THE IMPACT OF SOW GESTATION HOUSING SYSTEM (INDIVIDUAL VS. GROUP) ON THE REPRODUCTIVE PERFORMANCE OF SOWS ACROSS 6 PARITIES & THE EFFECT OF FARROWING PEN SIZE ON PRE-WEANING MORTALITY

BY

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THESIS

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ABSTRACT

Two studies were carried out on a commercial sow unit to evaluate the effects of gestation housing system and farrowing pen size, respectively, on sow and litter performance. The gestation housing system study used a randomized complete block design to compare 2 treatments: Individual and Group (8 females/pen) housing. The experimental unit was the individual female, and a replicate was 16 females (1 pen of 8, and 8 individually-housed). A total of 1,974 females were allotted to the study (at approximately day 35 of gestation) which was carried out over 6 parities resulting in 6,802 individual parity records.

There were a limited number of Gestation Housing treatment by parity interactions ($P < 0.05$); however, none of these were practically important. There were relatively few effects of Gestation Housing treatment on sow and litter performance. There were treatment differences ($P < 0.05$) for sow body condition score and body weight; however, differences between the housing systems were numerically small and not practically important. There was no effect ($P > 0.05$) of housing treatment on days from weaning to breeding, conception and farrowing rate, number of piglets born alive, mummified, total born, and weaned, piglet and litter weights (at birth and weaning), or the percentage of sows that were euthanized, died, or culled during the study. Pre-weaning mortality was greater ($P < 0.05$) for the Group (15.2%) compared to the Individual Gestation Housing treatment (14.2%). The percentage of sows removed from the study for any reason (euthanized, died, culled, or removed from allotment) was greater ($P < 0.05$) for the Group (14.3%) than the Individual Gestation Housing treatment (12.1%). This effect was due to the Group housing treatment having a greater ($P < 0.05$) percentage of sows removed from allotted gestation housing (16.3 %) (for treatment of injuries, disease, low body condition, or not being pregnant) compared to the Individual housing treatment (10.0 %).

The effect of farrowing pen size (in pens with farrowing crates) on pre-weaning mortality was evaluated in a study using a sub-sample of females from the sow gestation housing study described above. A Randomized Complete Block Design was used to compare two Farrowing Pen Size treatments: Standard (pen width = 1.52 m) and Increased (pen width = 1.68 m) pen size. The experimental unit was individual sow and litter and a replicate was 2 sows and litters (one per treatment). A total of 1,816 pregnant females were allotted to treatment, balanced for previous Gestation Housing treatment and parity, on day 112 of gestation when they were moved from the gestation to the farrowing facility. Management of the sows in the farrowing facility was according to the standard unit protocols. Cross-fostering was carried out within 24 hours of birth to standardize litter size between sows within a replicate. Piglet numbers and weights were recorded at birth and weaning.

There were few effects of farrowing pen size on any measures, and none of the differences between the pen sizes were of practical importance. Pre-weaning mortality was not different ($P > 0.05$) between the two treatments, which suggests that there was no benefit for the increased farrowing pen size.

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CHAPTER 1: LITERATURE REVIEW

SECTION 1: SOW GESTATION HOUSING SYSTEM

INTRODUCTION

In 2013 the European Union passed legislation (1.1.2013 EU) to abolish the use of individual crate housing for pregnant sows from 4 weeks after breeding until the week prior to farrowing, as well as requiring a minimum floor space allowance of $2.25m^2$/sow. Since this EU legislation was passed, there has been increasing consumer and retailer pressure in the US to enact similar legislation to require the group-housing of sows in gestation. The potential effects on production of sow gestation housing system (Individual crate or Group-housing) has been controversial, and research has been conducted to evaluate and quantify the impacts of gestation housing system on the reproductive performance for the sows. Several studies have been performed to evaluate these effects, however, the results from these studies have generally been highly variable. Some studies have showed greater litter performance for sows housed in individual stalls (Broom et al., 1995; Oliviero et al., 2009; Salak-Johnson et al., 2007), with others showing a performance advantage for sows housed in groups (Bates et al., 2003; Karlen et al., 2007; Seguin et al., 2006). In addition, several studies have shown no effect of individual compared to group gestation housing on sow performance (Cassar et al., 2008; Li et al., 2014; McGlone et al., 2004). Of the types of group sow housing available, the easiest and least expensive approach to change from individual crates to pens is to convert the existing crates into small pens. This retrofitting process allows the use of the same feeding system, and reduces the use of new materials. Although converting to small pens offers some reduction in conversion costs, there has been limited research carried out under commercial conditions evaluating the differences in sow productivity between gestation housing in small retrofitted pens compared to individual crates.

This literature review summarizes previous research evaluating the effect of sow gestation housing system on litter performance, breeding performance, removal rates, and body weights and condition score. These areas were reviewed in a previous thesis (Laudwig et al., 2015) and this review will expand on this original review.

EFFECT OF GESTATION HOUSING SYSTEM ON SOW AND LITTER PERFORMANCE

A total of 16 studies were reviewed to evaluate the effects of gestation housing system on sow and litter performance, and these are summarized in Table 1. Most studies found no effect of housing sows in groups compared to individual pens on litter performance. The total number of piglets born per litter was not different between group and individually-housed sows in 11 out of 12 studies. The number of piglets born alive per litter was not different between gestation housing systems for 13 out of 16 studies. The number of piglets born dead per litter was not different between gestation housing systems for 9 of 11 studies that reported this variable. McGlone et al. (2004; Table 1) also conducted a meta-analysis of studies that had compared group pen and individual stall gestation housing systems and also found no significant effects of gestation housing on the number of piglets born alive, stillborn, or the total number of piglets born per litter.

The number of piglets born mummified was not different between gestation housing system treatments for 6 out of 7 studies (Table 1). The number weaned per litter was not different between housing system treatments for 6 out of the 7 studies that reported this variable. Pre-weaning mortality rate was not different between housing systems in any of the 4 studies that reported this measure. Litter birth weight and litter weaning weight was not different between housing systems for 6 out of the 8 studies that reported these measures. The meta-analysis by

McGlone et al. (2004; Table 1) also reported no effect of gestation housing system on piglet birth weights.

The one study that reported a significant effect of gestation housing system for total number of piglets born per litter was that of Salak-Johnson et al. (2007; Table 1). Group-housed females housed at a floor space of 3.3 m^2 /sow had a greater total number of piglets born per litter (14.2) compared to sows kept in individual crates (11.1). However, sows housed in groups at a floor space of 2.3 or 1.4 m^2 /sow had a similar number of piglets born alive (12.0 and 12.4, respectively) to those in the individual crates. Of note, many the sows on the study of Salak-Johnson et al. (2007) (152 of the 217 sows) had been housed in individual crates in breeding cycles prior to being allotted to the group treatments, which could have had an influence on the results of this study.

