RESEARCH REPORT
ANIMAL WELFARE

**Title**: The effect of alleyway width on sow behavior and welfare in a free-access gestation stall system – NPB - #07-083 (revised)

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**Industry Summary**

The use of traditional gestation stalls is currently under public scrutiny due to restrictions on sow movement and social interaction. But before alternative housing is adopted, knowledge of its benefits and limitations is required. Free-access gestation stalls are designed to provide both the protection of a standard stall and the behavioral freedom of a group pen, however research on their implementation is limited. This purpose of this project was to examine the effects of alley width on physiology, behavior, and production of gestating sows in a free-access stall system. After the 1st month of gestation, 7 sows were placed in pens with 7 free-access stalls and a shared alley of 3', 7', or 10' wide where they remained until moving to the farrowing facility. Health measures collected through gestation included back fat depth, body weight, body condition score, lameness scores, and lesion scores. Blood samples were collected monthly for cortisol concentrations and immune function. Farrow rate, days to next estrus, percentage of sows rebred, and cull rate of the sows were calculated. Litter data collected were total litter size, live litter size, and litter weight. The health and physiology measures showed very few differences between alley sizes. Sows in pens with 3' alleys used the space less, had fewer and smaller social interactions, and were less active than sows with either 7' or 10'alleys. There was no difference in aggression between sows in different alley sizes. Neither sow productivity measures nor litter size

differed between treatments. However sows from pens with 3' alleys had heavier litters than sows with 10' alleys. In conclusion, alley width had little effect on sow health, physiology, or productivity. In contrast, the smallest alley width of 3' limited the sows' expression of normal behavior. The "Freedom to Express Normal Behavior" is one of the Five Freedoms of animal welfare whose foundation was laid by the Brambell Committee in 1965 and is still considered fundamental to farm animal welfare (FAWC, 2011).

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**Scientific Abstract**

Free-access stalls allow sows to choose the protection of a stall or use of a shared alley. This study investigated the effect of alley width in a free-access stall system on physiology, behavior, and production in gestating sows. At gestational day (GD) 35 ± 2.3, 9 replicates of 21 sows (N = 189) were assigned to 1 of 3 pens. Each pen contained 7 free-access stalls and a shared alley of 0.91, 2.13, or 3.05 m wide. Sows remained in pens until being moved to farrowing crates at GD 104 ± 3.5. Back fat depth at the tenth rib (BF), body weight (BW), body condition score (BCS), and lameness (LAM) were measured on experimental day (ED) 0, 5, 35, and 70. Additional BW was collected 1 d post-farrowing and on weaning day. Sows' body lesions were scored on ED 0, 3, and 6 during wk 1 and weekly afterward. Blood samples were collected on ED -1, 1, 36, and 75 for immune function and cortisol concentration analysis. Behavior was recorded 24 hr/d during wk 1 and 1x/wk for 24 hr during the remainder of the experiment and scored using 10 min scan samples. Farrow rate, days to next estrus (ESTR), percentage of sows rebred (RBRD), and cull rate (CULL) of the sows were calculated. Litter data collected were total litter size, live litter size, and litter weight. Data were analyzed in SAS 9.2 using PROC GLIMMIX with a post-hoc Tukey-Kramer adjustment. Alley width did not affect BW, BF, BCS, or lesion scores ($P > 0.05$). At wk 1, sows with 0.91 m alleys tended to have smaller lameness scores than sows with 2.13

m alleys ($0.05 \leq P \leq 0.10$); however this trend was reversed at wk 6 ($0.05 \leq P \leq 0.10$) and no longer existed at wk 11 ($P > 0.05$). Neither leukocyte populations nor cortisol concentration differed between alley widths ($P > 0.05$). The relative abundance of CD 14, a component of the lipopolysaccharide receptor complex and the level of opsonized phagocytosis tended to be greater in sows with 0.91 m alleys than 2.13 m ($0.05 \leq P \leq 0.10$) with sows from 3.05 m alleys intermediate. No other immune measure varied between treatments. As gestation progressed, sows used stalls less frequently ($P < 0.001$) and alley more frequently ($P < 0.0001$) with alley use lowest and increasing least in pens with 0.91 m alleys ($P < 0.01$). The percentage observations standing was greater in sows with 2.13 and 3.05 m alleys than 0.91 m at wk 3 ($P < 0.05$) and wk 5 ($P < 0.01$) but not overall, while lying was greatest in sows with 3.05 m at wk 1 and 4 ($P < 0.05$) and with 0.91 m at wk 5 ($P < 0.01$). Sows with 0.91 m performed oronasal facial pen investigation less than sows with 2.13 and 3.05 m ($P < 0.05$). Sows with 0.91 m were less frequently observed in groups than sows with 2.13 or 3.05 m ($P < 0.0001$) and group size was smaller ($P < 0.001$). Aggressive interactions did not vary between the alley widths. Farrow rate, RBRD, ESTR, CULL, and litter size did not vary with alley width ($P > 0.05$). Litters from sows from 0.91 m alleys weighed more than litters from sows with 3.05 m with 2.13 m intermediate ($P < 0.05$). In conclusion, there were very few differences in the physiology and productivity of the sows in the three alley widths. However sows from 0.91 m alleys behaved differently than sows in the larger 2 alleys suggesting 0.91 m is not a sufficiently large alley width for full behavioral expression a component of animal welfare.

**Introduction**

Swine production is a dynamic process responsive to economic, legislative, and consumer driven concerns. Gestation stalls are the most prevalent type of sow housing in the United States, but exact figures regarding their usage are unavailable. A review paper from 2001 estimated 60 – 70% of sows are kept in stalls (Barnett et al., 2001). Swine 2006 reported 79.7% of gestating sows are in “total confinement,” but this number includes all sows that have no access to outdoors (USDA, 2007). The Swine 2006 questionnaire did not include

a question to differentiate between types of confinement housing but the Swine 2012 questionnaire will due to growth in concerns about sow gestational housing during the past decade.

Concerns about swine welfare are driving a re-evaluation of sow housing worldwide. In the United States, the list of states phasing in bans limiting gestation stall use grows yearly. Globally the European Union, New Zealand, Australia, and Tasmania are in various stages of implementing bans. Coles, a large Australian supermarket, is ceasing to purchase imported meat from suppliers that use sow stalls. In the United States, Whole Foods and Chipotle only purchase pork from suppliers that allow greater freedom than provided by gestation stalls.

Gestation stall housing, like every sow housing method, has welfare advantages and disadvantages. Gestation stalls protect sows from aggression, but prevent movement and limit social interaction. Several reviews comparing productivity, behavior, and welfare of sows in group and stall housing have been previously published (Barnett et al., 2001; McGlone et al., 2004; Rhodes et al., 2005).

One housing alternative to traditional group and stall housing is the free-access stall (FAS) (Figure 1). It is a hybrid system which affords both security from aggression and allows sows to express greater behavioral diversity than a typical stall. Because sows can enter and leave stalls at will they exert greater control over their environment, an ability considered beneficial to welfare (Bassett and Buchanan-Smith, 2007; Morgan and Tromborg, 2007). In choice test between a FAS and an identical stall into which they were locked, sows strongly preferred the FAS (Jones, 2010). Free-access stalls appeal to producers also. In a Belgian survey of sow production from 2003 - 2009, FAS accounted for 31% of group housing and were the most common type of group system. Users rated FAS as 3.9/5.0 for overall satisfaction level. Producers cited their main reasons for choosing a particular group system as investment cost and sow health and welfare (Tuyttens et al., 2010).

