Evaluation of drop versus trickle-feeding systems for crated or group-penned gestating sows[1]

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ABSTRACT: A total of 160 gilts were used to evaluate the effects of pen vs. crated housing systems and drop- vs. trickle-fed feeding systems on sow productivity, occurrence of lesions during farrowing and weaning, immune measures, and behavioral responses during 2 consecutive gestation periods. Of the 160 eligible gilts, 117 farrowed in parity 1, and of those, 72 farrowed in parity 2. The gilts were randomly assigned to represent 1 of 4 factorially arranged treatment groups: pen drop-fed, crate drop-fed, pen trickle-fed, or crate trickle-fed. Replicate blocks were used for each parity with 5 sows per block initially in each treatment. At weaning, sows housed in pens had greater ($P < 0.05$) backfat thickness than sows housed in crates. The piglet weaning weight was greater ($P < 0.05$) for sows fed with the single drop compared with the trickle-feeding system. Lesions scores and all other productivity measures did not differ among treatments. An interaction was observed for percentage of neutrophil phagocytosis ($P < 0.05$) between penning and feeding systems. In pens, drop-fed sows had greater phagocytosis than trickle-fed sows, but in crates, drop-fed sows had a tendency for lower phagocytosis than trickle-fed sows. All other immune measures were not different among treatments. The occurrence of oral-nasal-facial (ONF) behaviors (chewing, rooting, and rubbing) and active behaviors increased, and lying behavior decreased ($P < 0.05$), from 0800 to 1200 for all sows. During the 0800 to 1200 period, crate drop-fed sows displayed more ($P < 0.05$) ONF and active behaviors than did sows in the 3 other treatments. Sows housed in groups of 5 had a greater ($P < 0.05$) duration of standing in the 0400 to 0800 period compared with crated sows. Housing systems had complex effects on sow behavioral sequences, but penned sows had more sequences associated with stress than did crated sows. Also, crate drop-fed gilts and sows expressed more ONF behaviors than gilts and sows in other treatments. Generally, productivity, skin lesions, and immune measures were not different, but behaviors at certain times of day and behavioral sequences were different for sows in pens and crates with drop or trickle-feeding systems. None of the environments evaluated were associated with significant physiological stress responses among the sows. Thus, sows were able to adapt within each environment through behavioral mechanisms without the need to invoke major physiological adjustments.

Key words: alternative housing, feeding system, gestation, sow

INTRODUCTION

The majority of sows within the United States are housed in individual crates and are fed once per day

with a single-drop feeding system (NRC, 1998). This common production system was implemented to optimize pig productivity, decrease labor, and increase disease control. There is growing concern about sow housing systems, and more emphasis is being placed on overall animal welfare (McGlone et al., 2004). Freedom to express normal behavior is an issue of much debate because the gestation crate (i.e., stall) does not allow expression of normal behavior (e.g., turning) and social interaction. When developing new sow housing systems, sow welfare as well as producer requirements should be met (den Hartog et al., 1993). A range of indicators may be used when evaluating the appropriate environment for an animal (Broom, 1997). Therefore, the objective of this study was to evaluate 2 types of penning systems, crates vs. group housing, and 2 feeding systems, a single drop vs. a trickle given over a 30-min period, using mea-

sures of sow and litter productivity and sow behavior and physiology. The trickle-feeding system (also called Biofix) was developed in Europe but has not yet been evaluated in North America.

MATERIALS AND METHODS

General

This project was approved by the Animal Care and Use Committee of Texas Tech University. All pigs were housed at the Texas Tech Swine Research Farm (New Deal, TX). Gilts were randomly assigned to 1 of 2 penning systems, pens or crates, and 1 of 2 feeding systems, single drop or a trickle over 30 min. All gilts and sows farrowed in a common farrowing room using farrowing crates. After weaning, sows returned to the same treatment to experience another complete gestation and lactation. Gilts and sows received a standard gestation diet (14% CP as-fed; corn and soybeans) of 2.7 kg/d.

Penning Systems

Pens were constructed using the same fencing and gating materials as was used for the crates. The back two-thirds of each crate were opened to form a 3.07- × 2.16-m pen with four 0.8- × 0.61-m partial stalls, creating 5 feeding stalls. This allowed sows or gilts about 6.6 m^2 of space or about 1.32 m^2 per pig. Crated sows had a 0.61 m wide stall that was 1.08 m tall and 2.1 m in length. This allowed crated sows 1.2 m^2 of space in which they could not turn around. If <5 sows were available in a given block, filler (nonstudy) sows were included to allow for similar space allowances and social experiences. The flooring under the crates and pens was concrete slats. The concrete slats included a 15.2-cm slat with a 2.5-cm slot or the full 2.1-m length of the crate. Sows in the pens had the same slatted area that extended the full length of the pen.

Feeding Systems

The feeding tubes entering the crates or pens were identical between the 2 feeding systems. Drop-fed sows had their entire meal delivered in a single moment. Trickle-fed sows had their same daily portion of feed delivered slowly, in a trickle, over a 30-min period. The trickle-feeding system was designed and built by Automated Production Systems (Assumption, IL) as a way to limit-feed group-housed sows; however, it can be used for individually housed sows as well.

Animals and Productivity Measures

A total of one hundred sixty, 7-mo-old gilts (Camborough 22, PIC, Franklin, KY) were eligible to enter the study. The gilts came from a single farm and arrived in 2 groups of 80 gilts each. Gilts with known dates of estrus were moved into a randomly assigned treatment before their next estrus. Gilts were then checked daily

for signs of estrus, and when they expressed standing estrus, they were bred by AI. Because the gilts were housed in a common large pen during isolation (i.e., acclimation), they were acquainted before being moved to the breeding and gestation barn.

Gilts and sows that completed gestation were transported about 300 m to common farrowing barns equipped with the previously described farrowing crates (Johnson et al., 2001). The farrowing rate was calculated as the number of gilts or sows that farrowed ÷ the number eligible to be bred × 100. If a gilt or sow did not express estrus or returned to estrus after being bred, she was removed from the study. This procedure yielded an apparently lower farrowing rate on a herd basis than when gilts or sows were rebred and placed in another breeding group. In this study, if gilts or sows were removed from a pen, another pregnant gilt or sow was added to the pen to maintain the same space allowance and group size. These filler sows were not included in the data set for measures of productivity, physiology, or behavior. Each treatment group had filler sows in parity 2 because the farrowing rates in parity 1 were <100%. Little antagonistic behavior was observed, probably because the gilts were reared in a common large pen before initiation of the study.