Thirteen out of 16 studies (Table 1) showed no effect of gestation housing system on the number of piglets born alive per litter. Broom et al. (1995; Table 1) reported that sows housed in individual crates had a greater number of piglets born alive compared to those housed in both small and large pens (12.6, 8.9, and 9.9 piglets/litter, respectively). Conversely, Seguin et al. (2006; Table 1) reported that sows housed in small or large group pens, with varying floor space allowances, had a greater number of piglets born alive than sows housed in crates, averaging 10.3 piglets born alive for all group-housed sows compared to 9.6 for individually-housed sows. Oliviero et al. (2009; Table 1) also reported an increased number of piglets born alive for group-housed sows, 12.3 vs 11.7 piglets born alive per litter for group and individually-housed sows, respectively.

Only one of the 7 studies that reported the number of piglets born mummified found an effect of sow housing treatment on this measure (Table 1). The study by Broom et al. (1995)

reported that sows in small pens had more mummified piglets (0.6 per litter) than those housed in either large pens or individual crates (0.1 and 0.0, respectively).

One out of 7 studies summarized showed an effect of sow housing system on the number of piglets weaned. Karlen et al. (2007; Table 1) reported a greater number of piglets weaned per litter for group-housed sows (9.0) compared to those kept in individual crates (8.3). Two of 7 studies reported an effect of housing system on litter weaning weight. Salak-Johnson et al. (2007; Table 1) reported that sows housed in individual crates had the highest litter weaning weight (52.4 kg) compared to sows housed in groups at a floor space of 2.3 m^2/ sow (45.5 kg). The sows housed in groups at floor spaces of 1.4 and 3.3 m^2 were intermediate for litter weaning weights (50.2 and 49.5 kg, respectively) to both the individual crate and 2.3 m^2 /sow group-housing treatment. Conversely, Bates et al. (2003; Table 1) reported higher litter weaning weights for group-housed sows compared to individually-housed sows (57.1 vs. 56.2 kg, respectively).

EFFECT OF GESTATION HOUSING SYSTEM ON SOW BREEDING PERFORMANCE AND REMOVAL RATES

A total of 8 studies were found that evaluated the effects of gestation housing system on sow breeding performance (summarized in Table 2). Five of the 8 studies reported a higher farrowing rate for sows in individual crates compared to those housed in groups. Bates et al. (2003; Table 2) reported that sows housed in individual crates had a higher farrowing rate than sows housed in pens of 30 to 60 sows (94.3% vs. 89.4% respectively). Hulbert et al. (2006) reported farrowing rates of 72.6% and 67.0% for individually-housed and group-housed sows, respectively. Johnston et al. (2013) reported that sows housed in individual crates had a higher farrowing rate (97.6%), than those housed in pens of 6 or 26 sows (94.8% and 92.2% respectively). Similarly, Karlen et al. (2007; Table 2) reported farrowing rates of 76.9% for sows housed in individual crates compared to 66.0% for those housed in a hoop structure in groups of 85. Knox et al. (2014) compared sows housed in either individual crates or group pens with an electronic sow feeder (ESF). The group pens were formed by mixing sows on day 3, 14, or 35 of gestation. The highest farrowing rate reported was for sows housed in individual crates (92.8%) and for group-housed sows mixed at day 35 post-insemination (90.5%). Group-housed sows mixed at day 3 had a lower farrowing rate than these two treatments (82.8%), and group-housed sows mixed at day 14 had a farrowing rate (87.8%) that was intermediate to and not significantly different from the other treatments. There were, however, 3 studies that found no effect of housing treatment on farrowing rate. Jansen et al. (2007) showed no difference in farrowing rate between sows housed in either individual crates (77.8%) or groups of 50 sows (76.6%). Cassar et al. (2008; Table 2) also found no differences in farrowing rate between individually-housed sows and sows housed in pens of 15, mixed at day 2, 7, 14, 21, or 28 of gestation. The meta-analysis of McGlone et al. (2004; Table 2) also suggested no significant effect of housing system (group or individual) on sow farrowing rates.

Weaning to insemination interval was reported in 4 studies (Table 2) with all of these showing no difference between group- and individual-housing systems. Two of the studies summarized evaluated the effect of gestation housing system on sow removal rates (Table 2). Sow removal rate was calculated as the percentage of sows assigned to the study that were culled, euthanized, or died during the study period. Neither of the studies that evaluated this measure reported any difference between individual- and group-housing treatments (Karlen et al., 2007; Li et al., 2014). However, Li et al. (2014) reported that sow removal rate after 3 reproductive cycles was significantly higher for sows housed in groups of 50 with an ESF compared to those housed in individual crates.

EFFECT OF GESTATION HOUSING SYSTEM ON SOW BODY WEIGHT AND CONDITION SCORE

Only 2 studies, summarized in Table 3, evaluated the impact of gestation housing system on body condition score (BCS), which is an indicator of body fat level. Salak-Johnson et al. (2007) reported that sows housed in individual crates had a higher average body condition score from allotment to farrowing compared to those housed in groups. Seguin et al. (2006) found no significant differences in average body condition scores between individually and group-housed sows (3.6 and 3.5 average scores, respectively).

Only 5 of the studies reviewed here reported sow body weights at farrowing and weaning. Three of these studies reported no difference between individual and group gestation housing systems. However, two studies showed conflicting results for the effect of housing systems on sow body weights at both farrowing and weaning. Johnston et al. (2013; Table 3) reported that sows housed in either small or large groups were lighter at farrowing than those in individual crates (256.6, 255.7, and 266.1 kg, respectively). Conversely, Salak-Johnson et al. (2007) found that group-housed sows kept at floor spaces of 2.3 and 3.3 m^2 (245.0 and 252.0 kg, respectively) were heavier at farrowing than sows housed in individual crates or kept in groups at a floor space of 1.4 m^2 (233.0 and 238.0 kg, respectively). Similarly for sow weaning weight, Johnston et al. (2013) reported that sows housed in individual crates during gestation were heavier at weaning than those housed in groups of 6 or 26 (229.3, 224.5, and 221.7 kg, respectively). In contrast, Salak-Johnson et al. (2007) reported that sows housed in groups at a floor space of 2.3 m^2 were heavier than those in individual crates or in groups at a floor space of 1.4 m^2/sow, with the 3.3 m^2/sow treatment being intermediate (238.0, 226.0, 226.0, 234.0 kg, respectively).

