic urea solution per liter distilled water (10 g urea ( $\text{CH}_4\text{NO}_2$ , 60,06 g/mol; Aqua bidest. A. Hartenstein, Würzburg, Germany).

Altogether the laboratory trail lasted for 17 days. On day 1 and 2 feces were obtained rectal from three individual sows in the morning after feeding and stored at 4 °C overnight. Samples from a day were assembled to a gross sample. On day 2, all specimens were rubbed uniformly per hand on the surfaces with 100 g feces, sampled on day 1. The 100 g feces were recommended by Braam and Swierstra (1999) as sufficient amount to cover the entire top surface of a specimen. Afterwards 100 ml of synthetic urea solution was sprayed uniformly over a fouled surface using a spray bottle with compressed air. The spraying of synthetic urea solution was repeated after 8 h. On day 3, feces that were applied the day before were removed per hand with a scraper. Afterwards all specimens were fouled again with 100 g feces, sampled on day 2, as described for day 1 and again sprayed with 100 ml synthetic urea solution. The application of synthetic urea solution was repeated again after 8 h. For the following 13 days, feces layer remained on the

surfaces, but spraying of synthetic urea solution was conducted twice a day (9:30 and 16:30 h) with 100 ml.

On day 17, the urease activity was measured. All samples were cleaned from fouling layer by hand using a scraper before the measurement. Per specimens, a total of three locations were determined and always same location per floor was measured almost simultaneously in one measurements (measurement 1 to 3) (see Figure 1).

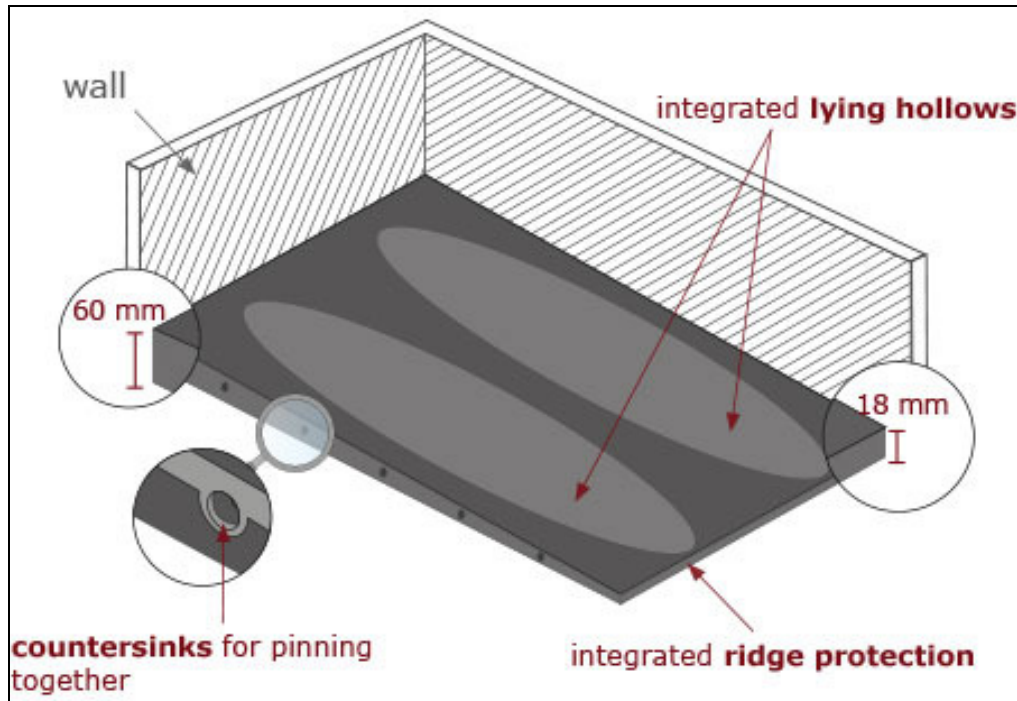


**Figure 1: Timing of measurements (schematic view)**

### ***Field Trial***

The field trial was conducted from May to July 2013 on a swine farm with piglet production in Lower Saxony, Germany. The farm included 480 productive sows (DAN; db-Viktoria) divided in stable subgroups of about 40 sows, managed in a three week rhythm. For the field trial group housed gestating sows kept in two buildings were used. The field trial was conducted in a new stable with two identically compartments (18.60 x 10.40 m) and 14 lying boxes (3.0 x 2.0 m) each, equipped with full concrete slats and a feeding station. For the field trial, lying boxes of one of the compartments were equipped with rubber mats (Porca relax S, Gummiwerk Kraiburg Elastik GmbH & Co. KG, Tittmoning, Germany, see Figure 2). Each rubber mat had a size of 110 x 185 cm.

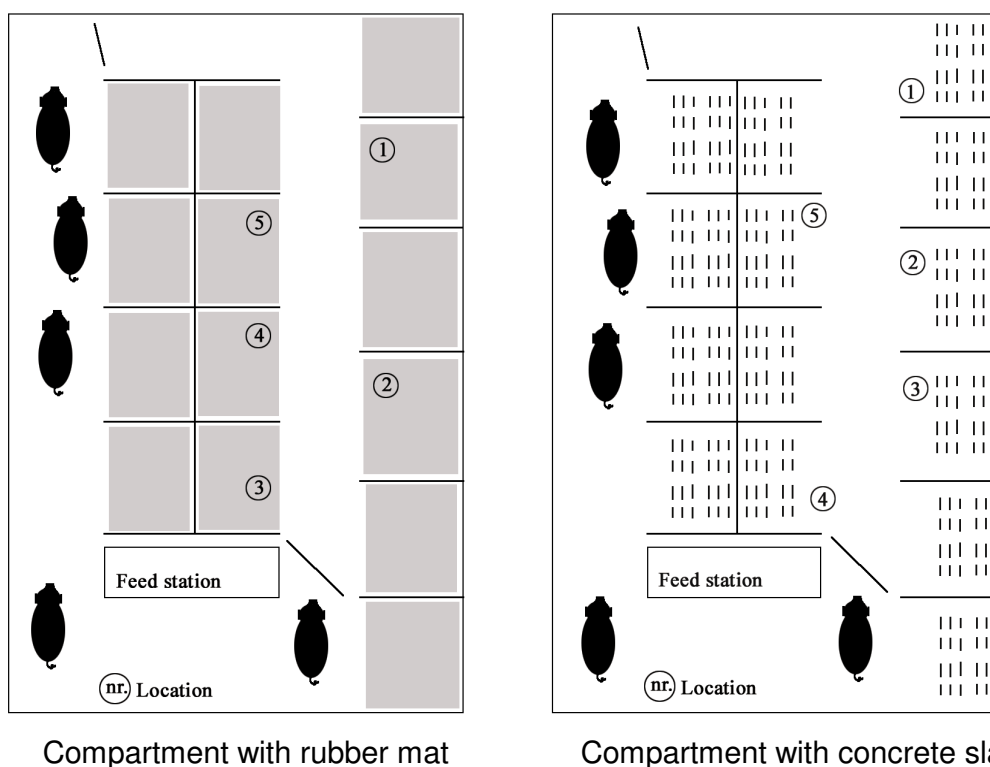
Urease activity was measured on two times. The first measurement was conducted in Mid-May and the second measurement in late July. On each measurement date five locations in the lying area were chosen in each compartment (see Figure 3), whereby the measurements on concrete slats were done on closed concrete area.



**Figure 2: Porca relax S** (© Gummiwerk Kraiburg Elastik GmbH & Co. KG)

To standardize the fouling rate of the single locations for all measurements, a piece of paper with a 10 x 10 cm cut out quadrate was placed on different locations in the lying area and compared with fouling rates as described in Schulze Westerath et al. (2006). Finally, the fouling rate 2 (25-50 % fouling) was determined as recurrent fouling rate for pigs because pigs prefer a clean and not fully fouled lying area. The uniform fouling of the lying area allowed choosing the same locations for both measurement dates.

During the measurements, the sows were kept in a separated area of the compartment for undisturbed measurements by the experimenter. At the time of measurements, the room temperature in the two compartments was in mean  $22.5 \pm 1.3$  °C for both measurement dates.



**Figure 3: Location of urease activity measurement in both compartments of field trial, concrete slats in walking area are not drawn (schematic view)**

### ***Sampling***

Both in the laboratory and field trial, urease activity was measured in a static chamber (B) with a cover (A), recreate referring on the description by Braam and Swierstra (1999). Each cylinder was encumbered with two 10 kg weight rings (C). To prevent leakage of analysis liquids, special silicon gaskets (D) were placed between floor and bottom of the cylinder (see Figure 4).

From all locations two samples, one at beginning ( $t_0$ ) and one after 30 minutes ( $t_{30}$ ) were taken by Braam and Swierstra (1999). For further analysis, all samples were frozen at  $-20\text{ }^{\circ}\text{C}$  and stored until being shipped to the analytical laboratory.

### ***Laboratory Analysis***

All samples were analyzed in the laboratory of the Livestock Systems Engineering Facility at the University Hohenheim, Germany. The analysis was done with defrosted samples and ammonium ( $\text{NH}_4^+\text{-N}$ ), as indirect criterion for urease activity. The ammonium was analyzed per liter (l) using the ammonium cuvette tests LCK nr. 303 and nr. 304 of Hach-Lange® and a photometer LASA® 10 (Fa. Hach-Lange®). Most samples were analyzed with LCK nr. 303 (range 2,0 to 47 mg  $\text{NH}_4^+\text{-N l}^{-1}$ ). In cases of expected lower ammonium concentrations, LCK nr. 304 (range 0,015 to 2,0 mg  $\text{NH}_4^+\text{-N l}^{-1}$ ) was chosen.



