Minimal floor space allowance for gestating sows kept in pens with electronic sow feeders on fully slatted floors

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ABSTRACT: A study was conducted to evaluate the minimal floor space allowance for gestating sows group-housed in pens with electronic sow feeders (ESF). Five floor space allowances were each tested in 4 pens: 1.5 m², 1.7 m², 1.9 m², 2.1 m² per sow, and 1.5 m² per sow with more space (2.1 m² per sow) during the first week of mixing (2.1/1.5 m²). The floor space allowances were achieved by adjusting pen size (from 80 to 88 m²) and group size (42, 46, and 51 sows per pen). Pregnant sows ($n = 928$, Large White $\times$ Landrace, parity = 1 to 9) were moved to ESF pens at about 5 wk of gestation and remained in their pens until about day 109 of gestation. Sows farrowed in individual stalls and weaned their litters at about 19 d after farrowing. Sows that were rebred within 1 wk after weaning were considered to have completed the study. Performance, skin lesions, and incidence of lameness in ESF pens were monitored for all sows. Data were analyzed using the Frequency, Glimmix, and Mixed procedures of the SAS software. Floor space allowance did not affect ($P = 0.18$ or greater) body weight, backfat depth, or condition score in ESF pens or during the lactation period. No differences ($P = 0.23$ or greater) were detected in farrowing rates (95, 92,

94, 94, and 95% for 1.5, 1.7, 1.9, 2.1, and 1.5/2.1 m², respectively), completion rates (83, 79, 80, 86, and 86%), live litter size farrowed (12.5, 12.7, 12.2, 12.3, and 12.5 pigs per litter, SE = 0.24), litter size weaned (10.4, 10.5, 10.2, 10.2, and 10.6 pigs per litter, SE = 0.22), litter weight farrowed, litter weight weaned, or wean-to-estrus interval among treatment groups. Skin lesion scores for the body and for the vulva 2 d after mixing into ESF pens and when moved from ESF pens to farrowing quarters were similar across treatment groups ($P = 0.54$ or greater). Incidence of lameness 2 d after mixing was higher ($\chi^2 = 21.1$, df = 4; $P = 0.01$) for sows allowed 2.1/1.5 m² (9.5%) and 2.1 m² (4.2%) than sows allowed 1.9 m² (1.8%), 1.7 m² (2.9%), and 1.5 m² (1.5%), which may be associated with fighting to establish dominance hierarchy during mixing in pens with larger open areas. No difference was observed in incidence of lameness when moved from ESF pens to farrowing quarters among treatment groups. These results suggest that the minimal floor space allowance of 1.5 m² appears to be acceptable for maintaining reproductive performance and welfare of gestating sows group-housed under conditions of the current study.

Key words: electronic sow feeders, floor space, gestating sows, group housing

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INTRODUCTION

Recommendations for the minimal floor space allowance of group-housed gestating sows in confinement systems with fully slatted floors do not exist in the United States. The minimal space allowance

often used for group-housed gestating sows on commercial farms was 1.5 m² per sow (Miller, 2012). This space allowance is close to the minimal space allowance of 1.4 m² per sow recommended years ago in Australia (PISC, 2007), but lower than recommendations in other countries (Council Directive 2008/120/EC, 2009; NFACC, 2014). The minimal standard for floor space allowance set up by the European Union (EU; Council Directive 2008/120/EC, 2009) is 2.25 m² per sow, and 1.64 m² per gilt. The EU standard varies with group sizes. When the number of sows in a group is more than 40, floor space allowance can be reduced by 10%; but when group size is less than 6, space allowance should be increased by 10%. In addition, the EU standard requires 58% of floor space be solid. The Canadian Code of Practice (NFACC, 2014) recommends a minimal floor space allowance of 1.8 to 2.2 m² per sow and 1.4 to 1.7 m² per gilt, which allows variation according to the floor type, group size, and feeding system used. These ranges exist because pigs housed on solid floors or partially slatted floors will require more space than pigs housed on fully slatted floors (Gonyou et al., 2006; Averos et al., 2010).

Previous studies (Salak-Johnson et al., 2007; Johnston and Li, 2013) indicate that limited floor space during gestation for group-housed sows can reduce farrowing rates, and increase culling rates and skin lesions in sows. In a recent study, Hemsworth et al. (2016) reported decreasing space allowance from 3.0 m² to 1.4 m² per sow decreased farrowing rate from 75% to 60%. Likewise, Salak-Johnson et al. (2007) noted that reducing space allowance from 2.3 to 1.4 m² increased skin lesion scores, and reduced body weight, backfat depth, and body condition scores of gestating sows. A recent on-farm study (Pluym et al., 2017) which involved 15 sow herds on different farms in Belgium indicates that when floor space allowance for gestating sows was decreased from 3.0 to 1.7 m², incidence of lameness was increase. However, exceptions exist. Among the 15 farms, 1 farm that provided space allowance of 1.8 m² to their sows had lower incidence of lameness than other farms that provide more space to their sows (Pluym et al., 2017). All these studies suggest that while space allowances of 1.4 m² are too small, the minimal space allowance for gestating sows could not be defined (Hemsworth et al., 2016).

In crowded pens where there is little space for sows to retreat, aggression among sows during mixing may be escalated and last for longer periods than in spacious pens (Arey and Edwards, 1998), resulting in injuries to sows. Hemsworth et al. (2013) suggested that newly mixed sows may need

more space to establish social hierarchy than sows in a stable social group. Providing more space during mixing might help sows establish social hierarchy and reduce injuries caused by fighting. Once a stable social group is formed, sows could be housed in pens with lower floor space allowance. If this approach proves successful, producers could use a few pens (mixing pens) with high space allowance during the mixing period and then move sows into their home pens with lower floor space allowance.

In the United States, about 25% of gestating sows are group-housed (National Pork Board, personal communication). These sows are usually housed in large groups (more than 50 sows per pen) with electronic sow feeders (ESF) on fully slatted floors. Both large group sizes and fully slatted floors may allow space sharing among sows and efficient utilization of floor space such that the minimal floor space allowance may be lower than EU and Canadian standards. Floor space allowance is associated with efficient utilization of barn space and profit of a swine operation. Consequently, the minimal floor space allowance that can maintain welfare and performance of sows in group housing systems and simultaneously maintain profitability of the farm needs to be investigated in the United States. The objectives of this study were to determine the minimal floor space allowance that will protect performance and welfare of gestating sows kept in pens with an ESF system, and to assess whether providing more space during mixing will improve welfare and performance of group-housed sows with limited floor space.

MATERIALS AND METHODS

The Institutional Animal Care and Use Committee of the University of Minnesota reviewed and approved the experimental protocol for this project (IACUC# 1406 – 31590A).

Animals, Housing, and Management

This study was conducted at the University of Minnesota's Southern Research and Outreach Center in Waseca, MN, between February 2015 and October 2016. The swine breeding herd was managed in groups. Every 2 wk, a group of 55 to 65 sows (Large White × Danish Landrace, TOPIGS 20; TOPIGS Inc., Winnipeg, Manitoba, Canada) were bred within a week. All sows were housed in pens with an ESF during their previous gestation, and no gilts were included in the study.