In the farrowing barn, feed intake of the sows was increased to ad libitum over the first 5 to 7 d postpartum. The diet contained 14% CP as-fed, corn, soybean meal, and vitamins and minerals. Sow lactation feed intake was recorded.

The sows were weighed at farrowing and weaning. The numbers of piglets born alive and dead and the number of pigs weaned were recorded. Piglet BW was determined at birth and weaning. The average weaning age was 22 d.

Productivity measures were taken to determine sow performance and occurrence and severity of lesions. Lesions were visually evaluated by a trained observer on the neck, shoulder, ear, side, back, ham, and feet of all sows and assigned a numerical value to indicate severity, where 1 = mild, 2 = medium, and 3 = severe. A mild lesion included superficial scratches that were not bleeding or infected. A medium lesion included small, deep lesions that had begun to heal with no signs of infection. A severe lesion included deep wounds that had not shown signs of healing and did show possible infection and, in some cases, bleeding. Lesions were assessed 1 wk after weaning when the sows were expected to have the most lesions. Backfat thickness was measured in millimeters at breeding, farrowing, and weaning.

Immune Measures

For parity 1, 78 pregnant gilts were used to collect and analyze immune measures. Blood (20 mL) was drawn from the jugular vein, and sodium heparin as used as the anticoagulant. Immune measures included white blood cell counts and differential cell type determined using a Cell Dyne (Abbott Labs, Santa Clara, CA),

neutrophil chemotaxis and chemokinesis (migration), and neutrophil phagocytosis.

Plasma cortisol levels were evaluated by RIA. Blood samples were collected from the external jugular vein with lithium heparin as the anticoagulant. Six hundred microliters of diluted plasma (1:2 dilution) was used to perform the assay. The Coat-a-Count cortisol kit (Diagnostic Products Corporation, Los Angeles, CA) was used, and all samples were analyzed in a single assay. The intraassay CV was 4.1%.

Neutrophil chemotaxis and chemokinesis were determined by methods previously described (McGlone et al., 1993; Morrow-Tesch et al., 1994). Briefly, neutrophils were isolated using 2 gradients of Histopaque 1077 and 1911 (Sigma-Aldrich, St. Louis, MO), and most of the erythrocytes were lysed using $10\times$ PBS (Sigma-Aldrich) and distilled water. Isolated neutrophils were then resuspended in RPMI medium (Sigma-Aldrich) with a concentration of 1×10^6 cells/mL for the chemotaxis, chemokinesis, and phagocytosis assays. A modified Boyden chamber (Neuro Probe, Cabin John, MD) was used to measure the migration of neutrophils toward media (chemokinesis) or toward 10^{-8} M recombinant human complement fragment (C5a, Sigma-Aldrich; chemotaxis). The medium and C5a were added to the bottom wells, and neutrophils were added to the top. The Boyden chambers were then incubated in a humidified CO_2 chamber for 1 h at 37°C. The filter was removed, fixed, and stained using Hematoxalin stain I and II (Fisher Scientific, Houston, TX). Five fields per well were counted at $1,000\times$ magnification, and the counters were blind to the treatments when the cells were counted.

Isolated neutrophils were also subjected to a phagocytosis assay to determine the percentage phagocytosis of opsonized latex beads (0.807-µL diameter, Sigma-Aldrich). To opsonize the latex beads, a 400-µL aliquot of sterile PBS was mixed with 50 µL of normal porcine serum (collected from healthy nursery pigs at the Texas Tech University Swine unit in New Deal, TX) and 250 µL of latex beads in a 50-mL conical tube. The bead and serum mix was incubated for 1 h in a humidified CO_2 chamber at 37°C, and then the beads were washed twice with PBS, centrifuged, and resuspended to 1×10^7 beads/ mL. The latex bead solution (500 µL) was added and mixed thoroughly in a conical tube containing each sample of 500 µL of isolated neutrophils to create a 1:5 cell-to-bead ratio. The neutrophil and bead mixture was then incubated for 10 min in a humidified CO_2 chamber at 37°C. The tubes were centrifuged at $40 \times g$ for 7 min at 8°C. The supernatant was removed with a pasteur pipette, taking care not to disturb the pellet of beads that had collected on the bottom. Then, 1 mL of media was added, and the solution was vortexed on high speed; this washing procedure was repeated until the solution was clear. The supernatant was removed, and 500 µL of the medium was added. The mixture was vortexed at high speed, ensuring that the pellet containing the beads was fully mixed into solution. A small volume (200 µL)

of solution was obtained from the bead and cell mixture and centrifuged at 8,500 rpm and $1,100 \times g$ (Cytofuge 2, model M801-22, StatSpin, Inc., Norwood, MA) for 2 min. A total of 100 neutrophils was counted. For each cell, the number of beads phagocytized was determined as 0, 1, 2, 3, 4, 5, or ≥6, and the percentage of cells that phagocytized at least one bead and the average numbers of beads phagocytized were determined.

Behavioral Measures

Behaviors were recorded for 24 h (Dailey and McGlone, 1997b) using time-lapse videography (0.8 frames/s) between d 50 and 75 of gestation. Sow behavior was observed using the Observer 5.1 behavior program (Noldus, Leesburg, VA). The recorded behaviors were drinking, eating, oral-nasal-facial (**ONF**), sitting, standing, and lying. The social behaviors were antagonistic, mounting, and nonaggressive interactions. From these behaviors, total active behaviors were calculated by subtracting lying behavior. All behavioral measures are defined in Table 1.

Statistical Analysis

The behavioral data were analyzed using SAS (SAS Inst., Inc., Cary, NC). The frequency and duration of behaviors for the 24-h d were averaged, and the 24-h d was divided into 4-h periods (or subplots). The experiment was a randomized complete block design with a 2 × 2 factorial arrangement of treatments with a split plot over time (parities). The productivity and immune measures were analyzed using a randomized complete block design with a 2 × 2 factorial arrangement of the treatments using a split plot over parities 1 and 2. Eight blocks were available for the productivity and behavioral measures; but for the immune data, 4 blocks were sampled. The behavioral data were a 2 × 2 factorial arrangement of treatments with a split-split plot over time (split 1 was parity, and split 2 was time of day).