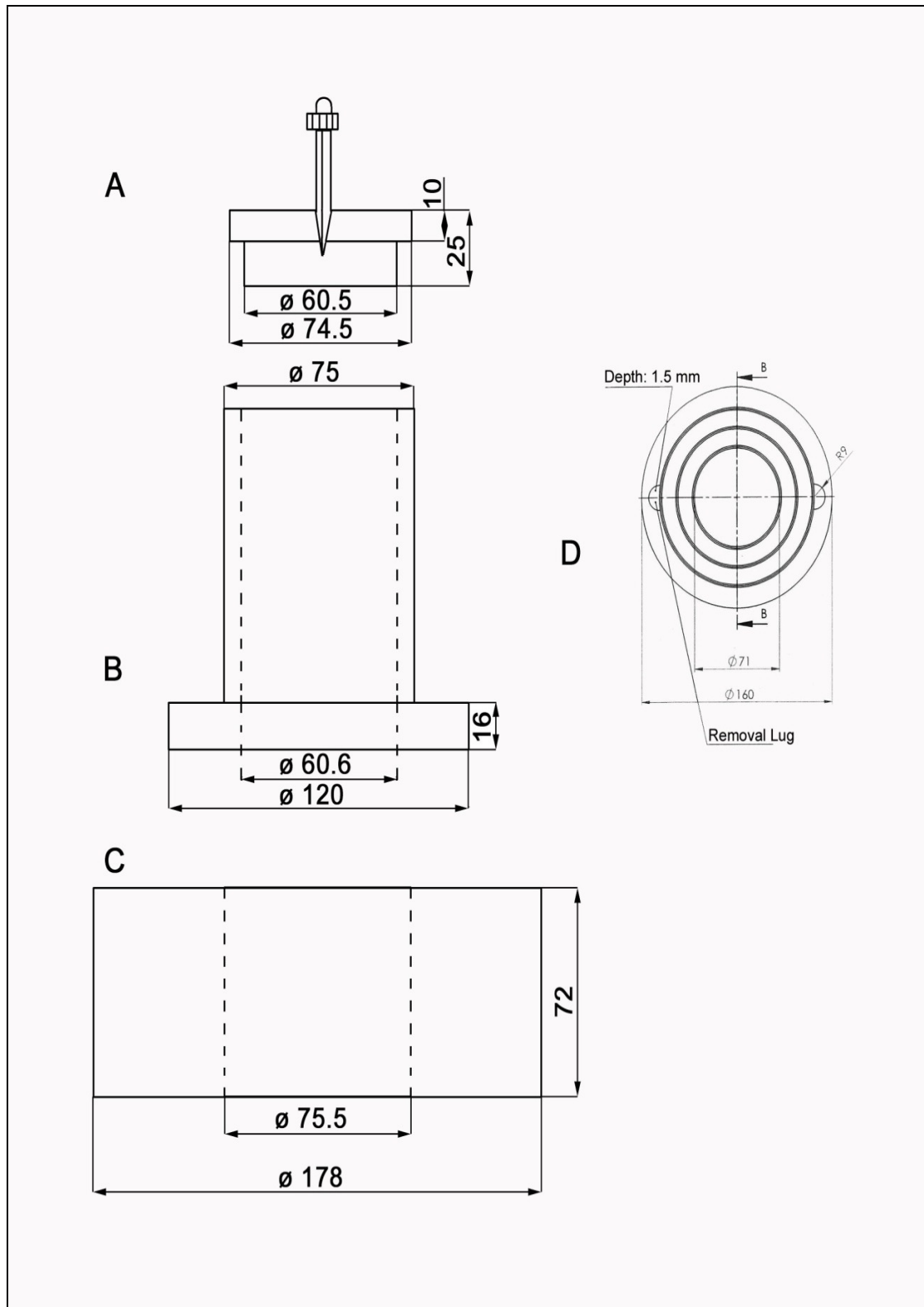


Figure 4: Cross section of the static chamber with cover (A), flange body (B), weight (C) and silicon gasket (D) (schematic view)

In the next step, the measured amount of ammonium per liter was converted to the unit of area (m<sup>2</sup>) and time (h) with the following formula according to the description by Leinker (2007).

$$\frac{1 \text{ mg NH}_4^+ - N * V * l * 2 * 10000 \text{ cm}^2}{l * 1000 \text{ ml} * h * \text{m}^2 * A} = 38,91 \text{ mg NH}_4^+ - N \text{ m}^{-2} \text{ h}^{-1},$$

whereas

V = is the operating volume of urea solution (50 ml) over 30 minutes, and

A = is the area of the silicon gasket in contrary to the bottom (28.3 cm<sup>2</sup>).

### **Calculation of Sufficient Sample Size**

The sample size was determined referring to the description of (Petrie and Watson, 2013) for comparison of two independent groups with numerical data. The usage of the Altman's nomogram (see Figure 5) for calculation of sample size requires normally distributed data. It was assumed that with increasing sample size a normal distribution may be achieved with the static chamber measurement method. Thus, data from laboratory trial may be used for calculation.

For calculation the sample size with the Altman's nomogram, the following measures should be specified:

1. The power of the test (usually this should exceed 80 %)
2. The two-side significance level (usually 0.05)
3. The biologically or clinically relevant difference ( $\delta$ )
4. The standard deviation of the observations in each group ( $\sigma$ )

The nomogram exists of two x-axis's. On the left x-axis the standardized difference is plotted from 0.0 to 1.2. The standardized difference is defined as  $\delta/\sigma$ . On the right x-axis the power of the test is plotted from 0.05 to 0.995. The number of sample size is ordered in a line, drawn in the middle of the nomogram. To determine sample size, an imaginary line from the estimated value for the standardized difference to the value of the defined test power has to be drawn. Where the imaginary line crosses the line with ordered number of sample size, the value can be assumed as correct sample size for the established test power and standardized difference.

To determine number of sample size for measuring urease activity for pigs a power test of 80 % and a significance level of 0.05 were assumed. Determination of sample size was done with the values of laboratory trial. As clinically relevant differences the mean for urease activities on all four mats and concrete were calculated and subtracted. As standard deviation of the differences the maximum standard deviation within the treatment mat and concrete slat was chosen for calculation. The amount of sample size may then divide by the amount of treatments needed for the study.

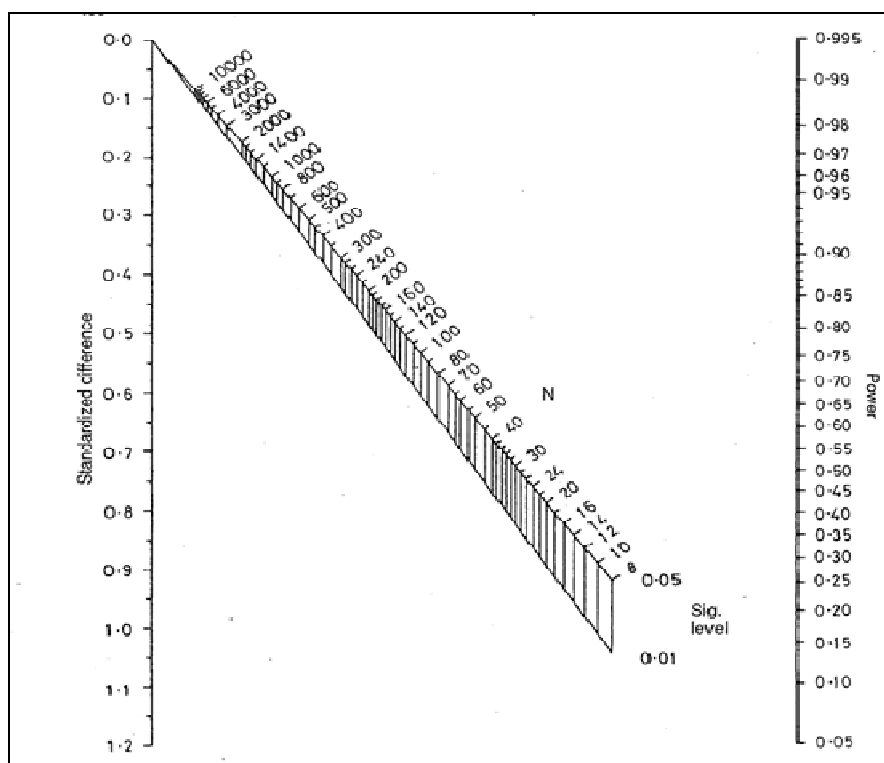


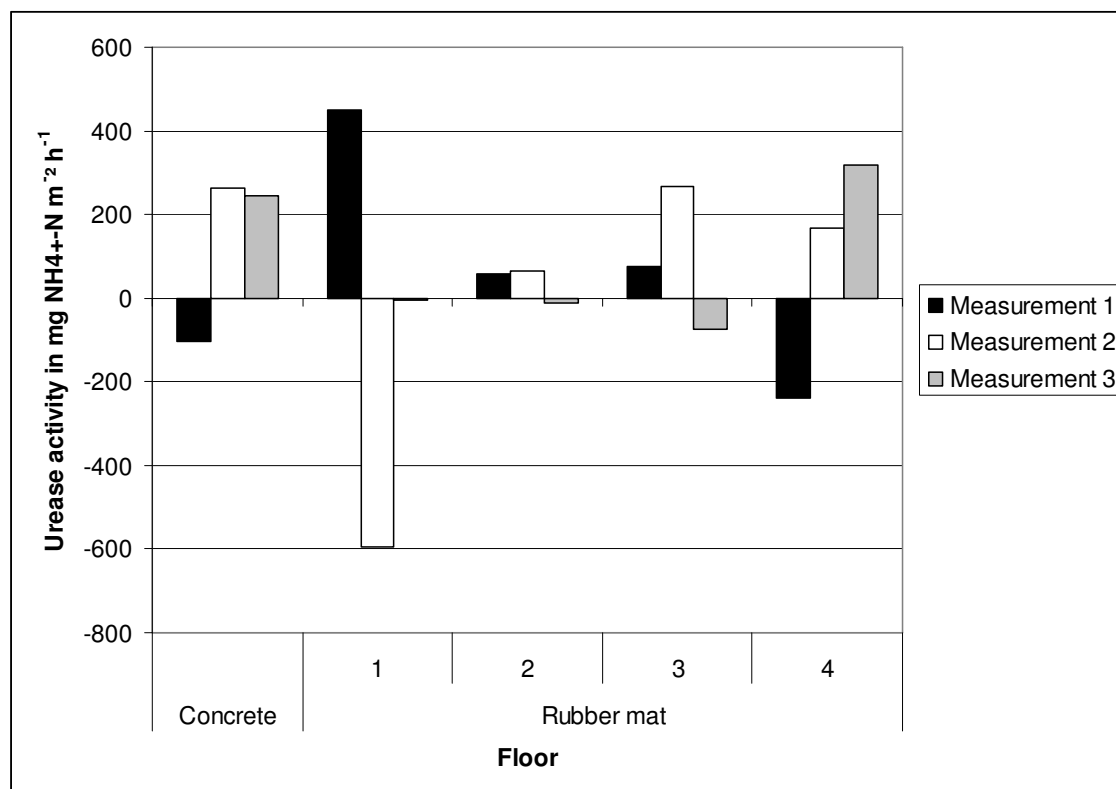
Figure 5: The Altman's nomogram for sample size determination (Petrie and Watson, 1999)

### **Statistical Analysis**

Data of laboratory trial were analyzed with Excel 2007® but not tested for differences between treatments due to insufficient number of repetitions. Samples of field trial from May and July 2013 were not separated for analysis. One sample on concrete slats was excluded from analysis due to incorrect measurement. For the statistical analysis of the samples of field trial, residuals were tested for normal distribution (Kolmogorov-Smirnov test) and as residuals were not normally distributed analyzed with non-parametric Wilcoxon test for two independent samples with PROC NPAR1WAY in SAS (Enterprise Guide, version 4.3., SAS Institute Inc., Cary, NC). The variance of the median was expressed with quartile 1 (Q1) and 3 (Q3).