A few studies have compared productivity, behavior and welfare in FAS to other forms of gestation housing (Backus et al., 1997; DeDecker, 2011; van der Peet-Schwering et al., 2003). This study examines several design options for installation of FAS systems. One method is to install 2 rows of FAS back-to-back with a shared alley of 1.5 – 2.5 m to which sows have continuous access. A second method is similar but

minimizes space use by shrinking the alley to 1 m and allowing only one row of sows alley access at a time while the other row remains locked in stalls. A third method is to retro-fit a barn containing traditional stalls by eliminating a row of stalls and creating a group space with the combined area of a pre-existing aisle plus the area gained by stall removal, approximately 3 m. The main objective of this study is to determine the effects of 3 different alley widths within a FAS system on sow behavior, welfare, and productivity.

## Objectives

The primary objective of this experiment was to determine how alley width interacts with sow welfare, behavior, and productivity within a free-access stall sow gestational housing system. Additional important objectives were:

1) to describe the welfare, behavior, and productivity of sows in a free-access stall gestation housing system

2) to elucidate the advantages and disadvantages of a free-access stall gestation housing system.

## Materials and Methods

### *Experimental Design, Animals, and Housing*

All procedures in this experiment were approved by the Purdue Animal Care and Use Committee prior to commencing (PACUC Number 07-116). All handlers and caretakers were qualified by PACUC for swine handling and techniques. Animals that became ill or injured during the experiment were removed from study and received appropriate medical attention.

Each of the 9 replications used 21 gestating Landrace x Yorkshire pigs (N = 189) in a complete randomized block design. The pigs' parities ranged from nulliparous to parity 6 (mean = 4.40 ± 0.31). Henceforth, all gestating pigs regardless of parity will be referred to as sows. At gestational day (GD) 35 ± 2.26, the confirmed pregnant sows were equally divided into 3 treatment pens containing 7 sows balanced by parity. The sows remained in treatment pens until moving to the farrowing facility at GD 104 ± 3.46.

Each pen contained fully slatted floors, a single row of 7- 2.26 x 0.69 m Laake free-access stalls (FAS) (Pig Tek, Milford, IN) and a shared alley to the rear of the stalls (Figure 2). Alley width (0.91, 2.13, and 3.05 m) differed between treatments. The total floor space, including both alley and stalls, was 1.86, 2.60, and 3.16 $m^2$/sow, respectively. When sows were removed from the experiment, 1 stall and an appropriate amount of alley space was blocked off to maintain the treatment specific per sow area. Sows had *ad libitum* access to water in a combined feed and water trough to the front of the FAS. Sows were fed approximately 2.3 kg of a standard sow gestational diet 1x/day. The location of the treatment pens within the barn was balanced between replications to prevent a location effect.

***Physical Measures***

Body weight (BW), back fat depth at the tenth rib (BF), lameness (LAM), and body condition scores (BCS) were collected on experimental day 0 (ED 0) before sows entered treatments for baseline data and again on ED 5, 35, and 70. Additional BW was collected 1 day post-farrowing and on weaning day. Back fat depth was measured at approximately 2.5 cm to the left and right of the dorsal midline and the mean measurement was analyzed. Back fat measurements were made using real-time ultrasound (Aloka Model 500V, Corometrics Medical Systems, Wallingford, CT). Body condition score was evaluated according to a protocol described by Coffey at al. (1999), with minimum score 1 corresponding to an emaciated sow and maximum score 5 to an overly fat sow (Table 1). The combination of visual inspection and application of palm pressure to a sow's backbone, ribs, and hips were used to determine score. The lameness scale designed by Harris et al. (2006) assesses both the standing posture and gait to yield a single lameness score. A score of 0 indicated no gait or postural abnormality and a score of 6 indicated an inability to stand (Table 2).

Skin lesions were evaluated on ED 0, 3, and 6 in the 1$^{st}$ week and thereafter 1x/wk until replication end using a scale adapted from Arey (1999) and Hodgkiss et al. (1998) (Table 3). Score 0 indicated normal skin with no reddening, thickening, or scratches and the maximum score 5 indicated ≥ 10 cuts, ≥ 2 deep wounds, or ≥ 5 superficial wounds. A scratch had unbroken skin, while a cut was defined as having a narrow line of separated skin. A wounds had separated skin that extended over a larger surface area than a cut. Seven regions

of the body were lesion scored independently for a total possible score of 35. Body regions were 1) head, neck, and shoulders (HEAD); 2) body and udder (BODY); 3) rump, tail, and vulva (RUMP); 4) hooves and feet (HOOF); 5) hock, knee, and pasterns (LLEG); 6) upper leg (ULEG); and 7) dewclaws (DCLAW). If lesions in one region met the criteria for more than 1 category, the greater of the 2 scores was used. For example, if the BODY had 1 abscess (score = 3) and 6 cuts (score = 4) a 4 was given.

***Physiological Measures***

***Blood Collection.*** Blood was collected by jugular venipuncture on ED -1, for baseline data, and then on ED 1, 36, and 71. Dependent on sow size, blood was drawn using a 3.8 or 5.0 cm 21 G needle into 2- 13 x 75 mm, 4.0 mL draw ethylenediaminetetraacetic acid (EDTA; 7.2 mg spray dried $K_2$EDTA) and a single 16 x 100 mm, 8.5 mL draw acid citrate dextrose [ACD; 1.5 mL of solution A (22.0 g of trisodium citrate, 8 g of citric acid, and 24.5 g of dextrose/L)] evacuated tubes (all blood collection supplies: Becton Dickinson, Franklin Lake, NJ). The 2 EDTA tubes were used for hematological analysis and plasma free cortisol concentration. Flow cytometry used blood collected into the ACD tube. The filled tubes were stored on ice prior to further preparation. Plasma was separated by centrifugation using a Sorvall RC 3B Plus centrifuge (Thermo-Fisher, Asheville, NC) at 1800 x *g* at for 15 min and stored at -80 $^0$C until analysis.

***Hematology.*** Samples were brought to room temperature on a test tube rocker for 20 min, before being analyzed with a Hemavet 950 hematology system (Drew Scientific, Oxford, CT). Hematological analysis included white blood cell count (WBC); percentages of neutrophils (%NEU), lymphocytes (%LYM), monocytes (%MON) and hematocrit (%HCT); and the ratio of neutrophils to lymphocytes (N: L).

***Immune Function.*** Cluster of differentiation 14 (CD14) and 18 (CD18) cell surface markers and microbead phagocytosis analyses were performed using an adaptation of the protocol described by Weedman et al. (2011). Samples were incubated for 45 min at 37 $^0$C, before being divided into 3- 500 µL aliquots. To the first aliquot, 20 µL monoclonal mouse anti-pig CD18a antibody conjugated to Fluorescein Isothiocyanate Isomer (FITC), clone PNK-I (AbD Serotec, Raleigh, NC) and 10 µL monoclonal mouse anti-human CD14 antibody conjugated to R-phycoerythrin (RPE), clone TÜK4 (DAKO North America, Carpinteria, CA) were

added. To the second aliquot 12.5 µL red fluorescent, carboxylate-modified 1.0 µm FluoroSpheres was added to detect phagocytosis (Invitrogen, Carlsbad, CA). The third aliquot acted as a control, therefore nothing additional was added. All tubes were incubated at 37 $^0$C for 30 min, after which the red blood cells (RBC) were hypotonically lysed by adding 900 µL cold, sterile water. Isotonicity was reestablished after 45 s by adding 100 µL 10x Hank's Balance Saline Solution (HBSS; GIBCO Invitrogen, Carlsbad, CA). The samples were centrifuged at 1800 x *g* for 3 min, the resulting supernatant poured off, and the lysed RBC pellet discarded. Samples were washed 2x in 1000 µL 1x HBSS, and then preserved in 500 µL of 2% paraformaldehyde in a phosphate buffered solution (paraformaldehyde: Sigma-Aldrich, St. Louis, MO) before flow cytometric analysis. Flow cytometry was performed with a Coulter Epics XL-MCL Flow Cytometer running System II software (Beckman-Coulter Inc., Miami, FL). The flow cytometer utilized a 488 nm air-cooled argon laser for excitation, a 525 nm band-pass filter for FITC detection, and a 575 nm band-pass filter for RPE detection. For each sample a population of 10,000 cells was used. Results were analyzed for percentage cells (%P) expressing CD14 and CD18 and phagocytosis (BPHAG). Additionally fluorescent intensity relative to control populations was calculated (FI).