Body weight change during gestation was reported in 2 of the studies summarized in Table 3. Salak-Johnson et al. (2007) did not find an effect of housing system on body weight change; however, Johnston et al. (2013) reported a greater body weight gain for sows housed in individual crates and small groups of 6 (41.5 and 39.5 kg, respectively) than those housed in large groups (33.4 kg). Body weight changes during lactation were also reported in these two studies (Table 3). Salak-Johnson et al. (2007) found no difference between the housing treatments. However, Johnston et al. (2013) reported a greater body weight change for sows housed in gestation in individual crates compared to group-housed sows. Sows housed in individual crates had the greatest body weight loss (37.0 kg) with sows housed in the large groups of 26 sows having the lowest weight loss (32.0 kg), and sows housed in the small groups of 6 sows having intermediate body weight loss compared to the other two treatments (34.1 kg; Johnston et al., 2013).

CONCLUSION

This literature review has summarized studies that have compared the effects of individual- and group-housing systems for sows during gestation on sow and litter performance, sow breeding performance, sow body weights and body condition scores, and sow removal rates. In general, the studies have shown variable effects on sow litter performance with some studies showing an advantage for group-housing, others showing a disadvantage, and some finding no differences. However, most of the studies that evaluated the effect of gestation housing system on farrowing rate found that this tended to be lower for group-housed sows compared to those kept in individual crates. This negative effect of group-housing on farrowing rates may be in part due to the timing of group formation. Knox et al. (2014) found that farrowing rate was lower when sows were mixed at day 3 compared to day 35 of gestation. The results of studies evaluating body weight were also conflicting, and only two studies evaluated body condition score. Sow gestation housing research is a relatively new area in the US, and only a few studies have been conducted comparing group and individual-housing systems in the same environment, and even fewer under commercial conditions. Furthermore, there is increasing consumer pressure to discontinue the use of gestation crates during parts of the production process. In general, many of the studies here were relatively small, not carried out over many parities, or were not conducted under commercial conditions. In order to quantify commercially important impacts of sow gestation housing on reproductive performance, further large-scale, long-term, commercial research is needed.

TABLES

Table 1. Summary of studies published evaluating the effect of sow housing systems on sow litter performance.

Study	Total # of sows on study	Housing systems compared	Treatment	# of sows/pen	Floor space, m^2 /sow	Day of gestation when groups established	# of piglets born alive per litter	# of piglets born dead per litter	# of piglets born mummified per litter	Total # of piglets born per litter	# of piglets weaned per litter	Piglet pre-weaning mortality, %	Litter birth wt, kg.	Litter weaning wt, kg.
Bates et al., 2003	1315	Group pens or Individual crates	Group	30-60	1.5-2.9	2-4	9.8	0.5[b]	0.1	10.4	8.5	13.3	17.7[a]	57.1[a]
			Crate	1	1.2	-	9.8	0.6[a]	0.2	10.6	8.7	11.2	16.7[b]	56.2[b]
			Significant	-	-	-	no	yes	no	no	no	no	yes	yes
Broom et al., 1995	65	Small and large ESF pens or Individual crates	Crate	1	-	-	12.6[a]	-	0.0[b]	-	-	-	-	-
			Small pen	5	1.3	49	8.9[b]	-	0.6[a]	-	-	-	-	-
			Large pen	38	1.65	49	9.9[b]	-	0.1[b]	-	-	-	-	-
			Significant	-	-	-	yes	-	yes	-	-	-	-	-
Cassar et al., 2008	617	Group pens or Individual crates	Crate	1	1.4	-	10.6	1	-	11.6	-	-	-	-
			Group	15	2.3	2	10.2	0.8	-	11	-	-	-	-
			Group	15	2.3	7	10.3	0.9	-	11.2	-	-	-	-
			Group	15	2.3	14	10.7	0.9	-	11.6	-	-	-	-
			Group	15	2.3	21	10.4	1	-	11.4	-	-	-	-
			Group	15	2.3	28	10.6	0.9	-	11.5	-	-	-	-
			Significant	-	-	-	no	no	-	no	-	-	-	-
DeDecker et al., 2014[1]	221	Group pens or Individual crates	Crate	1	-	-	-	-	-	-	-	-	-	-
			1.7 m^2	10	1.7	35	-	-	-	-	-	-	-	-
			2.3 m^2	10	2.3	35	-	-	-	-	-	-	-	-
			Significant	-	-	-	no	no	no	no	no	-	-	-
Harris et al., 2006	22	Group pens or Individual crates	Crate	1	1.3	-	8.9	-	-	9.6	-	18.1	16.8	-
			Mixing d7	4	2.4	7	7.8	-	-	9	-	13.4	15.2	-
			Significant	-	-	-	no	-	-	no	-	no	no	-
Hulbert et al., 2006	160	Group pens or Individual crates	Group	5	1.3	-	10	1.1	-	11.1	8.5	15	19	55.8
			Crate	1	1.2	-	10	1.1	-	11.1	8.5	15	19	55.8
			Significant	-	-	-	no	no	-	no	no	no	no	no

Table 1 (cont.). Summary of studies published evaluating the effect of sow housing systems on sow litter performance.

Study	Total # of sows on study	Housing systems compared	Treatment	# of sows/ pen	Floor space, m^2 /sow	Day of gestation when groups established	# of piglets born alive per litter	# of piglets born dead per litter	# of piglets born mummified per litter	Total # of piglets born per litter	# of piglets weaned per litter	Piglet pre-weaning mortality, %	Litter birth wt, kg.	Litter weaning wt, kg.
Jansen et al., 2007[3]	96	Group pens or Individual crates	Crate	1	-	-	10.5	-	-	-	-	-	-	-
			Pen	50	2.1	65-70	9.7	-	-	-	-	-	-	-
			Significant	-	-	-	no	-	-	-	-	-	-	-
Johnston et al., 2013[4]	815	Group pens or Individual crates	Crate	1	1.2	-	12.3	0.9	0.3	13.1	10.3	-	-	72.3
			Group	6	1.5	35	12.2	0.9	0.3	13.1	10.1	-	-	71.3
			Group	26	1.5	35	12.5	0.7	0.4	13.2	10.2	-	-	71.7
			Significant	-	-	-	no	no	no	no	no	-	-	no
Karlen et al., 2007	640	Group pens or Individual crates	Crate	1	-	-	10.1	0.7	0.3	11.2	8.3[b]	-	16.3	72
			Hoop pen	85	2.3	35	10.2	0.6	0.3	11.1	9.0[a]	-	16.1	71.3
			Significant	-	-	-	no	no	no	no	yes	-	no	no
Knox et al., 2014	1436	ESF pens or Individual crates	Crate	1	1.3	-	11.8	0.6	0.1	12.4	-	-	-	-
			Mixing d3	58	1.7	3	11.3	0.5	0.1	11.9	-	-	-	-
			Mixing d14	58	1.7	14	11.6	0.7	0.1	12.4	-	-	-	-
			Mixing d35	58	1.7	35	11.5	0.6	0	12.2	-	-	-	-
			Significant	-	-	-	no	no	no	no	-	-	-	-
Li et al., 2014[2]	401	ESF pens or Individual crates	Crate	1	1.3	-	11.6	0.5	-	12.2	10.1	9.3	17.5	64.6
			ESF pen	50	2.2	7	10.8	0.6	-	11.4	10	8.1	16.9	64.3
			Significant	-	-	-	no	no	-	no	no	no	no	no
McGlone et al., 2004	Meta-analysis	Group pens or Individual crates	Group	-	-	-	9.9	0.71	-	10.8	-	-	15.6	-
			Crate	1	-	-	9.8	0.63	-	10.5	-	-	15.1	-
			Significant	-	-	-	no	no	-	no	-	-	no	-
Munsterhjelm et al., 2008	275	Group pens or Individual crates	Crate	1	-	-	11.7	1.2	-	-	-	-	-	-
			Pen	8	5.1	28	12.1	1	-	-	-	-	-	-
			Significant	-	-	-	no	no	-	-	-	-	-	-

