Effects of Housing Management Strategies on Performance and Welfare in Production Swine Operations

THESIS

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By

Garth Randal Ruff

Graduate Program in Animal Sciences

The Ohio State University

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Master's Examination Committee:

Dr. Steven Moeller, Advisor

Dr. Henry Zerby

Dr. Monique Pairis-Garcia
Abstract

Two experiments were completed to evaluate the effects of different management strategies on commercial swine operations. Experiment 1 was divided into two separate studies. The objective of Study 1 was to evaluate the effects of floor space during the grow-finish period on pigs marketed at 136 kg. In Study 1, 170 commercial crossbred pigs were blocked by weight and sex, then randomly assigned to one of 5 floor space allocations of 0.71, 0.80, 0.89, 0.98, and 1.08 m²/per pig. Pigs remained on test at the assigned floor space until a pen averaged 136 kg, at which point Study 1 ended. Pigs were weighed and feed disappearance was recorded bi-weekly in order to calculate average daily gain (ADG), average daily feed intake (ADFI), and gain:feed ratio (G:F). Lameness and skin lesions were also recorded bi-weekly as indicators of individual pig welfare. Salivary cortisol was taken at 80 and 136 kg to evaluate physiological stress response to floor space allowance. The objective of Study 2 was to evaluate the effects of floor space allowance of pigs weighing 136 kg until marketing. In Study 2, 70 pigs were subjected to the same floor space allowances as in Study 1 for 14 days at which point they were weighed and feed disappearance was recorded to calculate performance characteristics previously described. Repeated measure analysis was used when analyzing performance data. There were no effects (P > 0.05) of floor space on ADG, ADFI, or G:F in Study 1. Additionally, there were no differences (P > 0.05) in salivary cortisol concentrations, or the incidence of lameness or skin lesions. Similarly, there were no differences (P > 0.05) in the performance
or welfare data collected in Study 2. The objective of the second experiment was to evaluate the effects of rubber mat flooring on the mitigation of lameness and performance of sows during farrowing and lactation. In this experiment 213 multiparous lame (L) and non-lame (NL) sows were assigned standard farrowing crate control (C), or a crate with a heavy duty rubber mat fixed to the floor underneath the sow (R) in a 2 x 2 factorial design. Piglet weights were measured the week of farrowing and the week of weaning, while lameness, lesion scores, sow weight, and body condition measurements were obtained weekly. Additionally, 2 hours of behavioral observations were taken, using 15 minute interval scans (lying, standing, sitting, drinking, feeding, and nursing), post morning feeding over the course of 4 weeks in the farrowing crate. Farrowing records and piglet mortality data were obtained post-hoc via records from the farm’s computer database PigKnows®. The implementation of rubber mats did not affect (P > 0.05) lameness prevalence in either L or NL sows, however all sows on rubber mat spent a reduced proportion of time lying (P < 0.05). Flooring treatment had an effect (P < 0.05) on piglet weaning weights as sows on rubber mats weaned lighter litters. Sows in the R flooring treatment had increased mortality (P < 0.05) of 0.74 piglets per litter primarily due to increased overlying of sows compared to in the control (P < 0.05). Rubber mats did not affect the total number of lesions (P > 0.05) but there was an overall decrease in the number lesions over time (P < 0.05). While the design and results of the two experiments differ in nature, overall it can be concluded that that there are many environmental variables that can affect swine performance and welfare in all stages of production. The results of Experiment 1 suggest that providing pigs with a space allowance greater than 0.71 m² does
not increase pig performance or welfare. In addition, results of Experiment 2 suggest that further research is needed in evaluating flooring alternatives that are optimal in mitigating sow lameness while maintaining animal comfort and performance.
Dedication

To my parents:
Dennis R. and Judith L. Ruff
I would like to extend a thank you to the people who have been a part of this adventure to obtain my Master’s Degree at The Ohio State University. Firstly, I would like to thank my advisor Dr. Steve Moeller for the great opportunity to work with and learn from him. Thank you to Drs. Henry Zerby, Monique Pairis-Garcia and Magnus Campler for taking the time to teach me about livestock production, meat science and animal well-being. Also, thank you to Ron Cramer for all of your support and help during my time at Ohio State. To all previously mentioned; your advice, having confidence in me, and your friendship was an integral part of the past few years. I also need to thank the people that work behind the scenes of the research done at the farm level; Ken Mays and his crew at the Don Scott Swine Unit, and everyone who helped with the rubber mat study. I would also like to thank my fellow graduate students for their fellowship and help along the way. To the faculty, staff and students from the animal sciences department that I have had the opportunity to work and interact with. Without you this journey wouldn’t have been the success it was.
Vita

May 2011 .......................................................... Morgan High School

2015...............................................................B.S. Agriculture, The Ohio State University

2015 to present ................................................ Graduate Research Associate, Department

of Animal Sciences, The Ohio State University

Fields of Study

Major Field: Animal Sciences

Emphasis: Livestock Production
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Chapter 1: Literature Review

Introduction

Swine housing and proper management of those facilities are an important component of a successful and profitable operation. Determining floor space requirements for optimal returns during the grow-finish phase involves many factors including, but not limited to, current production economics, individual pig welfare and performance variables, and target market weight. Current average live market weights are greater than 127 kg (USDA, 2015) with an upper range reported to exceed 136 kg within some production systems. Historical trends project that average market weights will continue to increase by approximately 0.45 kg carcass weight per year (USDA, 2015). Concurrent with increased market weight, efforts to study space requirements for pigs are being undertaken, as reported literature and industry targeted space allocation guidelines reflect pigs marketed at 113 kg. The primary objective of this experiment was to determine the optimal floor space allowance for growing-finishing pigs that are marketed at a pen average of 136 kg live weight. An additional objective of the present study is to evaluate the influence of space allocation on pigs started at 136 kg and continuing for two weeks following allocation. Measures of performance included growth rate, feed intake, and feed conversion ratio, with pig welfare measures included as salivary cortisol, incidence of lameness, tail biting, and overall health. An ultimate goal of the present research is to
provide space allocation recommendations to the US swine industry that reflect current and future pig market weight targets.

Other phases of swine production have also been of recent focus with regards to facility design and management. Gestation housing and the impacts on sow performance and welfare have been extensively researched as the swine industry is in the process of transitioning from individual to group housing during gestation. One negative effect of group housing is that sows are more likely to acquire lameness than when in individual stalls (Spoolder et al., 2009). Lameness in the sow population is similar to crowding of grow-finish pigs, in that it can affect economic, production, and welfare factors within the sow unit. Previously investigators have looked at various flooring substrates, including rubber mats in the gestation setting as a means to mitigate lameness in farrowing sows. In the experiment described in Chapter 3, the objective of the study was to evaluate the effectiveness of rubber mats in the farrowing crate on lameness mitigation and the effects of the mats on performance and welfare of the sow and her litter.

**Increasing Market Weights**

Globally, pig market weights have been increasing for the past three decades (Kim et al., 2005). According to USDA (2015), in the United States, market weights have increased by 20% since 1980. This trend will continue until pork quantity and or quality no longer meets the consumer’s (customer’s) needs, or the efficiency of pig production reaches economic unsustainability (Kim et al., 2005). Demand for pork, in addition to vertical integration and packer consolidation will further drive this demand for heavier pigs. Fewer pig owners and packer-owned pigs offers industry participants the means to
mitigate cost at either or both the production and packer levels, thereby increasing flexibility in changing market conditions. With a greater number of pigs sold, producers can operate on smaller profit margins per pig (Kliebenstein and Lawrence, 1995).

Economic conditions within the packing industry contribute significantly to the observed increase in market weight. As market weights increase, the packer’s cost of producing a unit of pork decreases, the result of lower fixed (building, equipment) costs per unit of pork (Kim et al., 2005) and the potential for reduced variable costs (labor per unit of pork) for the plant. This remains true as long as pork from heavy weight pigs meets leanness and quality standards.

Increasing market weight increases total weight of pork production and may result in a smaller breeding female population if the industry has a target level of production to maintain. In 2003, the Meat and Livestock Commission (MLC) estimated that the cost of increasing market weight from 100 to 120 kg was $12.50 per pig for the additional 26 days the pigs were fed and housed. A 20 kg increase in market weight could then reduce the number of pigs slaughtered by 15%, thus reducing the number of sows in the herd by 15% in order to produce the same amount of pork. The estimated net profit for the increased market weight was $0.90 per pig (MLC, 2003). In reality, based on the productivity measures reported within the US, increased market weights have had little or no effect on breeding herd size; rather the combination of greater market weight and increased breeding herd productivity have resulted in more pork being produced annually in the US.

Aside from packer demand, the average commercial pig, through genetic improvement, has become more efficient. Modern, highly selected genetic lines have
allowed for lean gain efficiency to be greater at heavier weight when compared to pigs 30-50 years ago (Kim et al., 2005). Currently, pigs can maintain feed efficiency to weights of 130 kg while producing carcasses with an increased lean to fat ratio (Kim et al., 2005).

Technology has also aided in the transformation of the pig and establishment of carcass value. Prior to the 1950’s, there was a greater demand for pig fat (lard) as it served as a primary food ingredient and was used in household goods (USDA, 2014). In the early 1990’s, consumers desired less fat in the diet coupled with, the development and increased use of plant based and marine oils as an alternative fat source, further promoting the production of leaner, more efficient pigs. Of note, demand, price and per capita consumption of bacon, and the continued use of pork fat in processed products such as sausage have been increasing since the late-1990’s (USDA, 2014), leading to increased value and return from the production of a heavier, more efficient, yet fatter pig.

Furthermore, an additional factor driving the increase of pig market weights is the use of the beta-agonist ractopamine hydrochloride (RAC). Feeding RAC improves pig growth rate and feed conversion through the action of increased muscle growth and a reduction in, or stabilization of, fat deposition in the late finishing period. Studies have shown that pigs fed RAC at the end of the finishing phase have less back fat at the 10th rib, coupled with an increased gain:feed ratio (Uttaro et al., 1993; Crome et al., 1996; See et al., 2004; Schinckel et al., 2000). Stoller et al. (2003) reported that feeding RAC at 10 ppm in the diet increased average daily gain (ADG) 0.09 kg/d and increased loin muscle area 1.40 cm² on average across three genetic lines of pigs fed to 110 kg average end weight. Additionally, Hinson et al. (2012) reported that pigs fed RAC at 5 ppm in the diet
had heavier hot carcass weight (HCW; 3.05 kg) at a standard day on feed, and sort losses at the plant were nearly eliminated for the packer in this study. The combination of improved growth rate (fewer days to reach a target end weight) and feed conversion efficiency (less feed to reach the target end weight) of pigs fed RAC increased profitability potential of pigs slaughtered at heavy market weights.

Pig market weights are expected to remain high for the foreseeable future. Recent pork production and short term consumption forecasts by USDA (2015) predict per capita pork consumption is projected to rise as industry production increases. The projected increase in US pork production corresponds to US producer’s response to lower feed costs, herd expansion, and a reversal of production losses associated with Porcine Epidemic Diarrhea Virus (PEDv) in 2014. While 2014 pig production numbers were decreased due to PEDv, market weights and carcass prices ($129.87 cwt) reached all-time record highs in the US (USDA, 2015), as many producers had production space and time to grow pigs to a heavier market weight and the lack of overall supply resulted in surge in pork prices. The 2014 PEDv experience fostered further interest in learning how to best feed and manage heavy market weight pigs. Projections to the year 2025 show gains in the volume of pork produced as a result of both increased domestic use through population expansion and rising US pork exports, although US per capita consumption of pork is expected to plateau by 2018 (USDA, 2015). Supplying the expected demand needs will likely come to the US in a combination increased market weight of pigs, herd expansion, and increased herd productivity.
Determining Floor Space Allowances

Determining how much floor space to allot per pig ultimately has an economic impact on the producer. In North America, a fixed pig space is traditionally provided regardless of pig weight throughout the grow finish phase. The National Pork Board (2003) recommends a space allowance of 0.74 m² for pigs weighing 68 kg to market weight. For pigs marketed at weights greater than 133 kg it is unlikely that the amount of space needed remains the same during the growth period (Anil et al., 2007). Canada’s National Farm Animal Care Council (NFACC) in conjunction with the Canadian Pork Board (2014) require 0.79 m², while their ideal minimum space allowance on partially or fully slatted floors is 0.92 m² for pigs marketed at the same standard weight target. Third party companies conducting packer sponsored welfare audits such as Certified Humane® require that a pig be allotted 1.5 times the minimum lying area based on the pigs weight. Certified Humane® audits require 0.85 m² for pigs weighing 120 kg. For pigs marketed at heavier weights, there is a deficit in the literature regarding the impact of pig space allocation on pig performance, welfare, and the impact of space allocation on costs of production and profitability (Powell and Brumm, 1992; Brumm et al., 1996).

Mathematically, pig space has been calculated using the formula \( A = kw^{0.667} \), where \( A \) represents area (m²), \( k \) is a constant based on the heaviest weight at the time of marketing, and \( w \) is the body weight of the pig in kg (Petherick, 1983). This formula was derived by comparing the allometric relationship of the size and shape of the pig to how the pig utilized pen space (Petherick and Baxter, 1981). The equation accounts for static space based on
the physical dimensions of the pig and free space, the space required to move, function, and interact with other pigs (Petherick, 1983).