Oxidative burst and opsonized phagocytotic activity were assayed using an adaptation of the protocol described by Eicher et al (2010). In preparation for use, 10 mg dihydrorhodamine-123 (DHR; Invitrogen, Carlsbad, CA) was diluted in 10 mL dimethyl sulfoxide (DMSO; Sigma-Aldrich, St. Louis, MO) to produce a 29 mM DHR solution, which was aliquoted into 25 µL allotments and frozen at -80 $^0$C. On the day of analysis, one allotment of the DHR solution was resuspended in 10 mL 1x HBSS before use. One hundred microliters of the resuspended DHR solution was added to 450 µL blood that had been incubated for 45 min at 37 $^0$C. The blood-DHR solution was then incubated for 10 min before 50 µL of it was aliquoted into each of 2 test tubes. To the first blood-DHR tube, 50 µL PI labeled opsonized Pansorbin was added, which had been prepared earlier by combining 650 µL Pansorbin (EMD4Biosciences, Darnstadt, Germany) and 650 µL PI (50 µg/mL) (propidium iodide; EMDMillipore, Darnstadt, Germany), incubating at 37 $^0$C for 30 min, washing twice with 1x HBSS, adding 0.25 µL *Staphylococcus aureus* BioParticles opsonizing reagent (Invitrogen, Carlsbad, CA),

incubating an additional 30 min, washing again and finally diluting with 1300 μL 1x HBSS. After opsonized Pansorbin-PI addition, the blood-DHR tube was incubated for 10 min at 37 $^{0}$C. The second blood-DHR tube served as a control, thus nothing else was added. When the 1$^{st}$ tube finished incubating, the RBC in both tubes were hypotonically lysed and preserved using the same procedure as above with 2 exceptions: centrifugation was extended to 5 min and only a single 1x HBSS wash was performed. Cytometric analysis was conducted on the Coulter Epics XL-MCL flow cytometer using a 525 nm band-pass filter for PI detection and a 575 nm band-pass filter for DHR detection. The %P cells exhibiting oxidative burst (OB) and opsonized phagocytosis (OPHAG) and their FI above control populations were calculated.

***Cortisol.*** Plasma free cortisol was assayed using duplicate samples with a commercial radioimmunoassay (RIA) kit (Clinical Assays GammaCoat Cortisol $^{125}$I RIA Kit, Stillwater, MN) according to manufacturer's instructions. The kit was previously validated for use with swine plasma (Haussmann et al., 2000). The intra- and inter- assay coefficients of variation were 14.2% and 16.6% respectively.

***Behavioral Measures***

Sow behavior was recorded using color IP cameras (Dinion NWC-0495W, Bosch Security Systems North America, Fairport, NY) and a hybrid digital video recorder (DiBos Micro 8, Bosch Security Systems North America, Fairport, NY) for 24 hr/d during the first wk of treatment and 1x/wk for 24 hr during the remainder of the treatment. Each pen contained 2 cameras with 1 oriented to record FAS interiors and the other recording the alley area. Hard drive failure resulted in video loss from the seventh replication.

Ten minute scan sampling was used to analyze the location, position, pen investigatory activity, and social contact of the sows (Table 4). Data were not collected while people were present in barn or for 5 min afterward to minimize behavioral disruption by human presence. Locations were recorded as FAS, alley, or in-between (IB) the two. Positions recorded were standing (UP), sitting (SI), and lying (LY). Oronasal facial (ONF) contact with pen walls or floor (WF); ONF contact with a closed FAS door or head inside an already occupied FAS (SC); and snout inside the combined feed and water trough (TR) were the pen investigatory activities observed. In the absence of those behaviors, no pen investigation (NONE) was recorded. The

percentage of observations in a social group (PGP) and the size of the group (SGP) were calculated. A group was defined as having 2 or more sows within 15 cm of each other. All aggressive interactions were recorded.

To determine social rank of sows, a feed competition test was performed at least 4 hr following feeding on ED 5, 35, and 70. Sows from a single treatment were moved into an unfamiliar pen and given time to acclimatize to the novel environment. The test was not conducted until 4 or more sows were lying down as indication of sow ease with the new pen. To conduct the test, the experimenter placed a bowl of feed in the pen's center and exited the pen. Sows were allowed to compete for access to the feed. The sow that defended the feed and prevented others access was declared "first rank," removed from the new pen, and returned to the home pen. If no dominance determination could be made, the bowl was refilled and presented again. After removing the highest ranking sow, the test was repeated with remaining sows. The next successful sow, second rank, was returned to the home pen, where the first and second rank sows were retested pair-wise to verify rank order. The test in the novel pen was repeated until only one sow remained. The first and second sows were defined as "high" rank, the third – fifth as "middle" rank, and the sixth and seventh as "low" rank.

***Productivity Measures***

***Sow Measures***. Farrow rate (FRW) = (number of sows that farrowed/number of sows pregnant at d 28) * 100 and percentage sows rebred (RBRD) = (number of sows bred within 30 d of weaning/number of sows weaned) * 100 were calculated. The days to the estrus (ESTR) was calculated as the difference between post-treatment weaning date and next breed date. The cull rate (CULL) was calculated as (number of sows culled within 90 d after weaning/number of sows weaned) * 100. The reasons for culling sows were collected and will be discussed descriptively.

***Litter Measures***. Litter data collected included total number of pigs born (TOTLIT), number of pigs born alive (LIVLIT), and litter weight at piglet processing, approximately 3 d old.

***Statistical Analysis***

The data were analyzed with SAS 9.2 (SAS Inst. Inc., Cary, NC) using PROC GLIMMIX. The data were transformed as necessary to normalize residuals. All reported means are least square means. The model

included the fixed effects of alley width and sow rank and used baseline measures as covariates. Time was included in the model for repeated measures. Replication was initially in the model as a random effect, but was removed because it was not significant. Simple effects of significant interactions were obtained using the slice option. The probability of multiple comparisons was adjusted using the Tukey-Kramer method. Statistical significance was set at $P < 0.05$ with a trend at $0.05 \leq P \leq 0.10$.

## Results

### *Physical Measures*

Body weight increased through gestation and decreased after farrowing (mean experimental gain = 51.13 ± 1.44 kg, mean lactational loss = 25.30 ± 1.63 kg; $P < 0.0001$), but did not differ with alleyway width ($P > 0.05$, Table 5). Back fat depth at the tenth rib also increased through gestation ($P < 0.0001$) without differing between treatments ($P > 0.05$, Table 5) as did BCS ($P < 0.0001$, alley: $P > 0.05$; Table 5). Lameness showed a treatment by time interaction ($P < 0.05$, Table 5) such that at wk 1 sows with 0.91 m alleys tended to have lower lameness scores than sows with 2.13 m alleys ($0.05 \leq P \leq 0.10$); however trend was reversed at wk 6 ($0.05 \leq P \leq 0.10$) and no longer existed at wk 11 ($P > 0.05$).