## Results

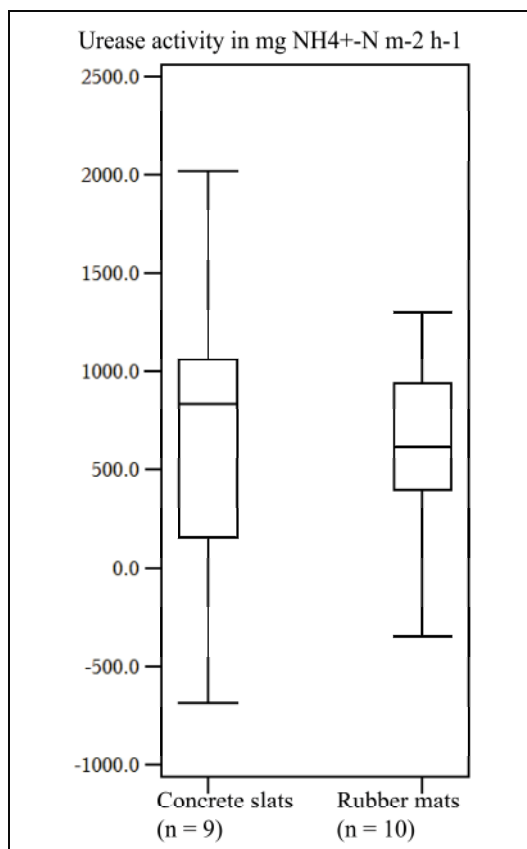
There were large differences between the values of the urease activity within the floors showing positive and negative values (see Figure 6 and 7). In laboratory trial, the urease activity showed a median of  $65.65 \text{ mg NH}_4^+\text{-N m}^{-2} \text{ h}^{-1}$  (Q1:  $-72.60 \text{ mg NH}_4^+\text{-N m}^{-2} \text{ h}^{-1}$ , Q3:  $264.16 \text{ mg NH}_4^+\text{-N m}^{-2} \text{ h}^{-1}$ ) over all floors.



**Figure 6: Urease activity for different specimens of floors in laboratory trial**

But sample size with simultaneously high variance between measurements 1-3 was too low for statistical data analysis. Thus, data were used for sample size calculation for further investigations on urease activity.

In field trial urease activity showed a median of  $657.04 \text{ mg NH}_4^+\text{-N m}^{-2} \text{ h}^{-1}$  (Q1:  $158.95 \text{ mg NH}_4^+\text{-N m}^{-2} \text{ h}^{-1}$ , Q3:  $1060.58 \text{ mg NH}_4^+\text{-N m}^{-2} \text{ h}^{-1}$ ) and, thus, was about ten-fold higher compared to the values from the laboratory trial. In field trial the urease activity did not differ between concrete slats and rubber mats ( $P = 0.84$ ) (see Figure 7).



**Figure 7: Urease activity on concrete slats and rubber mats in field trial**

### ***Required Sample Size***

The mean for all mat treatments was 39.8 mg NH<sub>4</sub><sup>+</sup>-N m<sup>-2</sup> h<sup>-1</sup> and for the concrete treatment 134.7 mg NH<sub>4</sub><sup>+</sup>-N m<sup>-2</sup> h<sup>-1</sup>. Thus, the clinical difference ( $\delta$ ) between mats and concrete slats was 94.9 mg NH<sub>4</sub><sup>+</sup>-N m<sup>-2</sup> h<sup>-1</sup> for the values of the laboratory trial. The maximum standard deviation obtained in laboratory trial was 271.6 mg NH<sub>4</sub><sup>+</sup>-N m<sup>-2</sup> h<sup>-1</sup> for the mat treatments. In comparison standard deviation for concrete was 207.1 NH<sub>4</sub><sup>+</sup>-N m<sup>-2</sup> h<sup>-1</sup>. Referring to the constant variance in both treatments, the standard deviation of the mat treatments was defined as standard deviation of the observations ( $\sigma$ ).

This resulted in a standard difference of 0.35. Assuming a test power of 80 % and a significance level of 0.05, a total of almost 240 samples is necessary to measure the urease activity (see Figure 8).

Divided into five treatments as conducted in laboratory trial, 48 samples should have been measured for analysing urease activity in each treatment.

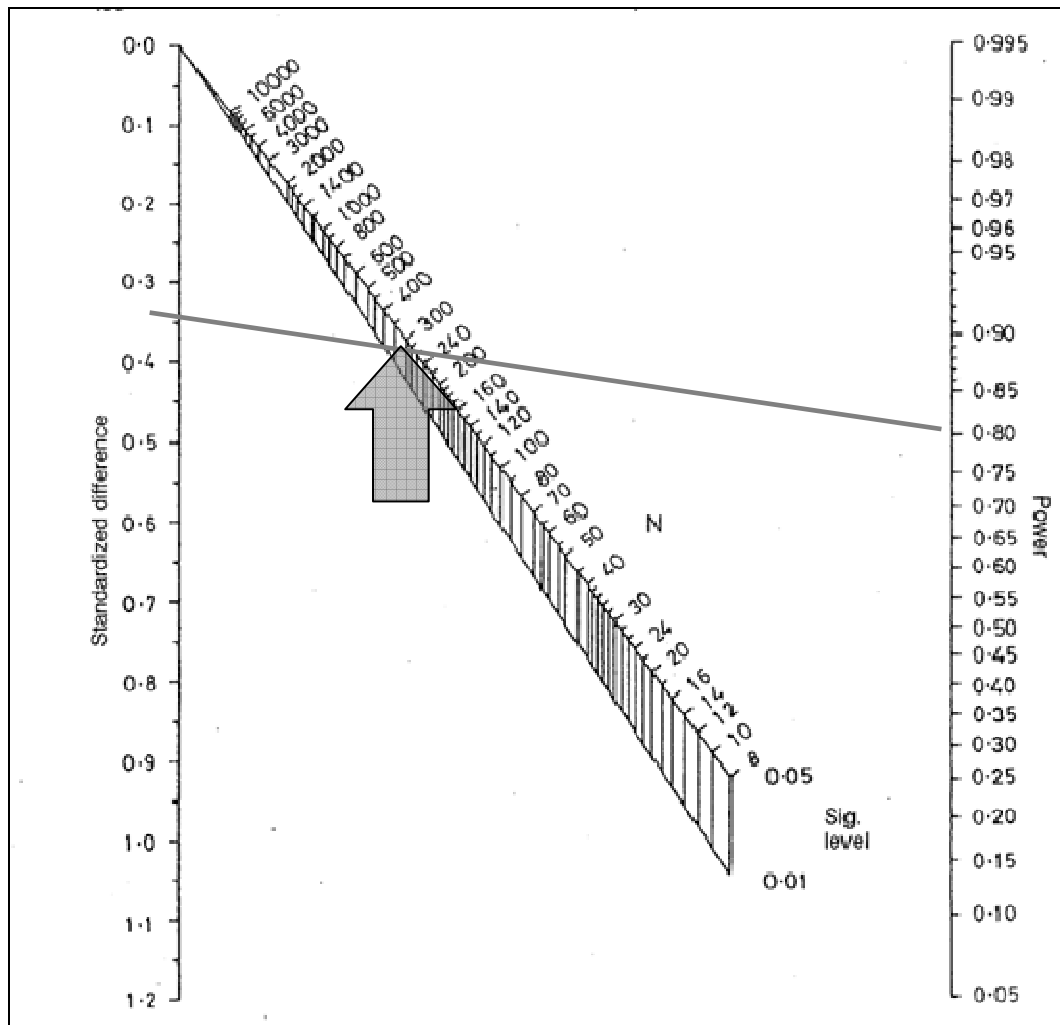


Figure 8: Calculated sample size of  $N=240$  with usage of the Altman's nomogram and specified variables for laboratory trial with a standardized difference of 0.35 and a test power of 80 %

## Discussion

In the pilot study, the measured urease activity showed a large variance because of positive and negative values. The negative urease activity was unexpected. Referring to Braam and Swierstra (1999), urease activity measured in a static chamber cannot be negative. However, Leinker (2007) also measured negative urease activity with the static chamber. He assumed that the negative urease activity values occurred due to subtraction of  $t_{30}$  versus  $t_0$  in cases where both samples had values of almost zero. In the current pilot study, negative urease activity were found in cases where the urease activity was higher at  $t_0$  in comparison to  $t_{30}$  and these values of same specimens or locations had to be subtracted for analysis. A higher amount of urease activity at  $t_0$  was not expected due to the theory that the urease activity rise with the time of measurement period.

So the negative values are caused from the measurement method and by the analysis method itself.

Due to the large variance of urease activity it was impossible to make a valid statement about the differences of urease activity on different surfaces of rubber mats in comparison to concrete in laboratory trial. Compared to this pilot study, Braam and Swierstra (1999) measured only one additional sample per specimen, but with one repetition in a laboratory trial. The urease activity they measured, (expressed as  $\text{NH}_4^+\text{-N/l}$ ) ranged from 1 to 162 mg depending from surface characteristics. Leinker (2007), who measured the urease activity on different specimens of floor types, used an irregular sample ranging from 6 to 28 samples. The measured urease activity, (expressed as  $\text{mg NH}_4^+\text{-N m}^2\text{ h}^{-1}$ ) ranged from 1 to 245 with a standard deviation ranging from 10 to 225  $\text{mg NH}_4^+\text{-N m}^2\text{ h}^{-1}$  dependent on floor type. In the present study, three locations per specimen were chosen to determine urease activity without replications in laboratory trial. In comparison to Braam and Swierstra (1999) and Leinker (2007) this sample size was too small.

Referring to the calculation of required sample size and the determined variance, a sample size of 240 samples in total should have been used for analysing urease activity on five different floor specimens. With the choice of three localisations for each specimen, 16 specimens per treatment would have been artificially fouled over a period of 16 days. Because of the limited static chambers and specimens as well as limited manpower, such a large sample size is not practicable for the experimenter. However, as Berg et al. (2001) already mentioned the high variability of urease activity was a disadvantage of the static chamber method.