Table 1 (cont.). Summary of studies published evaluating the effect of sow housing systems on sow litter performance.

Study	Total # of sows on study	Housing systems compared	Treatment	# of sows/ pen	Floor space, m² /sow	Day of gestation when groups established	# of piglets born alive per litter	# of piglets born dead per litter	# of piglets born mummified per litter	Total # of piglets born per litter	# of piglets weaned per litter	Piglet pre-weaning mortality, %	Litter birth wt, kg.	Litter weaning wt, kg.
Oliviero et al., 2009	172	Group pens or Individual crates	Group	40	-	0	12.3[a]	0.4[b]	-	12.7	-	-	-	-
			Crate	1	-	-	11.7[b]	1.0[a]	-	12.7	-	-	-	-
			Significant	-	-	-	yes	yes	-	no	-	-	-	-
Salak-Johnson et al., 2007	217	Group pens or Individual crates	Crate	1	1.3	-	9.4	-	-	11.1[b]	8.7	-	15	52.4[a]
			1.4 m²	5	1.4	28	10	-	-	12.4[b]	8.6	-	15.7	50.2[ab]
			2.3 m²	5	2.3	28	9.5	-	-	12.0[b]	8.1	-	15.2	45.5[b]
			3.3 m²	5	3.3	28	10.5	-	-	14.2[a]	8.8	-	16.6	49.5[ab]
			Significant	-	-	-	no	-	-	yes	no	-	no	yes
Seguin et al., 2006[6]	383	Group pens or Individual crates	Group	11-31	2.3-3.2	33-76	10.3[a]	-	-	-	-	-	16.3[a]	-
			Crate	1	2	-	9.6[b]	-	-	-	-	-	14.6[b]	-
			Significant	-	-	-	yes	-	-	-	-	-	yes	-
Zhao et al., 2013[5]	48	Group pens or Individual crates	Crate	1	-	-	11.1	1.9[ab]	0.5	13.4	-	-	16.8[a]	50.0[ab]
			High rank	3	2.5	35	9.6	2.6[a]	0.5	12.6	-	-	13.6[b]	43.1[b]
			Medium rank		2.5	35	10.3	1.2[b]	0.3	11.8	-	-	16.3[a]	47.8[ab]
			Low rank		2.5	35	11.2	1.4[b]	0.3	12.8	-	-	16.6[a]	51.8[a]
			Significant	-	-	-	no	no	no	no	-	-	no	no

[a,b]Within each study, means within a column with different superscripts differ ($P \leq 0.05$).

[1]Litter performance values were not reported; no statistical differences

[2]Data used was from 1 reproductive cycle; dynamic grouping, mixed at 8 week intervals; after 3 reproductive cycles removal rate was significantly higher for the group-housed treatment.

[3]Data recorded for the sows housed in pens, used 18 out of 50 in each pen to compare to the 18 sows housed in stalls.

[4]Average parity: crates 3.8, small pen 3.1, large pen 3.9.

[5]Pen of 3 separated into Social rank treatments (high, medium and low); significance was for the comparison between individual crates and group pens.

[6]Several group sizes and floor space allowances studied; no effect of either group size or floor space on reproductive performance. Only Group vs. Crate effects are presented.

Table 2. Summary of studies published evaluating the effect of sow housing systems on sow breeding performance and removal rate.

Study	Total # of sows on study	Housing systems compared	Treatment	# of sows/pen	Floor space, m^2 /sow	Day of gestation when groups established	Sow farrowing rate, %[1]	Sow removal rate, %[3]	Sow weaning to insemination interval, d[4]
Bates et al., 2003	1315	Group pens or Individual crates	Group	30-60	1.5-2.9	2-4	89.4[b]	-	-
			Crate	1	1.2	-	94.3[a]	-	-
			Significant	-	-	-	yes	-	-
Cassar et al., 2007	617	Group pens or Individual crates	Crate	1	1.4	-	82	-	-
			Group	15	2.3	2	77.5	-	-
			Group	15	2.3	7	75.3	-	-
			Group	15	2.3	14	72.3	-	-
			Group	15	2.3	21	83.2	-	-
			Group	15	2.3	28	82.6	-	-
			Significant	-	-	-	no	-	-
Hulbert et al., 2014[6]	160	Group pens or Individual crates	Group	5	1.3	-	67.0[b]	-	-
			Crate	1	1.2	-	72.6[a]	-	-
			Significant	-	-	-	yes	-	-
Li et al., 2014[2]	401	ESF pens or Individual crates	Crate	1	1.3	-	-	13.6	-
			ESF pen	50	2.2	7	-	19.4	-
			Significant	-	-	-	-	no	-
Jansen et al., 2007[3]	96	Group pens or Individual crates	Crate	1	-	-	77.8	-	10.2
			Pen	50	2.1	65-70	76.6	-	10.5
			Significant	-	-	-	no	-	no
Johnston et al., 2013[4]	815	Group pens or Individual crates	Crate	1	1.2	-	97.6[a]	-	5.2
			Group	6	1.5	35	94.8[b]	-	5.4
			Group	26	1.5	35	92.2[b]	-	5.6
			Significant	-	-	-	yes	-	no
Karlen et al., 2007	640	Group pens or Individual crates	Crate	1	-	-	76.9[a]	2.8	-
			Hoop pen	85	2.3	35	66.0[b]	1.7	-
			Significant	-	-	-	yes	no	-

Table 2 (cont.). Summary of studies published evaluating the effect of sow housing systems on sow breeding performance and removal rate.