Across all body regions, skin lesions did not significantly differ between sows with different alley widths ($P > 0.05$, data not shown). Dewclaw lesions tended to be greater in sows with 3.05 m alleys than sows with 0.91 m alleys ($0.05 \leq P \leq 0.10$), but no other trends were seen. Lesion scores in all body regions differed over time (Table 6). For every body region except lower leg, the lesion scores were greatest at wk 1 or 2 and the lowest near wk 9 (DCLAW: $P < 0.001$; all others: $P < 0.0001$). Lower leg lesions were the exception to the pattern. They exhibited very little change and did not reach their maximum score until wk 10 ($P < 0.05$).

### *Physiological Measures*

***Hematology***. None of the hematology measures differed with alley width ($P > 0.05$, Table 7). Neither WBC nor %HCT differed over time ($P > 0.05$). The %MO and %LYM were increased at wk 6 compared to wk 1 and 11 ($P < 0.0001$). Both %NEU ($P < 0.000$) and N: L ($P < 0.01$) were lowest at wk 6.

***Immune Function.*** The relative abundance of CD14 tended to be greater in cells from sows with 0.91 m alley than with 2.13 m ($0.05 \leq P \leq 0.10$, Table 8) but did not vary with time ($P > 0.05$). The FI of CD14 did not differ by alley width, but was greater at wk 1 than wk 6 or 11 ($P < 0.01$). The relative abundance CD18 differ not differ between alley widths but wk 1 was lower than wk 6 and 11 ($P < 0.0001$, Table 8) and its FI did not change by alley width or time ($P > 0.05$). Neither the %P BPHAG nor FI differed among alley widths ($P > 0.05$, Table 8), but both changed through time. The relative abundance of cells performing BPHAG was reduced at wk 11 compared to wk 1 and 6 ($P < 0.0001$) and FI was lower at wk 11 than wk 1 ($P < 0.05$). The %P OPHAG did not vary among alley widths or over time ($P > 0.05$, Table 8), but at wk 6 the relative abundance of phagocytosing cells was decreased compared to wk 1 and 11 ($P < 0.01$) The OPHAG FI showed an overall alley width effect ($P < 0.05$, Table 8), but no pair of alleys were significantly different from each other ($P > 0.05$). The FI tended to be greater in cells from sows with 0.91 m alleys than sows from 2.13 m alleys with 3.05 m intermediate ($0.05 \leq P \leq 0.10$, Table 8). Oxidative burst %P was not affected by alley width or time ($P > 0.05$, Table 8), but FI was increased at wk 6 compared to wk 1 ($P < 0.05$, Table 8) and tended to be greater at wk 6 compared to wk 11 ($0.05 \leq P \leq 0.10$).

***Cortisol***. There was no effect of alley width or time on CORT concentration ($P > 0.05$, Table 8).

***Behavioral Measures***

Alley use varied between treatments with 61.31 ± 2.32% of sows with 0.91 m alleys entering the alley at least 1x within 24 hr compared to 68.29 ± 2.32% for sows with 2.13 m ($0.05 \leq P \leq 0.10$) and 72.75 ± 2.30% for sows with 3.05 m ($P < 0.01$) alleys (Table 9). Overall alley use showed a treatment by time interaction ($P < 0.05$) in which both main effects were significant ($P < 0.0001$, Table 9, time effect not shown). Sows with 0.91 m used the alley less than sows with 2.13 ($P < 0.05$) and 3.05 m ($P < 0.001$) with the difference growing over time as sows with the larger alleys increased their usage while sows with 0.91 m alleys did not. Conversely, sows with 2.13 and 3.05 m decreased FAS use over time but sows with 0.91 m alleys did change their usage ($P < 0.05$). For FAS, the main effect of week was different ($P < 0.001$) but sows with 0.91 m alleys only tended to be observed more in FAS than sows with 3.05 m alleys ($0.05 \leq P \leq 0.10$, Table 9, time effect not shown).

Observations IB also showed an alley size by time interaction in which at wk 6 observations increase in pens with 0.91 and 3.05 m alleys, but not in pens with a 2.13 m alley ($P < 0.05$). Neither the main effect of alley width nor time was significant (Table 9, $P > 0.05$, time effect not shown).

The percentage observations standing was greater in sows with 2.13 and 3.05 m alleys than 0.91 m at wk 3 ($P < 0.05$) and wk 5 ($P < 0.01$), but not overall ($P > 0.05$, Table 9, time effect not shown). Percentage observations lying was greater in sows with 3.05 m alleys than 0.91 or 2.13 m alleys at wk 1 ($P < 0.05$) and with 2.13 m alleys at wk 4 ($P < 0.05$), but reduced in sows with 3.05 m alleys compared to sows with 0.91 m alleys at wk 5 ($P < 0.01$) and did not differ overall by alley width or time ($P > 0.05$, Table 9, time effect not shown). The percentage observations sitting did not change with alley size or through time ($P > 0.05$, Table 9, time effect not shown).

The percentage observations in which the sows showed no pen investigatory behavior was greater in sows with 0.91 m than 2.13 m alleys with 3.05 m intermediate ($P < 0.05$, Table 9). The percentage NONE also changed through time with wk 7 being greatest and wk 6 being smallest, but not displaying an apparent overall pattern ($P < 0.0001$). No pen investigatory behavior showed a tendency for a treatment by week interaction ($0.05 \leq P \leq 0.10$) such that pen investigation was greater in sows with 3.05 m than 2.13 m alleys at wk 1 ($P < 0.01$) and sows with 0.91 m than 2.13 ($P < 0.01$) and 3.05 m ($P < 0.05$) alleys at wk 2 of the treatment. There was no overall effect of alley width ($P > 0.05$, Table 9), but NONE differed over time ($P < 0.0001$). None of the individual pen investigatory behaviors (WF, SC, and TR) varied among alley widths ($P > 0.05$, Table 9), but all displayed a time effect. The percentage WF was greatest at wk 1 and 6 and smallest at wk 7 ($P < 0.0001$). Contact with an occupied stall was greatest wk 2 and decreased through time ($P < 0.001$). The percentage observations TR were greatest near the beginning and end of the treatment with the middle having the fewest TR observations ($P < 0.0001$).

The percentage observations a social group (PGP) was greater in pens with 2.13 and 3.05 m alleys than 0.91 m alleys ($P < 0.0001$, Table 8). The group size also differed in that sows with 0.91 m alleys formed smaller groups than sows with 2.13 m ($P < 0.001$) and 3.05 m alleys ($P < 0.0001$). Both PGP and SGP varied over time

being lowest at wk 1 and highest at wk 6 and 5 respectively (PGP: $P < 0.05$; SGP: $P < 0.0001$). Aggression was greatest at wk 1 and then declined ($P < 0.0001$), but was not affected by alley width ($P > 0.05$, Table 9).

***Productivity Measures***

***Sow data***. None of the sow measures: FRW, RBRD, ESTR, or CULL, varied with alley size ($P > 0.05$, Table 10). Across alley widths, the most common reason for culling within 90 d post-treatment were reproductive problems which included being open, having a poor litter, and not returning to heat. Reproductive problems accounted for 83.3% (0.91 m), 62.5% (2.13 m), and 71.4% (3.05 m) of the culls.

***Litter data.*** Neither total nor live litter size varied by alley width ($P > 0.05$, Table 10). At piglet processing, approximately 3 d old, litters from sows with a 0.91 m alleys weighed more than litters from sows with 3.05 m alleys (17.33 ± 1.09 kg); litters from sows with 2.13 m alleys were intermediate ($P < 0.05$, Table 10).

**Discussion**

The results indicate alley size in a free-access gestation stall system had few, small effects on physical, physiological, and productivity measures. In contrast, alley width strongly impacted space use and social interactions.