On the other hand, the advantage of the static chamber is its practicability. It is mobile as well as flexible useable in different location on floors directly in stables. While Leinker (2007) mentioned practical limitations depending on characteristics of surfaces, in the present study all different surfaces profiles were measured successfully. Because of the chosen surface profiles, the chamber was in firm contact with the surfaces. However, it can be assumed that with a higher degree of surface roughness, a leakage of the synthetic urea solution from the bottom of the static chamber could be difficult to prevent independent of the weights used to cumber the chamber because of the gaps arising from surface profiles.

The urease activity measured in the laboratory trail was 10-fold lower than the urease activity measured in the field trial. Ivanova-Peneva et al. (2006) reported that gestating sows defecate up to 4.0 times and urinate up to 4.8 times per day

with a ratio of feces and urine up to 1:1.2. In the laboratory trial synthetic urea solution was sprinkled twice as much as feces in a ratio of 1:2 per each day. In addition, the feces that were applied on the surfaces on day 2 of the fouling period, remained on specimens until the measurement on day 17. Thus, an artificial fouling was produced with a higher application of synthetic urea solution compared to the application of feces.

Ketelaars and Rap (1994) wrote that urease activity is catalyzed by the enzyme urease, produced by bacteria current in the feces and on surfaces that are frequently fouled with feces. It is likely that in laboratory trial, the applied amount of feces was not high enough to produce enough urease on surfaces. Beside this, Braam et al. (1997) found that urease activity depends on the amount of enzyme urease. So it could be possible that the sprinkling of synthetic urease twice a day in a ratio of 1:2 resulted into a dilution effect of the feces. Consequently, not enough urease could have been produced for catalyzation of urease activity. To avoid a diluting effect of the feces in future research, using a sprinkling ration of 1:1 for gestating sows referring to the observation of defecation behaviour of gestating sows from Ivanova-Peneva et al. (2006) is suggested.

In laboratory trial rectal obtained fresh feces were used for fouling period. Leinker (2007) reported for cattles, that fresh feces were less-than-ideal for measuring urease activity in contrary to stored slurry. Also Braam et al. (1997) noted for diary cattle, that fresh feces and urine normally do not contain much ammonia. Any ammonia which is emitted from the floor must be produced from degradation of nitrogenous compounds by microbial enzyme activity. The minor urease activity in laboratory trial provides evidence that even fresh pig feces are not recommend for artificial fouling.

Braam and Swierstra (1999) discussed the fouling period as limiting factor for the urease activity on a floor surface. They noted that in practice floors in cattle houses are fouled for considerably longer periods than the fouling period used in their experiment. Gestating sows are housed in waiting pens for almost three months. Lying areas usually are not cleaned during this period. Thus, a regular fouling is given, that, according Braam et al. (1997) develops enzyme activity on the floor surface over a period of days or weeks with positive effects on the amount of urease activity. Furthermore in the field trial rubber mats were measured 1.5 month after installation in compartments and were used from sows immediately after installation, whereas in the laboratory trial, brand new specimens were measured. This might explain, why the urease activity observed in the laboratory trial was almost 10-fold lower than in field trial, where only fresh feces were applied on the



first two days for regular fouling. Similarly, Leinker (2007) reported a minor urease activity for brand new surfaces in comparison to floors, which are fouled over a longer period of time, which confirms the differences observed in the amount of urease activity in laboratory compared to field trial in the present pilot study.

In field trial, the measured urease activity had a median  $575.7 \pm 661.5$  mg  $\text{NH}_4^+\text{-N m}^{-2} \text{ h}^{-1}$ . Leinker (2007), who investigated urease activity of floors for cattle and finishing pigs with pre- and absence of urease inhibitors, reported an urease activity on concrete floors for finishing pigs of  $1292$   $\text{NH}_4^+\text{-N m}^{-2} \text{ h}^{-1}$  in median. The lower urease activity in the present study could be connected with the higher space allotment for gestating sows (2.05 to 2.50  $\text{m}^2$  per sow) in comparison to finishing pigs (0.5 to 1.1  $\text{m}^2$  per pig) and the minor fouling of floors due to higher space requirements. Furthermore, urease activity was only measured on lying areas in a compartment for sows in group housing and with separated areas of activity, where the sows were feasible to avoid defecating on lying areas following their natural behaviour. Instead, Leinker (2007) used the whole compartment for measurements.

In field trial no statistical difference were found between urease activities on concrete slats compared to rubber mats. In his investigation for dairy cattle, Leinker (2007) found a significant higher urease activity for rubber mats in comparison to concrete floor. Braam and Swierstra (1999) observed that a concrete slat surface texture is relatively slip resistant which assist the movement of the animals. In addition, Braam and Swierstra (1999) pointed out that a decreasing roughness of floors, reduces the urease activity. Since in field trial, no significant differences were found between the different test floors, there is evidence of too little differences of surface profiles. While in the present pilot study, no measurements were conducted to determine roughness of the test floor, this should be considered in further investigations, on order to receive more information about the correlation of urease activity and roughness of floors.

## **Conclusion**

It is recommended to investigate urease activity directly in field trials due to the potentially higher urease activity in comparison to laboratory trials. The artificial fouling of floor specimens is not recommendable due to the intensity of labour, amount of repetitions and the difficulties to reproduce fouling as to be found under practice condition. When artificial fouling is favoured to investigate urease activity on different floors, however, fouling method should be adjust to the defecating behaviour of pigs with a ratio of 1:1.

For further investigations a sample size of at least 48 samples for each treatment should have been measured for analysing urease activity in each treatment in laboratory trials with artificially fouling. Three locations per specimens could have been measured. For further investigations with the same dimensions of specimens (30 x 30 cm), 16 specimens in each treatment should be artificially fouled for obtaining sufficient sample size to determine urease activity on artificially fouled floor.

Thus, measuring urease activity with the static chamber is only valid with a large sample size. The required sample size is a disadvantage in comparison to the practicability of this measurement method and makes the method labour-intensive. Future studies that make use of the static chamber determining the urease activity should take in account the relatively high manpower and costs for analysis.

In the current study no evidence could be found that rubber mats caused a higher urease activity in comparison to concrete slat. This indicates that the application of rubber mats can be recommended without negative effects on ammonia volatilization.

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## General Discussion

In the present study the impact of different types of rubber mats for gestating sows on lying and walking comfort and their potential of ammonia volatilization on stable climate was investigated with the help of pressure measurements, gait analysis and the analysis of urease activity with a static chamber. The measures of pressure load and pressure distribution on different body parts for sows lying in sternal and half recumbent position lead to valid results. However, the measures of pressure load in half and full kneeling position, the gait analysis and the analysis of urease activity were impaired by methodological restrictions. Thus, in this chapter the impact of comfortable lying mats on animal welfare will be discussed with regard to recent demanding on animal welfare on farms. Afterwards the deficiencies of the methods will be discussed in order to give valuable information for further investigations.

### ***Implementation of comfortable lying mats for sows with regard to animal welfare***

With the present study an important first input is presented on the comfort of different types of rubber mats for lying sows. It was assumed that a minimum peak force in combination with a maximum area of pressure distribution offers maximum lying comfort for sows. This was confirmed by the results showing that the softest mat reduced the pressure load strongest when sows are lying in sternal and in half recumbent position. Thus, lying comfort was increased on softest mat with a penetration depth of 43 mm.

In recent animal welfare initiatives lying comfort is required to improve animal welfare on farms. Currently, two animal welfare initiatives exist in Germany. One is the “Deutscher Tierschutzbund e.V.” that started at the beginning of this year with a label, the so called “Welfare Label” (Deutscher Tierschutzbund e.V., 2014). In two levels of criteria, farmers are invited to improve animal welfare on their farms. Until now, there only exists criteria for fattening pigs, but improvements in husbandry concerning the lying area include the supply of a littered lying area or equivalent materials such as rubber mats in the first level or straw bedding in the premium level.

The second initiative on animal welfare that is announced to start in 2015, including industry, meat producers, farmers and food retailers committed to fair and sustainable meat production involves the agreement of compensation of costs for farmers from industry, who generate services for more animal welfare that exceed statutory requirements. In this initiative farmers are free to choose their additional

input on animal welfare (ISN, 2014). In a section B of a catalogue of criteria, farmers may choose the creation of a comfortable lying area with soft floors like rubber mats or deep litter. For the implementation of the rubber mats, farmers would receive financial support by the industry.

The definition of comfortable flooring is often related to the absence of injuries on the animal's body arising from hard flooring (Webb and Nilsson, 1983). As already mentioned, the very soft rubber mats with a penetration depth of 43 mm reduced pressure load on certain body parts as the sternum and the shoulder significantly. Whereas no information exists about injuries on the sternum caused by high pressure load from hard floors, it is known, that hard floors can induce injuries on shoulder by sows (Zurbrigg, 2006). The sternum is the bony part that bears 10-20 % of pig's total body surface, when the pig is in contact with the floor (Arey, 1993; Baxter, 1984). While the sternum bone has no considerable prominences, the shoulder blade is characterized by a tongue-shaped bony prominence, the tuber spina scapulae (Jensen, 2009). The pressure load on the shoulder was nearly twice as high as on the sternum in sternal position. It is assumed, that the high pressure load is concentrated under the small-scaled structure of the tuber spina scapulae, explaining the appearance of shoulder lesions as described for sows from Zurbrigg (2006). Thus, even soft rubber mats as used in the present study can fulfill the requirements of the two animal welfare initiatives to improve lying comfort for sows.

Although the impact of rubber mats as an alternative floor to improve lying comfort was tested in different investigations for farrowing and gestating sows (Gravås, 1979; Boyle et al., 2000; Farmer et al., 2006; Zurbrigg, 2006; Tuytens et al. 2008; de Carvalho et al., 2009; Elmore et al. 2010) there exist only few information about the successfully long-term implementation of rubber mats on farms, because most of the studies were conducted for a limited duration on research farms. Thus, aid and hints will be needed for farmers, when requirements of the animal welfare initiatives shall be successfully implemented permanent, because lying comfort is not only influenced by floor type. In a recent study on the impact of rubber mats for gestating sows in group housing from Baumann et al. (2013) sows used independent from ambient temperature rubber mats for lying. However, lying position changed with increasing temperature (> 24-28 C) with preference of lateral position (84.6 to 91.4 %). Pigs often lie in lateral position at high temperatures to lose heat over body surface, because pigs do not have sweat glands and they can receive cooling only over their body surface. In summer, when cooling is needed from pigs in conventional stables by high ambient temperature, it can be observed, that rubber mats may be also neglected from pigs for lying. The

black colored surface may be heated by sunlight falling in through windows. Thus, pigs avoid lying on rubber mats and prefer lying on concrete slats in walking areas or dung area, where they get cooling from the slurry pit underneath with hygienic disadvantage for the animal and the potential to infect with bacteria or viruses. Thus, the implementation of rubber mats has to be calibrated with the air-handling system or should be used with possibilities for cooling with limited sprinkled showers in summer.