Previous investigators have evaluated floor space requirements using various parameters. Gonyou et al. (2006), using data from previous research, calculated the critical k-value at which an increase in space allocation did not result in increased ADG or average daily feed intake (ADFI) to be 0.034. Gonyou et al. (2006) continued to report that there was no relationship between floor space and gain:feed ratio. Based on the critical k-value, pigs marketed at 113 kg would need 0.82 m². When pig spaces were allocated below the critical k-value it was predicted that for every three percent reduction in space, there would be a one percent decrease in ADG and ADFI (Gonyou et al., 2006). Edwards et al. (1988) and Powell and Brumm (1992), after considering stocking density and various space pricing options, reported that to minimize the cost per pound of pork produced, the ideal pig space was 0.56 m² (k = 0.0235) for a pig marketed at 116 kg. Buhr et al. (2005) surveyed various segments of the US pork industry and calculated an average pig space in confinement operations to be 0.67 m² (k = 0.0281). Current finishing barn stocking practices and production data suggest that the space allotment optimal for pig performance is much greater than the economically ideal pig space (Buhr et al. 2005). Furthermore, the economically optimal k-values for the space allowances of Powell and Brumm (1992) and those reported by Buhr (2005) are lower than the critical k-value of 0.0340 (Gonyou et al., 2006).
Effect of Pen Space on Performance

Previous studies have evaluated the effect of pen space (area per pig) on performance during the grow-finish phase. However, few studies have evaluated the effect of space allotment on performance of pigs approaching 136 kg and heavier. Decreasing pig space can have a detrimental effect on pig performance, primarily demonstrated through decreased ADG and ADFI (Table 1.1). Of the studies summarized in Table 1.1, nearly all reported a significant decrease in ADG, either across treatments or between treatments, as space allocation was reduced. Experimental findings varied greatly when evaluating the impact of floor space on ADFI, with most studies demonstrating no influence on ADFI and few studies indicate a significant reduction in ADFI when space allocation was reduced (Table 1.1).

To date, the effect of floor space on feed conversion efficiency (G:F ratio) remains inconclusive. Early research by Heitman et al. (1966) showed that pigs allotted 1.86 m² had increased G:F ratios when compared with pig provided either 0.46 or 0.93 m² per pig. Other research suggests that as stocking density decreased G:F ratio decreased (Randolph et al., 1981; Moser et al., 1985; Street and Gonyou, 2008). However, in contrast to these results, Jensen et al. (1973), Dimsoski et al. (1997), Gonyou and Stricklin (1998), and Brumm et al. (2001, 2004) observed no differences of floor space allocation on G:F ratio.

In addition, limited information is available on the effect of floor space on carcass characteristics. When reported, daily lean gain, loin muscle depth and back fat thickness decreased ($P < 0.05$) as pen space is decreased (Brumm and Miller, 1996 Ex. 1,2,3; Brumm et al. 2004).
Effect of Group Size on Performance

Group sizes in finishing facilities vary depending of the design of the barn and the management practices established either in private ownership or in contract language agreed upon by the pig owner and contract grower. Traditionally in North America, pigs have been fed to market weight in groups of 20 to 40 pigs per pen. Within the past 10 years, some producers have transitioned to large pen systems with groups of 100 pigs or greater per pen. Street and Gonyou (2008) compared small groups of 18 and groups of 108 pigs per pen and found that G:F ratio was decreased (P = 0.005) in larger groups. While not significant, ADG was reported to be greater for pigs housed in the smaller groups (1.08 vs. 1.03 kg/day). Wolter et al. (2000) observed that weaned pigs in groups of 100 were lighter (P < 0.001) than pens of 20 pigs at the end of a 9 week trial and that larger groups had greater within-pen coefficient of variation in BW at the end of the study. Another experiment by Wolter et al. (2001) evaluated the effects of group size on wean to finish pigs, in groups of 25, 50, and 100 pigs. They reported no differences in performance, morbidity, or carcass traits across all treatments. Similarly, Schmolke et al. (2003) concluded that feeding grow-finish pigs in groups up to 80 pigs per pen was not detrimental to pig performance. Earlier research by Randolph et al. (1981) reported that, when given equal space allotments per head, groups of 20 had greater ADG (P < 0.05) than groups of 5 pigs. In contrast, Gelbach et al. (1966) found that groups of 8 and 12 finishing pigs displayed increased daily feed intake and ADG when compared with groups of 16 pigs receiving the same space allotment. The authors concluded that elevated ambient temperatures was the primary cause of decreased performance for the 16 head groups.
**Effect of Floor Space on Pig Welfare**

The space requirement for a pig includes static space, based on pig dimensions and free space, area for the pig to eat, drink, dung, and lay. As pigs get larger within a standard space allocation, the amount of available free space decreases and may lead to a decreased state of welfare, poorer efficiency, and reduced economic returns (Petherick, 1983). In order to minimize facility costs, there has been a focus on determining the extent to which free space can be reduced without having a negative impact on pig welfare. McGlone and Newby (1994) concluded that removing half of the available free space did not negatively impact pig performance to a weight of 106 kg. Free or unused shared space increases proportionally as the number of pigs increases per group, \( Y = 0.179 + 0.002092X \), where \( Y \) is free space and \( X \) is the number of pigs per pen. However, current pig space recommendations may not provide enough free space to promote maximal levels of pig welfare at current market weights (Anil et al., 2007).

Once free space within a pen is decreased there is evidence that welfare becomes compromised. Anil et al. (2007) noted that when pigs were given 0.64 m\(^2\) injury scores were greater when compared with pigs that were allotted 0.88 m\(^2\), with the greatest injury scores reported during weeks 12-14 of finishing (\( P < 0.05 \)). This contradicts the findings of Street and Gonyou (2008) who found no differences (\( P < 0.05 \)) in injury scores observed across a space allocation range (0.52 m\(^2\) vs. 0.78 m\(^2\)). In the majority of floor space trials there have been no effects (\( P < 0.05 \)) of floor space on mortality rates. However, Brumm and Miller (1996) reported in one experiment that a reduction in pen space allocation from 0.78 m\(^2\) to 0.56 m\(^2\) demonstrated an increase in mortality percentage and number of pigs.
removed from the reduced space treatment. Similarly, DeDecker et al. (2005) reported that morbidity and mortality increased from 8.5 to 10.2 and 12% when floor space was decreased from 0.79 to 0.64 and 0.54 m² respectively.

Stress levels, as a potential indicator of animal welfare, in swine can be measured by comparing the concentration of cortisol in plasma or saliva to baseline levels. Crowding of finishing pigs, which primarily occurs in the late stages of finishing, has been reported to have no effects (P < 0.05) on salivary (Anil et al., 2007; Street and Gonyou, 2008) or plasma (Meunier-Salaun et al., 1987) cortisol concentrations. However, cortisol concentrations have been observed to trend lower during the last half of the finishing period, suggesting that the acute stress response associated with mixing has subsided as pigs have been provided sufficient time to establish a hierarchy (Anil et al., 2007). Similarly, Street and Gonyou (2008) reported that there was no effect of crowding on cortisol measurements taken from the adrenal gland post-mortem.

**Effect of Floor Space on Pig Behavior**

Pig behavior is evaluated as one of several indicators of overall pig welfare. Crowding pigs or giving them too much free space may result in the development of abnormal behaviors that potentially compromise welfare and performance. Behaviors such as tail-biting have a direct negative economic impact, whereas behaviors such as time spent laying or eating may have an indirect economic cost associated with changes in their duration and subsequent influences on productivity measures.

Pigs spend a large proportion of their time lying down and a reduction in the amount of time a pig spends lying can be an indicator for welfare concerns (Fraser and Broom,
The average pig spends about 80% of its time lying while spending the remaining time standing, eating, and in locomotion. Posture while lying has a large influence on the k-value required to meet the pig’s needs, for example, a 116 kg pig lying laterally requires a k-value of 0.047 as compared to a k-value of 0.019 when the pig lies on its sternum (Petherick and Baxter, 1981). Pigs spend decreasingly less time lying in a lateral position as they become heavier, as the demand for static space per pig increases, thus decreasing free space (Pearce and Patterson, 1993). Additionally, Anil et al. (2007) reported that when floor space was decreased from 0.81 to 0.74 m² pigs spent a greater proportion of time lying in preferred areas, against a wall or gate panel (P < 0.01) and less time lying in isolation (P < 0.01). Furthermore, there is conflicting data evaluating the differences in the time spent sitting, standing, or walking. Some studies reported no differences in the time spent walking or standing as floor space decreased (Anil et al., 2007; Street and Gonyou, 2008). This contradicts the findings of Heitman (1966) and Bryant and Ewbank (1974) that showed that as stocking density was increased, the time spent standing and walking increased. After lying and walking, pigs spend the majority of their remaining time either standing or eating (Anil et al., 2007; Street and Gonyou, 2008). Crowding of pigs had no impact on ADFI even though crowded pigs spent less time (P < 0.05) eating than uncrowded pigs, supporting the idea that pigs ate faster during the shorter trips to the feeder (Meuiner-Salaun et al., 1987; Street and Gonyou, 2008).

Pigs also spend a small proportion of their time engaging in aggressive acts towards one another, which include threatening, displacing, fighting, attacking, and biting.
Decreasing floor space allotments has been shown to lead to an increase (P < 0.05) in the number aggressive actions (Randolph et al., 1981 Exp.1; Anil et al., 2007).

**Tail Biting**

Tail biting behavior is a complex behavioral vice that concerns producers as there is a direct correlation between tail bitten pigs and reduced carcass value. In the UK, 61.7% of multiple abscesses in pig carcasses have been reported to be the result of tail biting (Huey, 1996). Tail length appears to be an important factor in the pigs that become tail bitten. Docking tails has been shown to reduce tail biting from 8.5-9.2% to 2.4-3.1% in finishing pigs (Hunter et al., 2001).

In a review of tail biting, Taylor et al. (2010) separated tail biting events into three categories; two-stage tail biting, sudden-forceful tail biting, and obsessive tail biting. During two-stage tail biting events there is a pre-damage and a damage stage. Pre-damage refers to oral manipulation of the tail without breaking the skin (Schroder-Peterson and Simonson, 2001). While damage occurs once the skin is broken and bleeding which may attract other pigs to the bitten tail (Fraser, 1987a). This type of tail biting has been attributed to the need of the pig to satisfy natural exploratory behaviors (Day et al. 1995). Sudden-forceful tail biting events occur when a pig’s tail is bitten and flesh is exposed (Taylor et al. 2010) and is characterized as the result of the biting pig being unable to access resources, such as feed, water, or lying space (Georgsson and Svendson, 2001; Morrison et al., 2007). The third type of tail biting is described as obsessive, and the biting pigs should be identified and removed as quickly as possible. Obsessive biters tend to be smaller, poorer performing pigs that appear to have abnormal behavioral deviations as a
response dramatic changes to the environment or metabolism (Edwards, 2006). While tail biting can be classified, the lack of distinction and the unknown number of pigs culled due to tail biting make it difficult to determine to what degree a genetic component impacts this behavior.

Diet, health, gastro-intestinal physiology, genotype, gender, stocking density, and environmental factors have all been identified as possible motivations for tail-biting (Taylor et al., 2010). Pigs fed low protein (15%) (Jensen et al., 1993) and low salt diets (Fraser, 1987a) have been reported to show an increase in tail biting behavior when compared to pigs fed a high protein (20%) and high salt diet, respectively. Additionally, barrows tend to be tail bitten at a greater rate than gilts. Krittas and Morrison (2004) reported that barrows were 2.6 times more likely to be tail bitten than gilts, and that the proportion of tail bitten barrows increased in pens where there was a greater gilt:barrow ratio. In addition, Wallgren and Lindahl (1996) proposed that gilts prefer to engage in face-to-face contact, whereas barrows turn away, leaving their tail exposed, therefore split sex feeding may decrease the prevalence of tail biting. Stocking densities greater than 110 kg of pig mass per square meter of space have also been shown to increase the potential for tail biting (Moinard et al., 2003).

**Effect of Group Size on Welfare and Behavior**

The number of pigs within a pen can affect not only performance, but the social structure, behavior, and individual health for the given pen. Street and Gonyou (2008) reported that pigs in the large groups (108 pigs vs. 18) had greater prevalence of lameness (P < 0.05) coupled with poorer leg confirmation. However, when evaluating specific pig
behavior they found no difference in posture or feeding patterns among the group sizes evaluated.

Prior research has looked at the effect of group size on behavior and social interaction within a pen. When given equal space allotments (0.82 m²), a greater number (0.15 vs. 0.11) of aggressive actions, attacks, threats, and displacements per hour occur in pens with larger numbers (20 vs. 5) of pigs from 27 to 90 kg (Randolph et al., 1981). However, upon mixing and entering the finisher, the number of aggressive interactions increase during as group size increases, especially when feeder space is restricted (Nielsen et al., 1995). Additionally, group size did not appear to impact time spent performing routine behaviors, such as eating, drinking, standing, lying, or walking (Randolph et al., 1981 Exp. 2).

**Effect of Mixing Grow-Finish Pigs**

In commercial settings, litters of piglets are typically mixed at the time of weaning upon entering a nursery or wean to finish facility. At times, in order to manage pig flows or in increase facility output, groups of pigs within a finisher are mixed together. The need to establish a new social hierarchy further increases the stress experienced by the pig. Fighting, aggressive actions, and biting occurs just minutes after being introduced to a new pen and new pen mates (Tan and Shackleton, 1990). Pigs, by nature, are not territorial (Singer et al., 1981; Tisdell, 1982) however, when adding new pigs to a pen, the pig with previous occupancy often initiates the first aggressive action (Tan and Shackleton, 1990). When mixing pigs from different group sizes Turner et al. (2001) reported that pigs from
larger groups (80 pigs) were less likely to initiate aggressive interactions than those from small groups (20 pigs).

Early research on the subject showed that mixing pigs reduced F:G efficiency (Teague and Grifo, 1961). Additionally, Jensen et al. (1969) concluded that mixing pigs at weaning was less detrimental to performance than pigs mixed 4 weeks post weaning. As target market weights increase, the variation of pig weights are also expected to increase. Tindsley and Lean (1984) and O’Quinn et al. (2001) reported that sorting pigs in order to reduce within-pen variation upon entering the finishing barn had little effect on pig performance to slaughter. Brumm et al. (2002) tested the effects of removing and mixing lightweight pigs from various pens and observed no effect on performance and within pen weight variation at slaughter. In contrast, Hyun et al. (1998), in two different studies, concluded that mixing grower pigs (35.8 ± 0.86 kg) reduced ADG by 7.1 and 9.6% respectively, and that growth rate was further decreased when mixed pigs were in crowded conditions (0.25 m² vs. 0.56 m²). In an experiment conducted by Stookey and Gonyou (1994), pigs were either unmixed (Control), mixed (Mixed) for the duration of trial, or mixed for 24 hours or mixed-24 and regrouped with their original pen mates. Those pigs in the mixed-24 treatment exhibited intermediate performance for 2 weeks following mixing, demonstrating that negative stress for the 24 hour period was enough to have a negative effect on growth. Pigs in the mixed treatment were observed fighting 8 days post mixing, suggesting that pigs nearing market weight should not be mixed within 2 weeks of being harvested. While the aggressive behavior is routinely observed after mixing pigs,
there currently are no consistent results on the relationship between pig aggression and decreased productivity.