There were no differences in BW, BCS, or BF between alley widths, which corresponds to previous research indicating few differences among groups with different space allowances/sow (Remience et al., 2008; Salak-Johnson et al., 2007; Seguin et al., 2006).

Lameness tended to be greater in sows with 2.13 m than sows with 0.91 m alleys at wk 1 possibly due to greater locomotion of the sows with 2.13 m alleys during the first month of the treatment. Previous research conducted at the same facility as this study found increased lameness near the end of gestation in group housed gilts compared to stall housed gilts, which the authors attributed to walking on uneven slatted floors (Harris et al., 2006). The present study did not measure walking, but several pieces of evidence suggest that sows with 0.91 m walked less than sows with larger alleys, especially during the 1$^{st}$ half of the treatment. Sows with 0.91

m were upright less at wk 3 and 5 than sows from pens with larger alleys. Sows with the smallest alley were observed less in the alley than sows with larger alleys and performed less pen investigation than sows with 2.13 m alleys. Additionally sows with 0.91 m alleys tended to have lower dewclaw lesions scores than sows with 3.05 m alleys. Taken together, this suggests that sows in the smaller alley walked less than sows with larger alleys resulting in a tendency for reduced lameness at wk 1 than sows from pens with 2.13 m alleys.

Interestingly at wk 6, lameness tended to be greater in sows with 0.91 m alleys than sows with 2.13 m alleys. This may have been due to increased locomotion in 0.91 m sows. Across treatments pen investigatory behavior does not change between wk 5 and 6, but NONE decreases in sows with 0.91 m alleys suggesting higher activity. This was accompanied by a trend of slightly greater immune activation in sows with 0.91 than 2.13 m alleys indicating a potential infection. Cluster of differentiation 14, a component of the lipopolysaccharide receptor (Wright et al., 1990), expression and phagocytosis tended to be greater in sows with 0.91 m alleys compared with sows from 2.13 m indicating greater immune engagement.

Other measures of immune function and physiology did not show greater activation or stress response in sows with 0.91 m than larger alleys. Cortisol concentration did not differ between treatments which is in accordance with previous research comparing stalls to group housing (Barnett et al., 1989; Pol et al., 2002) and alternative group housing strategies (Backus et al., 1997; Hulbert and McGlone, 2006; Strawford et al., 2008) which generally show small to no differences in cortisol concentration. Neither did the leukocyte or hematocrit percentages differ between alley widths.

Most research studies show decreasing space allowance/sow increases injuries (Lynch et al., 2000; Salak-Johnson et al., 2007; Weng et al., 1998) and aggression (Jensen, 1984; Taylor et al., 1997; Weng et al., 1998) yet differences in alley width did not alter aggressive behavior or injuries, besides dewclaw lesions, presumably due to the protection provided by FAS. In most pens with small spaces, sows do not have room to adequately perform submissive or escape behaviors which leads to increased aggression (Ewbank and Bryant, 1972; Jensen, 1984). However aggression can be reduced by including barriers such as partial walls or feeding stalls to the pen design (Barnett et al., 1992; Edwards et al., 1993). Because free-access stalls fully enclose a

sow, they provide greater protection for subordinates than afforded by other pen structures thereby reducing aggression and injury.

The size of the alley changed both the quantity of time spent in the group space and the character of its use. In the pens with larger alleys, 2.13 and 3.05 m, sows used the alley more and their usage increased over time, unlike sows with 0.91 m in which use did not change over time. Interactions between stocking density and time affecting space use has been observed previously in gestating sows such that sows housed at lower density (2.8 $m^2$/sow) increased group area usage over time while at higher stocking density (2.0 $m^2$/sow) space usage did not change over time (Lynch et al., 2000). Not just the amount of time, but also the quality of the alley use was altered by available space. As previously stated, the results suggest an overall reduction in active behavior for sows with 0.91 m alleys. This is in concordance with research demonstrating decreasing space allowance (2.0 – 4.8 $m^2$/sow) decreases rooting behavior and activity level (Weng et al., 1998). Lastly, reduced alley space altered social interactions by decreasing both amount of time in a social group and its size. All behavioral differences between sows with 0.91 m alleys compared to sows with the 2 larger alleys indicate the smaller space was not sufficient for complete behavioral expression.

Increased litter weight in pigs with 0.91 m alleys versus 2.13 and 3.05 m alleys was the only productivity measure that differed between treatments. This result was unexpected as most research finds no effect of housing on piglet weight (Chapinal et al., 2010; DeDecker, 2011; Estienne and Harper, 2010), although studies have found confinement both increases (den Hartog et al., 1993) and decreases piglet weight (Bates et al., 2003).

In conclusion, free-access stalls present a potential alternative housing system to a standard gestation stall. The group space allows sows the opportunity for exercise and social interaction while the stall proffers protection against aggression. The size of the group space makes little difference in measures of sow health, physiology or production. But behavior is markedly changed in the smallest alley space with reduced alley usage, less time in exploration, and less social interaction, indicators that natural behavior was inhibited due to space restriction.

The “Freedom to Express Normal Behaviour” is one of the Five Freedoms, a group of statements that prescribe a framework for animal welfare analysis, whose ideas originated in the Brambell Report of 1965 and is still a well-respected set of standards (FAWC, 2011). Because a 0.91 m alley fails to meet this freedom, it provides the sows somewhat lower welfare than either a 2.13 or 3.05 m alley.

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**Figure 1.** Sows in free-access stall housing. Image from www.choretime.com

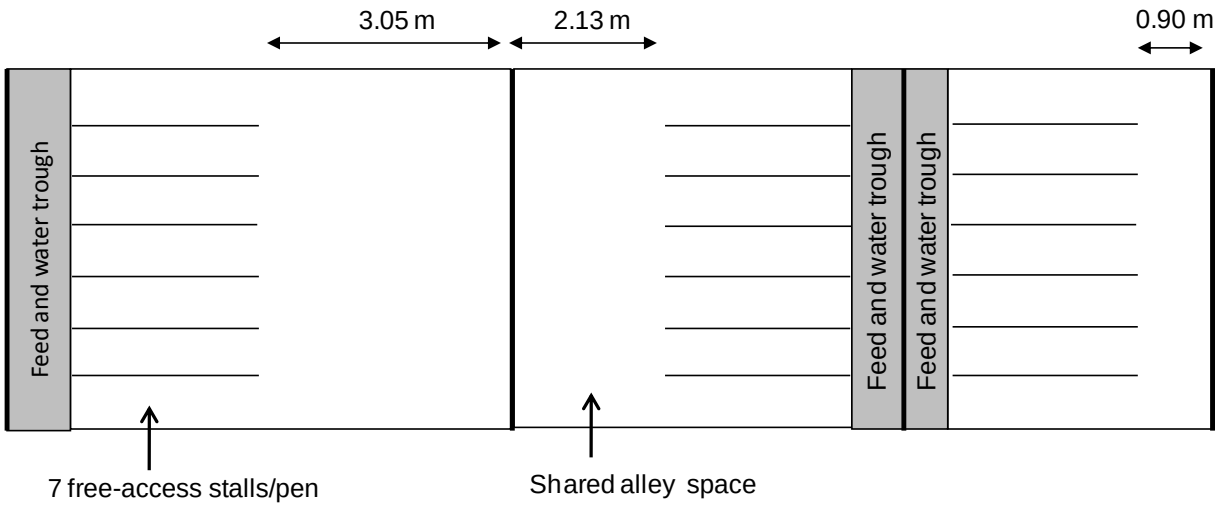


**Figure 2.** Layout of the 3 experimental pens each containing 7 free-access stalls and a shared alley with a width of 0.91, 2.13, or 3.05 m.