Sows were moved to breeding stalls (2.1 m × 0.6 m, Crystal Spring Hog Equipment, Ste. Agathe,

Manitoba, Canada) on the day of weaning. Sows were mated twice through artificial insemination and remained in stalls for 5 wk. Five weeks after mating, sows that were diagnosed pregnant were introduced into an experimental gestation pen and managed as a static group (Li and Gonyou, 2013). Each gestation pen was equipped with 4 nipple drinkers and an ESF station (3.7 m × 0.5 m; Porcode Model, Osborne Industries, Osborne, KS) on fully slatted floors. Drinkers were affixed on pen partitions, with 2 drinkers on each of 2 partitions. The ESF station, located in the center of the pen, controlled individual feed intake of sows using a RFID (radio-frequency identification) ear tag. The recommended stocking capacity of the ESF station by the manufacturer was 65 to 75 sows per feeding station. The slatted floors consisted of openings of 2-cm width, and slats of 10-cm width. Sows had continuous access to ESF stations, and the ESF feeding cycle started at 1600 h daily. Throughout the gestation period, each sow was provided 2 kg of a gestation diet daily, which was adjusted according to body condition of the sow to achieve a condition score of 3 (Coffey et al., 1999) at farrowing. On about day 109 of gestation, sows were moved to confinement farrowing quarters and fed 2 kg daily of a lactation diet. After parturition, sows were allowed ad libitum access to the lactation diet and water throughout the lactation period. To stimulate feed intake and maintain feed fresh, feed was added by hand to each individual feeder twice daily during the lactation period. Piglets were cross-fostered within each space allowance treatment (see Experimental Treatments and Design) within 24 h of birth to equalize litter size as much as possible. Tail docking and iron administration were completed on all litters within 24 h after farrowing. Male pigs were castrated within a week after birth. Piglets were weaned at about 19 d of age. Sows were rebred within 1 wk after weaning for the next gestation cycle. Sows that experienced compromised health during the study were treated according to the farm standard operating procedures and the treatment was recorded. If necessary, sows and piglets with compromised health or welfare were humanely euthanized according to the guidance of the National Pork Board (NPB, 2016). All diets were corn-soybean meal based in mash form and formulated according to NRC (2012) recommendations. Room temperature was controlled by a heating system and exhaust fans as close as possible to thermoneutral conditions for sows both in the gestation and lactation rooms. Lights in each room were on for 10 h daily starting at 0600 h in

both gestation and lactation quarters. More details about sow housing and management have been described by Ren et al. (2017).

Experimental Treatments and Design

To determine the minimal floor space allowance and evaluate the benefit of providing more space during the first week of mixing for sows with limited floor space, 5 floor space allowances were tested: 2.1 m² (control), 1.9 m², 1.7 m², 1.5 m² per sow, and 1.5 m² per sow with more space (2.1 m²) during the first week of mixing (2.1/1.5 m²). This range of space allowances was determined according to the EU and Canadian recommendations for the minimal floor space allowance for gestating sows, and the U.S. producers' desire to maintain sow inventory in existing buildings when moving from stalls to pens (Johnston and Li, 2013). The first 4 treatments enabled us to investigate effects of space allowance on performance and welfare of sows, with the ultimate goal of determining the minimal space allowance for gestating sows in an ESF system. The fifth treatment was designed to test whether providing more space during the mixing period would benefit sows that would ultimately be housed in the most crowded pens. For the fifth treatment, we provided floor space of 2.1 m² per sow during the first week after mixing, and then reduced space allowance to 1.5 m² per sow using an adjustable partition. Sows remained at 1.5 m² of floor space for the remaining gestation period. Floor space allowances did not include areas occupied by the ESF station.

Four pens with adjustable partitions were used. Each floor space treatment was achieved by adjusting both the pen size and the number of sows in the pen. Throughout the study, 2 pen sizes (13.1 m × 6.9 m; and 11.7 m × 6.9 m) and 3 group sizes (42, 46, and 51 sows per pen) were applied when sows entered the gestation pens (Table 1). Effort was made to maintain consistent sow parity across

Table 1. Pen sizes and number of sows in each pen for 5 floor space treatments

Floor space allowance ¹ (m ² per sow)	Pen size (m × m)	Group size (sows per pen)
1.5	11.7 × 6.9	51
1.7	13.1 × 6.9	51
1.9	13.1 × 6.9	46
2.1	13.1 × 6.9	42
2.1/1.5 ²	13.1 × 6.9	42

¹Sows were moved and mixed in ESF pens after pregnancy confirmation at 5 wk after mating.

²Floor space allowance was 2.1 m² during the first week after mixing into ESF pens, and then reduced to 1.5 m² until day 109 of gestation.

all pens. However, due to difference in parity composition and the available number of sows bred in each breeding group, sow parity composition in each pen varied. Across all pens, on average, parity 1 to 2 sows were accounted for 28%, parity 3 to 4 sows were accounted for 25%, parity 5 to 6 sows were accounted for 24%, and parity 7 to 9 sows were accounted for 23% of the total number of sows in a pen. At the individual pen level, the maximal variation in parity composition from the average composition was 8%. For instance, in a pen of 1.9 m² floor space allowance treatment, 36% of sows were parity 1 to 2, which was 8% higher than 28%, the average percentage for parity 1 to 2 across all pens. Likewise, in a pen of 2.1 m² floor space allowance treatment, 31% of sows were parity 7 to 9, which was 8% higher than the average 23%. Once assigned, sows remained in their pens until about day 109 of gestation. In case of sow removals due to compromised health or welfare, pen size was reduced for every 2 sows removed to maintain floor space consistent throughout the gestation period. To minimize sow removal and maintain group size, sows that were found not pregnant after entering the gestation pen remained with their pen mates until the end of the gestation cycle.

The 5 floor space treatments were tested in 4 pens, yielding 20 pens in total for the study. Sows from the first 5 available breeding groups were assigned to 5 floor space treatments in a random order. Five sequential groups were defined as a block. The study was conducted in 4 blocks to achieve 4 pens for each treatment. In total, 928 pregnant sows were assigned to treatments for the entire study. All sows had no evidence of lameness or skin lesions at entry to the study.

Data Collection

Data collection started before sows were moved into ESF pens, and ended when sows were rebred after weaning for the next gestation cycle. Data collected during this period included performance and welfare indicators of sows.

Reproductive performance. Standard production data including farrowing rate (number of sows farrowed/number of sows assigned to the study $\times$ 100%), removal rate (number of sows removed/number of sows assigned to the study $\times$ 100%), reasons for removal, total and live litter size, mummified and still born pigs per litter, litter size after cross-fostering, litter size at weaning, preweaning mortality (number of dead piglets

from birth to weaning/total born alive $\times$ 100%) for each litter, and litter weight at birth and at weaning were collected for all sows. Reasons for removal from the study were classified into the following categories: fail to conceive, abortion, lameness, sickness, old age, died or euthanized due to compromised welfare, and failure to show estrus within a week after weaning. Sows that farrowed and weaned a litter, and were rebred within 1 wk after weaning were considered to have completed the study. Completion rates (number of sows completing the study/number of sows assigned to the study $\times$ 100%) were calculated for each space allowance treatment. Dates that sows were bred, moved to ESF pens, moved out from ESF pens to farrowing quarters, farrowed, and weaned were recorded from which days in gestation, days in ESF pens, days in lactation, and wean-to-estrus interval were calculated for each sow.

Body weight, backfat depth, body condition, and feed intake of sows. Individual weight and backfat depth were recorded for all sows before mixing in ESF pens, when moved from gestation pens to farrowing quarters, and at weaning. Backfat depth was measured at the last rib 6 to 7 cm off the midline on the left and right side (P2 position) using an ultrasonic scanner (Lean-meter, Renco, Minneapolis, MN). Body condition was both assessed visually and measured objectively using a sow caliper (Knauer and Baitinger, 2015) before mixing in ESF pens and when moved from ESF pens to farrowing quarters. The method for visual assessment of body condition followed that of Coffey et al. (1999) using a scoring system of 1 to 5: score 1 = emaciated, score 2 = thin, score 3 = ideal, score 4 = fat, and score 5 = obese. The caliper measurement was taken at the P2 position where backfat depth was measured (Knauer and Baitinger, 2015). Both visual assessment and caliper measurement were recorded by 1 researcher throughout the study. Measurements of backfat depth and body condition using the sow caliper were recorded in gestation stalls the day before sows entered ESF pens, and in farrowing stalls on the day that sows entered farrowing rooms from ESF pens.