Furthermore, the implementation of rubber mats requires a separated lying area. Without separations of lying areas by walls, e.g., pigs may not recognize rubber mats as lying area and favor rubber mats as fecal area with hygienic problems as described above. Although rooting material is required by the order on the protection of animals and the keeping of production animals (Tierschutz-Nutztierhaltungsverordnung, 2014), in conventional stalls for pigs often rooting material is missing. Especially soft floors with a high penetration depth as used in the present study offer a target for the exploration behavior of pigs with negative effects on durability of such soft floors and higher costs for the farmers, when damaged mats have to be replaced. Thus, in stables where rubber mats are applied, manipulative material should be offered in form of toys, better yet, as straw or hay in racks. The latter satisfy pigs rooting motivation and also may reduce aggressive behavior between pigs in stables, that also may be an advantage for the required group housing of gestating sows since 2013, where sows are often fed with feeding stations. Because referring to Kirchner et al. (2012) the risk of agonistic interactions is increased by electronic feeding stations as they offer a restricted animal-feeding place ratio and access to feed is not predictable, thus increasing the competition between sows.

### ***Pressure measurements for lying down comfort on different types of rubber mats***

Pressure load on all mats were significantly higher in comparison to concrete. But pressure measurements during lying down resulted in a high amount of the value 3.81 N/cm<sup>2</sup> on mats in half and full kneeling position in comparison to concrete. In contrary, the duration sows spent for lying down differed not significantly between different floors. Due to the high amount of artifacts that were measured and referring to the results for the duration sows spent for lying down, it has to be assumed that probably no differences may occur concerning pressure load on carpal joints on different mats and concrete. Thus, it has to be assumed that deficiencies of the pressure measurement during lying down lead to no valid results and the used pressure measurement system was not capable to measure pressure load exactly during lying down.

The sensor map system was installed in an experimental pen, wherein sows individual were guided for measurements. Sensor maps in experimental pen were covered with protective foils to protect the measurement system against contamination by feces and urine. Furthermore, a second layer of lorry tarp was stretched, resulting in a plane surface which prevents sows from manipulation the experimental floor with their mouth and teeth. Whereas adaptations of pressure measurement system did not influence pressure measurement with lying sows, it has to be considered that the very small contact area of the carpal joint in connection with the cushioning effect of the mats caused traction and shearing forces on measurement foils that negatively influenced pressure measurements during lying down.

The contact area of the carpal joint is in comparison to the contact area of the sternum and the shoulder smaller. A carpal joint was pictured by nine sensor points in mean, whereby each sensor had a size of 2.89 cm<sup>2</sup>. Thus, one carpal joint sized in mean 26 cm<sup>2</sup>, while a high pressure load was concentrated under the carpal joints as a small pressure center. Furthermore, the carpal joint is a very bony body part without any fat and muscle layer as well as the sternum and the shoulder. Thus, traction and shearing forces, induced by the concentrated small pressure center of the carpal joint, had a high potential to irritate each sensor and due to the low number of sensors a carpal joint covered, irritations had been measured. This hypothesis is supported by the observation that on concrete no traction or shearing forces had influenced the measurement system, due to missing artifacts on concrete in comparison to rubber mats. Furthermore, pressure load consists of static and dynamic intervals. Dynamic pressure is measured for an animal in motion, whereas static pressure is measured then the animal is not in motion. Due to the high change of movements of the sow within lying down process, a high amount of dynamic pressure was measured. Different motions during dynamic intervals of pressure load could be resulted in peak loads that influenced pressure load measurements as artifacts.

Softness of rubber mats did not influence the appearance of traction and shearing forces. The tested rubber mats differed in softness up to a penetration depth of 43 mm. Distribution of detected artifacts within different rubber mats were nearly the same for half as well as for full kneeling position. The pressure measurement system was designed predominantly for static pressure measurements on mattresses for humans. Thus, it was assumed, that the system was capable to measure floors differing in softness for sows also with a higher weight as humans. In the present study, sows were analyzed for pressure load with a body weight up to 330 kg. In comparison to an adult humans average weight sows were heavier



and the pressure measurement system was used with a permanent overload. A manual two point calibration was applied in order to adjust overload of weight on the limited range from 0 to 255 raw within pressure load could have been measured. The overload was no problem when measuring pressure load on lying sows, but it is hypothesized, that the overload resulted in higher traction and shearing forces when measuring small body parts like the carpal joint on soft floors. Even small body areas prevent pressure distribution by a small contact area and in comparison with a high weight that burdens as high force on the floor, traction and shearing forces can occur even on very soft floors. On the other hand, the amount of dynamic pressure is higher for an animal that is measured in motion in comparison to pressure measurements for lying sows. Thus, high peak loads will be measured in dynamic intervals, which exceed expected pressure loads in static intervals in half and fully kneeling position a multiple.

For further investigations the appearance of traction and shearing forces should be considered. Furthermore it was obviously that the 5400 NTL reached its limitations in measuring small areas like the carpal joints on soft floors due to its spatial resolution of 0.3 sensors per cm<sup>3</sup>. Thus, a pressure measurement hardware system with higher spatial resolution possibly would have been more adequate (e.g. 1.4 sensors per cm<sup>2</sup>; Sensor Model 3150 HL; TEKSCAN<sup>®</sup>). However, pressure sensors with a higher spatial resolution cover a much smaller area. The named pressure measurement system has a matrix wide of 43.6 cm and length of 36.7 cm. With the size of 26 cm<sup>2</sup> of one carpal joint, it would be possible to cover this area on the matrix. McGlone et al. (2004) investigated the physical size of gestating sows, while they measured depth of three different genotypes of sows up to a known body weight of 240 kg in order to estimate sow width while lying down. Due to their investigations, shoulder width amounted to 43.5 ± 0.4 cm in maximum. Thus, the matrix wide of 43.6 cm of the sensor model 3150 HL could be sufficient to record pressure load on carpal joints in half and fully kneeling positions for sows up to a body weight of 240 kg. However, the limitation of the sensor model in length could be a disadvantage, because it could be difficult to direct sows to lie down on a limited matrix area.

The advantage of the pressure measurement system, used in the present study, was the combination of the sensor maps as so called “3er mapping”. On the one hand, a total measurement area of 1.5 m<sup>2</sup> was enabled to match the space requirement for sows of different weights referring to the calculation of Petherick and Baxter (1981) cited in Ekkel et al. (2003). Thus, sows were possible to lie in different lying positions in the experimental pen. On the other hand, due to the 3er mapping, a single picture of the sow’s body could be surrendered by the recording

software and not three different pictures of a divided body had to be fit for data analysis.

Thus, the 5400 NTL pressure measurement system is recommended for pressure load analysis with lying sows or lighter pigs as piglets and fattening pigs, but it is not useful when only small body parts and/or dynamic forces shall be analyzed, due to the potential that these forces influence measuring negatively.

***Gait analysis for analyzing walking comfort of different types of rubber mats***

For gait analysis there were no significant differences in stride parameters in fore or hind limb between floors except for swing time on hind limb. But sow's walking speed increased with measurement order, affected by test repetition. Thus, it was assumed that sows adapted on measurement but not on floor conditions.

In the present study, gait analysis was performed as repeated measurement and all floors were successively tested with concrete slats being the first and the last floor. The repeated measurement on concrete slats showed that sows adapted on measurement treatment with increasing walking speed but this effect was not related with floor type. For the present study two alternatives for the order for testing the different floors might have been implemented. First, the order of floors could have been systematically altered for each subset of sows, i.e. 5 sows could have been tested in the order CS, SmM, RM; another 5 sows in the order SmM, RM, CS; and 5 sows in the order RM, CS, SmM. However, retrofitting of the walkway was time consuming and, thus, this option was discarded. A second option would have been to install three walkways with the three different floors in the experimental room. In such a design the sows could have been tested in a random order for the different floors. However, this would have required a much larger room. As a consequence, the design with successive testing of floors was chosen. It was not expected that the sows would habituate to the treatment over a total time span of seven weeks and intervals of almost one week between trials.

In order to test for possible habituation the floor CS was tested both at the beginning and the end of trials. In recent studies about kinematic gait analysis on pigs, no reference floor was measured twice and no information is given whether animals adapted to measurements condition or not (Applegate et al., 1988; Thorup et al., 2007; von Wachenfelt et al., 2008, 2009a, 2009b and 2010). But von Wachenfelt et al. (2008, 2009a, 2009b and 2010) and Thorup et al. (2007) selected pigs randomly for each trial and Applegate et al. (1988) had randomly chosen the order of trials, whereby eight pigs were used in repeated measurement with two replications per floor without mentioning an trainings effect.

Gait analysis was conducted as a kinematic analysis study in the present study. In kinematic studies the change in body segment position during a specific time is analyzed (von Wachenfelt et al., 2008). As nonvasive technique gait was analyzed with a digital video camera. Thus, gait analysis could be done without repercussions on the subject and measurements were based on the images of the recorded video. As analysis parameters diverse stride parameters were analyzed like walking speed, stride length, stride time, swing time, and stance time. Parameters were surveyed on both limbs. Advantage of the kinematic gait analysis is the minor effort for experimental set-up and data recording. Disadvantage is the time-consuming data analysis of the video recordings and the calibration of the test-isle for video analysis.

A second method to analyze pigs's gait is the kinetic gait analysis, in which the focus is on locomotor forces. For kinetic gait analysis a special pressure measurement system is required. De Carvalho et al. (2009) investigated pressure distribution of pigs' claws as indirect parameter to analyze different types of rubber mats. They used the Matscan® pressure measurement system from the Tekscan Inc. with a resolution of 1.4 sensors per cm<sup>2</sup>. The pressure mat dimensions were 435.9 mm width x 368.8 mm height, what means that pigs have to hit the matrix area for pressure analysis, exactly. De Carvalho et al. (2009) used five animals with an average weight of 170 kg. In this present study, sows were used with a weight range from 108 to 310 kg for gait analysis. Thus, a fixed sensor mat on the test aisle could probably not have been hit by all sows due to their different size and stride length. It has to be assumed, that a high replication of measurement has to be conducted, although de Carvalho et al. (2009) do not report about the problem that pigs failed to hit the sensor map.