**Table 1**. Body condition score[1]

| Score | Condition | Ability to detect ribs, backbone, and hips with palm pressure |
|---|---|---|
| 1 | emaciated | obvious |
| 2 | thin | easily detected |
| 3 | ideal | barely felt |
| 4 | fat | none |
| 5 | overly fat | none |

[1]Adapted from Coffey et al. (1999).

**Table 2.** Lameness scoring system[1]

| Score | Standing Posture | Gait |
|---|---|---|
| 0 | Pig stands squarely on four legs. | Even strides. Caudal body sways slightly while walking. |
| 1 | Pig stands squarely on four legs. | Abnormal stride length. Movements are no longer fluent. |
| 2 | Uneven posture | Shortened stride. Lameness detected. Swagger of caudal body while walking. No hindrance in agility. |
| 3 | Uneven posture. Will not bear weight on affected limb. Appears to be standing on toes. | Shortened stride. Minimum weight bearing on affected limb. Swagger of caudal body while walking. Will still trot or gallop. |
| 4 | Affected limb elevated off the floor. | Pig may not place affected limb on the floor while moving. |
| 5 | Will not stand unaided. | Does not move. |

[1]From Harris et al. (2006).

**Table 3**. Skin lesion scores[1]

| Score | Description |
|---|---|
| 0 | Normal |
| 1 | Reddening or callus |
| 2 | < 10 scratches and no cuts |
| 3 | ≥ 10 scratches, < 5 cuts, 1 superficial wound, or 1 abscess |
| 4 | ≥ 5 cuts, 1 deep wound, ≥ 1 wound, or ≥ 1 abscess |
| 5 | ≥ 10 cuts, ≥ 2 deep wounds, or ≥ 5 wounds |

[1]Adapted from Arey (1999) and Hodgkiss et al. (1998).

**Table 4.** Behavioral ethogram

| Behavioral category | Behavior | Definition |
|---|---|---|
| Location | | |
| | Free-access stall | Sow deep enough in FAS door can be latched shut[1] |
| | Alley | Sow's entire body in alley |
| | In-between | Sow partly in alley and partly in FAS |
| Position | | |
| | Standing | Only feet in contact with floor |
| | Sitting | Rear of body and front feet on floor; rest of body elevated |
| | Lying | Body on floor; legs not supporting weight |
| | Head in trough | Snout in feed and water trough |
| Social contact | Group | Sow within 15 cm of 1 or more sows |
| Pen investigation | Wall/floor contact | Sow's snout in contact with pen floor or walls |
| | Closed stall | Sow's snout in contact with a closed FAS door |
| | Head in stall | Sow in alley has head inside an already occupied stall |
| Aggression | | One sow bites or head knocks a second sow |

[1]FAS = free-access stall.

**Table 5**. Physical measures

| | AW[1] | Wk 1 | Wk 6 | Wk 11 | Post-farrow | Weaning |
|---|---|---|---|---|---|---|
| BW, kg | 0.91 | 202.88 ± 4.34$^{d}$ | 229.87 ± 4.34$^{b,c}$ | 255.41 ± 4.33$^{a}$ | 251.55 ± 4.73$^{a}$ | 224.73 ± 4.40$^{c}$ |
| | 2.13 | 199.00 ± 4.38$^{d}$ | 224.68 ± 4.38$^{c}$ | 249.89 ± 4.37$^{a}$ | 251.28 ± 4.78$^{a}$ | 225.39 ± 4.44$^{c}$ |
| | 3.05 | 198.13 ± 4.74$^{d}$ | 223.25 ± 4.74$^{c}$ | 248.10 ± 4.73$^{a}$ | 242.90 ± 5.14$^{a,b}$ | 219.70 ± 4.86$^{c}$ |
| BF, cm | 0.91 | 2.17 ± 0.05$^{e}$ | 2.62 ± 0.06$^{b,c,d}$ | 2.80 ± 0.06$^{a}$ | | |
| | 2.13 | 2.14 ± 0.05$^{e}$ | 2.54 ± 0.06$^{d}$ | 2.59 ± 0.06$^{a,b,c}$ | | |
| | 3.05 | 2.24 ± 0.05$^{e}$ | 2.59 ± 0.06$^{c,d}$ | 2.72 ± 0.06$^{a,b}$ | | |
| BCS* | 0.91 | 1.14 ± 0.01$^{b,c}$ | 1.11 ± 0.01$^{a,b}$ | 1.13 ± 0.01$^{a,b}$ | | |
| | 2.13 | 1.10 ± 0.01$^{b,c}$ | 1.12 ± 0.01$^{b,c}$ | 1.14 ± 0.01$^{a,b}$ | | |
| | 3.05 | 1.12 ± 0.01$^{c}$ | 1.13 ± 0.01$^{b,c}$ | 1.10 ± 0.01$^{a}$ | | |
| LAM | 0.91 | 1.67 ± 0.12$^{b,c,d}$ | 1.78 ± 0.12$^{a,b}$ | 1.57 ± 0.13$^{c,d}$ | | |
| | 2.13 | 1.86 ± 0.12$^{a}$ | 1.59 ± 0.12$^{b,c,d}$ | 1.65 ± 0.12$^{a,b,c}$ | | |
| | 3.05 | 1.76 ± 0.12$^{a,b,c}$ | 1.65 ± 0.12$^{b,c,d}$ | 1.47 ± 0.13$^{d}$ | | |

*Data were logarithmically transformed to meet assumptions of normality.

$^{a,b,c,d,e}$Means with no common superscripts differ significantly ($P \leq 0.05$).

[1]AW = alley width, m; BCS = body condition score; BF = back fat depth; BW = body weight, LAM = lameness score.

**Table 6**. Lesion scores

| Body region | Wk 1 | Wk 2 | Wk 3 | Wk 4 | Wk 5 | Wk 6 | Wk 7 | Wk 8 | Wk 9 | Wk 10 | Wk 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Head[1] | 3.83 ± 0.08$^{a}$ | 4.01 ± 0.07$^{a,b}$ | 3.58 ± 0.07$^{b,c}$ | 3.13 ± 0.07$^{a,b}$ | 2.96 ± 0.06$^{b}$ | 2.83 ± 0.05$^{b}$ | 2.86 ± 0.05$^{b}$ | 2.81 ± 0.06$^{b}$ | 2.58 ± 0.07$^{c}$ | 2.70 ± 0.07$^{a,b}$ | 2.66 ± 0.09$^{a,b}$ |
| Body | 3.20 ± 0.07$^{a,b}$ | 3.40 ± 0.06$^{a}$ | 3.07 ± 0.06$^{b,c}$ | 2.77 ± 0.06$^{d}$ | 2.70 ± 0.07$^{d,e}$ | 2.65 ± 0.06$^{d,e}$ | 2.63 ± 0.07$^{d,e}$ | 2.67 ± 0.06$^{d,e}$ | 2.45 ± 0.07$^{e}$ | 2.57 ± 0.08$^{d,e}$ | 2.78 ± 0.07$^{c,d}$ |
| Rump | 2.88 ± 0.08$^{b}$ | 3.08 ± 0.07$^{a}$ | 2.90 ± 0.07$^{b}$ | 2.56 ± 0.07$^{c}$ | 2.35 ± 0.08$^{d,e}$ | 2.41 ± 0.08$^{c,d}$ | 2.36 ± 0.08$^{d,e}$ | 2.32 ± 0.09$^{d,e}$ | 2.03 ± 0.08$^{f}$ | 2.03 ± 0.08$^{d,e}$ | 2.34 ± 0.08$^{e,f}$ |
| Uleg | 2.80 ± 0.07$^{a}$ | 2.94 ± 0.07$^{a}$ | 2.92 ± 0.06$^{a}$ | 2.44 ± 0.07$^{b,c}$ | 2.53 ± 0.07$^{b}$ | 2.44 ± 0.07$^{b,c}$ | 2.36 ± 0.07$^{c,d}$ | 2.3 ± 0.08$^{c,d,e}$ | 2.25 ± 0.07$^{d,e}$ | 2.29 ± 0.08$^{c,d,e}$ | 2.09 ± 0.10$^{e}$ |
| Lleg | 2.38 ± 0.07$^{a,b}$ | 2.42 ± 0.08$^{a}$ | 2.30 ± 0.07$^{a,b}$ | 2.23 ± 0.07$^{a,b}$ | 2.11 ± 0.08$^{b}$ | 2.30 ± 0.07$^{a,b}$ | 2.35 ± 0.07$^{a,b}$ | 2.30 ± 0.07$^{a,b}$ | 2.27 ± 0.07$^{a,b}$ | 2.47 ± 0.07$^{a}$ | 2.37 ± 0.09$^{a,b}$ |
| Hoof | 1.99 ± 0.05$^{a}$ | 1.85 ± 0.05$^{b,c}$ | 1.81 ± 0.05$^{c}$ | 1.97 ± 0.06$^{a,b}$ | 1.84 ± 0.06$^{c}$ | 1.80 ± 0.05$^{c}$ | 1.9 ± 0.05$^{a,b,c}$ | 1.67 ± 0.04$^{a,b,c}$ | 1.67 ± 0.05$^{d}$ | 1.88 ± 0.05$^{a,b,c}$ | 1.93 ± 0.07$^{a,b,c}$ |
| Dclaw | 2.11 ± 0.05$^{a}$ | 1.97 ± 0.06$^{a,b}$ | 1.85 ± 0.06$^{b}$ | 1.97 ± 0.07$^{a,b}$ | 1.91 ± 0.06$^{a,b}$ | 1.89 ± 0.05$^{a,b}$ | 1.90 ± 0.05$^{a,b}$ | 1.90 ± 0.05$^{a,b}$ | 1.72 ± 0.07$^{b}$ | 2.01 ± 0.05$^{a,b}$ | 2.03 ± 0.09$^{a,b}$ |