Study	Total # of sows on study	Housing systems compared	Treatment	# of sows/pen	Floor space, m^2 /sow	Day of gestation when groups established	Sow farrowing rate, %[1]	Sow removal rate, %[3]	Sow weaning to insemination interval, d[4]
Knox et al., 2014[5]	1436	ESF pens or Individual crates	Crate	1	1.3	-	92.8[a]	-	4.5
			Mixing d3	58	1.7	3	82.8[b]	-	4.3
			Mixing d14	58	1.7	14	87.8[ab]	-	4.2
			Mixing d35	58	1.7	35	90.5[a]	-	4.4
			Significant	-	-	-	yes	-	no
McGlone et al., 2004	Meta-analysis	Group pens or Individual crates	Group	-	-	-	75.9	-	-
			Crate	1	-	-	80.6	-	-
			Significant	-	-	-	no	-	-
Munsterhjelm et al., 2008	275	Group pens or Individual crates	Crate	1	-	-	-	-	5.1
			Pen	8	5.1	28	-	-	5.3
			Significant	-	-	-	-	-	no
Zhao et al., 2013[5,7]	48	Group pens or Individual crates	Crate	1	-	-	87.5[ab]	-	-
			High rank	3	2.5	35	91.7[ab]	-	-
			Medium rank		2.5	35	95.7[a]	-	-
			Low rank		2.5	35	72.0[b]	-	-
			Significant	-	-	-	yes	-	-

[a,b]Within each study, means within a column with different superscripts differ ($P \leq 0.05$).

[1]Sow farrowing rate was calculated as the percentage of sows assigned to treatment that were inseminated and farrowed a litter.

[2]Sow weaning rate was calculated as the percentage of sows assigned to treatment that were breed and weaned a litter.

[3]Sow removal rate was calculated as the percentage of sows that were assigned to treatment that were culled, euthanized, or died while on study.

[4]Sow weaning to insemination interval was calculated as the number of days from weaning to insemination.

[5]Data used was from 1 reproductive cycle; dynamic grouping, mixed at 8 week intervals; after 3 reproductive cycles removal rate was significantly higher for the group-housed treatment.

[6]Average parity: crates 3.8, small pen 3.1, large pen 3.9.

[7]Pen of 3 separated into Social rank treatments (high, medium and low); significance was for the comparison between individual crates and group pens.

Table 3. Summary of studies published evaluating effect of sow housing systems on sow body weight and body condition score.

Study	Total # of sows on study	Housing systems compared	Treatment	# of sows/ pen	Floor space, m^2 /sow	Day of gestation when groups established	Sow weight at allotment, kg	Sow weight at farrowing, kg	Sow weight at weaning, kg	Sow body weight change, allotment to farrowing	Sow body weight change, farrowing to weaning	BCS[1]
Hulbert et al., 2014[8]	160	Group pens or Individual crates	Group	5	1.3	-	-	220.6	185.0	-	-	-
			Crate	1	1.2	-	-	220.6	185.0	-	-	-
			Significant	-	-	-	-	no	no	-	-	-
Li et al., 2014[2]	401	ESF pens or Individual crates	Crate	1	1.3	-	-	206	199	-	-8.5	-
			ESF pen	50	2.2	7	-	204	199	-	-5.8	-
			Significant	-	-	-	-	no	no	-	no	-
Johnston et al., 2013[4]	815	Group pens or Individual crates	Crate	1	1.2	-	225.0^{a}	266.1^{a}	229.3^{a}	+41.5^{a}	-37.0^{a}	-
			Group	6	1.5	35	217.4^{b}	256.6^{b}	224.5^{b}	+39.5^{a}	-34.1^{ab}	-
			Group	26	1.5	35	222.6^{ab}	255.7^{b}	221.7^{ab}	+33.4^{b}	-32.0^{b}	-
			Significant	-	-	-	yes	yes	yes	yes	yes	-
Salak-Johnson et al., 2007	217	Group pens or Individual crates	Crate	1	1.3	-	208	233.0^{b}	226.0^{b}	25	-	3.76^{a}
			1.4 m^2	5	1.4	28	209	238.0^{b}	226.0^{b}	31.5	-	3.17^{c}
			2.3 m^2	5	2.3	28	210	245.0^{a}	238.0^{a}	34.2	-	3.48^{b}
			3.3 m^2	5	3.3	28	214	252.0^{a}	234.0^{ab}	36.9	-	3.41^{b}
			Significant	-	-	-	no	yes	yes	no	-	yes
Seguin et al., 2006[7]	383	Group pens or Individual crates	Group	11-31	2.3-3.2	33-76	-	-	-	-	-	3.5
			Crate	1	2	-	-	-	-	-	-	3.6
			Significant	-	-	-	-	-	-	-	-	no
Zhao et al., 2013[5]	48	Group pens or Individual crates	Crate	1	-	-	240.5^{b}	282.1^{a}	272.0^{a}	-	-	-
			High rank	3	2.5	35	256.3^{a}	289.1^{a}	283.2^{a}	-	-	-
			Medium		2.5	35	237.6^{b}	260.4^{b}	256.2^{b}	-	-	-
			Low rank		2.5	35	233.8^{b}	262.9^{b}	258.2^{b}	-	-	-
			Significant	-	-	-	no	no	no	-	-	-

^{a,b}Within each study, means within a column with different superscripts differ ($P \le 0.05$).

[1]Body condition score (BCS) was based on a 1 to 5 scale; 1 being thin, 5 being fat, and 3 being ideal.

[2]Data used was from 1 reproductive cycle; dynamic grouping, mixed at 8 week intervals; after 3 reproductive cycles removal rate was significantly higher for the group-housed treatment; sow weight at farrowing was after parturition.

[3]Average parity: crates 3.8, small pen 3.1, large pen 3.9.

[4]BCS was for phase 2; BCS evaluations once a week while in gestation and once at the end of lactation.

[5]Pen of 3 separated into Social rank treatments (high, medium and low); significance was for the comparison between individual crates and group pens.