With the 5400 NTL pressure measurement system, kinetic pressure on claws could have been analyzed but due to the low resolution of 0.3 sensors per cm<sup>2</sup> it was not capable for kinetic gait analysis. But the advantage of the 5400 NTL pressure measurement system was its area of about 1.5 m<sup>2</sup>. With the experiences made in this present study measurement systems with a continuous walking area would be preferred for further investigations. TEKSCAN® offers map systems for analyzing pressure load during walking with a walkway. A system that is presented for gait analysis for sheep and humans is the sensor map system "3150 PL". The map system is characterized by a resolution of 1.4 sensors per cm<sup>2</sup> and a walkway with 508.0 mm width and 2242.6 mm length. In the present study, kinematic gait analysis was conducted on a walkway with 0.8 m width and 2.2 m length. The dimension of the sensor map system "3150 PL" does not fit with a width of 80 cm. Thus, in further investigation it should be tested, whether the brightness of a

walkway of 50 cm is sufficient enough for gait analysis. The length of the walkway is acceptable for measurements with sows up to a weight of  $196.9 \pm 52.7$  kg as performed in this study. But it is also possible to extend measurement system to 2678.4 mm length with the map system "3150 HL". Although, map system is not explicit recommended for pigs, for further investigations on pressure load during gait this system would be chosen due to the combination of an already tested resolution from de Carvalho et al. (2009) and the length of the walkway, where sows of different weights can walk on. Advantage of the kinetic analysis is, that with the measurement system an automatically analysis software is presented and pressure load can be used as indicator for the adaptations of sows on different floors. On the other hand, experimental set-up may be very time-consuming and labor-intensive.

Rubber mats used for gait analysis in the present study differed in surface profile but not in softness. With respect to the penetration depth the mats were comparable with the hard rubber mat (24 mm thickness) used in the pressure measurements for lying sows and during lying down. A smooth and a rough surface were chosen for gait analysis, because it was hypothesized that abrasiveness is the factor that influence sow's gait. According to Webb and Nilsson (1983) abrasion is a necessary prerequisite for foot health. Under worn as well as over worn hooves can be a serious problem. They wrote further on, that a floor designer's job is to find a floor with an acceptable level of abrasion and friction (Webb and Nilsson, 1983). It has to be assumed, that more factors than only abrasiveness should be considered for gait analysis as conducted in the present study. Because it does not seem to be the main factor that influence pig's gait.

In the present study all floors were dry and easy to walk on. With regard to the investigation made with pigs before test floors were mostly wetted or fouled to generate slippery conditions (Applegate et al., 1988; Thorup et al., 2007; von Wachenfelt et al., 2010). In these investigations significant differences have been established between different floor conditions. With regard to the remarks of Webb and Nilsson (1983) and regardless of study design, the analyzing of slippery conditions of tested floors should be considered in further investigation, when comfortable floors shall be established.

As already mentioned, floors used in the present study for gait analysis did not differ in softness. But it is known that pigs used to walk as cows on soft floors. The claw of the pigs is anatomically comparable with the claw of cows (Dyce et al., 1991). The anatomic structure of the dew claws is equivalent to the main claws. Dew claws do not touch the ground on hard floors and support the sinking main

claws on soft floors (Nickel et al., 1984). Baumann and Pflanz (2014) investigated walking preference of gestating sows in group housing, while they fitted different paths of rubber mats in the walking area equipped with concrete slats. Sows preferred significantly rubber mats path versus concrete slats, regardless the disposal of the rubber mats paths in the walking area (Baumann and Pflanz, 2014). So this is a hint that soft floors may be preferred by sows for walking and should also be considered in further investigation on comfortable walking floors.

### ***Impact of rubber mats on ammonia volatilization in comparison to concrete and concrete slats***

In the present study volatilization of ammonia on different rubber mats was measured indirect by the detection of the urease activity on defined fouled floors in two trials, a laboratory and a field trial, by use of a static chamber measuring system. In the laboratory trial, no differences of urease activity were established on different surface profiles of rubber mats in comparison to concrete due to insufficient sample size. In field trial, no significant differences were found on urease activity on rubber mats in comparison to concrete slats.

With the static chamber a measurement system is available that is characterized by its practicability and simple application in field trials, as reported from Berg et al. (2001). In comparison to the dynamic chamber, an alternative method to measure urease activity, where channelled air as the difference of the ammonia amount of the in-going and out-going air will be measured, with the static chamber a closed chamber is put over a defined area, wherein the increase of concentration through emitted ammonia is measured. But the very small measurement area (<1 m<sup>2</sup>) and the short measurement time (<1 h) are a disadvantage and require certain frequency of measurement (Berg et al., 2001).

As reported from Braam and Swiertra (1999), ammonia emitted from floors is produced by the breakdown of nitrogen in the urine of the animals. Thereby urine is excreted as urea and catalyzed by the enzyme urease. Urease is present in the feces and mainly formed in a persistent, solid layer on the floor surface. Thus, for measuring urease activity a certain and defined fouling of floors has to be ensured.

In the present study two different types of fouling were chosen for measuring urease activity on rubber mats. In laboratory trial artificially fouling was induced after the description of Braam and Swierstra (1999), whereas in field trial no artificially fouling was conducted. Furthermore, in laboratory trial four different types of surfaces with different roughness of rubber mats were compared with a concrete specimen. In field trial, one type of rubber mat was compared with concrete slats.

Due to the little knowledge about measuring ammonia volatilization on different floors for pigs, the results of the present study were used for calculation sample size and evaluation of the usage of the static chamber as measurement method.

In laboratory trial, no valid statements could have made about urease activity. It is hypothesized that sample size was too low and/or artificial fouling could not generate fouling condition as usual under field trial condition. For laboratory trial, three locations per specimen were chosen to determine urease activity without replications. In comparison to Braam and Swierstra (1999) and Leinker (2007) this sample size was too small. Thus, the high variability of the static chamber method, as reported from Berg et al. (2001) as disadvantage, can only handled by sample size higher than in the present study. Referring to the calculation of required sample, a sample size of 240 samples in total should have been used for analysing urease activity on five different floor specimens. With the choice of three localisations for each specimen, 16 specimens per treatment would have been artificially fouled over a period of 16 days.

The urease activity measured in the laboratory trail was 10-fold lower than the urease activity measured in the field trial. Ivanova-Peneva et al. (2006) reported that gestating sows defecate up to 4.0 times and urinate up to 4.8 times per day with a ratio of feces and urine up to 1:1.2. As already mentioned in chapter 4, it is likely that in laboratory trial, the applied amount of feces was not high enough to produce enough urease on surfaces. Beside this, Braam et al. (1997) found that urease activity depends on the amount of enzyme urease. So it could be possible that the sprinkling of synthetic urease twice a day in a ratio of 1:2 resulted into a dilution effect of the feces. Consequently, not enough urease could have been produced for catalyzation of urease activity. To avoid a diluting effect of the feces in future research, using a sprinkling ration of 1:1 for gestating sows referring to the observation of defecation behaviour of gestating sows from Ivanova-Peneva et al. (2006) is suggested. Furthermore, the fouling duration of 16 days might be too short in the laboratory trial. Braam and Swierstra (1999) discussed the fouling period as limiting factor for the urease activity on a floor surface. Braam et al. (1997) also mentioned that a regular fouling develops enzyme activity on the floor surface over a period of days or weeks would have positive effects on the amount of urease activity.

In their investigation on volatilization of ammonia from diary housing floors with different surface characteristics, Braam and Swierstra (1999) reported an increase of urease activity with increase of the surface roughness. Although they determined urease activity on different specimens of concrete with different finishing, it is

hypothesized that their result may be applied for different surface or rubber mats. But due to low sample size, high variability of the static chamber and the insufficient artificial fouling in the laboratory trial, this hypothesis could not sufficiently be tested.

In field trial no significant differences in urease activity were found between rubber mats and concrete slats. The rubber mat in the field trial had the same smooth surface profile like rubber mat 2 used in laboratory trial, but with integrated slope and lying hollows. The thickness of mats ranged from 18 to 60 mm. It is known that slopes promote drainage of urine in lying boxes, for example. Drainage reduces ammonia emissions from floors because ammonia is formed by the breakdown of nitrogen in the urine of the animals, excreted as urea (Braam and Swierstra, 1999). The urease activity on the rubber mat did not differ from urease activity on concrete slats. Thus a closed rubber mat with slope was able to produce the same ammonia emission from floor as well as concrete slats. The comfort of the lying hollows should be tested in further investigations.

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## General Conclusions

With the present study, rubber mats with a penetration depth of 43 mm are recommended to reduce pressure load under shoulder in half recumbancy and under sternum in sternal lying position. The penetration depth of the very soft rubber mat was 10-fold higher in comparison to hard mat as already used for implantation on farms. Due to the high penetration depth of the very soft rubber mat and the distinct oral exploration behavior of sows, the durability of such very soft mats should be tested in field trials in further investigations.

Due to the recent proceedings on animal welfare from different initiatives in Germany and the possible advantages of rubber mats to improve sow's welfare in innovate husbandry systems, the development of comfort rubber mats should be pursued and the conditions for their successful implementation on farms investigated, particularly.

Pressure measurements with the TEKSCAN 5400 NTL sensor map system were possible for lying sows within a range of body weight from 90 to 330 kg. For further investigations, however, a pressure measurement system over a maximum of 255 raw data will be recommended to minimize overload when measuring heavy sows up to 330 kg body weight. Furthermore, it is conceivable to calibrate sensor foils separately for different weight classes, when sows shall be measured in a wide range of weights as in the present study. In contrary, only sows with nearly same weights can be measured to minimize effort of calibration. Furthermore, it should be calculated once to which amount dynamic pressure arises, in comparison to static pressure, when pressure load will be measured within motions of animals.

The pressure measurement system cannot be recommended when small body parts like carpal joints or claws will be measured for sows because of its relative low resolution of 0.3 sensing points per cm<sup>2</sup>. Here, a sensor map system with a resolution of 1.4 sensing points per cm<sup>2</sup> should be used with a pressure range as recommended above. Furthermore, shearing and traction forces have to be considered when measuring small body parts on soft floors up to a penetration depth of 43 mm. The shearing and traction forces may increase the risk of measuring artifacts as reported in this study.

Moreover, for kinetic gait analysis sensor map systems with a walkway should be used. In the present study a walkway for kinematic gait analysis of 2.2 m length x 0.8 m wide was evident for analyzing gait per video, that's why this

dimension can be recommended for further investigations on kinetic and kinematic gait analysis.

In study designs on gait analysis with repeated measurements, habituation of sows on measurement condition should be considered, even if measurements last over a total time span of seven weeks with intervals of almost one week between trials. To control for habituation effects, reference floor should be measured at the beginning and the end.