**Effects and Costs of Pig Attrition**

Decreased pig performance and an increased number of injuries associated with pig crowding result in increased costs through attrition for pig owners and contract growers. Pig attrition is the difference between the number of pigs born and the number of pigs that reach a target market weight (Deen and Larriestra, 2004). Crowding pigs can lead to an increased percentage of pigs marketed as culls and light weights, and potentially increase the number of non-ambulatory and no-value pigs. Compromised or slow growing pigs negatively impact performance measures, efficiency, and subsequent profitability, as the compromised pigs occupies space and consume feed while producing few pounds of saleable pork.

Ritter (2013) analyzed data from the swine management site PigChamp (PigChamp Benchmarking, USA) for the calendar year 2011. The calculated industry average for wean to finish mortality and market culls was reported to be 9.3 and 2.2% respectively, with wean to finish losses accounting for 30.8% of total pig attrition. Bilbrey (2012) concluded that wean to finish mortality and market culls are consistently two of the top three most costly attrition pathways. The cost of attrition is incurred as both direct and opportunity costs. Direct costs reference the sum of weaned pig value, space costs, and feed cost already invested in the pig (Deen and Eggers, 2011). Opportunity costs is the difference of value of feed saved from the value of potential revenue for a full value pig (Deen and
Eggers, 2011). This further stresses the importance of maintaining pig performance which has been shown to decline in some studies as floor space decreases (Table 1.1).

**Contract Grower Considerations**

As the pork industry has further consolidated and integrated the percent of pigs finished by contract growers has increased by nearly 5% (Census of Agriculture, 2012). The size of the average finishing pig space has remained steady over the past decade at 0.67 m² per pig (Buhr *et al*., 2005; Ricker, 2015). However, capital investments during construction and equipping of new finishing facilities have risen from $145 to an estimated $275-300 per pig space from 1995 to 2015 due to increased costs associated with materials, equipment, and labor (Brumm, 2015). While building and utility costs have increased over time, contract payments per pig space have remained constant (Brumm, 2015; Ricker, 2015). Using the aforementioned figures, a 1,200 head finishing barn is an investment of $330,000 or $38.20 per square foot of pig space. Across the Midwest, contracts on average from 2005 to 2015 have paid $36 and $42 annually for grow-finish and wean-finish pig space respectively (Brumm, 2015; Ricker 2015). When contract payments are broken down, roughly $28 annually go towards maintenance, manure application, utilities, and cleaning, leaving about an $8 payment for labor related to pig management and care.

Some contract growers have voluntarily increased space allotments in new facilities from 0.67 to 0.70 m² to accommodate heavier pigs (Brumm, 2015). While the extra space increases construction costs of the facility it appears that pig owners have been reluctant to raise contract rates (Ricker, 2015). Contract incentives for performance will have to justify the investment of increasing floor space, until pig owners are more willing to pay. Aside
from increasing space, Brumm (2012) addressed the need for improved ventilation management and concerns about feeder size and design as market weights increase. Heat production (btu/hr) of growing pigs increases as weights increase, especially for leaner pigs (Brown-Brandl et al., 2004). As the upper critical temperature for pigs over 75 kg declines rapidly, ventilation and temperature management is crucial as heavier leaner pigs become more sensitive to heat stress (Nienaber et al., 1997; Renaudeau et al., 2011). Research from Gonyou and Lou (1997) concluded that the ideal feeder depth for 95 kg pigs was 32 cm, suggesting that many of today’s feeders with depths of 20.3 to 25.4 cm are limiting to the performance of growing pigs. Feeder width may also be limiting feeder access of heavy weight pigs. The width of a feeding space has been determined by the width of a pig’s shoulders. Shoulder width in relation to body weight can be calculated as;

$$\text{Width (mm)} = 64.0 \times \text{bodyweight, (kg)}^{0.33}$$ (Petherick, 1983). To allow access, feeder spaces should be 1.1 times greater than that of the pig’s shoulders (Brumm, 2012). To accommodate 136 to 145 kg pigs 35.6 cm of linear feeder space is recommended.

**Methods and Costs of Increasing Pig Space**

Increasing floor space allowances decreases the number of pigs that can be raised in a facility. Buhr et al. (2005) evaluated various marketing, management, and building strategies to determine if more pig spaces are needed as a result of increasing floor space allowances. Buhr et al. (2005) identified two potential solutions to manage pig flow in response to increasing space allotments within existing facilities. One option was to maintain the same number of pigs and market a portion of them at lighter than ideal weights.
when pens surpass the critical k-value of 0.034. The other option was to sell pigs prior to entering the finishing barn or to reduce the number of sows farrowing.

Buhr et al. (2005) also proposed three alternatives to reduce the number of pigs placed in a finishing unit. One option proposed was to reduce the breeding herd. Another option was to sell pigs at weaning and maintain the same level of finishing space. The third option was to build additional finishing barns to account for the increased need for pig spaces. A target k-value of 0.0336 (Gonyou et al., 2006) was established as a target to market the heaviest pigs in the pen. Surveys have shown that approximately 90% of the swine industry utilizes this practice, and is also known as “topping off” pens (Buhr et al., 2005). Topping off a pen refers to removing a small number of the heaviest pigs in each pen and marketing them as the first load out of a barn. DeDecker et al., (2005) using different group sizes and floor space allowances tested the effects of removing 25 and 50 percent of the heaviest pigs from a pen on the remaining population. Their results indicated that removing the heaviest pigs from a given pen, increased the growth rate of the remaining pigs. The increased performance was attributed in part to increased floor space as well as increased access to feeder spaces. The remaining pigs tended to be slower growing exhibited increased feed intake and G:F efficiency suggesting compensatory growth occurred once resources became more readily available. In a similar trial, using pens of 25 pigs, Jacela et al. (2009), evaluated the economic impact of pen topping by removing 0 or 2 of the heaviest pigs 20 days prior to emptying the barn. They then removed 0, 2, 4, or 6 pigs 10 days prior to barn closeout. While there no effects on carcass characteristics, weight discounts (sort loss) was reduced by almost half. While ADG and
ADFI increased in topped pens versus the control, income over feed cost (IOFC) decreased as more pigs were removed on day 10. Therefore, removing 2 pigs once from the pen was most effective in maintaining IOFC.

Buhr et al. (2005) tested the aforementioned options of reducing breeding inventory, selling weaned pigs, constructing new finishing spaces, and topping off pens to reach target k-value within a finishing pen. The scenarios were analyzed using both small versus large pens, and using marketing matrices that included sort loss and lean estimates from Tyson® (Springdale, AR) and Hormel® (Austin, MN). In every situation, construction of new finishing spaces produced the greatest return on equity. While marketing pigs early decreased the total volume of pork produced. Additionally, reducing breeding inventory drastically underutilized the resources invested into the most costly production facilities, gestation and farrowing, resulting in a 97% reduction on return of equity. Lastly, Buhr et al. (2005) suggested that consumer willingness to pay for larger pig spaces will be the driving force behind industry change and that the cost of new facilities will need to be passed on to packers and eventually to consumers.

**Challenges in the Sow Unit**

Animal housing has an impact on performance and welfare in all phases of swine production. Both the design and the management of these facilities can have impacts on performance, welfare, and economics of the production system.

Modern swine gestation and farrowing facilities are usually built with durability and cleanliness in mind. Floors and alleyways are often built using slatted concrete for traction and avoidance of manure deposits to build up and pen walls or crates are usually
constructed out of a combination of metal, wood or heavy-duty plastic. However, these environmental properties, may give arise to health concerns that compromises sow welfare as hard concrete flooring or slats in gestation housing increases the risk of sow lameness (Anil et al., 2007; Barnett et al., 2001; KilBride et al., 2009) and the risk of developing lesions in group housing (Barnett et al., 2001). The same challenges may also arise when sows are housed in individual crates during gestation or farrowing as crates usually are placed on top of slatted plastic or metal flooring. Farrowing crates were first introduced in the 1960’s to reduce piglet mortality (Fraser and Broom, 1997) and became increasingly popular with US swine producers (NAHMS, 2012). Despite the benefits of lowered piglet mortality and the possibility to implement individual care programs to monitor disease or sickness, current farrowing crates still create welfare concerns as few developed, applicable and economically viable alternatives are available to the US market. Examples of current welfare concerns in farrowing crates are; lameness or lesions (Barnett et al., 2001), high prevalence of decubital ulcers (Herskin et al., 2011), inability to be able to turn around, limited ability to perform adequate postural adjustments (Anil et al., 2002), and limited opportunity to perform natural behaviors such as locomotion (Jensen, 1986), and nest building (Algers and Uvnas-Moberg, 2007).

Although straw is widely accepted to improve sow comfort and welfare as well as promote nest building and other oral behaviors, straw is considered labor intensive, expensive and impractical in farrowing crates used in modern swine farming (Tuyttens, 2005). Moreover, the commonly used manure pit system does not allow for bedding materials such as straw to be placed in the crates as material will fall through the slats and
aggregate in the bottom of the pit and could potentially damage the pumping system. However, other materials such as rubber mats may be able to provide a flooring that is less likely to cause lameness and lesions as well as promote the transition between lying and standing, especially for sows that may have been subtly lame when moved from gestation housing. To date, studies have shown that flooring alternatives such as rubber mats may improve lameness and lesions in group housing (e.g. Calderón-Diaz et al., 2014; Elmore et al., 2010; Tuyttens et al., 2008), while few have looked at flooring alternatives in the farrowing environment.

**Effects of Sow Lameness**

As the swine industry transitions to housing sows in stalls to group housing systems the prevalence of lameness in the sow herd may increase (Spoolder et al., 2009). Lameness is recognized as a welfare issue with major economic impacts to the production system. Stalder et al. (2004) identified lameness as the most common reason for the involuntary culling of sows, while Deen et al. (2008) estimated that the cost or treatment and culling loss was $180 per lame sow in the US. Other authors have also reported effects of lameness on production performance, Anil et al. (2009), Pluym et al. (2013), and Bonde et al. (2004) reported lameness had negative effects on number born alive, incidence of mummified fetuses, and the risk of piglet crushing, respectively.

Aside from economic losses, lameness can result in negative affective states of pain. Pain has been defined by the International Association for the Study of Pain (1994) as “an unpleasant sensory and emotional experience associated with actual or potential tissue damage”. Lameness pain can attributed to several etiologies including hoof or limb
lesions, structural confirmation, trauma, and metabolic or infectious disease (Wells, 1984; Smith, 1988; Main et al., 2000). However, pain diagnosis is difficult due to each individual’s response to pain (Gaynor and Muir, 2009) and differences in breeds, sex, age, pain duration, and severity (Matthew, 2000). The ability to identify pain on farm through behavior observation and locomotion scores is critical to identifying interventions to mitigate lameness in sows, in order to improve welfare and longevity.

**Conclusion**

Individual animal performance, health, and welfare can all be affected by the facilities in which the animals are housed. Through proper design and management of these facilities, optimal production and economic returns are attainable, while maintaining a high standard of animal welfare. In the grow-finish period the goal is to provide enough space that meet the demands of rapid growth during that time, while being efficient in the use of the facility. In the sow unit the transition to group gestation housing may increase the prevalence and severity of sow lameness. Sow lameness is known to have a great impact on production economics and on sow welfare. Further research is needed to evaluate management options to mitigate animal lameness or crowding within existing facilities in all phases of swine production. Moreover, the potential limitations previously discussed need to be addressed in the design of future swine housing facilities.
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Table 1.1. Summary of previous floor space research.

<table>
<thead>
<tr>
<th>Study</th>
<th>Floor Space</th>
<th>k-Value</th>
<th>Pen Size</th>
<th>End weight</th>
<th>ADG</th>
<th>ADFI</th>
<th>G:F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heitman et al., 1961</td>
<td>0.46, 0.92, 1.86</td>
<td>0.0247, 0.0495, 0.1000</td>
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<td>80</td>
<td>&lt;0.01&lt;sup&gt;a&lt;/sup&gt;</td>
<td>NS</td>
<td>&lt;0.01&lt;sup&gt;b&lt;/sup&gt;</td>
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<tr>
<td>Gelbach et al., 1966</td>
<td>0.54, 0.72, 0.90</td>
<td>0.0268, 0.0358, 0.0447</td>
<td>Dynamic</td>
<td>90</td>
<td>&lt;0.01&lt;sup&gt;a&lt;/sup&gt;</td>
<td>NS</td>
<td>&lt;0.01&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Jensen et al., 1973</td>
<td>0.45, 0.72, 0.90</td>
<td>0.0209, 0.0334, 0.0417</td>
<td>Dynamic</td>
<td>100</td>
<td>&lt;0.05</td>
<td>&lt;0.05</td>
<td>NS</td>
</tr>
<tr>
<td>Randolph et al., 1981</td>
<td>0.82, 1.25, 1.64</td>
<td>0.0407, 0.0621, 0.0815</td>
<td>Static</td>
<td>90</td>
<td>&lt;0.05</td>
<td>&lt;0.05</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Moser et al., 1985</td>
<td>0.56, 0.66, 0.74</td>
<td>0.0260, 0.0306, 0.0343</td>
<td>Static</td>
<td>100</td>
<td>&lt;0.01</td>
<td>NS</td>
<td>&lt;0.05</td>
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<tr>
<td>Meunier-Salun et al., 1987</td>
<td>0.34, 0.68, 1.01</td>
<td>0.0158, 0.0315, 0.0468</td>
<td>Static</td>
<td>100</td>
<td>&lt;0.01&lt;sup&gt;a&lt;/sup&gt;</td>
<td>NS</td>
<td>&lt;0.01&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Brumm and NCR-89, 1996 Ex1</td>
<td>0.65, 0.84, 1.02</td>
<td>0.0245, 0.0317, 0.0385</td>
<td>Static</td>
<td>136</td>
<td>0.089</td>
<td>NS</td>
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<td>Brumm and NCR-89, 1996 Ex2</td>
<td>0.65, 0.93, 1.20</td>
<td>0.0245, 0.0351, 0.0453</td>
<td>Static</td>
<td>136</td>
<td>0.089</td>
<td>0.055</td>
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<tr>
<td>Brumm and Miller, 1996 Ex 1</td>
<td>0.56, 0.78</td>
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<td>&lt;0.001</td>
<td>NS</td>
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<tr>
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<td>&lt;0.1</td>
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<td>&lt;0.05&lt;sup&gt;a&lt;/sup&gt;</td>
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<tr>
<td>Gonyou and Stricklin, 1998</td>
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<td>0.0300, 0.0390, 0.0480</td>
<td>Dynamic</td>
<td>97</td>
<td>&lt;0.05&lt;sup&gt;b&lt;/sup&gt;</td>
<td>&lt;0.05&lt;sup&gt;b&lt;/sup&gt;</td>
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<td>Brumm et al., 2001</td>
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<td>0.0244, 0.0322</td>
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<td>&lt;0.003</td>
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<td>Brumm et al., 2004</td>
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<td>0.0242, 0.0326</td>
<td>Static</td>
<td>108</td>
<td>0.01</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>DeDecker et al., 2005</td>
<td>0.54, 0.64, 0.79</td>
<td>0.0225, 0.0267, 0.0329</td>
<td>Static</td>
<td>117</td>
<td>&lt;0.0001</td>
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<td>-</td>
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<td>Anil et al., 2007</td>
<td>0.64, 0.74, 0.81, 0.88</td>
<td>0.0269, 0.0304, 0.0340, 0.0360</td>
<td>Static</td>
<td>116</td>
<td>&lt;0.05&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Street and Gounyou, 2008</td>
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<td>0.0250, 0.0374</td>
<td>Static</td>
<td>95</td>
<td>0.018</td>
<td>NS</td>
<td>0.002</td>
</tr>
</tbody>
</table>