Individual feed intake of sows in ESF pens was retrieved from a computer that controlled the ESF system, from which ADFI was calculated. The number of days that sows failed to consume their entire allotment of feed in ESF pens were registered for each sow. Average daily feed intake during the lactation period was calculated for each sow from daily feed additions between the day of farrowing and the day of weaning.

Skin lesions and lameness. To evaluate effects of floor space allowance on sow welfare, skin lesions resulting from aggression, wounds, and lameness were assessed visually for all sows in ESF pens. All assessments took place 2 d after sows were mixed in ESF pens and 2 d before sows were moved from ESF pens to farrowing quarters. Skin lesions were assessed on 12 regions of each sow: the head, 2 ears, 2 shoulders, 2 flanks, 2 hindquarters/thighs, the back, the tail, and the vulva. Each region was assigned a score of 0 to 3 according to the method described by [Hodgkiss et al. \(1998\)](#): score 0 = no scratches, score 1 = 1 to 5 superficial scratches, score 2 = 6 to 10 superficial scratches and/or 1 to 3 deep scratches, score 3 = more than 10 superficial scratches and/or more than 3 deep scratches. Superficial scratches were defined as red marks without visible blood on the skin, and deep scratches were defined as scratches with visible blood on the skin. Wounds and lameness were assessed using the method described by [Li and Gonyou \(2013\)](#). Wounds included cuts into the skin, swelling (skin is red with signs of inflammation), and open or healed abscesses. Due to the low incidence of wounds, the total number of cuts, swellings, and abscesses was registered for each sow. For assessment of lameness, a subjective scoring system was used: score 1 = no lameness (bare weight on 4 legs evenly), score 2 = slightly lame (cannot bare full weight on 1 leg), score 3 = lame (cannot put weight on 1 or more legs). A total score for skin lesions on the body which included 12 regions except the vulva, a score for skin lesions on the vulva, a total number of wounds, and a score for lameness were calculated for each sow.

Data Analysis

Data were analyzed using the FREQ, Glimmix, and Mixed procedures of the SAS software (SAS Inst. Inc., Cary, NC). The FREQ procedure with chi-square test was used to analyze farrowing rate, removal rate, and completion rate. The Glimmix procedure was used to analyze gestation and lactation performance, and injury scores. Within the Glimmix model, Poisson distribution was used to analyze count data (litter size, wean-to-estrus interval, condition scores, skin lesion scores, lameness scores, and the number of wounds) and Gaussian distribution was used to analyze continuous data (backfat depth, sow caliper measurement, and pre-weaning mortality). The Mixed procedure was used to analyze all other variables. To analyze parity

effect, sows were classified into 4 categories: parity 1 and 2, parity 3 and 4, parity 5 and 6, and parity 7 to 9. Within each model, floor space allowance, parity category, interactions of space allowance and parity, and gestation period (if applicable) were fixed effects, and block was the random effect. Parity nested within pen was the experimental unit for analysis of gestation performance data, scores for skin lesions and lameness, and the number of wounds. For analysis of farrowing performance data, individual sow was the experimental unit. Repeated measurements were used to analyze treatment effects on response variables measured over time. Differences among multiple means were tested by the Tukey's test, and significant differences were identified at $P < 0.05$ and trends at $P < 0.10$. Data are reported as least square means and SEs.

RESULTS

Floor space allowance in ESF pens did not affect farrowing rates, gestation length, or ADFI in gestation pens ($P = 0.15$ or greater; [Table 2](#)). Sows provided with 1.7 m² failed to consume their total daily feed allotment more frequently (0.8 d per sow vs. 0.3 to 0.4 d per sow; $P < 0.05$) compared with sows provided with 1.9, 2.1, and 1.5 m², but did not differ from sows provided with 2.1/1.5 m². No differences were observed in body weight, weight change, backfat depth, or body condition (visual scores and caliper measurements) among treatment groups at any time point ($P = 0.18$ or greater).

No interactions of floor space allowance and sow parity category were detected on any variables measured ($P = 0.42$ or greater), indicating that sows in different parity categories responded to floor space allowance in a similar way. Sow parity tended to influence farrowing rate ($P = 0.06$; [Table 3](#)), with sows in parity 3 and 4 tending to have higher farrowing rate than older sows in parity 7 to 9, with other sows being intermediate. Although provided with the same amount of daily allotment, sows in parity 1 and 2 had lower ADFI ($P < 0.05$) in gestation pens than sows in parity 3 and 4 and sows in parity 5 and 6, with sows in parity 7 to 9 being intermediate. There were no differences in the number of days that sows failed to consume the entire allotment in the ESF among sows in different parities. Older sows in parity 7 to 9 were heavier than young sows in parity 1 and 2, with other sows being intermediate when they entered gestation pens, left gestation pens for farrowing, and weaned their litter (all $P < 0.001$). No differences were observed in weight change in gestation pens among sows in

Table 2. Performance of sows provided with different floor space allowances in ESF pens during gestation

Item	Floor space allowance in ESF pens (m ² per sow)					SE	P-value
	1.5	1.7	1.9	2.1	2.1/1.5 ¹		Floor space
Number of pens	4	4	4	4	4	—	—
Sows per pen	51	51	46	42	42	—	—
Average parity	4.3	4.4	4.2	4.9	4.3	0.18	0.12
Farrowing rate (%) ²	94.6	91.7	93.5	93.5	95.2	—	0.66 ³
Gestation length (d) ⁴	115.7	115.6	115.6	115.9	115.5	0.13	0.15
ADFI in ESF pens (kg) ⁵	2.1	2.0	2.0	2.1	2.0	0.01	0.43
Days failed to consume allotment in ESF pens (d per sow) ⁶	0.3 ^c	0.8 ^a	0.4 ^{bc}	0.3 ^{bc}	0.5 ^{ab}	0.06	0.01
Weight (kg)							
Move to ESF pens ⁷	207.2	210.5	206.0	209.2	208.3	3.69	0.83
Move to farrowing ⁸	242.0	241.5	236.4	244.4	239.8	4.74	0.84
Weaning ⁹	232.2	235.2	230.8	235.7	232.9	4.49	0.89
Weight change (kg)							
In ESF pens ⁵	34.2	30.1	30.7	35.4	31.7	2.82	0.18
During lactation ¹⁰	−9.2	−6.5	−5.6	−8.3	−7.0	1.1	0.31
Backfat thickness (mm)							
Move to ESF pens ⁷	13.2	13.6	13.2	13.3	13.2	0.48	0.92
Move to farrowing ⁸	14.3	15.2	14.2	15.1	14.4	0.71	0.37
Weaning ⁹	12.3	13.0	13.3	13.6	12.8	0.81	0.31
Body condition scores							
Move to ESF pens ⁷	3.1	3.1	3.0	3.0	3.2	0.21	0.87
Move to farrowing ⁸	3.2	3.2	3.1	3.2	3.2	0.21	0.96
Body condition (caliper measurement)							
Move to ESF pens ⁷	11.2	11.5	11.3	10.9	11.2	0.29	0.64
Move to farrowing ⁸	11.5	11.8	11.4	11.7	11.6	0.31	0.74

^{a-c}Means within a row without a common superscript differ ($P < 0.05$).

¹Floor space allowance was 2.1 m² during the first week after mixing into ESF pens, and then reduced to 1.5 m² until day 109 of gestation.

²Percent of sows assigned to the study.

³Chi-square test ($\chi^2 = 2.39$; $df = 4$).

⁴Days between first mating and farrowing.

⁵Between day 35 and day 109 of gestation.

⁶Number of days that sows consumed partial but not entire daily feed allotment in ESF pens.