$^{a,b,c,d,e,f}$Means with no common superscripts differ significantly ($P \leq 0.05$).

[1]Body = body and udder; Dclaw = dewclaw; Head = head, neck and shoulders, Hoof = hooves and feet; Lleg = hock, knee, and pasterns; Uleg = upper leg; Rump = rump, tail, and vulva.

**Table 7**. Hematology and cortisol analysis

| | AW[1] | Wk 1 | Wk 6 | Wk 11 |
|---|---|---|---|---|
| WBC | 0.91 | $14.49 \pm 0.77^{a,b,c}$ | $13.23 \pm 0.78^{b,c}$ | $13.02 \pm 0.68^{c}$ |
| | 2.13 | $15.45 \pm 0.84^{a,b}$ | $13.4 \pm 0.78^{a,b,c}$ | $13.99 \pm 0.66^{a,b,c}$ |
| | 3.05 | $14.24 \pm 0.93^{a,b,c}$ | $16.42 \pm 1.34^{a}$ | $14.56 \pm 0.77^{a,b,c}$ |
| %NE | 0.91 | $36.93 \pm 1.75^{a,b,c,d}$ | $32.76 \pm 1.79^{c,d,e}$ | $38.95 \pm 1.68^{a}$ |
| | 2.13 | $37.18 \pm 2.02^{a,b,c,d}$ | $31.17 \pm 1.88^{e}$ | $31.25 \pm 2.52^{a}$ |
| | 3.05 | $34.68 \pm 2.27^{b,c,d,e}$ | $31.25 \pm 2.52^{d,e}$ | $40.36 \pm 1.72^{a,b,c}$ |
| %LYM | 0.91 | $42.39 \pm 1.97^{b}$ | $48.49 \pm 2.62^{a,b}$ | $45.91 \pm 1.64^{a,b}$ |
| | 2.13 | $42.61 \pm 2.31^{b}$ | $51.53 \pm 2.75^{a}$ | $43.97 \pm 1.69^{b}$ |
| | 3.05 | $40.68 \pm 2.54^{b}$ | $48.54 \pm 3.70^{a,b}$ | $43.58 \pm 1.96^{b}$ |
| N:L | 0.91 | $1.04 \pm 0.10^{a}$ | $0.82 \pm 0.08^{a,b}$ | $0.93 \pm 0.06^{a,b}$ |
| | 2.13 | $0.95 \pm 0.12^{a,b}$ | $0.68 \pm 0.08^{b}$ | $0.97 \pm 0.06^{a}$ |
| | 3.05 | $0.94 \pm 0.13^{a,b}$ | $0.70 \pm 0.11^{b}$ | $0.87 \pm 0.07^{a,b}$ |
| %MON | 0.91 | $4.14 \pm 0.68^{b,c}$ | $6.73 \pm 0.89^{a}$ | $3.39 \pm 0.33^{c}$ |
| | 2.13 | $5.95 \pm 0.78^{a,b}$ | $6.15 \pm 0.94^{a,b}$ | $3.57 \pm 0.34^{c}$ |
| | 3.05 | $4.31 \pm 0.89^{a,b,c}$ | $7.09 \pm 1.25^{a}$ | $3.74 \pm 0.39^{c}$ |
| %HCT | 0.91 | $33.96 \pm 1.21^{a,b}$ | $34.78 \pm 0.78^{a,b}$ | $36.05 \pm 1.46^{a}$ |
| | 2.13 | $34.39 \pm 1.34^{a,b}$ | $34.33 \pm 0.77^{a,b}$ | $32.92 \pm 1.42^{a,b}$ |
| | 3.05 | $35.27 \pm 1.46^{a,b}$ | $32.18 \pm 1.04^{b}$ | $33.89 \pm 1.67^{a,b}$ |
| CORT* | 0.91 | $5.10 \pm 0.33^{a}$ | $4.10 \pm 0.35^{a}$ | $4.40 \pm 0.36^{a}$ |
| | 2.13 | $4.77 \pm 0.36^{a}$ | $4.38 \pm 0.37^{a}$ | $4.33 \pm 0.43^{a}$ |
| | 3.05 | $4.67 \pm 0.37^{a}$ | $5.04 \pm 0.40^{a}$ | $4.43 \pm 0.41^{a}$ |

*Data were square root transformed to meet assumptions of normality.

[a,b,c,d,e]Means with no common superscripts differ significantly ($P \leq 0.05$).

[1]%LYM = lymphocyte percentage of leukocytes; %HCT = percentage hematocrit; %NE = neutrophil percentage of leukocytes; AW = alley width, m; CORT = plasma free cortisol, μg/dL; N:L = ratio of neutrophils to lymphocytes; WBC = white blood cell count,106/μL.