Continued
Continued Table 1.1 Footnotes. Summary of previous floor space research.

1 Floor space at end of trial expressed in m$^2$; varying floor space treatments separated by a comma
2 $k$ represents a constant $A=k*BW^{.667}$ (Petherick, 1983), corresponds to floor space respectively
a significant difference between the smallest floor space treatment
b only significant difference between smallest and largest space treatment
NS denotes non significant result
(-) denotes performance factor not tested and/or reported
Chapter 2.
Effect of floor space allowance on heavy weight market pig performance and welfare.

Abstract

Two studies were conducted to determine the effects of floor space on the growth, performance, and individual welfare of pigs marketed at 136 kg or greater. In each study, floor space allowances of 0.70, 0.80, 0.90, 0.98, and 1.08 m$^2$/pig served as treatments. Pigs were blocked by weight and sex and randomly assigned to a floor space treatment in each study. Study 1 evaluated the effects of floor space from 25 to 136 kg of body weight (BW), and Study 2 evaluated pigs starting at 136 kg BW for a period of 14 d. Records of average daily gain (ADG), average daily feed intake (ADFI) and gain:feed efficiency (G:F) were collected for pens of pigs every 14 d. Lameness and skin lesions were also recorded at the start and every 14 d as indicators of pig welfare. Salivary cortisol was measured at 80 kg and 136 kg to evaluate the physiological response to space allocation in Study 1. In Study 1 there were no space effects (P > 0.05) on final pig body weight, ADG, ADFI, or G:F. In addition, no differences (P > 0.05) in lameness frequency, number of skin lesions, or level of salivary cortisol concentration were identified across Study 1 space treatments. Similar results were observed in Study 2, whereby there were no differences (P > 0.05) in pig performance or welfare measurements. The lack of significant results in these studies suggest floors space allowance of 0.70 m$^2$ are sufficient for optimizing performance and welfare of pigs weighing 136 kg or greater.
**Keywords:** floor space, k-value, performance, pig

**Introduction**

Since the 1960’s, several investigators have evaluated the effect of floor space allotment on growing-finishing pig performance measures when marketed at 113 kg or less. However, market weight in finisher swine in the US has trended heavier for the past decade or more and reached an historical high average weight of 128 kg in 2015, with an upper range reported to exceed 136 kg in some production systems (USDA, 2015). Given that industry standards for floor space allocation are based primarily on lighter market weight pigs, investigation of space requirements in heavier weight pigs is warranted.

Gonyou et al. (2006), in a meta-analysis using data generated from previous studies, predicted floor space requirements for maximum pig performance based on allometric body weight. Using the mathematical equation, $A = k \times BW^{0.667}$ (Petherick, 1983) where $A =$ area (m$^2$), $BW =$ body weight (kg), and $k =$ the critical value at which a measure of performance declined, their summary suggested a critical k-value of .0317 to 0.0348. The allometric approach suggested has been a primary means to establish industry standards for space allocation across a range of market weights; however, the equation and establishment of a critical k-value has not been fully evaluated for pigs marketed at 136 kg or greater.

Space allowance decisions have a significant impact on the economic efficiency of a swine production system. Production output, including rate and efficiency of growth, is commonly measured as pounds of pork produced and the revenue generated per unit of barn space (Powell and Brumm, 1992). In the US, 54% of pigs are produced in a contract
grow-finish system (USDA, 2014), where both the pig owner and contract grower have the opportunity to gain greater returns by marketing pigs at heavier weights while providing the minimum space allocation that does not negatively affect performance and pig welfare. Minimizing space allocation allows the fixed cost of the building to be spread over more revenue generating animal units, thereby reducing the overall cost of production.

Additionally, pig welfare has become increasingly important in US swine production. Pork packer implementation of on-farm PQA Plus™ on-site welfare assessments and subsequent successful compliance with the Common Swine Industry Audit (CSIA) have resulted in a greater focus on space requirement. Crowded pigs may be more likely to display an increased frequency and severity of skin lesions such as tail biting due to close proximity.

Effects of asset economics, pig performance, and animal welfare should be considered when determining appropriate floor space allowances. Therefore, the objectives of the present study were to 1) determine the optimal floor space allowance for growing-finishing pigs that are marketed at 136 kg BW and 2) provide space allocation recommendations to the US swine industry that reflect current and future pig market weight targets.
Materials and Methods

Study 1

Animals and Housing

The present study was approved by The Ohio State University Institutional Animal Care and Use Committee.

The present study was conducted in four replicates over an 18 month period using the Ohio State University, Don Scott Swine facility (Table 2.1). Pigs were derived from matings of commercial crossbred females (Yorkshire x Landrace F1, or ¾ Yorkshire x ¼ Landrace) to a Duroc sire line. Pigs were housed indoors in a mechanically ventilated confinement facility with partially slatted-floored pens (1/3 concrete slatted, 2/3 solid concrete) in one room. Each pen contained one, three-hole wean-to-finish feeder (106.7 cm total length; 30.5 cm depth, 11.4 cm height) and two nipple drinkers.

Pigs were provided ad libitum access to feed and water throughout the duration of the study. Diets were formulated to meet nutrient requirements described by NRC (2012) and were fed in three phases (Table 2.2). Dietary phase changes were made to all pens within a replicate when the average body weight of the heaviest pen within a replicate reached 45 and 80 kg. Diets were standardized across replicates and treatments. Ractopamine was not fed in the experiment.

Experimental Treatments

Within a replicate, pigs were blocked by sex, weight, and litter, then randomly assigned to one of five floor space treatment pens (0.71, 0.80, 0.89, 0.98, and 1.08 m²/pig) with an equal number of pigs in a pen within a replicate. Pens within the facility were
assigned randomly within replicate to floor space treatments and all treatment pens within a replicate contained an equal barrow to gilt ratio (Table 2.1). Floor space treatments were achieved by adjusting pen length, maintaining equal slatted floor area across all treatments. Pen dimensions excluded the feeder in all calculations of floor space allowances. A variance of $\pm 0.02 \text{ m}^2$ from the designated treatment was allowed to accommodate specific conditions within the physical constraints of the facility.

Pigs remained in their assigned floor space treatments from the start of the study (25.4 ± 0.14 kg, SD) until the average weight of pigs in the heaviest treatment pen within a replicate reached 136 kg. No “topping off”, (i.e. the removal of pigs from pens before the average weight of the pen reached 136 kg) was conducted. In situations where a pig died or had to be removed from a pen for welfare reasons, the pen area was reduced to maintain the initial treatment floor space allowance.

**Data Collection and Analysis**

Pigs were weighed and feed consumption data was collected every 14 d throughout the experiment. Weight of all feed added and feed remaining in the feeder were recorded to measure feed disappearance. Average daily gain (ADG), average daily feed intake (ADFI) and gain:feed ratio (G:F) were calculated and reported on a per pen basis. Upon conclusion of the study, backfat depth (BF) and loin muscle area (LMA) were measured on live pigs using real-time ultrasound. Live measures of BF, LMA and BW were used to estimate percent fat-free lean (FFL) using a prediction equation (National Pork Board, 2000).
Welfare assessment included measures of pig lameness, lesion frequency and severity, salivary cortisol, and general health observations. The incidence of lameness was recorded for each pig on each weigh day using the following scale: 1 = normal walking, 2 = slight lameness, may have an arched back, 3 = obviously limping, but able to keep up with pen mates when group is walking, 4 = not able to keep up with pen mates due to lameness, and 5 = can barely walk. During the last week of the study, skin lesions were recorded. Skin lesions were categorized as cuts, swelling, and wounds. The number and severity of each skin lesion was recorded for each pig using the following injury score: 1 = no cut, no swelling, or previous wounds had healed; 2 = minor cut (cut did not go through the skin), slight swelling (redness with inflammation), presence of scabs; 3 = major cut (cuts went through the skin), remarkable swelling, or open wounds. Total lesion scores by pen were calculated and used in analyses. Salivary cortisol was measured on a pen basis at 80 kg and in the final week of the test using a cotton rope for collection of saliva. Cotton ropes were hung in pens, allowing pigs access for a period of 10 to 15 min. Chewed ropes were removed, liquid saliva extracted from the rope, and aliquots were frozen until analysis. Salivary cortisol analyses were conducted by Salimetrics (State College, PA) and were reported as the average concentration of two replicate samples.

Treatment and treatment dates of all sick pigs were recorded according to research station’s SOP’s. Weight, date, and possible cause of death of dead pigs were noted, and if possible a vet was contacted to conduct a postmortem examination. Analyses accounted for pig days accumulated in a pen to the point an animal was removed. Incidences of behavioral vices (tailbiting and ear-biting) for each pen were recorded. GILTS were also
observed for occurrence of estrus daily during the experiment and any detection of estrus was recorded.

Growth and performance data were not normally distributed and were analyzed using the Glimmix procedure in SAS Version 9.4 (SAS Institute, Cary NC) with repeated measures in time used where appropriate. Coefficient of variation (CV) for bodyweight within each pen at initiation and throughout the experiment were calculated and analyzed to determine the effects of floor space on within-pen body weight variation. Effects of floor space treatment were included as a fixed effect in the model with pen within replicate included as a random effect. Pen served as the experimental unit in all analyses. Effects of floor space treatment on incidence of lameness, lesion scores, and cortisol concentration were analyzed and reported as frequencies. Effects of floor space were considered significant when P ≤ 0.05.

**Study 2**

**Animals and Housing**

Pigs used in the study were of the same genetic composition as described previously and were housed in the same confinement grow-finish swine facility as previously described. Pigs were blocked by sex, weight and previous space allocation one week prior to initiation of the study and assigned to a space allocation treatment pen. Treatment pens were assigned randomly within the facility. The study consisted of three replicates of commercial crossbred barrows and gilts with an equal barrow to gilt ratio maintained within a replicate as described in Study 1.
Seventy pigs, weighing $132 \pm 2.27$ kg (SD) (45 from Study 1 and 25 from another group of available pigs), were utilized in the experiment. Pigs were commingled for one week prior to initiation of the experiment, providing $1.08 \text{ m}^2$ per pig, to establish hierarchy within a pen. When pigs from Study 1 were used, they were mixed into treatment pens so that previous floor space treatments were equally represented in each pen.

**Experimental Treatments:**

Following the 7 day acclimation period, pigs were assigned to one of five floor space treatments ($0.70, 0.80, 0.90, 0.98,$ and $1.08 \text{ m}^2$/pig). Pigs remained in their assigned floor space treatments from the start of the study for 14 d. When a pig died or had to be removed from a pen for welfare reasons, the pen area was reduced to maintain the treatment floor space allowance per pig. The third phase diet was fed across all treatments (Table 2.2).

**Data Collection and Analysis:**

Data were collected similar to that of Study 1. Weight of all feed added to each feeder were recorded at time of feeding. Pigs were weighed individually at the start of the experiment and 14 d later to calculate average daily gain. Feed added and remaining at the end of trial were recorded and used to calculate ADFI and G:F efficiency on a pen basis. Morbidity, mortality, and the incidence of lameness were also recorded as previously described in Study 1. Behavioral vices and the occurrence of estrus in gilts were recorded. Growth and performance data were not normally distributed and measures were analyzed as described in Study 1.
Results and Discussion

Study 1

There were no observed effects (P > 0.05) of floor space allowance on final body weight or BW coefficient of variation (Table 3). This finding is in agreement with Brumm et al. (1996) who reported no difference in final BW or BW CV of pigs housed with 0.65 to 1.02 m² space allocation and removed from trial at a 136 kg target weight. Weight variation within each space allocation increased from the start of the trial to the end of the study, as expected when initial weight at allocation was controlled. Of note, there was a quadratic response (P < 0.05) for CV on week 8 of the trial (Table 2.3) whereby intermediate space allocations were less variable than both the least and greatest space allocation. The observed quadratic response is not easily explained.