⁷Sows were moved to ESF pens after pregnancy confirmation at about 5 wk after breeding.

⁸Sows were moved from ESF pens to farrowing quarters at about day 109 of gestation.

⁹Sows weaned their litter at about 19 d after farrowing.

¹⁰From day 109 of gestation to the day of weaning.

different parities. During the lactation period as parity increased, sows lost less weight ($P < 0.001$). Sows in parity 1 and 2 had greater backfat depth compared with sows in other parities at both entering ($P < 0.001$) and leaving ESF pens ($P < 0.001$). The difference in backfat depth among sows in different parities was not observed at weaning. In agreement with measurements of backfat depth, body condition scores were greater for parity 1 and 2 sows than for sows in other parities ($P < 0.001$). Body condition measured using the sow caliper demonstrated the same pattern as condition scores obtained by visual assessment.

In general, floor space treatment (Table 4) did not affect farrowing performance, including the number of pigs born in total or alive, the number of pigs born still or mummified, the number of piglets

weaned, preweaning mortality, litter weight at birth or litter weight at weaning ($P = 0.18$ or greater). However, space allowance treatment affected lactation length ($P = 0.01$), with sows allowed 1.9 m² and 2.1/1.5 m² having longer lactation duration than sows allowed 1.7 and 2.1 m². In addition, sows allowed 1.7 m² of floor space had greater ADFI during the lactation period than sows allowed 1.5 m², with sows in other treatment groups being intermediate ($P = 0.01$).

No interactions of floor space allowance and sow parity were observed for any variables of farrowing performance ($P = 0.44$ or greater). Parity affected most farrowing variables ($P < 0.01$; Table 5). Sows in parity 3 and 4 farrowed larger number of total pigs per litter ($P < 0.001$) than older sows (parity 5 to 9). As parity increased,

Table 3. Effect of parity on gestational performance of sows

Item ¹	Parity category				SE	<i>P</i> -value Parity
	Parity 1–2	Parity 3–4	Parity 5–6	Parity 7–9		
Number of sows assigned	263	237	212	216		–
Farrowing rate (%)	93.2	96.2	94.8	90.3	–	0.06 ²
Gestation length (d)	115.6	115.6	115.5	115.9	0.13	0.23
ADFI in ESF pens (kg)	1.9 ^b	2.1 ^a	2.1 ^a	2.0 ^{ab}	0.01	0.01
Days failed to consume allotment in ESF pens (d per sow)	0.6	0.4	0.4	0.4	0.08	0.13
Weight (kg)						
Move to ESF pens	199.4 ^c	203.4 ^b	211.5 ^b	221.9 ^a	2.36	<0.001
Move to farrowing	232.1 ^c	236.6 ^b	244.3 ^b	253.1 ^a	2.62	<0.001
Weaning	215.9 ^d	230.4 ^c	239.3 ^b	253.5 ^a	2.61	<0.001
Weight change (kg)						
In ESF pens	32.4	33.3	32.8	31.4	1.58	0.84
During lactation	–15.7 ^d	–6.4 ^c	–4.9 ^b	0.3 ^a	1.59	<0.001
Backfat thickness (mm)						
Move to ESF pens	14.7 ^a	12.5 ^b	12.4 ^b	13.4 ^b	0.36	<0.001
Move to farrowing	16.2 ^a	13.9 ^b	13.6 ^b	14.6 ^b	0.43	<0.001
Weaning	13.5	12.5	12.7	13.5	0.45	0.21
Body condition scores						
Move to ESF pens	3.4 ^a	3.0 ^b	2.9 ^b	3.0 ^b	0.10	0.01
Move to farrowing	3.4 ^a	3.1 ^b	3.0 ^b	3.1 ^b	0.10	0.01
Body condition (caliper measurement)						
Move to ESF pens	12.1 ^a	10.8 ^b	10.8 ^b	11.1 ^b	0.21	<0.001
Move to farrowing	12.6 ^a	11.3 ^b	11.2 ^b	11.3 ^b	0.22	<0.001

No interactions of floor space allowance and parity were detected for any variables ($P = 0.42$ or greater).

^{a–d}Means within a row without a common superscript differ ($P < 0.05$).

¹All variables are same as in Table 1.

²Chi-square test ($\chi^2 = 7.31$; $df = 3$).

the number of piglets born alive was decreased ($P < 0.001$), with sows in parity 1 and 2 farrowing the most and sows in parity 7 to 9 farrowing the least live piglets. Sows in parity 1 and 2 had fewer stillbirth ($P < 0.001$), lost fewer piglets during the lactation period ($P < 0.001$), and had lower pre-weaning mortality ($P < 0.001$) than sows in other parities. As a result, sows in parity 1 and 2 weaned the largest litters, and sows in parity 7 to 9 weaned the smallest litters ($P < 0.001$). Similar to litter size born alive and litter size at weaning, litter weights at both birth and weaning were decreased as parity increased. Sows in parity 1 and 2 had the heaviest litters, sows in parity 7 to 9 had the lightest litters at both birth and weaning. Compared with sows in other parities, sows in parity 1 and 2 had lower ADFI during lactation ($P < 0.001$). Parity did not affect the number of piglets born mummified, the length of lactation period, or wean-to-estrus interval for the next breeding cycle.

Floor space allowance did not affect skin lesions or the number of wounds sustained by sows at any time point that measurements were recorded ($P = 0.54$ or greater; Table 6). Across floor space treatments, sows had higher lesion scores on the

body ($P < 0.001$) after mixing into ESF pens than before moving to farrowing quarters. In contrast to lesion scores for the body, lesion scores for the vulva were lower ($P < 0.001$) after mixing in ESF pens compared to scores before moving for farrowing. In general, the number of wounds was low (<0.5 wounds per sow). No difference in the total number of wounds was detected after mixing compared with before farrowing. Likewise, the incidence of lameness was low and no sows with lameness score 3 were observed at any time point of assessment. Sows with severe lameness were treated or removed to hospital pens immediately when observed. As a result, incidence of lameness was evaluated by the number of sows that were scored 2 for lameness as a percentage of sows assigned to each treatment. Sows allowed 2.1/1.5 m² and 2.1 m² were more frequently scored 2 for lameness compared with sows in other treatment groups after mixing in ESF pens ($\chi^2 = 21.1$, $df = 4$; $P = 0.01$). This difference in lameness among floor space treatments disappeared when sows were moved from ESF pens to farrowing quarters.

No interactions of space allowance and parity on skin lesions, wounds, or lameness were detected

Table 4. Farrowing performance of sows allowed different floor space in ESF pens during gestation

Item	Floor space allowance in ESF pens (m ² per sow)					P-value	
	1.5	1.7	1.9	2.1	2.1/1.5 ¹	SE	Floor space
Number of sows assigned	204	204	184	168	168	–	–
Number of sows farrowed	193	187	172	157	160	–	–
Parity of sows farrowed	4.3	4.4	4.2	4.9	4.3	0.18	0.12
Litter size (piglets per litter)							
Total born	14.9	14.7	14.6	14.5	14.7	0.28	0.95
Born alive	12.5	12.7	12.2	12.3	12.5	0.25	0.50
After cross-fostering ²	11.2	11.3	11.0	11.1	11.3	0.25	0.93
Stillborn	1.8	1.5	1.9	1.7	1.6	0.13	0.18
Mummy	0.5	0.5	0.5	0.5	0.6	0.07	0.76
Weaned	10.4	10.5	10.2	10.2	10.6	0.23	0.83
Preweaning mortality (%) ³	17.9	19.8	18.6	17.0	19.4	1.48	0.70
Litter weight (kg per litter)							
At birth	17.3	17.4	16.9	17.1	16.6	0.39	0.40
At weaning	61.9	63.4	60.3	62.5	62.5	0.96	0.28
Lactation length (d) ⁴	18.9 ^{ab}	18.6 ^b	19.3 ^a	18.6 ^b	19.2 ^a	0.15	0.01
ADFI during lactation (kg) ⁴	6.3 ^b	6.9 ^a	6.8 ^{ab}	6.4 ^{ab}	6.3 ^{ab}	0.15	0.01
Wean-to-estrus interval (d)	5.4	5.5	5.5	5.8	5.3	0.18	0.23

^{ab}Means within a row without a common superscript differ ($P < 0.05$).