**Table 8**. Immune function

| | AW[1] | Wk 1 | Wk 6 | Wk 11 |
|---|---|---|---|---|
| CD14 %P* | 0.91 | 2.28 ± 0.21[a,b] | 2.46 ± 0.23[a,b] | 2.51 ± 0.22[a] |
| | 2.13 | 1.85 ± 0.22[b] | 2.26 ± 0.26[a,b] | 1.68 ± 0.25[b] |
| | 3.05 | 2.24 ± 0.27[a,b] | 2.47 ± 0.31[a,b] | 2.45 ± 0.35[a,b] |
| CD14 FI* | 0.91 | 2.81 ± 0.10[a] | 2.84 ± 0.08[b,c] | 2.88 ± 0.09[a,b,c] |
| | 2.13 | 2.93 ± 0.11[a,b] | 2.85 ± 0.08[a,b,c] | 2.62 ± 0.11[c] |
| | 3.05 | 2.77 ± 0.13[a,b,c] | 2.72 ± 0.09[b,c] | 2.69 ± 0.14[c] |
| CD18 %P* | 0.91 | 1.22 ± 0.33[d,e] | 2.02 ± 0.35[a,b,c,d] | 2.29 ± 0.38[a,b,c] |
| | 2.13 | 1.37 ± 0.35[c,d,e] | 2.33 ± 0.39[a,b] | 1.58 ± 0.39[b,c,d,e] |
| | 3.05 | 0.70 ± 0.47[e] | 2.83 ± 0.48[a] | 2.63 ± 0.53[a,b] |
| CD18 FI^ | 0.91 | 4.58 ± 0.27[a,b] | 4.50 ± 0.29[a,b] | 4.86 ± 0.29[a] |
| | 2.13 | 4.50 ± 0.29[a,b] | 4.44 ± 0.33[a,b] | 4.63 ± 0.31[a,b] |
| | 3.05 | 3.94 ± 0.36[b] | 4.10 ± 0.39[a,b] | 3.90 ± 0.38[b] |
| BPhago %P | 0.91 | 34.82 ± 4.19[b,c,d] | 43.37 ± 4.53[a,b] | 30.65 ± 4.48[c,d] |
| | 2.13 | 41.30 ± 4.28[a,b,c] | 44.00 ± 4.91[a,b] | 25.73 ± 4.62[d] |
| | 3.05 | 50.67 ± 5.72[a] | 40.06 ± 6.14[a,b,c,d] | 27.11 ± 6.66[c,d] |
| BPhago FI^ | 0.91 | 4.42 ± 0.38[a] | 3.42 ± 0.41[a] | 3.37 ± 0.41[a] |
| | 2.13 | 4.45 ± 0.38[a] | 4.03 ± 0.45[a] | 3.90 ± 0.41[a] |
| | 3.05 | 4.36 ± 0.51[a] | 4.31 ± 0.56[a] | 3.22 ± 0.61[a] |
| OPhago %P^ | 0.91 | 3.00 ± 0.45[b] | 2.13 ± 0.50[b] | 4.65 ± 0.52[a] |
| | 2.13 | 3.34 ± 0.47[a,b] | 2.22 ± 0.57[b] | 2.84 ± 0.54[b] |
| | 3.05 | 3.60 ± 0.60[a,b] | 2.21 ± 0.64[b] | 3.20 ± 0.74[a,b] |
| OPhago FI^ | 0.91 | 6.10 ± 0.50[a] | 5.60 ± 0.55[a] | 5.75 ± 0.57[a] |
| | 2.13 | 5.16 ± 0.52[a,b] | 3.77 ± 0.61[b] | 4.82 ± 0.59[a,b] |
| | 3.05 | 5.11 ± 0.65[a,b] | 4.90 ± 0.69[a,b] | 3.54 ± 0.79[b] |
| OB %P | 0.91 | 55.98 ± 10.53[a] | 51.38 ± 8.30[a] | 47.36 ± 10.52[a] |
| | 2.13 | 53.66 ± 11.74[a] | 54.39 ± 8.53[a] | 44.66 ± 11.02[a] |
| | 3.05 | 44.20 ± 14.25[a] | 44.07 ± 8.92[a] | 42.53 ± 14.46[a] |
| OB FI^ | 0.91 | 6.39 ± 0.54[a,b] | 7.91 ± 0.60[a] | 6.35 ± 0.62[a,b] |
| | 2.13 | 6.51 ± 0.56[a,b] | 7.35 ± 0.68[a,b] | 5.78 ± 0.64[b] |
| | 3.05 | 5.92 ± 0.71[b] | 7.45 ± 0.77[a,b] | 6.61 ± 0.89[a,b] |

*,^Data were logarithmically or square root transformed, respectively, to meet assumptions of normality.
[a,b,c,d,e]Means with no common superscripts differ significantly ($P \leq 0.05$).
[1]%P = percentage of positive cells relative to control population; AW = alley width, m; BPhago = bead phagocytosis; CD = cluster of differentiation; FI = fluorescent intensity relative to control population; OB = oxidative burst; OPhago = opsonized phagocytosis.

**Table 9**. Sow behavior

| | Alley width, m | | |
|---|---|---|---|
| | 0.91 | 2.13 | 3.05 |
| Alley use, % | 61.31 ± 2.32[b] | 68.29 ± 2.32[a,b] | 72.75 ± 2.30[a] |
| Free-access stall obs, %* | 1.06 ± 0.05[a] | 0.90 ± 0.05[b] | 0.88 ± 0.05[b] |
| Alley obs, %^ | 2.63 ± 0.32[b] | 3.98 ± 0.32[a] | 4.34 ± 0.33[a] |
| In-between obs, %^ | 1.44 ± 0.28[a] | 1.28 ± 0.28[a] | 1.03 ± 0.28[a] |
| Standing, %* | 0.21 ± 0.01[a] | 0.24 ± 0.01[a] | 0.23 ± 0.01[a] |
| Sitting, %* | 0.10 ± 0.01[a] | 0.09 ± 0.01[a] | 0.10 ± 0.01[a] |
| Lying, % | 88.76 ± 0.65[a] | 87.81 ± 0.63[a] | 88.08 ± 0.64[a] |
| Wall-floor contact, %^ | 1.57 ± 0.10[a] | 1.74 ± 0.10[a] | 1.65 ± 0.10[a] |
| Occupied stall contact, %* | 0.03 ± 0.00[a] | 0.02 ± 0.00[a] | 0.02 ± 0.00[a] |
| Snout in trough, %^ | 0.15 ± 0.01[a] | 0.14 ± 0.01[a] | 0.14 ± 0.01[a] |
| No contact, % | 96.59 ± 0.45[a] | 94.73 ± 0.46[b] | 95.49 ± 0.45[a,b] |
| Social group presence, %* | 0.20 ± 0.02[c] | 0.36 ± 0.02[b] | 0.39 ± 0.02[a] |
| Social group size, %* | 0.16 ± 0.00[c] | 0.17 ± 0.00[b] | 0.17 ± 0.00[a] |
| Aggression, %* | 0.003 ± 0.001[a] | 0.003 ± 0.001[a] | 0.004 ± 0.001[a] |

*,^,#Data were angularly, square root, or logarithmically transformed, respectively, to meet assumptions of normality.

[a,b,c,]Means with no common superscripts differ significantly ($P \leq 0.05$).

[1]AW = alley width, m.

**Table 10**. Sow productivity and litter data

| | Alley width, m | | |
|---|---|---|---|
| | 0.9 | 2.13 | 3.05 |
| Farrow rate, %* | 4.51 ± 0.05[a] | 4.49 ± 0.05[a] | 4.40 ± 0.05[a] |
| Rebred, % | 85.56 ± 5.55[a] | 83.33 ± 5.55[a] | 78.01 ± 5.66[a] |
| Days to estrus | 5.98 ± 0.68[a] | 5.92 ± 0.68[a] | 7.18 ± 0.78[a] |
| Culling rate | 20.49 ± 5.88[a] | 19.14 ± 5.88[a] | 24.07 ± 5.88[a] |
| Total litter size | 11.58 ± 0.58[a] | 10.6 ± 0.78[a] | 10.11 ± 0.74[a] |
| Live litter size | 10.4 ± 0.53[a] | 9.87 ± 0.71[a] | 9.21 ± 0.68[a] |
| Litter weight, kg | 20.56 ± 0.84[a] | 19.42 ± 1.15[b] | 17.33 ± 1.09[a,b] |

*Data were logarithmically transformed, respectively, to meet assumptions of normality.

[a,b]Means with different superscripts are statistically different ($P \leq 0.05$).