Chi square was used to evaluate behavioral sequences based on a Markov Chain analysis of the transition matrix using an advanced technique that builds on simple transitional analysis (Dailey and McGlone, 1997a). Briefly, behavioral sequences were counted and entered into a transitional matrix; rows and columns represented the first and second behaviors found in each sequence. This modified Markov Chain method accounts for structural zeros (Goodman, 1983). As an additional set, significant ($P < 0.05$) sequences were identified and placed in a second Chi-square table that included each sequence in rows and treatments in columns. Behavioral sequences were identified that were found at greater or lower frequencies than expected because of random chance. Behavioral trills were identified in this analysis; a trill is a repeating sequence of behavior (e.g., A-B-A-B-A-B, where A and B are unique behaviors), which indicates a linked behavioral mechanism. Behaviors were then placed in a diagram that indicated which

Table 1. Definitions of observed behaviors[1]

Behavior	Definition
Active	All behaviors summed except lying
Antagonistic	Behavior indicative of social conflict; aggressive and submissive responses
ONF[2]	Rubbing; sniffing; licking; biting; touching the mouth, snout, or face with the bars, floor, or feed trough; a nonfeeding behavior by definition, in that no feed was present in the trough when ONF was recorded
Lying	Animal not supported by its legs
Stand	Animal supported by all legs with or without locomotion; no oral actions
Sit	Animal supported by front legs only; no oral actions
Drink	Mouth contact with waterer
Feed	Snout contact with feed and/or feeder while moving the jaw with feed present
Stall	Head in the stall
Pen	Head in the pen

[1]Adapted from Dailey and McGlone (1997a).
[2]ONF = oral-nasal-facial.

behavioral sequences were found at greater or lower than expected levels as assessed by Chi-square analysis.

RESULTS

Productivity Measures

Farrowing rates for gilts and sows in this study averaged 73.2% in parity 1 and 62% in parity 2 (Table 2). During parity 1, gilts in pens had a tendency ($P < 0.10$) to have a lower farrowing rate (penned gilts had an 11% lower farrowing rate than crated gilts). In parities 1 and 2, gilts and sows fed by drop or trickle systems did not differ in farrowing rate. In parity 1, the relationship between penning and feeding system was significant in the Chi-square analysis ($P < 0.05$). Gilts in crates that were trickle fed had the greatest farrowing rate (7 to 15% greater than other treatment groups). In parity 2, no significant differences among penning or feeding system were identified in farrowing rate (Table 2).

At breeding and farrowing, backfat thickness did not differ among treatment groups (Table 3). At weaning, sows housed in pens during gestation and all sows lactating in farrowing crates had 12% greater ($P < 0.05$) backfat thickness than those sows housed in crates (Table 3). Body weight was different ($P < 0.05$) among treatments at farrowing (Figure 1). Farrowing weight was lower ($P < 0.05$) in drop-fed crated sows compared with trickle-fed crated sows, but there was no difference between drop-fed penned sows and trickle-fed penned sows. Body weights of sows that farrowed showed a significant parity by feeding system effect ($P < 0.01$). However, the means were very similar, and the effect was probably not biologically important (<4 kg difference among treatment groups).

Average piglet weaning weight was greater ($P < 0.05$) for gilts and sows fed with the drop feeding system vs. the trickle-feeding system. The lesion and wound scores were not significant among treatments (Table 3), and the overall level of skin lesions and wounds was low.

Table 2. Farrowing rate by housing and feeding systems and housing by feeding systems

Item	Housing system		Feeding system		Crate; drop	Crate; trickle	Pen; drop	Pen; trickle
	Crate[1]	Pen[2]	Drop[3]	Trickle[4]				
Blocks, no.	8	8	8	8	8	8	8	8
Eligible to be bred	80	80	80	80	40	40	40	40
Farrowed during parity 1	63	54	57	60	30	33	27	27
Parity 1 farrowing rate, %	78.8	67.5	71.2	75.0	75.0	82.5*	67.5	67.5
Chi-square value (P-value)	3.30 (0.10)		0.37 (0.10)		7.87 (0.05)			
Farrowed during parity 2 and eligible to be bred in parity 2	37	35	35	37	18	19	17	18
Parity 2 farrowing rate, %	58.7	64.8	61.4	61.7	60.0	57.5	62.9	66.7
Chi-square value (P-value)	0.79 (0.10)		0.002 (0.10)		1.99 (0.10)			

[1]Crate = individually stalled sows.
[2]Pen = groups of 5 sows.
[3]Drop = entire meal delivered in a single moment.
[4]Trickle = entire meal delivered over a 30-min period.
*This value contributed the most to a significant P-value.

Table 3. Sow performance and lesions by housing and feeding systems

| Item | Housing system | | | Feeding system | | | P-values | | |
	Crate[1]	Pen[2]	SE[3]	Drop[4]	Trickle[5]	SE[3]	Feeding (F)	Penning (P)	F × P
Blocks, no.	8	8		8	8				
Backfat thickness, mm									
Breeding	11.6	11.6	0.77	11.6	11.6	0.77	0.47	0.55	0.90
Farrowing	13.0	13.0	1.2	13.3	13.4	1.2	0.89	0.23	0.40
Weaning	10.4	10.4	0.83	11.3	10.7	0.83	0.31	0.02	0.90
Sow farrowing weight, kg	220.6	220.6	2.74	218.6	221.7	2.74	0.42	0.83	0.01
Number born per litter	11.1	11.1	0.51	11.3	10.8	0.51	0.49	0.84	0.63
Number born alive per litter	10.0	10.0	0.49	10.2	10.0	0.49	0.67	0.86	0.44
Number stillborn per litter	1.05	1.05	0.13	1.02	0.81	0.13	0.25	0.14	0.30
Litter birth weight, kg	1.78	1.78	0.05	20.0	18.7	0.87	0.32	0.60	0.46
Weight per piglet, kg	19.0	19.0	0.87	1.84	1.79	0.05	0.53	0.36	0.85
Lactation length, d	22.2	22.2	0.31	22.4	21.6	0.31	0.12	0.52	0.65
Lactation feed intake, d	6.0	6.0	0.14	6.1	6.3	0.14	0.10	0.26	0.65
Number weaned per litter	8.5	8.5	0.32	8.4	8.6	0.32	0.62	0.78	0.76
Litter weaning weight, kg	55.8	55.8	2.27	56.4	55.5	2.27	0.79	0.94	0.75
Weaning weight per piglet, kg	6.7	6.7	0.1	6.8	6.5	0.1	0.03	0.74	0.71
Sow weaning weight, kg	185.0	185.0	8.98	187.9	179.0	8.98	0.12	0.15	0.38
Lesions, wounds, and scratches[6]									
Neck lesions	0.06	0.06	0.04	0.09	0.07	0.04	0.66	0.48	0.77
Shoulder lesions	0.72	0.72	0.11	0.65	0.81	0.1	0.28	0.88	0.10
Ear lesions	0.08	0.08	0.03	0.08	0.06	0.03	0.73	0.42	0.82
Side lesions	0.03	0.03	0.03	0.08	0.04	0.03	0.39	0.13	0.13
Back lesions	0.06	0.06	0.06	0.10	0.05	0.04	0.39	0.67	0.78
Ham lesions	0.08	0.08	0.08	0.10	0.18	0.06	0.38	0.20	0.16
Feet lesions	0.13	0.13	0.13	0.06	0.14	0.04	0.20	0.42	0.23
Total lesions	1.16	1.16	1.16	1.16	1.34	1.15	0.34	0.38	0.19