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SECTION 2: FARROWING PEN SIZE AND DESIGN

INTRODUCTION

Producers have been developing and improving housing for farrowing sows and their piglets for years, with the principal aim of decreasing piglet mortality. Farrowing crates were developed in the late 1980's, and studies were conducted evaluating litter performance of sows housed in pens with and without farrowing crates. In the last 25 years, there have been substantial improvements in the design of these farrowing crates. In addition, improvements in sow management and genetics that have resulted in increased number of piglets born per litter. Estimates suggest that litter size at birth has increased by approximately 2 piglets per litter over the last 20 years (USDA, 2016). In addition, sow body size has also increased; McGlone et al. (2004) suggested that the standards for gestation and farrowing stall sizes and floor space allowances used in commercial production need to be increased to accommodate these larger sows. Despite increases in sow and litter sizes, farrowing pen size (sow crate plus piglet area) in commercial facilities has not generally changed. While crate design and farrowing management have been studied, there have been few studies evaluating the space requirements for sows with larger litters. The following literature review summarizes previous research evaluating the effect of farrowing pen design on sow litter performance and pre-weaning mortality. These areas were previously reviewed by Laudwig et al. (2015) and the following literature review will expand on that review to include more recent publication.

SOW LITTER PERFORMANCE

A total of 10 studies were found that evaluated the effects of farrowing crate design or compared farrowing pens with or without crates with respect to sow litter performance, and these are summarized in Table 4. Nine of the 10 studies reported no significant effect between farrowing crate designs, or farrowing pens with or without crates for the number of piglets born alive per litter. Of the 7 studies that reported the number of piglets born dead, none of them found any significant differences between farrowing crate designs, or the use of crates in farrowing pens. Five of 9 studies summarized found significant differences in the number of piglets weaned per litter, and 4 out of 7 studies reported significant effects on pre-weaning mortality. The two studies that evaluated mortality due to crushing found significant effects of farrowing crate design or the use of crates in farrowing pens. Four of the 6 studies that recorded litter weaning weight also found significant differences between farrowing crate designs, and farrowing pens with or without crates.

Only one of 10 studies reported a difference between treatments for the number of piglets born alive. Pedersen et al. (2011) found the median number of piglets born alive for farrowing crates was lower (13) than for farrowing pens without crates (14, Table 4). However, sows on the farrowing crate treatment weaned more piglets (13) than those in farrowing pens without crates (12, Table 4). This suggests the farrowing crates caused a reduction in pre-weaning mortality, though this study did not actually report pre-weaning mortality levels.

Five of 9 studies showed a difference in the number of piglets weaned per litter, all of which showed improved numbers weaned per litter for pens with standard farrowing crates compared to farrowing pens without crates and farrowing crates with side barriers compared to crates without side barriers. Bates et al. (2003), Pedersen et al. (2011), and Robertson et al. (1966) all showed an improvement in number of piglets weaned per litter with farrowing crate use compared to farrowing pens without crates. Nevrkla et al. (2015) found that crates with side barriers also increased the number of piglets weaned compared to crates without side barriers (10.0 vs 8.8 piglets, respectively; Table 4). Marchant et al. (2000) also showed an increased number of piglets weaned from pens with standard farrowing crates compared to either pens with communal farrowing crates (sows crated, piglets loose in the pen shared with other litters), or communal farrowing pens (sows and piglets loose in a shared pen) (9.7, 8.1, 8.5 piglets, respectively; Table 4).

Four of the 6 studies that reported pre-weaning mortality showed decreased levels for standard farrowing crates compared to farrowing pens without crates, and for farrowing crates with side barriers (metal bars in the sow space to increase time taken in lying down) compared to crates without side barriers (Nevrkla et al., 2015; Marchant et al., 2000; Robertson et al., 1966; Bates at al., 2003). Gu et al. (2011) also showed reduced pre-weaning mortality due to crushing for farrowing crates and freedom pens compared to farrowing pens without crates (9.3, 10.8, 25.5 percent of pre-weaning mortality, respectively; Table 4). Marchant et al. (2000) found decreased mortality due to crushing in communal farrowing crates and standard farrowing crates compared to communal farrowing pens (51.7, 52.9, 67.9% of pre-weaning mortality, respectively; Table 4).

Four of 6 studies found significant differences in piglet or litter weaning weight between farrowing pens with or without crates, and between farrowing crate designs. Robertson et al. (1966) and Bates et al. (2003) both showed increases in litter weaning weight for farrowing pens with crates compared to farrowing pens without crates. Curtis et al. (1989) compared 4 different farrowing crate designs, and showed that modifying farrowing crate side bar design can improve piglet weaning weight. Marchant et al. (2000) found increased piglet weaning weights for standard farrowing crates compared to either pens with communal farrowing crates or communal farrowing pens without crates (7.9, 6.3, and 6.7 kg, respectively; Table 4).

One of the few studies that specifically evaluated the effects of farrowing pen size was that of Cronin et al. (1998). In this study, farrowing pens of varying sizes and widths were compared (large/wide, large/narrow, small/wide, and small/narrow) for pre-weaning mortality. Though the study found no significant effects, there were large numerical differences that were not statistically significant due to the low number of replicates (9/treatment for weaning data). Pre-weaning mortality levels for large/wide, large/narrow, small/wide, and small/narrow farrowing pens were 14, 4, 18, and 22%, respectively (Table 4). Fels et al. (2016) recently completed a study to assess the creep space requirements of suckling piglets using planimetric measurement (computer calculated lying or standing area of the animal). They suggested that the space requirements for piglets weighing up to 6 kg were: litters of 12 piglets require 0.76 m^2, 14 piglets require 0.9 m^2, and for 16 piglets 1.01 m^2. With continuously increasing litter sizes, they suggested a creep area of approximately 0.9 m^2 for piglets up to three weeks of age, based on a space requirement of 0.06 m^2 per piglet. Creep areas commonly used on commercial facilities are currently between 0.6 to 0.7 m^2, which is less than suggested by Fels et al. (2016) for litters of 12 or more.

CONCLUSION

The results of this literature review suggest that utilizing farrowing pens with crates reduces overall piglet mortality compared to pens without crates, especially piglet mortality due to crushing. Most commercial operations use farrowing crates because piglet crushing has long been a major cause of piglet losses regardless of pen design. Since the wide-spread use of farrowing crates began, there has been limited research on farrowing facility design and management, and consequently, there is limited published literature on the requirements for farrowing pen and creep areas for larger litters. The study by Fels et al. (2016) suggests current commercial pen sizes may not be meeting the space requirements of the piglets due to the increase in the number of piglets born alive per litter. The study by Cronin et al. (1998) reported 13% pre-weaning mortality in large farrowing pens compared to 20% mortality in small farrowing pens. While these results were not statistically significant, they do suggest that further larger-scale research into farrowing pen size is necessary to determine what effects it may have on piglet pre-weaning mortality.

TABLE

Table 4. Summary of studies published evaluating the effect of farrowing pen or crate design on litter performance.