Space allowance had no significant effects (P > 0.05) on ADG, ADFI, or G:F efficiency for any individual diet phase or through the course of the experiment (Table 2.4). In disagreement with the present study, several authors (Brumm and Miller, 1996; Brumm et al., 1996, 2001, 2004; Dimsoski et al., 1997; Gonyou and Stricklin, 1998; Moser et al., 1985, and Street and Gonyou, 2008), have previously completed similar studies in which investigators tested floor space allowances ranging from 0.55 to 1.30 m²/pig and k-values from 0.024 to 0.049 on pigs weighing 136 kg or less. In all experiments, except for Brumm et al. (1996) there was an observed decrease (P < 0.05) in ADG as floor space was decreased. Moreover, Brumm and Miller (1996) in 2 of 3 trials, Brumm et al. (2001, 2004), Dimsoski et al. (1997), and Gonyou and Stricklin (1998) reported significant decreases (P < 0.05) in ADFI as floor space decreased within their various experiments. Of studies
evaluating the effects of floor space on performance since 1985, only Brumm and Miller (1996) in one experiment, Moser et al. (1985) and Street and Gonyou (2008) were able to report an effect of floor space on G:F efficiency, whereby in each instance ADG decreased as floor space decreased and ADFI was not affected by space allowance. As G:F efficiency is a ratio of ADG to ADFI, differences of G:F as an effect of floor space would not be expected in trials in which both ADG and ADFI decreased as an effect of space allowance.

Additionally, the findings of the current study are in contrast to the summary by Gonyou et al. (2006) whereby previously reported studies have suggested ADG will be reduced when the k-value is reduced below 0.034 (0.89 m² in the present study) which represents space allowances of 0.71 (k-value = 0.026) and 0.80 m² (k-value = 0.030) in the present study. Gonyou et al. (2006) predicted that this decrease in space would correlate to a 0.98% decrease in ADG for every 0.001 (approximately 3%) of the critical k-value. Therefore, in the present study one would have expected that pigs allowed 0.71 (k-value = 0.026) and 0.80 m² (k-value = 0.030) would have exhibited reduced ADG by approximately 8 and 4% respectively, when compared to pigs allowed 0.90 m². However, in the present study there was only a 1% decrease in ADG observed in pigs as space decreases from 0.89 to 0.71 m² and only a 2% decrease in ADG as floor space decreased from 1.08 to 0.70 m². The results of present study are in support Gonyou et al. (2006), in that there were no observed benefits to performance in space allowances representing a k-value greater than 0.034, which represent space allowances of 0.98 (k = 0.037) and 1.08 m² (k = 0.041).

Measures of carcass composition, including BF, LMA, and percent fat-free lean were unaffected (P > 0.05) by floor space treatment (Table 2.5). Fewer studies have
evaluated the effects of floor space allowance on carcass traits than on gross indicators of performance (ADG, ADFI, and G:F). The present study is in agreement with previous research in that a reduction of floor space allowance did not influence (P > 0.05) backfat depth when pigs where fed to 108 (Brumm et al., 2004) or 136 kg (Brumm et al., 1996;Dimsoski et al., 1997) of body weight. Brumm et al. (2004), also reported there was no differences (P >0.05) in FFL percent in pigs weighing 108 kg when floor space ranged from 0.55 to 0.74 m²/pig. However, Brumm and Miller (1996) and Brumm et al. (2004) have indicated that floor space does have a significant impact (P < 0.05) on the rate FFL daily gain due to reduced rates of ADG rather than changes in carcass composition.

With regard to growth, efficiency, and carcass composition measures, results of the present study suggest that floor space allocations ranging from 0.71 to 1.08 m² had no effect on pigs taken to a market weight of 136 kg. The lack of effects on pig performance and efficiency, especially within the 0.71 and 0.80 m² floor space treatments suggest there is little need to increase the space allowances of 0.67 to 0.70 m² currently used in most contract grow-finish systems. This finding allows producers to maintain current efficiencies and infrastructure costs on a per m² basis. An increase in space requirements would require additional grow-finish facilities to maintain current production, thus increasing the cost to produce a unit of pork. However, should pig market weights exceed 136 kg in the future per packer demand or in response to short supply, floor space requirements may need to be re-evaluated at that time. Future floor space recommendations for heavier pigs should be made in order to maintain compliance with the Common Industry Swine Audit (National Pork Board, 2015), whereby 90% of pigs
must have sufficient space to lie down with full lateral recumbency without having to lie on another pig.

When evaluating pig welfare, floor space did not have any effect (P > 0.05) on the frequency of pig morbidity or pig removal during the study (Table 2.6). Similarly there were no differences (P > 0.05) in visual indicators of pig welfare including lameness, skin lesions across treatments (Table 2.6). Tail biting only occurred in the 0.98 and 1.08 m² floor spaces during one replicate of the study. In addition there were no gilts that exhibited signs of estrus in the present study. There was no effect of either floor space or time period of collection on salivary cortisol concentration, a known physiological indicator of stress in finishing pigs (Street and Gonyou, 2008). The initial cortisol concentration was measured when pigs weighed 80 kg, at which point according to Gonyou et al. (2006) pigs should have not yet experienced crowding in any of the floor space treatments (k = 0.038, 0.043, 0.048, 0.053, and 0.058 for space allowances of 0.71, 0.80, 0.89, 0.98, and 1.08 m²/pig, respectively). Samples taken the week of marketing should have been representative of the point in time where pigs were the most crowded (k = 0.026, 0.030, 0.034, 0.037, and 0.041 for space treatments 0.70, 0.80, 0.90, 0.98, and 1.08 m²/pig, respectively).

Performance and welfare data from Study 1 suggest that current space allowances of 0.67 to 0.70 m² used in most grow-finish contracts are likely sufficient for optimal performance. Gonyou et al. (2006), using the results from previous experiments, estimated that producing pigs weighing 136 kg would require a minimum of 0.89 m²; however, it appears that the pigs in the present study were able to adapt to the lesser space allowances evaluated in the present study. There is no indication that pigs given more space than 0.89
m² had improved performance, or that pigs allotted less than 0.89 m² were poorer performing or displayed signs of compromised welfare. The lack of negative effects on pig performance may be due to the fact that pigs experienced crowding for only the last few weeks of the study. Pigs in the 0.71 m² treatment according to Gonyou et al. (2006), would have experienced decreased performance at 95 kg, at which point pigs had completed over half of the grow-finish phase. Another point to consider is that even the smallest floor space treatment in the present study is slightly larger than the current industry standard for space allowance used in most contract grower systems, which may be too large to see the effect of crowding that may occur on commercial operations.

**Study 2**

The primary objective of Study 2 was to evaluate the effects of floor space on pigs weighing 136 kg, as only a few studies have taken pigs to similar weights (Brumm et al., 1996; andDimsoski et al., 1997). Similar to results obtained in Study 1, there was no difference in initial and final body weight across floor space treatments (Table 2.8). While within pen body weight CV were not different across floor space treatments, there was a numerical reduction in weight variation at the end of the 14 period, suggesting a narrowing of weight variance in the pens. In addition, there were no effects of floor space allowance on ADG, ADFI, and G:F in the heavy weight set of pigs assessed. Visual observations of pig lameness or the incidence of skin lesions (Table 2.9) were consistent across space allocations evaluated, indicating no increased risk of injury as space was lessened. The findings of Study 2 suggest that the crowding effects predicted by Gonyou et al. (2006) may not apply to fast growing pigs taken to a heavier market weight.
Conclusion

Results of Study 1 did not yield a floor space allowance that optimized pig growth, performance, or individual pig welfare. This result is likely due to pigs not experiencing crowding early in the grow-finish period when the majority of growth takes place. Moreover, Study 2 yielded similar results to Study 1, in that performance was not affected by floor space in pigs marketed at 136 kg or greater. Based on results of both studies in the project, providing pigs with 0.70 m² will provide the optimal combination of pig performance and floor space efficiency. In addition, the practice of “topping off”, in commercial grow-finish facilities would likely alleviate any potential effects of crowding prior to marketing. The results of this project also suggests further investigation needs to be focused on the effects of space allowance of heavy weight pigs to determine if previous estimation methods are still valid in making recommendations for industry standards of floor space that meet the requirements of modern grow-finish pigs.

References


Table 2.1. Description of Study 1 replicates.

<table>
<thead>
<tr>
<th></th>
<th>Replicate</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Total number of pigs</td>
<td>55</td>
<td>55</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Total pigs/pen</td>
<td>11</td>
<td>11</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Number of pigs in pen</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barrows</td>
<td>5</td>
<td>5</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Gilts</td>
<td>6</td>
<td>6</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Start Date</td>
<td>12/23/15</td>
<td></td>
<td>1/27/15</td>
<td>1/27/15</td>
</tr>
<tr>
<td>End Date</td>
<td>4/6/16</td>
<td></td>
<td>5/12/15</td>
<td>5/26/15</td>
</tr>
</tbody>
</table>
Table 2.2. Experiment diets offered to pigs during grow-finish period.

<table>
<thead>
<tr>
<th>Item</th>
<th>Pig Weight, kg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>23-45</td>
</tr>
<tr>
<td>Ingredient, %</td>
<td></td>
</tr>
<tr>
<td>Corn</td>
<td>70.96</td>
</tr>
<tr>
<td>Soybean meal</td>
<td>24.55</td>
</tr>
<tr>
<td>Fat</td>
<td>2.00</td>
</tr>
<tr>
<td>Calcium carbonate</td>
<td>1.10</td>
</tr>
<tr>
<td>Salt</td>
<td>0.40</td>
</tr>
<tr>
<td>L-Lysine</td>
<td>0.34</td>
</tr>
<tr>
<td>Dicalcium phosphate</td>
<td>0.30</td>
</tr>
<tr>
<td>Vitamin and mineral premix</td>
<td>0.20</td>
</tr>
<tr>
<td>L-Threonine</td>
<td>0.07</td>
</tr>
<tr>
<td>DL Methionine</td>
<td>0.06</td>
</tr>
<tr>
<td>Copper sulfate</td>
<td>0.05</td>
</tr>
<tr>
<td>Tylan 100</td>
<td>0.02</td>
</tr>
<tr>
<td>Calculated composition</td>
<td></td>
</tr>
<tr>
<td>Protein, %</td>
<td>17.01</td>
</tr>
<tr>
<td>Lysine, %</td>
<td>1.07</td>
</tr>
<tr>
<td>Fat, %</td>
<td>4.93</td>
</tr>
<tr>
<td>Calcium, %</td>
<td>0.57</td>
</tr>
<tr>
<td>Phosphorus, %</td>
<td>0.30</td>
</tr>
<tr>
<td>M energy, kcal/lb</td>
<td>1499</td>
</tr>
</tbody>
</table>

<sup>1</sup> Diet fed in Study 2
Table 2.3. Effects of floor space on pig body weight over the grow-finish period (Study 1).

<table>
<thead>
<tr>
<th>Body weight, kg</th>
<th>Floor space allotments (m²/pig)</th>
<th>SE</th>
<th>Significance (P &lt; 0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.71</td>
<td>0.80</td>
<td>0.89</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>25.3</th>
<th>25.4</th>
<th>25.5</th>
<th>25.5</th>
<th>25.4</th>
<th>0.14</th>
<th>NS¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV², %</td>
<td>6.6</td>
<td>5.7</td>
<td>5.9</td>
<td>6.1</td>
<td>5.4</td>
<td>0.66</td>
<td>NS</td>
</tr>
<tr>
<td>Week 4 weight³</td>
<td>50.1</td>
<td>49.8</td>
<td>50.2</td>
<td>50.3</td>
<td>50.0</td>
<td>0.39</td>
<td>NS</td>
</tr>
<tr>
<td>CV, %</td>
<td>5.7</td>
<td>5.5</td>
<td>4.9</td>
<td>4.7</td>
<td>6.4</td>
<td>1.44</td>
<td>NS</td>
</tr>
<tr>
<td>Week 8 weight³</td>
<td>79.3</td>
<td>79.3</td>
<td>80.2</td>
<td>78.5</td>
<td>79.8</td>
<td>0.91</td>
<td>NS</td>
</tr>
<tr>
<td>CV, %</td>
<td>7.0</td>
<td>5.7</td>
<td>5.9</td>
<td>4.4</td>
<td>6.8</td>
<td>0.93</td>
<td>Quadratic P = 0.039</td>
</tr>
<tr>
<td>Final</td>
<td>132.7</td>
<td>133.9</td>
<td>134.0</td>
<td>132.9</td>
<td>135.0</td>
<td>1.83</td>
<td>NS</td>
</tr>
<tr>
<td>CV, %</td>
<td>7.6</td>
<td>5.2</td>
<td>6.4</td>
<td>6.3</td>
<td>6.4</td>
<td>0.87</td>
<td>NS</td>
</tr>
</tbody>
</table>

¹NS = not significant.
²Coefficient of variation for body weight.
³Weight at diet phase change.
Table 2.4. Effects of floor space allocation on pig performance during each diet phase and the entire grow-finish period (Study 1).

<table>
<thead>
<tr>
<th>Floor space allotments (m²/pig)</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SE (P &lt; 0.05)</td>
</tr>
<tr>
<td>0.71</td>
<td>0.035</td>
</tr>
<tr>
<td>0.80</td>
<td>0.062</td>
</tr>
<tr>
<td>0.89</td>
<td>0.106</td>
</tr>
<tr>
<td>0.98</td>
<td>0.022</td>
</tr>
<tr>
<td>1.08</td>
<td>0.022</td>
</tr>
</tbody>
</table>

| Average daily gain, kg/d        |               |
| Weeks 1 – 4                     | 0.86          |
| Weeks 5 – 8                     | 1.03          |
| Weeks 9 - 16                    | 0.93          |
| Weeks 1 - 16                    | 1.00          |
|                                 | 0.035         |
|                                 | NS¹           |
|                                 |               |
| Average daily feed intake, kg/d |               |
| Weeks 1 – 4                     | 1.55          |
| Weeks 5 – 8                     | 2.74          |
| Weeks 9 - 16                    | 3.28          |
| Weeks 1 - 16                    | 2.92          |
|                                 | 0.022         |
|                                 | NS            |
|                                 |               |
| Gain:feed kg/kg                 |               |
| Weeks 1 – 4                     | 0.559         |
| Weeks 5 – 8                     | 0.376         |
| Weeks 9 – 16                    | 0.279         |
| Weeks 1 - 16                    | 0.414         |
|                                 | 0.0230        |
|                                 | NS            |

¹NS = not significant.
Table 2.5. Effects of floor space on pig carcass characteristics when evaluated at 136 kg with real time ultrasound (Study 1).