[1]Crate = individually stalled sows.
[2]Pen = groups of 5 sows.
[3]Pooled SE.
[4]Drop = entire meal delivered in a single moment.
[5]Trickle = entire meal delivered over a 30-min period.
[6]Lesions and scratches were visually evaluated by a trained observer on the neck, shoulder, ear, side, back, ham, and feet of all sows and were assigned a numerical value to indicate severity, where 1 = mild, 2 = medium, and 3 = severe.

All other productivity measures were not significantly different among treatments.

Immune Measures

Immunological response was not greatly influenced by housing or feeding systems (Table 4). However, the percentage of phagocytosis by neutrophils was lower ($P < 0.05$) for the trickle-fed penned sows and the drop-fed crated sows vs. the drop-fed penned sows and the trickle-fed crated sows (Figure 2). Plasma cortisol was not different among treatments (Table 3), and mean values in the treatment groups were very close to each other.

Behavioral Measures

No significant differences ($P > 0.05$) were found in behavior over the entire 24-h d among gilts and sows (Table 5). Low frequencies and durations of agonistic behaviors were observed in all treatment groups. Significant ($P < 0.05$) interactions were observed among the 4-h periods and treatments (Figure 3). During the 0800 period, drop-fed crated sows displayed more ($P < 0.05$) ONF and active behaviors than did gilts and sows in other treatment groups.

Among group-penned sows, frequency of entering and exiting the feeding stall during feeding was greater ($P < 0.05$) among trickled-fed gilts and sows compared with drop-fed gilts and sows (Figure 4). However, 1 h after feeding, there were no differences for pen entering and stall exiting among feeding systems.

Sequences of behaviors were evaluated for each parity and treatment. For each arrow shown in Figure 5, the level of frequency of a given sequence is greater, lower, or not different than expected because of random chance in the Chi-square analysis. Thus, the thickness of the arrows in Figure 5 indicates relative differences in number of behavioral sequences observed among treatment groups.

The behavioral sequence that was most common overall involved ONF behaviors, drinking, and standing (typically, but not exclusively a triangle). This triangle was common among gilts and sows in all treatment groups except for parity 1 trickle-fed crated gilts and parity 2 drop-fed penned sows. However, this sequence increased from parity 1 to 2, and the stand-to-ONF behavior sequence was elevated among penned sows (parity 2) compared with crated sows. The other differences in behavioral sequences among treatment groups were smaller in magnitude.
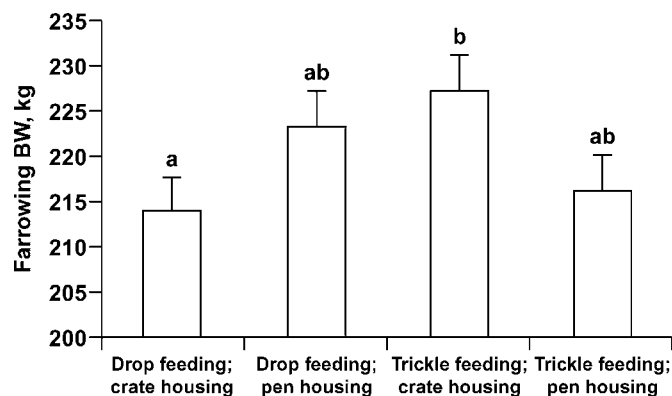
Figure 1. Farrowing BW (kg). Farrowing BW was lower ($P < 0.05$) for sows on the drop feeding, crate housing treatment compared with those on the drop feeding, pen housing and trickle feeding, crate housing treatments, but was not different ($P > 0.05$) from those on the trickle feeding, pen housing treatment (n = 8 blocks per treatment; 160 sows and litters). Pen = groups of 5 sows; crate = individually stalled sows; drop = entire meal delivered in a single moment; trickle = entire meal delivered over a 30-min period. [a,b]Means with different letters differ ($P < 0.05$).

Figure 2. Neutrophil phagocytosis. An interaction ($P < 0.05$) of housing by feeding system was observed (n = 4 blocks; 79 gilts and sows). Pen = groups of 5 sows; crate = individually stalled sows; drop = entire meal delivered in a single moment; trickle = entire meal delivered over a 30-min period. [a,b]Means with different letters differ ($P < 0.05$).

Another way to evaluate sequencing results is to compare the industry standard system (drop feeding and crate housing) to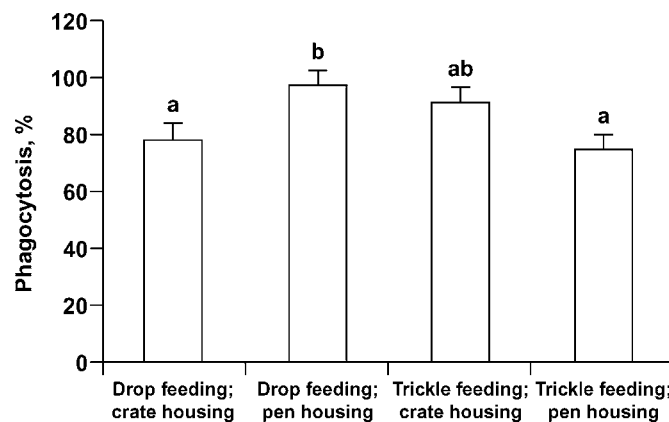 other groups. In parity 1, pregnant gilts in the drop-fed, pen housing treatment had high frequencies of the ONF behavior-drink-stand triangle. In parity 2, crated sows had a high level of ONF behavior-drink trill; sows on the drop-fed, pen housing treatment and on the trickle-fed, pen housing treatment had fewer ONF behavior-drink trills and more stand-ONF behav-