Study	Total # of sows on study	Treatments	Number of sows per farrowing pen	# of piglets born alive	# of piglets born dead	# of piglets weaned	Piglet mortality (pre-weaning), %	Piglets crushed (% of total pre-weaning mortality)	Litter weaning wt., kg
Bates et al., 2003[1]	1315	Farrowing pen- ESF	12	9.7	0.6	-	-	-	55.5[b]
		Farrowing crate	1	9.8	0.5	-	-	-	58.4[a]
		Significant	-	no	no	yes	yes	-	yes
Collins et al., 1987[1]	118	Farrowing crate	1	10	0.5	8.7	12	-	-
		Sloped floor pen	1	10.5	0.4	8.9	12.4	-	-
		Significant	-	no	no	no	no	-	-
Cronin et al., 1998[3,4]	72	Farrowing pen, large/wide	1	9.1	0.2	8.9	14.0	-	-
		Farrowing pen, large/narrow	1	9.4	0.3	8.6	4.0	-	-
		Farrowing pen, small/wide	1	8.8	0.4	8.3	18.0	-	-
		Farrowing pen, small/narrow	1	8.9	0.6	7.9	22.0	-	-
		Significant	-	no	no	no	no	-	-
Curtis et al., 1989[2]	111	Fingered	1	9.4	0.4	8.4	-	-	6.4[a]
		Bowed	1	9.5	0.2	8.2	-	-	6.1[ab]
		Straight bar 20 cm	1	9.7	0.5	8.2	-	-	6.0[b]
		Straight bar 25 cm	1	9.5	0.4	8.5	-	-	6.3[a]
		Significant	-	no	no	no	-	-	yes
Gu et al., 2011[1]	18	Farrowing crate	1	11.2	-	-	-	10.8[b]	-
		Freedom pen	1	10.6	-	-	-	9.3[b]	-
		Farrowing pen	1	10.5	-	-	-	25.5[a]	-
		Significant	-	no	-	-	-	yes	-
Marchant et al., 2000[1]	198	Communal farrowing pen	5	11.3	0.7	8.5[b]	25[a]	67.9[a]	6.7[b]
		Communal farrowing crates	5	10.9	1.5	8.1[b]	26[a]	51.7[b]	6.3[b]
		Standard farrowing crates	1	11.2	1.1	9.7[a]	13[b]	52.9[b]	7.9[a]
		Significant	-	no	no	yes	yes	yes	yes
McGlone et al., 1990[1]	40	Level floor crate	1	8.3	1.1	8.2	10.8	-	32.5
		Level floor pen	1	9.1	0.6	6.6	27.1	-	24.3
		Sloped floor crate	1	10.4	0.5	7.6	17.2	-	36.2
		Sloped floor pen	1	9.6	1	8.4	9.1	-	36.3
		Significant	-	no	no	no	no	-	no
Nevrkla et al., 2015[2]	80	Crates with side barriers	1	11.5	1.7	10.0[a]	12.6[b]	-	-
		Crates without side barriers	1	11.4	1.7	8.8[b]	22.3[a]	-	-
		Significant	-	no	no	yes	yes	-	-
Pedersen et al., 2011[1,3]	42	Farrowing crate	1	13[b]	-	13[a]	-	-	6.3
		Farrowing pen	1	14[a]	-	12[b]	-	-	7.1
		Significant	-	yes	-	yes	-	-	no
Robertson et al., 1966[1]	150	Farrowing pen	1	11.0	-	8.7[b]	21.3[a]	-	41.3[b]
		Farrowing crate	1	10.9	-	9.2[a]	15.5[b]	-	47.4[a]
		Significant	-	no	-	yes	yes	-	yes

[a,b]Within each study, means within a column with different superscripts differ ($P \leq 0.05$).

[1]Evaluated sows housed in crates versus pen during lactation.

[2]Farrowing crate design was evaluated

[3]Number after fostering was used not born alive; and the median was used for all variables.

[4]Wean data from a sub-sample of treatment data (9 litters/treatment)

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CHAPTER 2: THE IMPACT OF SOW GESTATION HOUSING SYSTEM (INDIVIDUAL VS. GROUP) ON THE REPRODUCTIVE PERFORMANCE OF SOWS ACROSS 6 PARITIES

INTRODUCTION

Commercial facilities commonly keep sows in individual crates during gestation. However, there has been recent pressure to convert commercial facilities to group gestation housing. One low-cost option to convert existing crate-gestation facilities to pens is to remove the back sections of crates from two opposite-facing rows and install gates to create pens. This allows the use of the original feeding and watering systems, and reduces the cost of conversion. Although there has been some published research comparing group and individual gestation housing systems, there is a need to validate these studies under commercial conditions and compare group-housing designs (i.e. pen design, feeding system, water access, and group size) for sow productivity and longevity.

Therefore, the objective of this study was to compare the reproductive performance and longevity of females housed in individual crates or in converted pens during gestation under commercial conditions.

MATERIALS AND METHODS

This study was conducted at South Ridge Sow Farm, a breed-to-wean facility located near Pittsfield, IL, owned and operated by The Maschhoffs LLC (Carlyle, IL). The experimental protocol was approved by the University of Illinois Institutional Animal Care and Use Committee. The results for the performance of the sows for this study's first two parities (parities 1 and 2) were presented by Laudwig at al. (2015). Results reported in this thesis include a continuation of this study with sows from parity 1 through parity 6.

Background

After crate to pen conversions for this study were completed, South Ridge Sow Farm was repopulated in August 2014 with gilts (parity 1). Gilts were bred at an offsite facility (Honeycreek Farm), where they were kept in pens of approximately 100. They were checked for estrus daily by farm personnel using fence line presence of a boar and the back-pressure test. When estrus was observed, females were artificially inseminated once every 24 hours until estrus was no longer observed. After breeding, gilts were moved into pens of approximately 80 and were checked for return to estrus and rebred if estrus was observed. Pregnancy was confirmed between day 28 and 35 of gestation using an EZ ultra-sound machine. Gilts between day 21 and 107 of gestation were transported to South Ridge Sow Farm over a 4-week period, with the earliest-bred females transported first. All gilts had *ad-libitum* access to feed and water throughout the duration of time at Honeycreek Farm.

Experimental Design and Treatments

This study was carried out as a Randomized Complete Block Design; the blocking factor was breeding group (females bred within 7 days). Two sow gestation-housing systems were compared: 1). Individual-Housing, 2). Group-Housing. This study was designed to monitor the reproductive performance of females from allotment at day 35 of parity 1 (gilts between first insemination and weaning of the first litter) through to weaning after parity 6. The study began when gilts of parity 1 arrived at South Ridge between day 35 and 85 of gestation and were allotted to treatment on arrival. Females arriving at less than day 35 of gestation were housed in individual stalls until pregnancy was confirmed at day 35, at which time they were allotted to treatment. Females arriving at greater than day 85 of gestation were not assigned to treatment as parity 1 animals, but were kept in individual gestation stalls for the remainder of their pregnancy, and were allotted to treatment as parity 2 sows at day 35 of the following gestation.