<table>
<thead>
<tr>
<th></th>
<th>Floor space allotments (m²/pig)</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.70</td>
<td>0.80</td>
</tr>
<tr>
<td>Back fat, cm</td>
<td>2.02</td>
<td>2.03</td>
</tr>
<tr>
<td>Loin muscle area, cm²</td>
<td>47.0</td>
<td>46.3</td>
</tr>
<tr>
<td>Percent Lean², %</td>
<td>51.62</td>
<td>51.64</td>
</tr>
</tbody>
</table>

¹ NS = not significant.

² Calculated using a prediction equation from National Pork Board (2000).
### Table 2.6. Effect of floor space allowance on pig mortality, morbidity, lesion scores, and incidence of lameness (Study 1).

<table>
<thead>
<tr>
<th>Trait</th>
<th>Floor space allotments (m²/pig)</th>
<th>Significance (P &lt; 0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.70</td>
<td>0.80</td>
</tr>
<tr>
<td>No. of pigs starting the trial</td>
<td>34</td>
<td>34</td>
</tr>
<tr>
<td>No. of pigs removed/dead</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>No. of days pigs treated&lt;sup&gt;1&lt;/sup&gt;</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>No. of pigs with lesions&lt;sup&gt;2&lt;/sup&gt;</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Average lesion score&lt;sup&gt;3&lt;/sup&gt;</td>
<td>1.20</td>
<td>1.12</td>
</tr>
<tr>
<td>No. of pigs with lameness score &gt;&lt;sup&gt;1&lt;/sup&gt;</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

<sup>1</sup> Number of days pigs required therapeutic treatment due to lameness or ill health.

<sup>2</sup> Number of pigs with at least one lesion observed at some time during the experiment. A single pig could be counted more than once if fresh lesions appeared.

<sup>3</sup> Lesion scoring system was: 1 = no cut, swelling, or previous wounds have healed; 2 = minor cut (cut does not go through the skin), slight swelling (skin is red with inflammation), presence of scabs; 3 = major cut (cuts through the skin), remarkable swelling, or open wounds.

<sup>4</sup> NS = not significant.

<sup>5</sup> Lameness data for last week before marketing. Lameness scoring system was: 1 = Normal walking; 2 = Slight lameness, may have an arched back; 3 = Obviously limping, but able to keep up with pen mates when group is walking; 4 = Not able to keep up with pen mates due to lameness; 5 = Can barely walk.
Table 2.7. Effects of floor space on salivary cortisol concentration (µg/dL) in pigs\(^1\) during the grow-finish period (Study 1).

<table>
<thead>
<tr>
<th>Floor space allotments (m(^2)/pig)</th>
<th>Significance (P &lt; 0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.70</td>
</tr>
<tr>
<td>Initial (80 kg)</td>
<td>0.146</td>
</tr>
<tr>
<td>Week of marketing</td>
<td>0.194</td>
</tr>
</tbody>
</table>

\(^1\)n = 22 pigs/floor space allotment.
\(^2\)NS = not significant.
Table 2.8. Effects of floor space on performance of pigs weighing greater than 136 kg. (Study 2).

<table>
<thead>
<tr>
<th></th>
<th>Floor space allotments (m²/pig)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>Significance (P &lt; 0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.70</td>
<td>0.80</td>
<td>0.90</td>
<td>0.98</td>
<td>1.08</td>
<td>SE</td>
<td></td>
</tr>
<tr>
<td>Body weight, kg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial</td>
<td>138.9</td>
<td>136.7</td>
<td>139.4</td>
<td>137.6</td>
<td>138.9</td>
<td>1.62</td>
<td>NS¹</td>
</tr>
<tr>
<td>CV², %</td>
<td>4.8</td>
<td>4.4</td>
<td>4.3</td>
<td>4.6</td>
<td>4.1</td>
<td>0.08</td>
<td>NS</td>
</tr>
<tr>
<td>Final</td>
<td>150.5</td>
<td>149.1</td>
<td>150.8</td>
<td>151.6</td>
<td>151.9</td>
<td>1.83</td>
<td>NS</td>
</tr>
<tr>
<td>CV, %</td>
<td>4.1</td>
<td>3.6</td>
<td>4.0</td>
<td>4.2</td>
<td>3.4</td>
<td>0.08</td>
<td>NS</td>
</tr>
<tr>
<td>Average daily gain, kg/d</td>
<td>0.83</td>
<td>0.88</td>
<td>0.81</td>
<td>1.00</td>
<td>0.93</td>
<td>0.10</td>
<td>NS</td>
</tr>
<tr>
<td>Average daily feed intake, kg/d</td>
<td>2.76</td>
<td>2.79</td>
<td>2.83</td>
<td>2.87</td>
<td>2.85</td>
<td>0.15</td>
<td>NS</td>
</tr>
<tr>
<td>Gain:feed, kg/kg</td>
<td>0.306</td>
<td>0.332</td>
<td>0.291</td>
<td>0.357</td>
<td>0.322</td>
<td>0.033</td>
<td>NS</td>
</tr>
</tbody>
</table>

¹ NS = not significant.
² Coefficient of variation for body weight.
Table 2.9. Effect of floor space allowance on estrus expression, lesion scores, and incidence of lameness in pigs weighing greater than 136 kg (Study 2).

<table>
<thead>
<tr>
<th>Trait</th>
<th>Floor space allotments (m²/pig)</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.70</td>
<td>0.80</td>
</tr>
<tr>
<td>No. of pigs</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>No. of gilts in estrus</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>No. of pigs with lesions¹</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Average lesion score²</td>
<td>1.55</td>
<td>2.23</td>
</tr>
<tr>
<td>No. of pigs with lameness score &gt; 1⁴</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

¹ Number of pigs with at least one lesion observed at some time during the experiment

² Lesion scoring system was: 1 = no cut, swelling, or previous wounds have healed; 2 = minor cut (cut does not go through the skin), slight swelling (skin is red with inflammation), presence of scabs; 3 = major cut (cuts through the skin), remarkable swelling, or open wounds.

³ NS = not significant.

⁴ Lameness data at the end of the 14 day trial. Lameness scoring system was: 1 = Normal walking; 2 = Slight lameness, may have an arched back; 3 = Obviously limping, but able to keep up with pen mates when group is walking; 4 = Not able to keep up with pen mates due to lameness; 5 = Can barely walk.
Chapter 3.
Rubber lying mat effects on lameness, behavior, sow production and litter performance during lactation

Abstract

The objective of the present study was to evaluate the effect of rubber lying mats on lameness mitigation, behavior, sow production and litter performance throughout lactation. In total, 213 multiparous, late gestation, group housed sows were enrolled in the study after being blocked by parity and classified as lame or non-lame. Sows were placed into farrowing crates with one of two treatments; R; farrowing crate with rubber lying mat or C; farrowing crate with standard flooring. Sow behavior, lameness and lesion scores, sow weight, and body condition measurements were obtained once weekly over the course of 4 weeks around the farrowing event (1 week prior to 3 weeks post farrowing day). Piglet weights were recorded during the weeks of farrowing and weaning. Wean to estrus intervals and piglet mortality data were obtained post-hoc via records from the farm’s computer database PigKnows®. Rubber mat treatment did not have an effect on overall lameness status with 53.3 and 57.5% of sows achieving improved lameness scores by the end of the trial for the C and R treatment respectively (P > 0.05). Sows housed on the R treatment reduced the proportion of time spent lying (P < 0.05) and tended to increase the proportion of time spent standing (P < 0.10). Sows that were lame and sows housed on R treatment weaned piglets with lower body weights when compared to non-lame sows and
sows housed on C treatment (P < 0.05). Sows on the R treatment had a higher number of crushed piglets when compared to C treatment sows (P < 0.05). Rubber mats did not affect the total number of body lesions, sow BCS or sow body weight (P > 0.05). In conclusion, rubber mats did not affect lameness status during lactation but impacted weaning weights and total piglet mortality due to crushing. Further research evaluating alternative flooring substrates is needed to mitigate lameness in the farrowing and lactation period in order to improve sow comfort and longevity while protecting piglet health and viability.

**Keywords:** sow; lameness; rubber mat; farrowing; lesions

**Funding:** This research was funded by the National Pork Board Project #14-005.

**Introduction**

Sow lameness has been identified as a major animal welfare concern due to negative affective states associated with the condition (Whay et al., 2003). Pain has been defined as “an unpleasant sensory and emotional experience associated with actual or potential tissue damage” (IASP, 1994). Lameness resulting in pain has been attributed to several etiologies including claw lesions, inadequate structural conformation, and disease (D’Allaire and Drolet, 2006). Lameness pain can be assessed utilizing a multi-modal approach and includes evaluating deviations in gait, physiological parameters and behavior
(Heinonen et al., 2013). As demonstrated by Gregiore et al. (2013), lame sows have a shorter stride and slower pace when walking. Physiologically, lame sows demonstrate changes in heart rate (Gregory, 2004) and behaviorally, lame sows have increased inactivity and are more reluctant to move (Underwood, 2002).

Lameness also has a significant economic impact to the breeding unit. When evaluating factors associated with culling and death rates, Jensen et al. (2010) demonstrated that lameness was a primary reason for involuntarily culling sows. In the US, economic loss per lame sow has been estimated at $180 and takes into account several factors including treatment cost and sow loss (i.e. culling from the farm or euthanasia; Deen et al., 2008). The ability to prevent or reduce both the prevalence and severity of lameness throughout the reproductive cycle will in turn increase overall sow longevity and decrease the economic impact of lameness to the farm (Anil et al., 2008).

Lameness may also indirectly affect sow performance as it reduces feed intake during lactation and decreases subsequent reproductive efficiency (Baidoo et al., 1992). Healthy, non-lame sows spend less time lying and more time eating than lame sows (Weary et al., 2009). Calderon-Diaz et al. (2015) observed that healthy lactating sows spent almost double the time actively eating post feed delivery than sows with claw injuries indicative of lameness (12.98 vs. 7.45 min; P < 0.05).

Additionally, lameness during the gestation period has also had a negative effect on farrowing performance. Lame farrowing sows have fewer piglets born alive (Anil et al., 2009) and greater frequencies of mummified fetuses than non-lame sows (Pluym et al., 2013) demonstrating the impact of lameness on reproductive efficiency. Lameness can also increase the risk of piglet mortality due to crushing. Bonde et al. (2004) indicated that
abnormal lying-down behavior (described as interruptions in the lying-down process which included slipping and falling) could result in an increased risk for piglet crushing.

The prevalence of lameness in farrowing sows often depends on gestation housing conditions. Spoolder et al. (2009), in a review on group housing, suggested that as the global swine industry transitions from individual crates to group gestation housing, the prevalence of lameness in the sow herd may likely increase. In group sow housing, aggression and flooring quality are two major factors that influence lameness prevalence. Aggression, defined as agonistic interactions (attacking, biting, pushing, displacement), is common in swine (D’Eath, 2002) during the first 48 hours post mixing until the social hierarchy of the group is established (Pritchard, 1996).

Flooring quality can also influence lameness prevalence and severity. Flooring commonly used in both gestation and farrowing housing consists of a combination of solid and slatted floors composed of concrete, plastic or metal. All three substrates offer minimal support for the sow and increase risk of lameness and injury due to suboptimal factors such as poor traction, rough surface and hardness (Calderon-Diaz et al., 2013). Providing sows a bedding material, such as straw, may reduce the incidence of lameness and increase comfort; however, this option is considered labor intensive, expensive and impractical for liquid manure handling systems used in modern swine farming (Tuyttens, 2005).

Identifying alternative management practices to improve comfort in commercial swine operations is critical. One alternative to straw bedding is the implementation of rubber mats as a flooring substrate. Previous research has implemented rubber mats in gestation systems and have demonstrated positive effects on lameness prevalence and sow welfare (e.g. Calderón-Diaz et al., 2014; Elmore et al., 2010; Tuyttens et al., 2008).
However, limited research has focused on how placement of rubber mats in a farrowing crate system impacts lameness severity, behavior and overall sow productivity. Therefore, the objective of the present study was to evaluate the effects of rubber lying mats placed in the farrowing crate on the mitigation of lameness and the impact on behavior, sow production, and litter performance during lactation.

**Materials and methods**

The protocol for the present study was approved by the Ohio State University Institutional Animal Care and Use Committee.

**Animals and housing**

The present study was conducted on a 5000 sow commercial swine farm located in the eastern Midwest United States between April and December, 2015. Sows were housed in 1.20 m$^2$ individual gestation crates (0.60 x 2.00 m) with partially slatted floors for the first 6 weeks post-weaning. Upon pregnancy confirmation, sows were moved to group gestation housing where they were allotted 1.86-2.04 m$^2$ per sow, on fully slatted concrete floors and fed using an electronic sow feeding system (ESF, Schauer Agrotronic Prambachkirchen, Austria). Sows had access to the ESF system for 22 hours/day and were fed a ration (2.05 kg daily) to meet or exceed the requirements for gestating swine (National Research Council, 2012). Sows were moved to a 1.30 m$^2$, bow bar farrowing crate (0.60 x 2.20 m) three days prior to expected farrowing. Crate flooring under the sow consisted of slatted metal (1 cm gap) while the creep area on both sides of the sow (0.55 x 2.20 m) were constructed with plastic slatted (1 cm gap) flooring. A single heat lamp was provided
over the creep area on one side of the sow, near the rear of the crate. Following entry, sows were provided ad libitum access to feed and water throughout lactation.

Piglets received an iron injection (200 mg, IM) and a dose of antibiotic on day 2 in compliance with farm operating procedures. Tail docking for all piglets and castration of male piglets occurred between days 3 and 7. Cross-fostering was performed between days 3 and 8 to maintain litter size and utilize available teat space according to the farm’s standard operating protocol. Cross-fostering was random and not restricted to within treatments, as piglets were moved to and from sows within and outside the study. Piglet mortality was recorded and categorized by farm staff and data were later accessed via PigKnows® V.2.8 swine management software (PigKnows LLC, Greeley, CO, USA).