Table 4. Immune measures for parity 1 gilts by housing and feeding systems (n = 4 blocks)

Item[1]	Penning system			Feeding system			P-values		
	Crate[2]	Pen[3]	SE[4]	Drop[5]	Trickle[6]	SE[4]	Feeding (F)	Penning (P)	F × P
WBC, no./mL × 10^3	11.37	11.28	1.06	10.83	11.82	1.06	0.53	0.96	0.41
Neutrophils, %	27.20	26.75	2.34	30.32	23.62	2.34	0.07	0.89	0.76
Lymphocytes, %	59.79	61.29	2.95	56.75	64.32	2.95	0.10	0.73	0.76
Eosinophils, %	0.72	0.75	0.09	0.69	0.77	0.09	0.52	0.85	0.40
Monocytes, %	0.66	0.63	0.07	0.58	0.71	0.07	0.24	0.73	0.12
Basophils, %	0.09	0.10	0.01	0.08	0.11	0.01	0.23	0.44	0.15
Red blood cells, million/μL	7.34	7.63	0.48	7.73	7.23	0.48	0.48	0.68	0.47
HCT, %	39.04	40.26	1.97	40.97	38.32	1.97	0.37	0.67	0.84
MCV, fL	50.29	50.98	1.31	51.95	49.32	1.31	0.19	0.72	0.75
MCH, pg	32.86	32.09	2.03	30.24	34.71	2.03	0.15	0.79	0.68
MCHC, g/dL	56.23	58.09	0.68	57.42	56.90	0.68	0.60	0.08	0.29
RDW, %	22.79	23.18	0.425	23.19	22.78	0.425	0.51	0.53	0.78
PLT, thousand/μL	228.8	192.3	18.06	212.8	208.3	18.06	0.86	0.19	0.42
Phagocytosis, %	94.46	91.79	0.56	94.29	91.96	0.56	0.06	0.04	0.05
Number phagocytized	5.46	5.39	0.09	5.49	5.35	0.44	0.31	0.58	0.12
Cortisol, ng/mL	38.0	40.0	55.89	38.0	40.0	55.85	0.29	0.77	0.79
Neutrophil migration, cells per 5 fields									
Chemokinesis	154.9	133.4	38.72	135.7	152.6	38.7	0.77	0.70	0.43
C5a	344.5	295.0	39.47	324.4	315.2	39.47	0.87	0.40	0.79
Chemotaxis	193.4	159.0	18.84	192.6	159.9	18.84	0.25	0.23	0.30

[1]WBC = total white blood cell numbers; HCT = hematocrit; MCV = mean corpuscular volume; MCH = mean corpuscular hemoglobin; MCHC = mean corpuscular hemoglobin volume; RDW = red cell distribution width; PLT = platelet.
[2]Crate = individually stalled sows.
[3]Pen = groups of 5 sows.
[4]Pooled SE.
[5]Drop = entire meal delivered in a single moment.
[6]Trickle = entire meal delivered over a 30-min period.

Table 5. The duration of behaviors expressed as a percentage of time over 24 h by housing and feeding systems

| | Penned[1] | | | Crate[2] | | | P-values | | |
	Drop[3]	Trickle[4]	SE[5]	Drop[3]	Trickle[4]	SE[5]	Feeding (F)	Penning (P)	F × P
Blocks,[6] no.	4	4		4	4				
Behavior[7]									
Agonistic	0	0	0	0	0	0	0.99	0.99	0.99
Active	3.89	3.39	0.04	3.32	3.01	0.04	0.82	0.55	0.92
Oral-nasal-facial	2.24	1.19	0.02	2.23	2.06	0.02	0.42	0.36	0.51
Lie	96.10	96.61	0.04	96.68	96.66	0.04	0.82	0.55	0.92
Stand	0.44	1.34	0.02	0.24	0.17	0.02	0.52	0.26	0.43
Sit	0.60	0.62	0.01	7.42	0.59	0.01	0.85	0.94	0.47
Drink	0.01	0.17	0.01	0.53	0.09	0.01	0.84	0.46	0.08
Feed	0.61	0.00	0.01	0.00	0.00	0.01	0.31	0.31	0.31
Social	0.00	0.05	0.00	0.00	0.09	0.00	0.19	0.77	0.74
Stall	1.72	4.45	0.10	100.00	100.00	0.10	0.89	—[8]	—[8]
Pen	98.30	95.53	0.10	0.00	0.00	0.10	0.77	—[8]	—[8]

[1]Penned = groups of 5 sows.
[2]Crate = individually stalled sows.
[3]Drop = entire meal delivered in a single moment.
[4]Trickle = entire meal delivered over a 30-min period.
[5]Pooled SE.
[6]n = 8 blocks.
[7]Definitions by Dailey and McGlone (1997a) as presented in Table 1.
[8]Statistical analyses were not appropriate because the sows in crates could not be in the pen area (only penned sows could). Thus, the P-value for the feeding system effect referred to the difference in duration of time spent in the stall or pen areas between drop- and trickle-fed gilts and sows that were penned.

ior trills (trickle feeding and pen housing) and more ONF behavior-stand trills (drop feeding and pen housing).

DISCUSSION

Sow reproductive performance is related to both producer profitability and animal welfare. Reproductive performance is negatively influenced by stress, including restraint stress (Norman et al., 1994; Varley and Stedman, 1994). From an evolutionary perspective, females would have reduced fitness if severely stressed, and this would lower reproductive rates in an attempt to limit the population growth until more favorable times. Langendijk et al. (2000) suggested that group housing and the associated social stress could affect the onset of ovulation and behavior related to estrus. Reduced sow welfare and reduced fitness would be associated with either a reduced farrowing rate or reduced litter size. Because reproductive rates are sensitive to stress, they are an important measure of sow welfare.