¹Floor space allowance was 2.1 m² during the first week after mixing into ESF pens, and then reduced to 1.5 m² and remained until day 109 of gestation.

²Piglets that were euthanized after birth due to low viability were not included.

³Piglets that died or euthanized from birth to weaning as a percentage of born alive.

⁴Days between farrowing and weaning.

Table 5. Effect of parity category on farrowing performance of sows

Item ¹	Parity category				SE	P-value
	Parity 1–2	Parity 3–4	Parity 5–6	Parity 7–9		Parity
Number of sows farrowed	245	228	201	195		
Litter size (piglets per litter)						
Total born	15.4 ^{ab}	15.5 ^a	14.5 ^b	13.0 ^c	0.27	<0.001
Born alive	13.7 ^a	13.1 ^a	11.9 ^b	10.8 ^c	0.24	<0.001
After cross-fostering	11.7 ^a	11.4 ^{abc}	11.2 ^{ab}	10.5 ^{bf}	0.22	0.01
Stillborn	1.2 ^b	1.8 ^a	2.0 ^a	1.8 ^a	0.15	<0.001
Mummy	0.5	0.6	0.6	0.4	0.07	0.24
Dead	1.6 ^b	2.4 ^a	2.6 ^a	2.3 ^a	0.16	<0.001
Weaned	11.1 ^a	10.4 ^{ab}	10.2 ^{bc}	9.5 ^c	0.22	<0.001
Preweaning mortality (%)	11.8 ^b	18.9 ^a	21.8 ^a	21.7 ^a	1.26	<0.001
Live litter weight (kg per litter)						
At birth	19.5 ^a	18.0 ^b	15.8 ^c	14.3 ^d	0.30	<0.001
At weaning	68.8 ^a	63.6 ^b	60.5 ^c	55.6 ^d	0.84	<0.001
Lactation length (d)	18.9	19.1	19.1	18.7	0.14	0.22
ADFI during lactation (kg)	6.0 ^b	6.7 ^a	6.6 ^a	6.8 ^a	0.14	0.001
Wean-to-estrus interval (d)	5.8	5.6	5.3	5.4	0.21	0.33

No interactions of floor space allowance and parity were detected for any variables ($P = 0.44$ or greater).

^{a–d}Means within a row without a common superscript differ ($P < 0.05$).

^{ab}Means within a row without a common superscript tend to differ ($P < 0.10$).

¹All variables are same as in Table 4.

($P = 0.13$ or greater). Sow parity affected skin lesion scores for the body ($P < 0.001$; Table 7). After mixing in ESF pens, sows in parity 3 and 4

had lower skin lesion scores ($P = 0.001$) for the body than sows in parity 7 to 9, with sows in other parities being intermediate. Parity did not affect

Table 6. Skin lesions and prevalence of lameness in sows allowed different levels of floor space in ESF pens during gestation

Item	Floor space allowance in ESF pens (m ² per sow)					SE	P-values	
	1.5	1.7	1.9	2.1	2.1/1.5 ¹		Floor space	Period
Number of pens	4	4	4	4	4			
Sows per pen	51	51	46	42	42			
Lesion scores for body (score per sow) ²								
After mixing ³	11.5	11.9	11.0	11.8	12.0	1.55	0.99	<0.001
Before farrowing ⁴	6.4	6.6	6.6	6.0	7.0	0.87		
Lesion scores for vulva (score per sow) ⁵								
After mixing	0.7	0.6	0.4	0.8	0.7	0.15	0.54	<0.001
Before farrowing	1.4	0.9	1.0	1.3	1.2	0.30		
Number of wounds (# per sow) ⁶								
After mixing	0.4	0.3	0.4	0.3	0.4	0.16	0.98	0.18
Before farrowing	0.2	0.3	0.3	0.2	0.2	0.04		
Sows with lameness (%) ⁷								
After mixing	1.5	2.9	1.6	4.2	9.5	–	0.01 ⁸	–
Before farrowing	1.0	2.0	3.3	1.2	3.0	–	0.43 ⁸	–

¹Floor space allowance was 2.1 m² during the first week after mixing into ESF pens, and then reduced to 1.5 m² and remained until day 109 of gestation.

²Body surface of sows was divided into 11 regions: head, 2 shoulders, 2 ears, 2 flanks, 2 hindquarters, back, and tail. Each region received a score between 0 and 3: 0 = no scratch, 1 = 1 to 5 superficial scratches, 2 = 6 to 10 superficial scratches and/or 1 to 3 deep scratches with visible blood, 3 = more than 10 superficial scratches and/or more than 3 deep scratches. The scores represent total scores across all regions.

³Assessed 2 d after mixing in ESF pens.

⁴Assessed in ESF pens 2 d before sows were moved to farrowing quarters.

⁵Vulva received a score between 0 and 3, using the same scoring system as for the body.

⁶Included cuts, swellings, and abscesses (healed or open).

⁷Sows that were slightly lame (cannot bear full weight on a leg) as a percentage of sows assigned to the study. There was no severe lameness at the time of assessment. Sows with severe lameness were treated or removed immediately when observed. All sows had no sign of lameness at entering ESF pens.

⁸Chi-square test ($\chi^2 = 21.1$ and 3.85 for after mixing and before farrowing, respectively; df = 4 for both variables).

Table 7. Skin lesions and prevalence of lameness among gestating sows in different parity categories

Item ¹	Parity category				SE	P-value
	Parity 1–2	Parity 3–4	Parity 5–6	Parity 7–9		Parity
Number of sows assigned	263	237	212	216		
Lesion scores for body (score per sow)						
After mixing	11.8 ^{ab}	10.9 ^b	11.7 ^{ab}	12.2 ^a	0.73	<0.001
Before farrowing	7.3 ^a	6.6 ^{ab}	6.3 ^b	5.9 ^c	0.47	
Lesion scores for vulva (score per sow)						
After mixing	0.6	0.6	0.6	0.7	0.07	0.50
Before farrowing	1.3	1.3	1.1	1.0	0.13	
Number of wounds (# per sow)						
After mixing	0.3 ^b	0.4 ^{ab}	0.7 ^a	0.5 ^{ab}	0.08	0.01
Before farrowing	0.2	0.3	0.3	0.3		
Sows with lameness (%)						
After mixing	1.5	2.9	1.6	4.2	–	0.10
Before farrowing	1.0	2.0	3.3	1.2	–	0.36

No interactions of floor space allowance and parity were detected for any variables ($P = 0.13$ or greater).

^{a–c}Means within a row without a common superscript differ ($P < 0.05$).

¹All variables are same as in Table 6.

lesion scores for the vulva. After mixing in ESF pens, sows in parity 1 to 2 had fewer wounds than sows in parity 5 and 6. However, no difference was observed in the number of wounds among sows of

different parities before farrowing. Sows in parity 7 to 9 tended ($P = 0.10$) to have more incidence of lameness than sows in other parities after entering to ESF pens. This difference in lameness among

sows in different parities disappeared by the time when sows left ESF pens for farrowing.