Daily temperature during the enrollment period and humidity data for the day of enrollment were collected via access to the National Weather Service daily summary for the area. Information was used to calculate an estimated weekly temperature-humidity index (THI; \( \text{THI} = T - \left(0.55 - (0.0055 \times RH_{\text{decimal}})\right) \right) (T-14.5) \} \) National Oceanic and Atmospheric Administration, 1976), in which \( T \) is ambient temperature and RH is relative humidity) for data collection days.

**Experimental design**

A total of 213 multiparous commercial sows (227.1 ± 20.8 kg, average parity 3.0, range: 1-8) were enrolled. All sows underwent a physical examination by a trained veterinarian to assess overall health status prior to selection. Any sow demonstrating clinical signs of disease (with the exception of lameness) were not eligible for enrollment. At enrollment, lameness was evaluated by a trained veterinarian by assessing sow gait
during locomotion and the severity of visible toe-tapping while standing. Sows were evaluated for lameness between 100-109 days of gestation while housed in group pens utilizing an adapted three point standing and walking lameness scoring system (Table 3.1). Lameness scores of ≥ 1 in gestation were classified as lame. Any sow receiving a score 0 was classified as non-lame.

Sows were blocked by parity and assigned to one of four treatment groups, in a 2 x 2 factorial arrangement of treatments, based on their gestation lameness classification (Lame (L) or non-lame (NL)) at enrollment and floor treatment (Rubber mat (R) or Control (C)) in the farrowing crate, resulting in: Lame Control (LC; n = 45); Lame Rubber Mat (LR; n = 48); Non-Lame Control (NLC; n = 61); and Non-Lame Rubber Mat (NLR; n = 59). Sows were allocated to farrowing rooms with 60 crates in a rotational schedule based on expected farrowing day. Sows were randomly placed within a room by farm staff and mixed in with the normal population of sows based on the order they were brought from gestation housing. Allocation to rooms was on a weekly rotation. Number of sows was balanced to ensure that sows of each treatment combination were enrolled onto the study each week.

The control flooring treatment (C) consisted of a standard farrowing crate with slatted flooring in the sow and piglet area as described previously, while the rubber mat flooring treatment (R) consisted of a farrowing crate fitted with a perforated rubber boar mat (heavy duty rubber mat, width x length x thickness: 99 x 150 x 1.9 cm, perforation size: 1.4 cm, FarmerBoy Ag, Meyerstown, PA, USA; $78.08). Mats covered an area from the front of the sow’s shoulder through her hindquarters (Campler et al., 2016; Figure 1)
and remained in the farrowing crate until weaning. Mats were removed from all crates following weaning, power-washed and disinfected, and reused the following week.

**Sow measurements**

Sow observations were conducted by a team of five trained observers including one veterinarian. Data was collected within a 120 minute period on the same day each week within four defined stages post enrollment. Weekly stages included: Gestation (G) encompassed entry to the farrowing crate and prior to parturition; Farrowing (F) encompassed the observation in the week of parturition; Week one post farrowing (F1) encompassed the week after the F observation; and Weaning (W) encompassed the week a sow was weaned.

For each stage, lameness was classified (L vs. NL) for each sow by a trained veterinarian utilizing the standing scoring system described previously. Sow body weights were estimated for each stage by taking flank to flank measurements collected with a graduated measuring tape (Kansas State University, Manhattan, Kansas). Body Condition Scores (BCS) were calculated for each stage using a sow body condition caliper, which calculates sow body condition score based on fat accumulation around the vertebrae on a 1 to 3 scale (Knauer, 2015). Skin lesions were evaluated for each stage based on region (head, back, side, legs) and lesion type (redness, alopecia, calluses, mild and severe wounds). Behavior was evaluated for each stage utilizing a live 15 minute instantaneous scan method. Observations were initiated at 10:30 a.m., immediately following a single, timed feed delivery of approximately 6.35 kg. Observers were trained prior to initiation of the study by one behaviorist. All observers achieved a strong inter-observer agreement.
prior to start of the study (Correlation coefficient level; r ≥ 0.90; P < 0.05). The behavioral ethogram is described in Table 3.2.

**Litter measurements**

Total number of piglets born, born alive, stillborn, mummified, after cross-foster, and weaned were collected using information on each sow’s card. Records of piglet mortality cause (low viability, deformed, micro, spraddle legged, starved, rupture, crushed, and injured), and subsequent sow wean to estrus interval were recorded by on-farm staff and collected utilizing the PigKnows® computer software. Individual piglet body weights were recorded using a digital scale and collected between days 1-7 of age (farrowing weight) and 14-23 days of age (weaning weight). Individual piglet weights were summed and averaged to obtain litter and average piglet weights.

**Data Analysis**

**Sow measurements**

Data were analyzed using SAS software version 9.4 (SAS Institute, Cary NC). Sow lameness, body weights and BCS were analyzed using a multivariate ANOVA, PROC Mixed procedure in SAS. Floor treatment (C, R), lameness classification (L, NL) and stage (G, F, F1, and W) were used as fixed effects, with parity as a co-variate, and sow as a random effect. Lesion and behavioral data were not normally distributed and were analyzed using the PROC Glimmix procedure in SAS and included the same fixed and random effects as described above. For the behavioral analysis, parity and THI were used as covariates.
**Litter measurements**

Piglet mortality and cross-foster number was analyzed using the PROC Glimmix procedure in SAS. Floor treatment (C, R), lameness classification (L, NL) and stage (G, F, F1, and W) were used as fixed effects, with parity as a co-variate, and sow as a random effect. When estimating number of weaned piglets within treatments, the number of pigs that the sow was allowed to nurse was used as a covariate in order to standardize for piglet number after cross-fostering. Average piglet weaning weight was adjusted for day of age in the model using a linear covariate. Differences were considered significant when P ≤ 0.05.

**Results**

**Sow Measurements**

Of the 213 enrolled sows, 1 sow died and 15 sows were either culled or euthanized during the study (Table 3.3). Their data were subsequently removed leaving 197 sows in the final analysis. When evaluating weaning stage lameness classification, 53.3 and 57.5% of lame sows at enrollment had an improved lameness score and classification for the control and rubber mat treatments, respectively, with no difference (P > 0.05) when comparing flooring treatments. The incidence of acquired lameness, for NL classified sows at allocation, was approximately 23% at the weaning stage, with no difference (P > 0.05) between control (23.1%) and rubber mat (23.6%) treatments. Sow body weight and BCS measured at weaning were not impacted by either lameness status or flooring treatment (P > 0.05, Table 3.4). Of the 197 sows that completed the study, 133 exhibited a return to estrus 4 to 6 days post weaning. Of 48 sows that were identified as not serviced
post weaning, 32 were lame at weaning. All sows had a greater number of total lesions while in gestation when compared to measurements at the weaning stage (P < 0.05). When evaluating the effects of the rubber mats on the presence of skin lesions or abrasions, the frequency of redness at the lesion/abrasion site increased (P < 0.05). Lesion frequency, measured per sow for each body region, at each week of the study are summarized in Table 3.5.

**Behavioral measurements**

No differences in sow behavior were found when comparing lame and non-lame sow classifications (P > 0.05). When provided with a rubber mat, sows tended to stand more (P = 0.07) and spent significantly less time lying (P = 0.02) when compared to sows in the control flooring treatment. Stage (G, F, F1, W) within the farrowing facility influenced the amount of time sows spent lying, standing, sitting, eating (P < 0.001), and drinking (P < 0.05; Table 3.6).

**Litter Measurements**

At farrowing, there were no observed effects of sow lameness at enrollment on total born, number born alive, stillborn, or mummified piglets per litter (P > 0.05, Table 3.4). However, sows placed on rubber mats did have a greater number of piglets born alive (P< 0.05). Additionally, no differences (P > 0.05) in average piglet farrowing weight were observed across floor treatments or lameness classification at enrollment. A floor treatment effect (P < 0.05) was observed for piglet mortality due to increased overlying by sows on rubber mats (Table 3.4). There were no effects (P > 0.05) on the frequency of other
identified causes of piglet mortality within lameness classification or floor treatment. Total piglet mortality per litter, across lameness classification, was greater (P < 0.01) in sows housed on rubber mats when compared with the control (Table 3.4). While the presence of a rubber mat increased piglet mortality, there was no effect of rubber mats on the number of pigs weaned per sow (Table 3.4) or the number of piglets added or removed during cross-fostering (P > 0.05, data not shown), when adjusting for a standard number of pigs allowed to nurse. Lame sows at enrollment weaned fewer piglets than non-lame sows (Table 3.4).

**Discussion**

While the use of rubber mat flooring in gestation facilities may aid in the mitigation of sow lameness during gestation, results of the present study suggest there is little improvement when rubber mats are placed in a conventional farrowing crate as a means to mitigate lameness during the farrowing and lactation period. The results of the present study are in agreement with Elmore *et al.* (2010) which demonstrated that rubber as a flooring alternative did not improve sow lameness. Work conducted by Bos *et al.* (2016) reported that regardless of flooring type (rubber or slats), lameness improves during the short time spent in a farrowing crate when assessing group housed sows specifically. This improvement is likely a result of decreased risk of injury due to agonistic interactions within the group and allows for time in which the sow can heal. Given this, it is possible that any treatment effect was difficult to identify given the population of lame sows regardless of flooring were likely to improve.

Results from the present study also suggest that flooring treatment and lameness status did not have an impact on sow performance and productivity. These results differ
from previous research which found that lameness influenced piglet mortality (Grandjot, 2007), number born alive (Anil et al., 2009), and litter weights (Fitzgerald et al., 2012). Differences in our study may be a result of lameness severity among the population of sows enrolled on trial. Due to strict farm management procedures regarding treatment and culling standards related to lameness, the population of sows evaluated in the current trial were categorized primarily with mild lameness (i.e. lameness score 1). Of the 213 enrolled sows, only 2 sows fit the criteria of a lameness score 2 (i.e. non-weight bearing on one or more leg). With a lack of severely lame sows in the population, the trial compared non-lame sows to mildly lame sows with lameness indicators that ranged anywhere from slight toe-tapping while standing to abnormal deviations in gait. The lack of lameness severity within this population may have resulted in lameness having very limited impact on sow performance overall. Given the subjectivity of evaluating lameness through visual observation alone, future research is necessary to refine objective measurements for gait evaluation that can be utilized in a commercial setting. In addition, within the present breeding female population, a strong nutrition program and highly selective replacement female identification process may have also contributed to strong sow performance regardless of lameness status. This is likely due to generations of females chosen and mated to improve economically important production traits such as number born alive, litter size, and number of teats (Rydhmer, 2000).

Previous studies have found that rubber mats increase standing bout frequency and decrease lying bout frequency (Elmore et al., 2010). The results from the present study are in agreement with Elmore et al. (2010), whereby sows with rubber mats tended to stand more and lie less than sows on slatted flooring, an indication of increased ability or desire
to change posture, seek food and water more frequently, and potentially to rise and stand with less pain. This increase in standing behavior may also improve feed intake which is a significant challenge observed in lame or ill sows post-parturition.

Sow behavior in the present study was not influenced by lameness status. In previous work, lame sows demonstrate decreased time spent standing (Pairis-Garcia et al., 2015) eating (Fitzgerald et al., 2012; Gregoire et al., 2013) and more time spent lying (Pairis-Garcia et al., 2015). However, in the present study, lame sows did not demonstrate any deviations in standing or lying behavior when compared to control sows. When evaluating feeding behavior of lactating sows, Dourmad (1993) concluded that sows were most active, standing and eating, after each morning feed drop. Therefore, sow behavior was evaluated during the 2 hours post-morning feed drop to capture the most consistent active behavioral period for the sows on trial.

Evaluation of lesions to the integument was conducted primarily to assess physical abrasiveness of the mat and negative consequences of mat use by the sow. No differences were found between lesion frequency in lame or non-lame sows, and total lesion frequencies, regardless of treatment, decreased over the study. The environment of the individual crate allowed time for most skin lesions originating in gestation to heal over the course of farrowing and lactation and concurs with Zurbigg, 2006. However, there was an increased frequency of observed skin redness in sows housed on the rubber mat flooring compared to control sows. This may be an indicator of the increased friction and abrasiveness of the rubber mat on the skin of the sow (Christison and Farmer, 1983).

It should be noted that, of the 213 sows enrolled, three sows developed lesions on the front shoulder which required treatment. These lesions did not fit the criteria of a shoulder sore
(defined as a lesion resulting from pressure compressing the blood vessels supplying the skin and tissues covering the shoulder blade; National Pork Board, 2015) but appeared to be a superficial skin abrasion caudal to the shoulder blade. In all three cases, the sows were older and larger in size and the lesion appeared at the location where the rubber mat ended. Added weight and longer body length in the sows at the point where the mat ended may have contributed to the observed lesions. This coincides with results from Schubbert et al. (2014) whereby total contact area was reported to increase as sow weight increased. Therefore, when utilizing rubber mats in a farrowing stall, length and width of the mat should be taken into consideration to avoid uneven contact area in larger sows.