Farrowing rate (as measured in the present study) in the pig is influenced by a combination of expression of estrus and maintenance of pregnancy. If stress impacted either the expression of estrus or the maintenance of pregnancy, then farrowing rate would be impacted. Thus, examination of farrowing rate among production systems may indicate whether a given system is stressful. Farrowing rate was influenced by treatment in parity 1, but treatment did not significantly affect farrowing rate in parity 2 (Table 2). Sows had reduced farrowing rates in parity 2, which is a common observation in the field (reduced primiparous sow farrowing rates). In

parity 2, sow farrowing rate was reduced regardless of treatment. This result may imply that sows had adapted to the environments by the second parity. Alternatively, gilts that failed to attain or maintain pregnancy were dropped from the study by the second parity; therefore, there were fewer litters farrowed in the second parity. The data indicate that among gilts, the trickle feeding system improved farrowing rate of crated sows by 7% compared with the more common drop feeding system. Overall, gilts in pens had a tendency (P < 0.10) to have 11% lower farrowing rates than did gilts in gestation crates, but no difference was observed in farrowing rates among second parity sows in the treatments evaluated.

The level of backfat thickness in this study was generally low (10 to 13 mm) compared with industry standards. Gilts and sows kept in pens during gestation had greater backfat thickness than gilts and sows in crates. Pregnant females are able to effectively huddle in pens. Because treatment groups were fed identical amounts of feed, the more effective huddling among penned gilts and sows might have conserved heat and lead to greater backfat thickness. If this hypothesis holds, then it might be possible to feed group-penned sows slightly less feed than crated sows to maintain the same body condition.

The number of pigs born per litter ranged from 10.8 to 11.3 (not a significant difference). Still, because subtle differences in birth weights and numbers born per litter may influence or exacerbate numbers and weights of piglets at weaning, we considered these measures relevant. The average weaning weight was lower for piglets from trickle-fed gilts and sows than from drop-fed gilts and sows (Table 3). This effect was smaller (P = 0.06
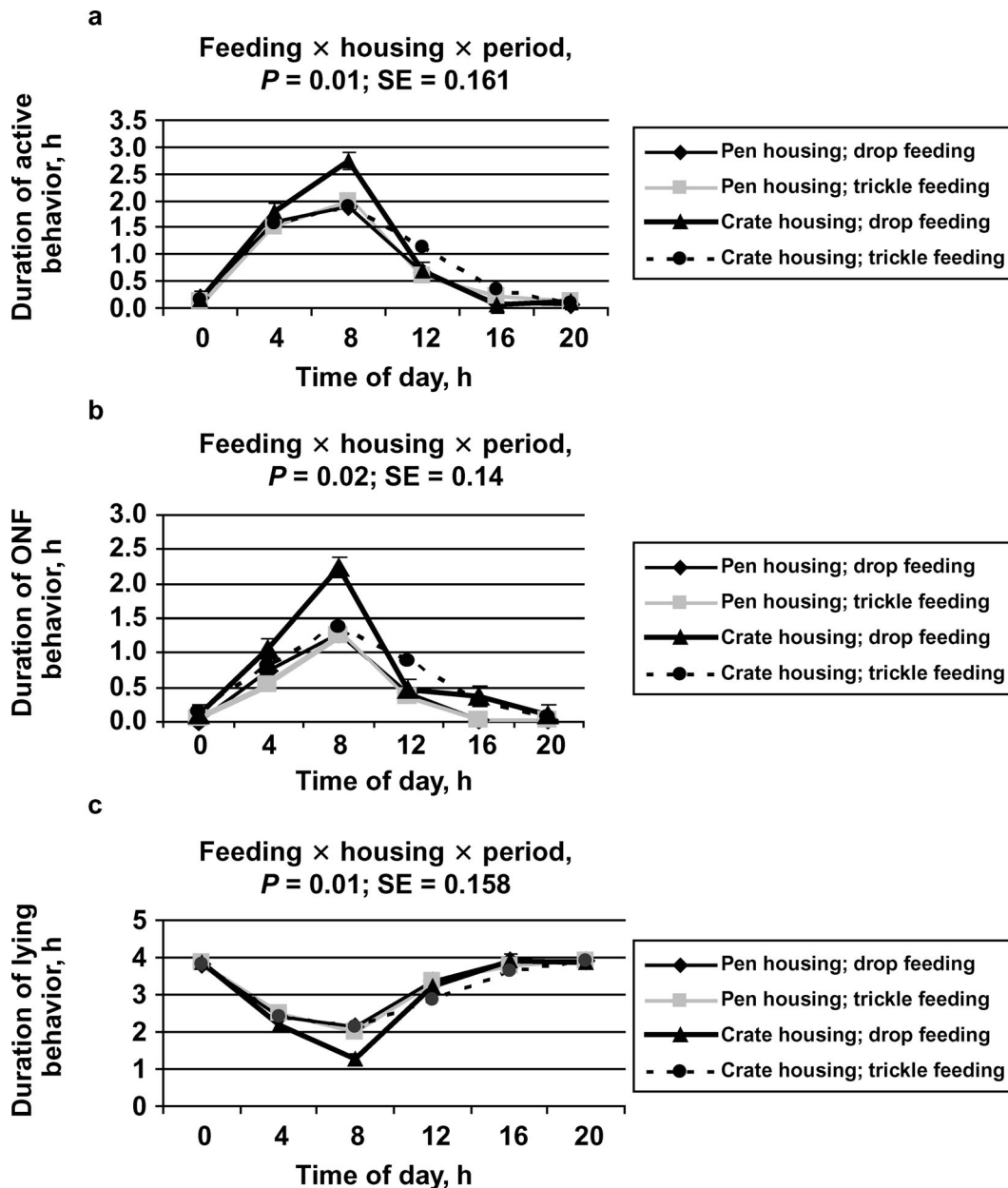
a

Feeding × housing × period, $P = 0.01$; SE = 0.161

b

Feeding × housing × period, $P = 0.02$; SE = 0.14

c

Feeding × housing × period, $P = 0.01$; SE = 0.158

Figure 3. Lying, active, and oral-nasal-facial (ONF) behaviors over time of day by housing and feeding system. The feeding × housing × period interaction was significant ($P < 0.05$) for each behavior. Drop-fed, crated sows showed more activity (a), more ONF behavior (b), and spent less time lying (c) during the period beginning at 0800 compared with all other treatments. Data represent pregnant gilts and sows from 8 complete blocks. SE = pooled SE; pen = groups of 5 sows; crate = individually stalled sows; drop = entire meal delivered in a single moment; trickle = entire meal delivered over a 30-min period.

instead of $P = 0.03$) when the average number of pigs weaned per litter was included as a covariate. Slowing down the rate of eating (taking 30 min instead of 10 to15 min to eat a meal) might have subtle metabolic consequences.