Floor space allowance did not affect the number of sows that completed the study or were removed from the study (Table 8). In total, 765 sows were rebred for the next breeding cycle within a week after weaning their litter, resulting in a completion rate of 85.2% for this study. Among the 162 sows that did not complete the study, 37% were removed for old age, 33% for not being pregnant, 15% for failing to show estrus within a week after weaning, 6% died or were euthanized due to compromised health or welfare, and 3% for lameness. Old age was defined as sows that were in parity 6 or greater, and farrowed or weaned small litters.

DISCUSSION

In the current study, floor space treatments did not affect performance or skin lesion scores of sows. In other words, increasing floor space allowance from 1.5 to 2.1 m² did not benefit sows under conditions of the current study. Although many factors can affect floor space allowance for sows (Bench et al., 2013), the minimal floor space of 1.5 m² is lower than expected. DeDecker et al. (2014) reported that sows group-housed with a floor feeding system had more skin lesions when allowed 1.7 m² of floor space compared with sows allowed 2.3 m² of floor space in gestation pens, suggesting that 1.7 m² of space allowance may compromise welfare of sows. Likewise, using a small group size of 5 sows per pen with floor feeding,

Salak-Johnson et al. (2007) noted that skin lesion scores were increased when sows were provided with 1.4 m² of floor space compared with sows provided with 2.3 or 3.3 m², although reproductive performance was not affected by space allowance. Hemsworth et al. (2013) reported sows that were allowed 1.4 m² of floor space on partially slatted floors displayed increased plasma cortisol concentrations and scratches after mixing compared with sows that were allowed 1.8 m² in the same barn. But further increases in space allowance from 1.8 to 3.0 m did not affect cortisol concentrations or skin lesion scores. As a result, Hemsworth et al. (2013) and Verdon et al. (2015) concluded that floor space allowance of 1.4 m² is smaller than the minimal space allowance of gestating sows, and that the minimal space allowance may be between 1.8 and 2.4 m² for sows under conditions of their studies. In a previous study, Johnston and Li (2013) found that sows allowed 1.5 m² per sow (26 sows per pen) of floor space in a floor feeding system exhibited a 5% reduction in farrowing rate compared to sows that gestated in stalls, suggesting that 1.5 m² of space allowance was too small for sows in pens with a floor feeding system.

Due to many affecting factors, such as feeding systems, floor types, management practices (group size, static or dynamic, gestation stage at mixing), genetics, and previous experience of the sows (Bench et al., 2013; Verdon et al., 2015), it is difficult to compare floor space allowance for sows housed in different systems. As a result, comparison of floor space allowance within a specific housing

Table 8. Frequency of sows that completed or were removed from the study

Item	Floor space allowance in ESF pens (m ² per sow)					χ^2	P-value
	1.5	1.7	1.9	2.1	2.1/1.5 ¹		
Number of sows assigned	204	204	184	168	168	—	—
Number of sows farrowed	193	187	172	157	160		
Number of sows completed study ²	170 (83.3%) ³	161 (78.9%)	146 (79.3%)	144 (85.7%)	144 (85.7%)	35.5	0.31
Number of sows removed	34 (17.7%) ³	43 (21.1%)	37 (20.2%)	24 (14.3%)	24 (14.3%)		
Abortion	0	3	0	1	1	30.6	0.34
Died or euthanized	4	4	0	0	2		
Lameness	1	1	3	0	0		
Not pregnant	10	13	16	10	5		
Sick	0	0	1	0	2		
Culled for old age ⁴	13	15	11	9	12		
Did not show estrus	6	7	6	4	2		

¹Floor space allowance was 2.1 m² during the first week after mixing into ESF pens, and then reduced to 1.5 m² and remained until day 109 of gestation.

²Sows that farrowed and weaned their subsequent litters, and rebred within a week after weaning for the next gestation cycle were considered to have completed the study.

³Percent of sows that were assigned to each floor space allowance treatment.

⁴Sows that were in parity 6 or greater, and farrowed or weaned small litters.

and feeding system has been recommended (Bench et al., 2013). In general, sows in ESF systems may need less floor space than sows in floor feeding systems (Bench et al., 2013), because the ESF system can help reduce competition among sows for feed, and consequently, reduce skin lesions caused by aggression at feeding time. Li and Gonyou (2013) compared the performance and welfare among sows that were housed in ESF pens and sows in gestation stalls. They reported no difference in reproductive performance (farrowing rate and litter size farrowed), lameness, or skin injuries between sows that were provided with space allowance of 1.9 m² (45 sows per pen) in the ESF system and sows that gestated in stalls, suggesting that space allowance of 1.9 m² can maintain performance and welfare of sows. However, they did not test different floor space allowances within the ESF system. To our knowledge, the current study is the first that investigated floor space allowance for gestating sows that were group-housed in ESF systems under near-production conditions in the United States.

The minimal space allowance of 1.5 m² per sow obtained from this study is lower than that reported by Li and Gonyou (2013), and the standards set up by EU (Council Directive 2008/120/EC, 2009) and in the Canadian Code of Practice (NFACC, 2014). We theorize that 6 factors may have contributed to the fact that the minimal space allowance in the current study (1.5 m²) maintained reproductive performance and most welfare indicators of sows. First, all sows used in the current study had been group-housed in this ESF system since they entered the breeding herd as gilts. All sows knew how to use the ESF system without being trained during the study. Adaptation to the group-housing system may help sows avoid aggression during feeding and consequently reduce injuries caused by fighting. Hemsworth et al. (2013) reported that the restriction of floor space for sows that were group-housed and fed by drop feeders can increase fighting at the feeders, resulting in injuries to sows, which was not observed in the current study (unpublished data). Alternatively, overcrowding may result in difficulties for sows to access the ESF station, which could increase the number of sows that did not have the opportunity to consume their entire daily ration. When comparing the number of days that sows failed to consume their entire daily ration among the treatment groups in the current study, we found that sows allowed 1.7 m² had more days (0.8 d per sow) than sows allowed 1.5 m² (0.3 d per sow) and 2.1 m² (0.3 d per sow). In addition, no difference in ADFI in ESF pens was detected among treatment groups.

These results indicate that reducing floor space allowance did not affect sows' access to the ESF station. Sows' previous experience with this housing system on ESF could have mitigated potential negative effects of limited floor space on access to the ESF station. With consistent access to the ESF, negative effects of low floor space observed in other studies were presumably minimized. Secondly, sows in the current study were managed as static groups in ESF pens. As a result, 50% to 70% of sows in a pen were housed together in their previous gestation, and could be considered familiar to each other (Arey, 1999). Familiar sows may fight less compared to unfamiliar sows at mixing in gestation pens (Arey and Edwards, 1998). This may diminish differences in fighting and associated injuries during the initial mixing period among treatment groups. Consequently, providing more space during the first week of mixing for sows to retreat from fighting and reduce injuries associated with fighting (Weng et al., 1998; Verdon et al., 2015) may not have been effective in the current study. In contrast, Johnston and Li (2013) demonstrated that limited floor space could negatively affect performance and welfare of sows dramatically when sows had no previous experience with group housing, were not familiar with each other, and were housed in groups of 6 or 26 with floor feeding. So, familiarity among sows in the current study may have played a role in the ability of sows to adapt to the lowest floor space allowance. Thirdly, in the current study, all sows had been provided with 1.5 m² of floor space in the ESF system before the study started. These sows may have adapted to 1.5 m² of floor space allowance. Hemsworth et al. (2013) reported that restriction of space allowance increased plasma cortisol concentrations of sows on day 2 after mixing, but not on day 9 or day 51 after mixing, suggesting that sows may be able to adapt to spatial restrictions. The previous experience of sows with limited floor space in the current study probably also contributed to the minimal space allowance obtained in the current study. Fourth, sows in the current study appeared to be lighter than sows in other studies. Average weight of sows in the current study was about 210 kg at mixing into ESF pens, and about 240 kg when moving from ESF pens to farrowing quarters. These body weights were about 20 to 40 kg lighter than average body weights of sows in previous studies (Li et al., 2012; Johnston and Li, 2013; Li and Gonyou, 2013). Lighter weight is associated with smaller body size which may have contributed to the minimal space allowance in the current study (Ekkel et al., 2003). Fifth, sows in the current study