For developing comfortable floors for walking sows, not only dry and clean conditions, but also wet and soiled conditions should be tested for gait analysis. Even the quality of floors to compensate slippery conditions on floor surfaces due to moisture and fouling is an important requirement for floors to improve animal welfare, because slippery is a main reason for injuries and lameness in sows.

Measuring urease activity with the static chamber was practically, but results showed a high variance. In laboratory trial sample size of three measurements for each treatment was too low. Regarding the high variance of data a total sample size of 240 samples would be necessary to estimate the amount of urease activity on five different floors, whereby 16 specimens would be needed for each treatment for artificially fouling, when three locations would be used for measuring urease activity on each specimen. The high amount of required sample size drastically would increase labor-intensity of the usage of the static chamber in combination with artificially fouling. That has to be considered in further investigations.

In laboratory trial the artificial fouling for 16 days in combination with the 1:2 ratio between feces and urine as used in the present study did result in a much lower urease activity compared to the values measured in field trial. For further investigation artificial fouling should be conducted with a ratio of 1:1.2 of feces and urine according to the defecating behavior of sows under field condition, whereby it is recommended to use a fouling period with more than 16 days to raise time for cultivation of microorganism, which produce urease. On the other hand, due to the deficiency to receive standardized condition in laboratory trials, it is suggested to measure urease activity in field trial, directly.

Urease activity on rubber mats in field trial did not differ significantly in comparison to concrete slats. A rubber mat with a slope and integrated lying hollows as used for measurement on urease activity on field trial could be used on farms to improve animal welfare as well, without increasing ammonia volatilization in stables. But evidence for an improved lying comfort by pressure measurement is still missing. Due to the uneven surface of the rubber mat by integrated lying hollows,

measurement with sensor foils may be difficult due to the possible appearance of shearing and tractions forces on the edge and inside of the lying hollows. Thus, assessment of acceptance and lying comfort might be conducted as choice test with gestating sows.

## Summary

Floors positively influence sows' welfare while they promote lying or walking comfort or negatively, while they cause injuries on body and locomotor system due to deficient design. The main factors to be considered for floor design are softness, abrasiveness and slippery. Whereas all named factors influence each other, floors do not only influence sows' welfare, they also influence ammonia emissions through rough surface profiles. Rubber mats are recommended as alternative to straw bedding and investigated for gestating and farrowing sows. Investigations almost confined on lying behavior or injuries, whereas detailed information about the softness of applied rubber mats is still missing. In the present study information for the design of rubber mats for comfortable lying and walking was collected. Furthermore the impact of surface profiles of rubber mats on the ammonia volatilization in stables for sows was analyzed.

The lying comfort of different types of rubber mats were tested with a pressure measurement system (5400 NTL; Tekscan Inc., Boston, MA). There for, a total of 68 sows (German Landrace x German Landrace) with a body weight between 90 and 330 kg were used in order to measure peak force (PF) and contact area (CA) under different body parts during lying in sternal and half recumbent position. Tested rubber mats differed in degree of softness and penetration depth (hard mat [HM]: 4.0 mm, soft mat [SM]: 14.6 mm, very soft mat [VSM]: 43 mm). As reference floor concrete (C) were used. It was hypothesized that a minimum peak force in combination with a maximum area of pressure distribution offers maximum lying comfort. Body parts with the highest pressure load in median were sternum (1.62 N/cm<sup>2</sup>, Q1: 1.17 N/cm<sup>2</sup>, Q3: 2.10 N/cm<sup>2</sup>) in sternal and shoulder (2.72 N/cm<sup>2</sup>, Q1: 2.09 N/cm<sup>2</sup>, Q3: 3.81 N/cm<sup>2</sup>) in half recumbent position. PF was affected by floor type on sternum ( $P = 0.0132$ ) and on shoulder ( $P = 0.0388$ ). Weight class affected pressure load on sternum significantly ( $P = 0.0012$ ), but not on shoulder. CA was different between floors ( $P = 0.0301$ ) and weight class ( $P < 0.0001$ ) with interaction between floor type and weight class ( $P = 0.0002$ ) under the sternum. CA under the shoulder was only affected by weight class ( $P = 0.0097$ ). PF under the shoulder was higher on C ( $P = 0.0128$ ) and HM ( $P = 0.0113$ ) in comparison to VSM but did not differ for SM. Under the sternum PF was lower on VSM ( $P = 0.0012$ ) in comparison to C, but did not differ between other floors. To reduce pressure load under shoulder in half recumbancy and under sternum in sternal lying position, rubber mats with a penetration depth of 43 mm are recommended. In recent animal welfare initiatives lying comfort is required to improve animal welfare. Very soft mats may contribute lying comfort for gestating sows on farms. For a successful implementation of very soft rubber mats long-term field trials should be conducted

on different farms concerning durability of mats with a penetration depth of 43 mm and acceptance by sows.

In a second investigation pressure load was analyzed during lying down in half and full kneeling position on the same floors and with the same sows as mentioned above. Duration of time sows spent in half and full kneeling position on different floors were determined, additionally during pressure measurements. Pressure load in half and full kneeling position during lying down was affected by floor type ( $P = 0.0020$ ) and was on all mats significantly higher in comparison to C. The subsequent analysis of the data of pressure load showed a high amount of the value of  $3.81 \text{ N/cm}^2$  at all floors in half and full kneeling position. It was assumed, that it was a measured artifact. The duration of time sows spent in half ( $P = 0.0940$ ) and full kneeling position ( $P = 0.6774$ ) did not differ between floors. Whereas pressure measurement system was recommended for lying sows, the TEKSCAN 5400 NTL was not capable to measure pressure load on small body areas like carpal joints with sows in motion. It is recommended to use pressure measurement system with a resolution of 1.4 sensing points per  $\text{cm}^2$  and to regard the appearance of shearing and traction forces during measurements on soft floors as well as disturbances of dynamic pressure intervals for pressure measurements with sows in motion.

Comfort of walking mats was tested within kinematic gait analysis. There for, a total of 15 sows (German Landrace x German Landrace) with a body weight in mean of  $196 \pm 52.7 \text{ kg}$  were used in repeated measurement. Gait analysis was performed on 3 m long test section in the middle of a 17 m long trail. As test floor two different rubber mats were used with different surface profiles (rough vs. smooth). Both mats were tested in comparison to concrete slats. All floors were tested successive, while gait of sows on concrete slats were measured repeatedly at the end. Different stride parameters were reordered per video and analyzed separately for fore and hind limb. The hypothesis was that pigs would adapt their gait on different floor condition. In gait analysis, sow's walking speed increased with measurement order independent from floor type and was in mean  $1.27 \pm 0.28 \text{ m/sec}$  over all floors. Walking speed differed significantly between floors/test repetitions ( $P = 0.0049$ ). For stride parameters no significance difference were estimate except for swing time on hind limb ( $P = 0.0266$ ). Due to the adaptation on measurement condition in gait analysis, no valid statement was possible to the influence of smooth and rough surface on pig's gait. Thus, in study designs on gait analysis with repeated measurements, habituation of sows on measurement should be considered. Furthermore, for developing comfortable floors for walking sows, not only dry and clean conditions, but also wet and soiled conditions should be tested for gait

analysis. In contrary to kinematic gait analysis, kinetic gait analysis with pressure measurement systems with a resolution of 1.4 sensing points per cm<sup>2</sup> and a walkway, covered with sensor foils, of 2.2 m length could be considered for further investigations.

The potential of ammonia released was tested as urease activity on different floor surfaces in a laboratory and a field trial as urease activity with a static chamber as standard measurement method. In laboratory trial four different rubber mat surfaces profiles were analyzed in comparison to concrete as reference after artificial fouling with pig feces and synthetic urea solution after 16 days. It was hypothesized that urease activity would be lower on rubber mats with smooth surface profile compared to rough surface profiles. Urease activity in laboratory trial did not differ between different surface profiles. Over all floors the urease activity showed a median of 65.65 mg NH<sub>4</sub><sup>+</sup>-N m<sup>-2</sup> h<sup>-1</sup> (Q1: -72.60 mg NH<sub>4</sub><sup>+</sup>-N m<sup>-2</sup> h<sup>-1</sup>, Q3: 264.16 mg NH<sub>4</sub><sup>+</sup>-N m<sup>-2</sup> h<sup>-1</sup>). A high variance was measured between different measurements due to positive and negative values of urease activity assessed with the static chamber measurement method. Impact of surface profile on urease activity could not be estimate in laboratory trial due to high variance and the low sample size. A total of 240 samples would be necessary to estimate the amount of urease activity on five different floors, whereby 16 specimens would be needed for each treatment for artificially fouling, when three locations would be used for measuring urease activity on each specimen. Due to the labor-intensitiy of the usage of the static chamber and the artificially fouling, urease activity should be measured in field trials, directly. In field trial one type of rubber mat with a slope and integrated lying hollows was tested for urease activity in comparison to concrete slats on a pig farm. Further on it was suspected that urease activity would be lower on rubber mats compared to concrete slats. In field trial urease activity was about ten-fold higher compared to values from the laboratory trial and did not differ significantly between concrete slats and rubber mats with a slope and integrated lying hollows ( $P = 0.84$ ). Rubber mats with a slope and integrated lying hollows could be used on farms to improve animal welfare, without increasing ammonia volatilization in stables. In further investigations lying comfort of these mats should be determined with pressure measurements or as choice test with gestating sows.



## Zusammenfassung

Böden beeinflussen das Wohlbefinden von Sauen positiv, indem sie Liege- und Laufkomfort bieten oder negativ, wenn sie Verletzungen am Körper oder Bewegungsapparat aufgrund von unzureichender Ausgestaltung verursachen. Hauptkriterien, die für die Ausgestaltung von Böden berücksichtigt werden sollten, sind die Weichheit, Abrasivität und Trittsicherheit. Trotzdem alle Faktoren einander beeinflussen, besitzen Böden nicht nur einen Einfluss auf das Wohlbefinden von Sauen, sondern beeinflussen auch die Ammoniakfreisetzung durch raue Oberflächenprofile. Gummimatten bieten sich dabei als Alternative zu Stroheinstreu an und wurden bislang vor allem für tragende und ferkelführende Sauen untersucht. Die Untersuchungen beschränkten sich dabei vorwiegend auf Liegeverhalten oder Verletzungserscheinungen, wobei detaillierte Informationen über die Weichheit der verwendeten Gummimatten fehlten. In der vorliegenden Untersuchung wurden Informationen für die Gestaltung von komfortablen Gummimatten für den Liege- und Laufbereich gesammelt. Weiterhin wurde der Einfluss von Oberflächenprofilen von Gummimatten auf die Ammoniakfreisetzung in Ställen für Sauen analysiert.