We selected one time point to determine immune measures during gestation because a previous study of ours (McGlone and Fullwood, 2001) found no interaction between stage of gestation and treatments on immune measures. In addition, we focused on measures that are more responsive to stress in the pig. Neutrophil function,

including phagocytosis, is a sensitive measure of stress (Salak et al., 1993; Salak-Johnson et al., 1997). Among crated gilts and sows, trickle feeding increased neutrophil phagocytosis; among penned sows, trickle feeding reduced neutrophil phagocytosis.

Sows in the drop-fed, penned housing treatment group had elevated farrowing weights and elevated neutrophil phagocytosis compared with sows in the drop-fed, crated housing treatment group (Figures 1 and 2). Among trickle-fed sows, the findings were opposite; trickle-fed penned sows had lower farrowing weights and lower
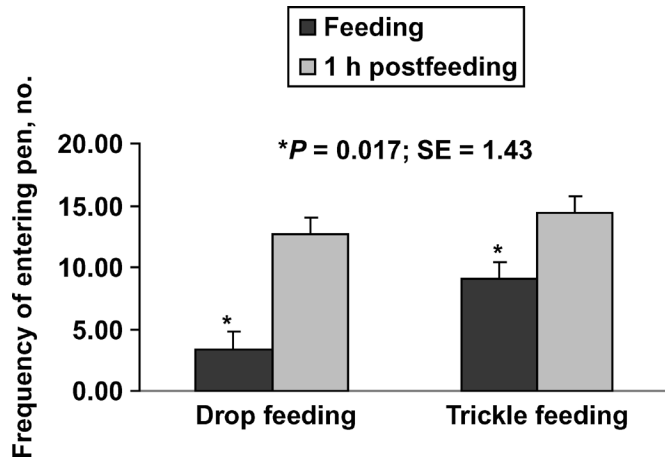
Figure 4. Frequency of entering and exiting stall by feeding systems. Each bar represents 20 gilts and sows for drop feeding and 24 gilts and sows for trickle feeding, each from 4 complete blocks. Drop = entire meal delivered in a single moment; trickle = entire meal delivered over a 30-min period. SE = pooled SE.

neutrophil phagocytosis than did trickle-fed crated sows. Differential weight gain while on the same controlled-calorie diet may indicate the relative stressfulness of an environment (among other possible explanations) because nutrient utilization is negatively affected by stress (McGlone and Curtis, 1985). Similarly, neutrophil phagocytosis is expected to be suppressed when sows are stressed (Salak et al., 1993). Therefore, based on these 2 diverse measures, penned sows are expected to be more stressed when drop-fed, and crated sows are expected to be more stressed when trickle-fed. However, many measures were not influenced by any of the treatments.

The overall proportion of sows that displayed stereotypies was reported to be lower among group-housed sows compared with individually housed sows in some studies (Broom et al., 1995; Vieulle-Thomas et al., 1995). We did not find this effect for trickle-fed sows in pens or crates, but it was the case during one period for crated, drop-fed sows. The occurrence of ONF and active behaviors increased at 0800 (postfeeding period) for those sows housed in individual stalls compared with the other treatments (Figure 3). However, for the overall 24-h period, stereotypies did not differ among treatments. This finding was consistent with the results of Backus (1997), who showed that stalled sows and trickle-fed groups of 6 to 8 sows showed similar ONF activities during parity 1.

The presence of high levels of stereotypies may be an indicator of an inadequate social or physical environment (Barnett et al., 2001) or elevation in brain stress neuropeptides (Salak-Johnson et al., 1997). Alternatively, pregnant sows may have a strong motivation to express oral behavior regardless of environment (Dailey and McGlone, 1997b). Von Borrell et al. (1992) classified stereotypies as repetitive behavioral actions of unusual form or function characterized by sequences of repetitive movements. Stereotypies are, by definition, trills; however, not all trills are stereotypies. Quantitative behavioral sequence data are often not summarized in studies of farm animal behavior. However, behavioral sequences may provide insights into complex effects of environments on brain and behavior. Behavioral sequences associated with stress in other models are being investigated, for example among young pigs, injection of corticotrophin-releasing factor (**CRF**) into the lateral cerebral ventricle elicits extensive ONF behaviors (Salak-Johnson et al., 1997). Also, Von Borrell and Hurnik's study (1991) found that sows stimulated with adrenocorticotropin releasing hormone increase stereotypical behaviors. Recently, it has been shown that the trill ONF behavior-stand is a reliable indicator of activation of brain CRF (Salak-Johnson et al., 2004). We have recently completed studies that showed that central CRF also causes exaggerated ONF behaviors among crated sows (unpublished observations). First parity drop-fed gilts had an elevated ONF behavior-stand trill compared with all other treatments, but by the second parity, trickle-fed penned sows displayed increased ONF behavior-stand sequences compared with crated sows. Based on the behavioral bioassay developed by brain injections of CRF in young pigs and sows, we hypothesized that the gilts and sows in the drop-fed pen and sows in the trickle-fed pen might have experienced elevated brain CRF. By this possible behavioral bioassay for central CRF, penned gilts and sows [compared with those in stalls and second parity sows (in all treatments)] might have had small increases in brain CRF. These hypotheses will have to be tested in other studies. Interestingly, gilts and sows in stalls that were drop-fed expressed longer durations of ONF behaviors without the increase in the ONF behavior-stand sequence. Gilts were so concentrated on ONF behaviors that they had fewer sequences of entering and exiting from this behavior as compared with the ONF behavior-stand sequence. These results lead to another hypothesis, i.e., that the brain mechanisms for expression of enhanced ONF may be different than for enhanced expression of the ONF behavior-stand sequence.