were moved into ESF pens after being diagnosed as pregnant at 5 wk after breeding. There is evidence that sows are less aggressive when mixed post-implantation compared with sows mixed pre-implantation (Li and Gonyou, 2013; Stevens et al., 2015). In addition, sows may be more sensitive to stress of mixing during the implantation period compared to sows after diagnosed pregnant (Li and Gonyou, 2013; Verdon et al., 2015). Hemsworth et al. (2013) reported that when sows were mixed into group pens within a week after breeding, farrowing rates were increased as floor space allowance increased from 1.4 to 3.0 m². So, mixing sows into ESF pens after establishment of pregnancy may not only reduce fighting among sows and associated injuries to sows, but also reduce the stress response and its negative impact on reproductive performance. In agreement with our results, Salak-Johnson et al. (2007) reported that floor space allowance did not affect farrowing rate or other reproductive performance when sows were mixed in pens 4 wk after breeding, and were housed in groups of 5 with floor feeding. Gestating sows may need more space when mixed into pens during the pre-implantation period than mixed during the post-implantation period. Finally, the minimal space allowance could be influenced by the relatively large group size used in the current study. The EU standard and the Canadian Code of Practice recommend that for group sizes greater than 40 sows, floor space allowance can be reduced by 10%, which recognizes space sharing by sows in large groups (Arey and Edwards, 1998; Bench et al., 2013). In the current study, group sizes were in the range of 42 to 51 sows so that space sharing by sows can be expected (Taylor et al., 1997; Turner et al., 2000).

One concern about sows in ESF systems is vulva biting. Vulva biting may be related to the sequential nature of feeding in ESF systems. Generally, vulva biting is associated with overcrowding at the feeder station due to a high ratio of sows to ESF stations, and is not affected by floor space allowance (Bench et al., 2013). In the current study, no difference in skin lesions on the vulva among floor space treatments was observed, which demonstrates that floor space treatments likely do not affect vulva biting in sows. Across floor space treatments, sows had more skin lesions on the vulva before leaving ESF pens compared to 2 d after entering the ESF pens. This may be attributed to the enlarged vulva before farrowing that could be more vulnerable to injury than the vulva during early stages of gestation.

In the current study, floor space allowance affected incidence of lameness in sows 2 d after

mixing. Sows allowed larger floor space (2.1/1.5 m² and 2.1 m²) had a higher incidence of lameness than sows in other treatment groups. Because all sows had no signs of lameness at entering the ESF pens, lameness observed 2 d after mixing likely was caused by initial fighting among sows in ESF pens. One contributor to fighting induced lameness might be slippery, fully slatted floors in the current study. As observed in the current study, floors were wet and slippery during the initial mixing period because sows usually urinate and defecate when entering new pens due to either stress or excitement. The slippery concrete-slatted floors combined with larger open space in the pen may result in falling of sows when they were engaged in fighting, which may have caused injuries to their legs. The difference in lameness among treatment groups was not observed when sows were moved from ESF pens to farrowing quarters, probably due to the minimal aggression among sows after the social hierarchy was established.

Group size (or pen size) is another factor that may affect the minimal floor space allowance for sows (Bench et al., 2013). Pigs in large pens may have enough room to retreat during fighting to avoid injury, and consequently will have fewer skin lesions compared with pigs in small pens (Seguin et al., 2006; Turner et al., 2006; Samarakone and Gonyou, 2009). However, pigs in large pens also encounter more pen mates and may have more social conflicts to solve (Spooler et al., 2009; Gonyou et al., 2013), resulting in more fighting and associated injuries. Some early studies (Arey and Edwards, 1998; Turner et al., 2001) suggest that sows in large groups may take longer to establish dominance hierarchy than sows in small pens, causing more skin lesions to them. When comparing sows among groups of 10, 30, and 80, Hemsworth et al. (2013) noted that sows in groups of 10 had less skin lesions than sows in larger groups of 30 and 80, but there was no difference between group sizes of 30 and 80. In the current study, floor space treatments were achieved by changing both group size and pen size, resulting in variation of both floor space allowance and social space. However, due to the relatively large group sizes (greater than 40) and the small range of variation in group sizes (42 to 51 sows per pen), we did not expect any influence of group size (or social space) on variables measured in the current study.

Sows in different parities responded to floor space allowances in a similar pattern in the current study. Across floor space treatments, sows in parity 3 and 4 performed better than older sows in parity

7 to 9. Sows of parity 3 and 4 had fewer scratches after mixing, tended to have higher farrowing rate (96% vs. 90%), farrowed larger litters (both total and alive), and weaned more piglets than the older sows. Similar results have been reported by other researchers (O'Connell et al., 2003; Strawford et al., 2008). In general, the minimal floor space of 1.5 m² appears not to compromise the welfare or performance of sows in any parity category.

In summary, results of this study indicate that the minimal floor space allowance of 1.5 m² appears to be acceptable for maintaining welfare and performance of gestating sows under conditions of the current study. Increasing floor space from 1.5 to 2.1 m², either throughout the gestation period or during the initial mixing period, did not affect skin lesion scores, the number of wounds, incidence of lameness, or reproductive performance (farrowing rates, litter size and weight farrowed and weaned, culling rates and the number of sows that completed the study) of sows in any parity category. These results suggest that the benefit of providing extra space above the minimal requirement to improve welfare and performance of sows may be not obvious. The minimal floor space allowance obtained from this study appears lower than most recommendations for sows using other group housing systems and managed differently. When applying results of this study in swine production, producers should consider other factors which may affect the floor space allowances, such as housing and feeding systems used, management protocols adopted, and genetics and experience of sows.