Der Liegekomfort verschiedener Typen von Gummimatten wurde mit einem Druckmesssystem (5400 NTL; Tekscan Inc., Boston, MA) getestet. Dafür wurden insgesamt 68 Sauen (Deutsche Landrasse x Deutsche Landrasse) mit einem Körpergewicht zwischen 90 und 330 kg verwendet, um den Maximaldruck (PF) und die Druckverteilung (CA) unter verschiedenen Körperteilen in Bauch- und Halbseitenlage zu messen. Die getesteten Gummimatten unterschieden sich in ihrem Grad der Weichheit und Eindringtiefe (harte Matte [HM]: 4.0 mm, weiche Matte [SM]: 14.6 mm, sehr weiche Matte [VSM]: 43 mm). Als Referenz wurde Betonboden [C] verwendet. Es wurde angenommen, dass ein geringer Maximaldruck in Kombination mit einer maximalen Fläche an Druckverteilung Liegekomfort bietet. Die Körperteile mit der höchsten Druckbelastung im Median waren das Sternum (1.62 N/cm<sup>2</sup>, Q1: 1.17 N/cm<sup>2</sup>, Q3: 2.10 N/cm<sup>2</sup>) in der Bauch- und die Schulter (2.72 N/cm<sup>2</sup>, Q1: 2.09 N/cm<sup>2</sup>, Q3: 3.81 N/cm<sup>2</sup>) in der Halbseitenlage. PF war beeinflusst durch den Bodentyp unter dem Sternum ( $P = 0.0132$ ) und unter der Schulter ( $P = 0.0012$ ). Die Gewichtsklasse beeinflusste die Druckbelastung unter dem Sternum signifikant ( $P = 0.0012$ ), aber nicht unter der Schulter. CA unterschied sich zwischen den Böden ( $P = 0.0301$ ) und der Gewichtsklasse ( $P < 0.0001$ ) unter dem Sternum. CA unter der Schulter wurde nur durch die Gewichtsklasse ( $P = 0.0097$ ) beeinflusst. PF unter der Schulter war größer auf C ( $P = 0.0128$ ) und HM ( $P = 0.0113$ ) im Vergleich zu VSM ohne Unterschied der SM zu den restlichen Matten. Unter dem Sternum war PF niedriger

auf VSM ( $P = 0.0012$ ) im Vergleich zu C, jedoch ohne Unterschied zwischen den anderen Böden. Um die Druckbelastung unter der Schulter in Halbseitenlage und unter dem Sternum in Bauchlage zu reduzieren, sind Gummimatten mit einer Eindringtiefe von 43 mm empfehlenswert. In aktuellen Tierwohliniitiativen ist Liegekomfort vorgeschrieben, um das Tierwohl zu verbessern. Sehr weiche Matten können einen Beitrag leisten, um den Liegekomfort für tragende Sauen auf Betrieben zu verbessern. Für eine erfolgreiche Implementierung der sehr weichen Gummimatten sollten Langzeitversuche auf verschiedenen Betrieben durchgeführt werden, um die Haltbarkeit von sehr weichen Matten mit einer Eindringtiefe von 43 mm und die Akzeptanz durch Sauen zu untersuchen.

In einer zweiten Untersuchung wurde die Druckbelastung während dem Abliegen in halb und voll knieender Position untersucht. Die Zeitdauer, die Sauen in halb und voll knieender Position auf den unterschiedlichen Böden verbrachten wurde neben den Druckmessungen zusätzlich bestimmt. Die Druckbelastung in halb und voll knieender Position war beeinflusst durch den Boden ( $P = 0.0020$ ) und war auf allen Matten signifikant höher im Vergleich zu C. Die anschließende Analyse der Daten zur Druckbelastung zeigte einen hohen Anteil des Wertes  $3.81 \text{ N/cm}^2$  in halb und voll knieender Position auf allen Böden. Dabei wurde davon ausgegangen, dass es sich um ein gemessenes Artefakt handelte. Die Zeitdauer, die Sauen in halb ( $P = 0.0940$ ) und voll knieender Position ( $P = 0.6774$ ) verbrachten unterschied sich nicht zwischen den Böden. Wohingegen das Druckmesssystem sich für die Messungen für liegende Sauen anbot, war es mit dem TEKSCAN 5400 NTL nicht möglich die Druckbelastung an kleinen Körperteilen wie den Karpalgelenken bei Sauen in Bewegung zu ermitteln. Es wird empfohlen Druckmesssysteme zu verwenden mit einer Auflösung von  $1.4 \text{ sensing points per cm}^2$  und das Auftreten von Scher- und Ziehkräften auf weichen Böden sowie Störungen durch dynamische Druckintervalle bei Druckmessungen von Sauen in Bewegung zu berücksichtigen.

Der Komfort von Laufmatten wurde mit Hilfe einer kinematischen Laufganganalyse getestet. Hierfür wurden insgesamt 15 Sauen (Deutsche Landrasse x Deutsche Landrasse) mit einem Körpergewicht im Durchschnitt von  $196 \pm 52.7 \text{ kg}$  genutzt und wiederholt gemessen. Die Laufganganalyse wurde auf einem 3 m langen Testabschnitt in der Mitte eines 17.0 m langen Laufwegs durchgeführt. Als Testböden wurden zwei unterschiedliche Gummimatten mit verschiedenen Oberflächenprofilen verwendet (glatt vs. rau). Beide Matten wurden im Vergleich zu Betonspalten getestet. Alle Böden wurden nacheinander getestet, während der Gang der Sauen auf den Betonspalten am Ende der Versuchsreihe wiederholt gemessen wurde. Verschiedene Schrittparameter wurden per Video aufgenommen und getrennt für Vorder- und Hinterbein analysiert. Es wurde angenommen, dass

Schweine sich an unterschiedliche Bodenbedingungen mit ihrem Gang anpassen. In der Laufanganalyse stieg die Laufgeschwindigkeit der Sauen innerhalb der Messreihen unabhängig vom Untergrund an und betrug im Durchschnitt  $1.27 \pm 0.28$  m/sek über alle Böden/Messwiederholungen. Die Laufgeschwindigkeit unterschied sich dabei zwischen den Böden signifikant ( $P = 0.0049$ ). Für die Schrittparameter wurden bis auf die Schwungzeit für das Hinterbein ( $P = 0.0266$ ) keine signifikanten Unterschiede festgestellt. Aufgrund der Anpassung an die Messbedingungen während der Laufanganalyse, waren keine zuverlässigen Aussagen über den Einfluss glatter und rauer Oberflächen möglich. Daher sollte im Versuchsdesign für Laufanganalysen mit wiederholten Messungen, die Gewöhnung der Sauen an die Messung berücksichtigt werden. Weiterhin sollte für die Entwicklung von komfortablen Laufböden für Sauen, diese nicht nur unter trockenen und sauberen Bedingungen, sondern auch feuchte und verschmutzte Zustände in der Laufanganalyse getestet werden. Im Gegensatz zu kinematischen Laufanganalysen, könnten auch kinetische Laufanganalysen mit Druckmesssystemen mit einer Auflösung von 1.4 sensing points per  $\text{cm}^2$  und einem Laufweg, bedeckt mit Druckmessfolien, von 2.2 m Länge in Betracht gezogen werden für zukünftige Untersuchungen.

Das Potential der Ammoniakfreisetzung wurde als Ureaseaktivität auf unterschiedlichen Bodenoberflächenprofilen in einem Labor- und Feldversuch mit einer statischen Kammer als Standardmessmethode getestet. Im Laborversuch wurden vier unterschiedlichen Oberflächenprofilen von Gummimatten im Vergleich zu einer Betonoberfläche als Referenz, nachdem sie künstlich mit Schweinekot und künstlichem Harnstoff für 16 Tage verschmutzt wurden, analysiert. Es wurde angenommen, dass die Ureaseaktivität niedriger ist auf Gummimatten mit glatter Oberfläche im Vergleich zu Gummimatten mit rauen Oberflächenprofilen. Die Ureaseaktivität im Laborversuch unterschied sich nicht zwischen den verschiedenen Oberflächenprofilen. Über alle Böden betrug die Ureaseaktivität im Median  $65.65 \text{ mg NH}_4^+\text{-N m}^{-2} \text{ h}^{-1}$  (Q1:  $-72.60 \text{ mg NH}_4^+\text{-N m}^{-2} \text{ h}^{-1}$ , Q3:  $264.16 \text{ mg NH}_4^+\text{-N m}^{-2} \text{ h}^{-1}$ ). Es wurde eine hohe Varianz zwischen den verschiedenen Messungen aufgrund positiver und negativer Werte an Ureaseaktivität ermittelt, die mit der statischen Kammer als Messmethode erfasst wurden. Somit konnte der Einfluss des Oberflächenprofils auf die Ureaseaktivität im Laborversuch nicht bestimmt werden, aufgrund der hohen Varianz und der zu geringen Stichprobengröße. Insgesamt 240 Proben wären nötig gewesen, um die Höhe an Ureaseaktivität auf fünf unterschiedlichen Böden zu bestimmen, wobei 16 Muster für jede Messreihe hätten künstlich verschmutzt werden müssen, wenn drei Lokalisationen auf jedem Muster gemessen werden sollen. Aufgrund der hohen

Arbeitsintensität bei der Benutzung der statischen Kammer und für die künstliche Beschmutzung empfiehlt es sich die Ureaseaktivität direkt im Feldversuch zu messen. Im Feldversuch wurde ein Typ einer Gummimatte mit einem Gefälle und integrierten Liegemulden auf Ureaseaktivität im Vergleich zu Betonspalten auf einem Schweinebetrieb getestet. Weiterhin wurde vermutet, dass die Ureaseaktivität im Feldversuch auf den Gummimatten niedriger sein würde im Vergleich zu Betonspalten. Im Feldversuch war die Ureaseaktivität 10 mal so hoch verglichen mit den Werten aus dem Laborversuch und unterschied sich nicht signifikant zwischen Betonspalten und Gummimatten mit Gefälle ( $P = 0.84$ ). Gummimatten mit einem Gefälle und integrierten Liegemulden könnten auf Betrieben verwendet werden, um den Liegekomfort zu verbessern, ohne die Ammoniakfreisetzung in Ställen negativ zu beeinflussen. In zukünftigen Untersuchungen sollte der Liegekomfort dieser Matten mit Hilfe von Druckmessungen oder als Wahlversuche mit tragenden Sauen untersucht werden.

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