Meunier-Salaün and Dantzer (1990) reported that pigs exhibited a threshold to adaptive capabilities in their physical and social environments. Once a threshold was reached, behavioral alterations appeared with possible negative effects on health and performance. When feeding and penning systems were previously evaluated (Backus, 1997; Boyle et al., 2000), sows housed in groups had an increased occurrence of locomotive disorders and a greater occurrence of lesions after weaning. Van Putten and van de Burgwal (1990) suggested that stressful situations may be one of several factors associated with agonistic behaviors (and wounds). The mixing of sows can lead to concerns of increased aggression, although sow dominance order is quickly established within the group. Reproductive performance within group-housed sows
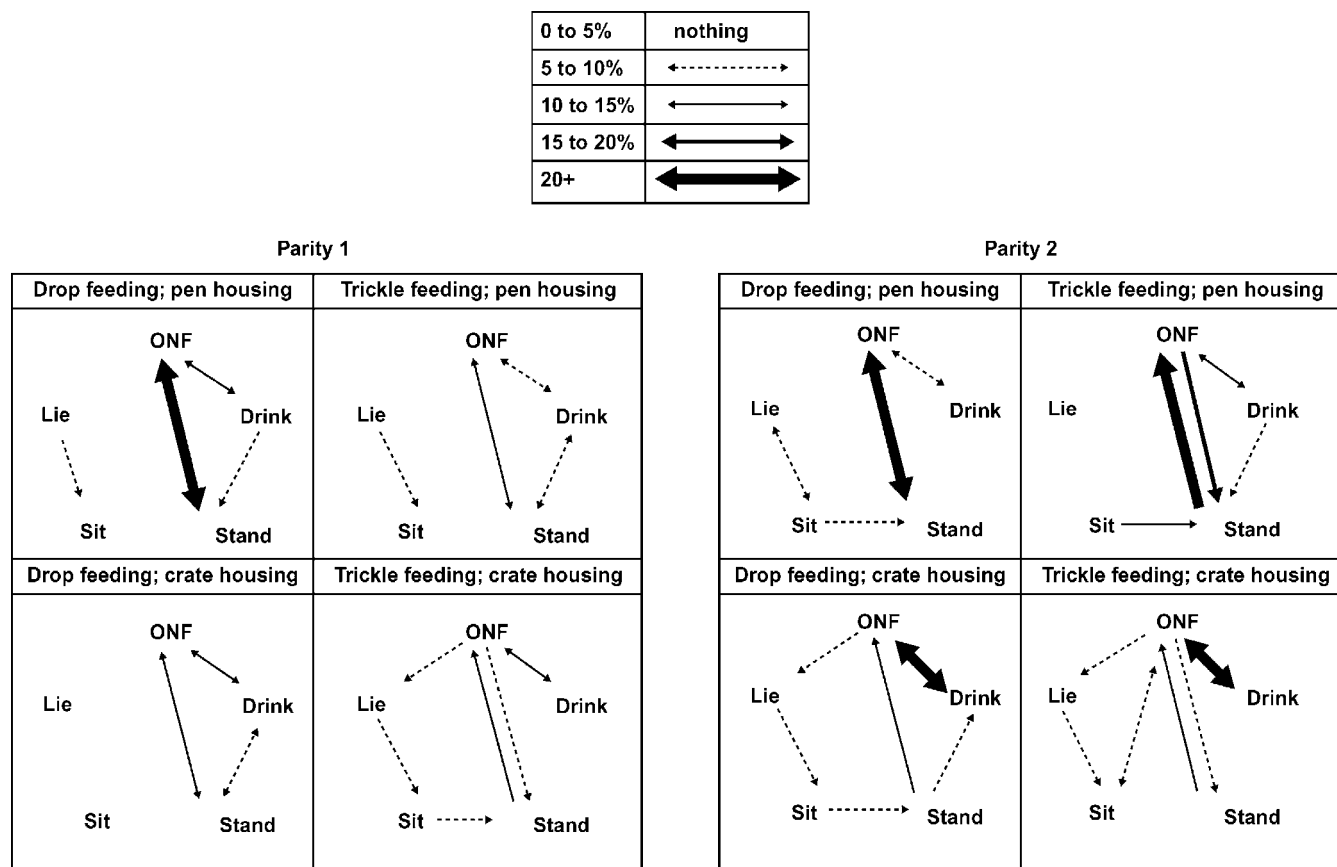
Figure 5. Sequential analysis of the behaviors. The Chi-square analysis included adjustment for structural zeros. Sample sizes for parity 1: 13 gilts for pen housing and drop feeding, 15 gilts for pen housing and trickle feeding, 15 gilts for crate housing and drop feeding, and 16 each with 4 blocks for crate housing and trickle feeding; for parity 2: 8 sows for pen housing and drop feeding, 9 sows for pen housing and trickle feeding, 10 sows for crate housing and drop feeding, and 8 each with 4 blocks for crate housing and trickle feeding. Thicker arrows indicate behavioral sequences found at a greater percentage of observations. Certain sequences were found at a greater level among sows in certain treatment groups. The graphs can be used to compare changes in behavioral sequences from parity 1 to 2 and to compare differences in sow behavioral sequences among treatment groups. ONF = oral, nasal, facial; pen = groups of 5 sows; crate = individually stalled sows; drop = entire meal delivered in a single moment; trickle = entire meal delivered over a 30-min period.

can be equal to that of individually crated sows with good management practices (Arey and Edwards, 1998).

No differences in skin lesions were observed after farrowing and weaning. This study was unique in that gilts were previously acclimated to social groups for a minimum of 2 mo before the study started. In this model, the mixing of gilts and even second parity sows was associated with no measurable agonistic behavior and very few wounds, lesions, or injures. This study provided breeding-eligible gilts and regrouped sows the least stressful experience that is practically possible.

Overall productivity was not greatly influenced by housing or feeding system. This observation is consistent with other reports (England and Spurr, 1969; Brouns and Edwards, 1992; McGlone et al., 2004), suggesting that housing systems in general have few consistent effects on overall productivity.

Von Borrell et al. (1992) suggested that sow health and production were not compromised by housing sows

in small social groups. This study showed that the immune measures were comparable for the crated and penned sows, indicating that no benefits or disadvantages with immune response occurred with either housing or feeding system for parity 1 sows, which is in agreement with the results from Nind et al. (1997). The suppressed percentage of phagocytosis observed with the trickle feeding, pen housing treatment might have been due to an increase in competition during feeding. Cortisol levels are often used as an indicator of stress. There were no differences in cortisol levels among treatments. Barnett et al. (1985) also reported that there were no differences in cortisol levels among different sow housing systems; this may be indicative of a lack of severe stress expressed by the sow during the gestation period.

In conclusion, the environments evaluated did not have major effects on gilt or sow physiology or reproductive performance. Crated, drop-fed sows expressed more stereotyped ONF behaviors during the 4-h postprandial

period but had few physiological or performance signs of stress. Penned sows, which may experience low levels of social stress, had elevated ONF behavior-stand trills that may indicate low level activation of central CRF but few other physiological or performance signs of stress.

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