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LITERATURE CITED

- Arey, D. S. 1999. Time course for the formation and disruption of social organization in group-housed sows. *Appl. Anim. Behav. Sci.* 62:199–207. doi:10.1016/S0168-1591(98)00224-X
- Arey, D. S., and S. A. Edwards. 1998. Factors influencing aggression between sows after mixing and the consequences for welfare and production. *Livest. Prod. Sci.* 56:61–70.
- Averos, X., L. Brossard, J. Y. Dourmad, K. H. de Greef, H. L. Edge, S. A. Edwards, and M. C. Meunier-Salaün. 2010. Quantitative assessment of the effects of space allowance, group size and floor characteristics on the lying behaviour of growing-finishing pigs. *Animal* 4:777–783. doi:10.1017/S1751731109991613
- Bench, C. J., F. C. Rioja-Lang, S. M. Hayne, and H. W. Gonyou. 2013. Group housing with individual feeding—II: how space allowance, group size and composition, and flooring affect sow welfare. *Livest. Sci.* 152:218–227. doi:10.1016/j.livsci.2012.12.020
- Coffey, R. D., G. R. Parker, and K. M. Laurent. 1999. Assessing sow body condition. Cooperative Extension Service, University of Kentucky, ASC-158.
- Council Directive 2008/120/EC. 2009. Laying down minimum standards for the protection of pigs (codified version). Official J. European Union. 18.2.2009. <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=O-J:L:2009:047:0005:0013:EN:PDF> (Accessed 5 April 2018).
- DeDecker, A. E., A. R. Hanson, P. M. Walker, and J. L. Salak-Johnson. 2014. Space allowance and high fiber diet impact performance and behavior of group-kept gestating sows. *J. Anim. Sci.* 92:1666–1674. doi:10.2527/jas.2013-6776
- Ekkel, E. D., H. A. M. Spooler, I. Hulsege, and H. Hopster. 2003. Lying characteristics as determinants for space requirements in pigs. *Appl. Anim. Behav. Sci.* 80:19–30. doi:10.1016/S0168-1591(02)00154-5
- Gonyou, H. W., M. C. Brumm, E. Bush, J. Deen, S. A. Edwards, T. Fangman, J. J. McGlone, M. Meunier-Salaün, R. B. Morrison, H. Spooler, et al. 2006. Application of broken-line analysis to assess floor space requirements of nursery and grower-finisher pigs expressed on an allometric basis. *J. Anim. Sci.* 84:229–235.
- Gonyou, H. W., F. Rioja-Lang, and Y. Seddon. 2013. Group housing systems: floor space allowance and group size. *Natl. Pork Board Factsheet #03645-3/13*. Natl. Pork Board, Des Moines, IA.
- Hemsworth, P. H., R. S. Morrison, A. J. Tilbrook, K. L. Butler, M. Rice, and S. J. Moeller. 2016. Effects of varying floor space on aggressive behavior and cortisol concentrations in group-housed sows. *J. Anim. Sci.* 94:4809–4818. doi:10.2527/jas.2016-0583
- Hemsworth, P. H., M. Rice, J. Nash, K. Giri, K. L. Butler, A. J. Tilbrook, and R. S. Morrison. 2013. Effects of group size and floor space allowance on grouped sows: aggression, stress, skin injuries, and reproductive performance. *J. Anim. Sci.* 91:4953–4964. doi:10.2527/jas.2012-5807
- Hodgkiss, N. J., J. C. Eddison, P. H. Brooks, and P. Bugg. 1998. Assessment of the injuries sustained by pregnant sows housed in groups using electronic feeders. *Vet. Rec.* 143:604–607.
- Johnston, L. J., and Y. Z. Li. 2013. Performance and well-being of sows housed in pens retrofitted from gestation stalls. *J. Anim. Sci.* 91:5937–5945. doi:10.2527/jas.2013-6767
- Knauer, M. T., and D. J. Baitinger. 2015. The sow body condition caliper. *Appl. Eng. Agr.* 31:175–178. doi:10.13031/aea.31.10632
- Li, Y. Z., and H. W. Gonyou. 2013. Comparison of management options for sows kept in pens with electronic feeding stations. *Can. J. Anim. Sci.* 93:445–452. doi:10.4141/cjas2013-044
- Li, Y. Z., L. H. Wang, and L. J. Johnston. 2012. Sorting by parity to reduce aggression toward first-parity sows in group-gestation housing systems. *J. Anim. Sci.* 90:4514–4522. doi:10.2527/jas.2011-4869
- Miller, D. 2012. How housing affects sow performance. *Natl. Hog Farm.* 15 March. p. 34–35.
- NFACC (National Farm Animal Care Council). 2014. Code of practice: for the care and handling of pigs. http://www.nfacc.ca/pdfs/codes/pig_code_of_practice.pdf (Accessed 5 April 2018).

- NPB (National Pork Board). 2016. On-farm euthanasia of swine: recommendations for the swine producer. National Pork Board, Des Moines, IA. p. 3–18. <https://www.aasv.org/aasv/documents/SwineEuthanasia.pdf> (Accessed 5 April 2017).
- NRC (National Research Council). 2012. Nutrient requirements of swine. 11th ed. Natl. Acad. Press, Washington, DC.
- O'Connell, N. E., V. E. Beattie, and B. W. Moss. 2003. Influence of social status on the welfare of sows in static and dynamic groups. *Anim. Welf.* 12:239–249.
- PISC (Primary Industries Ministerial Council). 2007. Model code of practice for the welfare of animals – pigs (revised). CSIRO Publishing, Collingwood, Victoria, Australia.
- Pluym, L. M., D. Maes, S. Van Weyenberg, and A. Van Nuffel. 2017. Risk factors for development of lameness in gestating sows within the first days after moving to group housing. *Vet. J.* 220:28–33. doi:10.1016/j.tvjl.2016.11.008
- Ren, P., X. J. Yang, J. S. Kim, D. Menon, and S. K. Baidoo. 2017. Effect of different feeding levels during three short periods of gestation on sow and litter performance over two reproductive cycles. *Anim. Reprod. Sci.* 177:42–55. doi:10.1016/j.anireprosci.2016.12.005
- Salak-Johnson, J. L., S. R. Niekamp, S. L. Rodriguez-Zas, M. Ellis, and S. E. Curtis. 2007. Space allowance for dry, pregnant sows in pens: body condition, skin lesions, and performance. *J. Anim. Sci.* 85:1758–1769. doi:10.2527/jas.2006-510
- Samarakone, T. S., and H. W. Gonyou. 2009. Domestic pigs alter their social strategy in response to group size. *Appl. Anim. Behav. Sci.* 121:8–15. doi:10.1016/j.applanim.2009.08.006
- Seguin, M. J., D. Barney, and T. M. Widowski. 2006. Assessment of a group-housing system for gestating sows: effects of space allowance and pen size on the incidence of superficial skin lesions, changes in body condition, and farrowing performance. *J. Swine Health Prod.* 14:89–96.
- Spooler, H. A. M., M. J. Geudeke, C. M. C. Van der Peet-Schwering, and N. M. Soede. 2009. Group housing of sows in early pregnancy: a review of success and risk factors. *Livest. Sci.* 125:1–14. doi:10.1016/j.livsci.2009.03.009
- Stevens, B., F. M. Karlen, R. Morrison, H. W. Gonyou, K. L. Butler, K. J. Kerswell, and P. H. Hemsworth. 2015. Effects of stage of gestation at mixing on aggression, injuries and stress in sows. *Appl. Anim. Behav. Sci.* 165:40–46. doi:10.1016/j.applanim.2015.02.002
- Strawford, M. L., Y. Z. Li, and H. W. Gonyou. 2008. The effect of management strategies and parity on behavior and physiology of gestating sows housed in an electronic sow feeding system. *Can. J. Anim. Sci.* 88:559–567. doi:10.4141/cjas07114
- Taylor, I. A., J. L. Barnett, and G. M. Cronin. 1997. Optimum group size for pigs. In: R. W. Bottcher and S. J. Hoff, editors, *Livestock Environment V, Volume II. Proc. 5th Int. Symp. American Soc. Agric. Engin., Bloomington, Michigan. Am. Soc. of Agricultural Engineers, St. Joseph, MI.* p. 965–971.
- Turner, S. P., M. Ewen, J. A. Rooke, and S. A. Edwards. 2000. The effect of space allowance on performance, aggression and immune competence of growing pigs housed on straw deep-litter at different group sizes. *Livest. Prod. Sci.* 66:47–55.
- Turner, S. P., M. J. Farnworth, I. M. S. White, M. Mendl, P. Knap, P. Penny, and A. B. Lawrence. 2006. The accumulation of skin lesions and their use as a predictor of individual aggressiveness in pigs. *Appl. Anim. Behav. Sci.* 96:245–259. doi:10.1016/j.applanim.2005.06.009
- Turner, S. P., W. W. Horgan, and S. A. Edwards. 2001. Effect of social group size on aggressive behavior between unacquainted domestic pigs. *Appl. Anim. Behav. Sci.* 74:203–215. doi:10.1016/S0168-159(01)00168-X
- Verdon, M., C. F. Hansen, J. L. Rault, E. Jongman, L. U. Hansen, K. Plush, and P. H. Hemsworth. 2015. Effects of group housing on sow welfare: a review. *J. Anim. Sci.* 93:1999–2017. doi:10.2527/jas.2014-8742
- Weng, R. C., S. A. Edwards, and P. R. English. 1998. Behavior, social interactions and lesion scores of group-housed sows in relation to floor space allowance. *Appl. Anim. Behav. Sci.* 59:307–316.