Sow lameness will not only have a negative impact on the welfare of the sow but can have severe consequences to the health and viability of her litter. In the present study, lameness status at enrollment did not have an effect on the number of live, stillborn or mummified piglets, indicating that lameness did not influence reproduction rates. This concurs with research findings reported by Anil et al. (2008). However, sows that remained lame for the duration of lactation weaned lighter pigs which may result in longer term economic consequences to the producer as lighter weaned pigs require more days on feed and a greater total amount of feed throughout the growing and finishing phases (Mahan and Lepine, 1991). Pigs weaned from crates with rubber mats were also lighter in the present study regardless of lameness status at enrollment. The rubber mats covering the slatted floor may have reduced air circulation through the crate floor, a potential factor influencing piglet performance. Reduced air quality in the micro climate of the piglets may have negatively influenced piglet health, and therefore negatively affected weight gain (Lee et al., 2005).
An unexpected outcome of the rubber mat treatment in the present study was the increased overall piglet mortality, driven by an increase in the number of piglets crushed by the sow. This finding is in contrast of Gu et al. (2010) where neoprene mats reduced the number of pigs crushed in farrowing crates, but is in agreement with a recent study evaluating rubber mat use in pen systems (Andersen and Morland, 2016). Crushing of piglets has been identified as the most common reported cause of pre-weaning mortality on commercial swine farms (NAHMS, 2012). The majority of crushed piglets are laid on within the first 48 hours post farrowing as an attempt to place themselves closer to the sow to manage cold stress and hunger (Weary et al., 1996). In the present study, piglets housed in farrowing crates with rubber mats demonstrated increased mortality associated with crushing. Black rubber mats have greater insulating ability compared to metal or plastic flooring, thus conserve heat more efficiently (Christison and Farmer, 1982). A potential reason for this increase in total crushed pigs may be due to the piglet seeking a warmer environment and placing themselves in close proximity to the sow by utilizing the rubber mat. Presence of a rubber mat may have also encouraged natural rooting behavior among piglets who are highly motivated to manipulate substrates (Stolba and Wood-Gush, 1989). As the obtained piglet mortality information was not categorized by age, it is unclear if the incidence of piglets crushed occurred within the first 48 hours (indicative of seeking the rubber mat for warmth) or later on (indicative of potential piglet interest in manipulating the substrate). The number of pigs crushed in the rubber mat treatment may be partially attributed to the fact that sows placed with that treatment had a greater number of piglets born alive, increasing the probability of crushing. In the present study, to fairly compare weaned piglet numbers across treatments, a linear covariate for number allowed to nurse
was used resulting in an unbiased estimate and no difference between floor treatment; however, birthing and maintaining a larger litter birth to weaning is important and as space within a stall is reduced with a larger number of piglets the probability of crushing will increase. Future research evaluating the impact of environment on piglet behavior, and more detailed identification of the timing of piglet crushing is needed to better understand the factors influencing piglet mortality.

**Conclusion**

Rubber mat placement in the farrowing crate had no effect on sow lameness. Presence of a rubber mat decreased piglet weaning weight and increased piglet mortality as demonstrated by an increased number of pigs crushed in both lame and non-lame sows. Findings demonstrate that altering the farrowing environment must take into account not only the sow but unintended consequences to her litter. Further research evaluating alternative flooring substrates is needed to mitigate lameness in the farrowing and lactation period in order to improve sow comfort and longevity while protecting piglet health and viability.

**References**


PigKnows. PigKnows V.2.8. 2008. PigKnows LLC. Greeley, CO. USA.


Table 3.1. Standing and walking lameness scoring system. Adapted from Welfare Quality, 2011 and Mustonen et al., 2011.

<table>
<thead>
<tr>
<th>Score</th>
<th>Lameness</th>
<th>Standing</th>
<th>Walking</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Non</td>
<td>No lameness. Sow places equal weight on all four limbs</td>
<td>No lameness.</td>
</tr>
<tr>
<td>1</td>
<td>Moderately</td>
<td>Sow places unequal amount of weight on one or more limbs. Includes evident toe tapping or shifting of weight</td>
<td>Stiff, ataxic or swaying gait, shortened stride. Limp visible, but sow unconcerned and exercises normally</td>
</tr>
<tr>
<td>2</td>
<td>Severely</td>
<td>Sow is non-weight bearing on one leg.</td>
<td>Obvious limp present at all times (with head bobbing) sow having some difficulty with exercise, moderate kyphotic posture</td>
</tr>
</tbody>
</table>
Table 3.2. Behavioral ethogram. Sows evaluated in weekly, two-hour observation windows while housed in the farrowing facility

<table>
<thead>
<tr>
<th>Behavior</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lying</td>
<td>Sow is lying down with her sternum touching the floor or fully recumbent</td>
</tr>
<tr>
<td>Standing</td>
<td>Sow is standing upright with at least 3 legs touching the floor</td>
</tr>
<tr>
<td>Sitting</td>
<td>Sow is sitting on her hind quarters with two legs straightened while touching the floor</td>
</tr>
<tr>
<td>Drinking</td>
<td>Sow is standing upright with at least 3 legs touching the floor and with mouth touching the water nipple</td>
</tr>
<tr>
<td>Nursing</td>
<td>Sow is fully recumbent and piglets are suckling or manipulating teat</td>
</tr>
<tr>
<td>Eating</td>
<td>Sow is standing upright with head in the feeder</td>
</tr>
</tbody>
</table>
Table 3.3. Reasons for sow removal from the study as identified in records obtained from the farm database (PigKnows®).

<table>
<thead>
<tr>
<th>Reason for removal</th>
<th>Lame</th>
<th>Non-lame</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dead</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Not pregnant</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Poor milk production</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Off-feed</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Retained piglets</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Did not conceive</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Reason not given</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>6</strong></td>
<td><strong>10</strong></td>
</tr>
</tbody>
</table>
Table 3.4. Least squared means of sow reproductive performance factors\(^1\) as influenced by lameness status at enrollment and farrowing floor treatment.

<table>
<thead>
<tr>
<th>Sow Measures</th>
<th>Lameness(^2)</th>
<th>Flooring Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L</td>
<td>NL</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>216.6</td>
<td>212.4</td>
</tr>
<tr>
<td>BCS(^3)</td>
<td>1.58</td>
<td>1.50</td>
</tr>
</tbody>
</table>

Farrowing Measures

<p>| | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Born</td>
<td>14.55</td>
<td>14.08</td>
<td>0.384</td>
<td>13.59(^b)</td>
<td>15.04(^a)</td>
<td>0.386</td>
<td>Floor (P &lt; 0.01)</td>
</tr>
<tr>
<td>Born Alive</td>
<td>14.01</td>
<td>13.26</td>
<td>0.338</td>
<td>13.17(^b)</td>
<td>14.11(^a)</td>
<td>0.338</td>
<td>Floor (P = 0.05)</td>
</tr>
<tr>
<td>Mummies</td>
<td>0.36</td>
<td>0.25</td>
<td>0.064</td>
<td>0.28</td>
<td>0.33</td>
<td>0.064</td>
<td>NS</td>
</tr>
<tr>
<td>Stillbirths</td>
<td>0.51</td>
<td>0.70</td>
<td>0.100</td>
<td>0.60</td>
<td>0.61</td>
<td>0.100</td>
<td>NS</td>
</tr>
<tr>
<td>Piglet Weight, kg</td>
<td>2.0</td>
<td>2.1</td>
<td>0.07</td>
<td>2.1</td>
<td>2.0</td>
<td>0.07</td>
<td>NS</td>
</tr>
</tbody>
</table>

Mortality Measures

<p>| | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Viability</td>
<td>0.19</td>
<td>0.08</td>
<td>0.056</td>
<td>0.16</td>
<td>0.12</td>
<td>0.055</td>
<td>NS</td>
</tr>
<tr>
<td>Deformed</td>
<td>0.09</td>
<td>0.02</td>
<td>0.039</td>
<td>0.02</td>
<td>0.09</td>
<td>0.039</td>
<td>NS</td>
</tr>
<tr>
<td>Micro (Runts)</td>
<td>0.30</td>
<td>0.36</td>
<td>0.078</td>
<td>0.31</td>
<td>0.34</td>
<td>0.078</td>
<td>NS</td>
</tr>
<tr>
<td>Ruptured</td>
<td>0.28</td>
<td>0.02</td>
<td>0.140</td>
<td>0.14</td>
<td>0.17</td>
<td>0.100</td>
<td>NS</td>
</tr>
<tr>
<td>Spradlle Legged</td>
<td>0.04</td>
<td>0.01</td>
<td>0.017</td>
<td>0.00(^b)</td>
<td>0.05(^a)</td>
<td>0.017</td>
<td>Floor (P &lt; 0.05)</td>
</tr>
<tr>
<td>Overlaved</td>
<td>1.03</td>
<td>0.93</td>
<td>0.130</td>
<td>0.68(^b)</td>
<td>1.28(^a)</td>
<td>0.130</td>
<td>Floor (P &lt; 0.01)</td>
</tr>
<tr>
<td>Injured</td>
<td>0.05</td>
<td>0.09</td>
<td>0.029</td>
<td>0.09</td>
<td>0.04</td>
<td>0.029</td>
<td>NS</td>
</tr>
<tr>
<td>Starved</td>
<td>0.17</td>
<td>0.07</td>
<td>0.068</td>
<td>0.07</td>
<td>0.17</td>
<td>0.068</td>
<td>NS</td>
</tr>
<tr>
<td>Total</td>
<td>2.08(^a)</td>
<td>1.47(^b)</td>
<td>0.185</td>
<td>1.40(^b)</td>
<td>2.14(^a)</td>
<td>0.185</td>
<td>Lame (P &lt; 0.05)</td>
</tr>
</tbody>
</table>

Weaning Measures

<p>| | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number Weaned</td>
<td>11.17(^b)</td>
<td>11.75(^a)</td>
<td>0.214</td>
<td>11.52</td>
<td>11.75</td>
<td>0.214</td>
<td>Lame (P = 0.05)</td>
</tr>
<tr>
<td>Piglet Weight, kg</td>
<td>5.6</td>
<td>5.7</td>
<td>0.11</td>
<td>5.8(^a)</td>
<td>5.4(^b)</td>
<td>0.11</td>
<td>Floor (P &lt; 0.05)</td>
</tr>
</tbody>
</table>

\(^1\)Sow weight, BCS measured during week of weaning.
\(^2\)Lameness (L = Lame, N = Non-lame), Floor Treatment (C = control, slotted metal flooring under the sow; R = slotted-holed rubber mat placed under the sow lying space from front of shoulder to posterior of hindquarter.
\(^3\)Sow Body Condition Scores are reported on 1-3 scale (1 = thin, 2 = Average, 3 = Fat)
\(^a\)^\(^b\) Least squares means within a row without a common superscript differ (P <0.05).\(^1\) Sow weight, BCS measured during week of weaning.
Table 3.5. Mean frequency of total lesions\(^1\) per sow (n=197) per body region for rubber mat and control flooring treatments while sows were housed in the farrowing crate.

<table>
<thead>
<tr>
<th>Body Region</th>
<th>Treatment</th>
<th>Stage(^1)</th>
<th>Stage SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>Control</td>
<td>G         2.57(^a)</td>
<td>0.79(^b)</td>
</tr>
<tr>
<td></td>
<td>Rubber</td>
<td>F         2.95(^a)</td>
<td>0.77(^b)</td>
</tr>
<tr>
<td></td>
<td>Flooring</td>
<td>SE       0.245</td>
<td>0.129</td>
</tr>
<tr>
<td>Back</td>
<td>Control</td>
<td>G         4.67**</td>
<td>0.75(^b)</td>
</tr>
<tr>
<td></td>
<td>Rubber</td>
<td>F         3.37(^a)</td>
<td>0.79(^b)</td>
</tr>
<tr>
<td></td>
<td>Flooring</td>
<td>SE       0.414</td>
<td>0.178</td>
</tr>
<tr>
<td>Side</td>
<td>Control</td>
<td>G         12.84(^a)</td>
<td>3.18(^b)**</td>
</tr>
<tr>
<td></td>
<td>Rubber</td>
<td>F         13.19(^a)</td>
<td>2.18(^b)</td>
</tr>
<tr>
<td></td>
<td>Flooring</td>
<td>SE       0.823</td>
<td>0.366</td>
</tr>
<tr>
<td>Legs</td>
<td>Control</td>
<td>G         5.85(^a)</td>
<td>1.50(^b)</td>
</tr>
<tr>
<td></td>
<td>Rubber</td>
<td>F         6.42(^a)</td>
<td>1.47(^b)</td>
</tr>
<tr>
<td></td>
<td>Flooring</td>
<td>SE       0.418</td>
<td>0.201</td>
</tr>
</tbody>
</table>

\(^1\)Stages: G = gestating, F = week of farrowing, F1 = 1 week post farrowing, and W = week of weaning.

\(^a-d\) Least squares means within a row without a common superscript differ (P <0.05).

* Least squares means within a specific body region column without a common superscript differ (P <0.05).
Table 3.6. Least square means for percentage of time for sow\textsuperscript{1} behavior over four weekly production stages (Gestation (G), Farrowing (F), Post Farrowing (F1), and Weaning (W)) and across farrowing stall floor treatments.

<table>
<thead>
<tr>
<th>Behavior</th>
<th>Stage</th>
<th>Floor Treatment</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>G</td>
<td>F</td>
<td>F1</td>
</tr>
<tr>
<td>Lying</td>
<td>78.9\textsuperscript{a}</td>
<td>71.1\textsuperscript{b}</td>
<td>62.4\textsuperscript{c}</td>
</tr>
<tr>
<td>Standing</td>
<td>4.3\textsuperscript{a}</td>
<td>3.0\textsuperscript{a}</td>
<td>3.8\textsuperscript{a}</td>
</tr>
<tr>
<td>Sitting</td>
<td>3.9\textsuperscript{a}</td>
<td>4.1\textsuperscript{a}</td>
<td>6.4\textsuperscript{b}</td>
</tr>
<tr>
<td>Nursing</td>
<td>N/A</td>
<td>15.2\textsuperscript{a}</td>
<td>13.8\textsuperscript{ab}</td>
</tr>
<tr>
<td>Eating</td>
<td>8.8\textsuperscript{a}</td>
<td>6.6\textsuperscript{a}</td>
<td>11.4\textsuperscript{b}</td>
</tr>
<tr>
<td>Drinking</td>
<td>1.5\textsuperscript{ab}</td>
<td>1.6\textsuperscript{ab}</td>
<td>0.9\textsuperscript{a}</td>
</tr>
</tbody>
</table>

\textsuperscript{1} 197 multiparous commercial sows (227.1± 20.8 kg, average parity 3.0)

\textsuperscript{2} Floor Treatment: C = control, slotted metal flooring under the sow; R = rubber mat, slotted-holed rubber mat placed under the sow lying space from front of shoulder to posterior of hindquarter.

\textsuperscript{a-d} Least squares means within a row and main effect without a common superscript differ (P < 0.05).
Figure 3.1. Farrowing crate with rubber floor mat in place from front of shoulder to posterior of hindquarters (Campler et al., 2016).
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