Animals and Allotment to Study

A total of 1662 crossbred females from 27 genetic lines (mainly of Landrace and Yorkshire origin) were used in this study. Only gilts that had been confirmed pregnant and did not have injuries or structural abnormalities that might prevent them from completing six parities were allotted. Allotments were carried out on day 35 of gestation within genetic line and breeding group, with the exception of gilts between day 36 and 84 of gestation on arrival at South Ridge, which were allotted to treatment on arrival. Females were formed into outcome groups of 2 of the same parity, genotype, and body condition and were randomly allotted from within outcome group to either the Individual or Group-Housing treatment to form replicates of 8 females/treatment. This process was repeated until all females in the breeding group were allotted to the study. If there was an incomplete replicate of females from within one breeding group, then females from the next breeding group were used to complete the replicate. After allotment to treatment, females were moved from the breeding area of the barn to the gestation area within the barn (Figure 1). The females allotted to the Group-Housing treatment were moved to their designated pens, where they were kept in groups of 8. The females allotted to the Individual-Housing treatment were moved to individual crates in sets of 8 located in the gestation area closest to the Group-Housed females from the same replicate.

For subsequent parities (parity 2+), pregnancy was confirmed at day 28 of gestation. At day 35 of gestation, sows were moved to either crates or group pens according to previous housing treatment to form replicates of 16 sows (8/housing treatment; 1 group of 8 sows and 8 sows in individual crates). Replicates were formed by sows of similar parity (± 1 parity within a pen), body condition score (BCS), and breeding date. If insufficient sows were available to make a complete replicate, then replacement gilts were allotted equally to each treatment, balanced by genetic line. If insufficient replacement gilts were available, females from the next breeding group were used. Lame or ill sows at day 35 of gestation were managed according to housing treatment as follows: Group-housed sows were removed from the study for that breeding cycle, placed in an individual stall and closely monitored until farrowing; they received health treatment, according to unit protocol. If they were suitable for allotment in their subsequent parity, they were re-allotted to the group-housing treatment. Individually-Housed sows: lame or ill sows remained on the study and were closely monitored until farrowing; they received health treatment, according to unit protocol.

Animal Housing

The gestation facility consisted of two housing types: crates and converted pens. Crate dimensions were 0.54 m x 2.07 m, giving a floor space of 1.12 m^2 per female. Pens dimensions were 2.20 m x 4.71 m, giving a floor space of 1.30 m^2 per female (Figure 3). All pens and crates in the breeding and gestation facility were equipped with one drop-type feeder per sow, and were fed twice daily at approximately 6:00 and 11:00 hours. Individual crates for breeding were equipped with a nipple-type water drinker located between two crates. The pens and crates used for the gestation-housing treatments were equipped with a continuously filled water trough. Temperature in the gestation barn was maintained at a set point of 21 ˚C using a thermostat and fan ventilation, and evaporative cooling cells used in warm weather.

The farrowing facility consisted of 9 rooms with either 24 or 26 farrowing pens per room. Farrowing crates, which were located within each farrowing pen, were 0.55 m wide and either 1.95 m (rooms 1-7) or 2.19 m (rooms 8 and 9) long, giving a total floor space per sow within a crate of

1.07 m^2 or 1.20 m^2, respectively. Crates were equipped with a trickle-type feeder that dropped feed into a trough and a cup-type drinker. The thermostat in each room was set at 22.5° C until all sows in the room had farrowed, then decreased by 0.25° C per day for 10 days to 20.0° C, then decreased over the next 5 days to 19° C, and remained at this temperature until weaning.

Breeding and Gestation Management

Sows after weaning and gilts prior to mating were housed in individual crates until allotment at day 35 post-insemination. Gilts and sows were checked for estrus daily by farm personnel using fence line presence of a boar and the back-pressure test. When standing estrus was observed, females were artificially inseminated once every 24 hours until standing estrus was no longer observed.

Water troughs were checked daily to ensure all animals had *ad-libitum* access to water. Every animal was visually evaluated for health issues (e.g. off feed, lameness, injury, fever, respiratory conditions, etc.) twice-daily at feeding. Any animal that was not standing and eating at the time of feeding was assisted to stand, evaluated, and treated as necessary according to unit procedures.

Sow Removals

Criteria for animal removal from a pen included females 0.5 of a body condition score below the average of the sows in the pen, animals that were not responsive to 3 days of treatment for any condition, had injuries that warranted immediate removal, aborted, or were found not pregnant. Any animal that was removed from a pen after day 35 of gestation was placed in a non-study individual crate and monitored until farrowing. Criteria for animal removal from an allotment crate included animals which aborted or were found not pregnant. Animals in the allotment crates that were ill or injured were not removed, but treated according to farm protocol and monitored until farrowing. All sow mortalities and their causes were recorded throughout the study period.

Farrowing Management

At approximately day 112 of gestation, females were moved from the gestation facility into the farrowing facility and were assigned to an available room and crate by breeding date. Management in the farrowing facility was generally in accordance with standard unit procedures. For the first 6.5 months of the study period, cross-fostering of piglets between litters was only carried out between sows of the same housing treatment. However, due to practical problems with this approach, from April 5, 2015 onwards the protocol was amended to allow cross-fostering between sows of either treatment. On December 31, 2015, South Ridge Sow Farm was tested for and confirmed as having a PRRSv infection. Upon veterinary recommendation, no cross-fostering or piglet weights were performed until the farm was no longer under an active infection. The 4-day old and weaned piglets were tested weekly, and when both groups tested negative for 4 consecutive weeks (July 8, 2016), the farm was declared as no longer under an active PRRSv infection and cross-fostering was resumed. Sows were weaned at 21 ± 2.1 days.

Diet Formulation and Feeding

Diets were formulated to meet or exceed the nutrient requirements for breeding, gestation and lactating pigs, as proposed by the NRC (2012). In breeding and gestation, animals were fed twice daily at approximately 6:00 h and 11:00 h. Feeding levels for gilts were based on body weight at breeding (Table 9) and feeding levels for sows were adjusted by body condition score (Table 10), which was evaluated on days 7, 35, 60, and 90 of gestation. Females in group-gestation pens were fed by the average body condition score of all females in the pen; females housed in individual crates were fed according to individual body condition score. In farrowing, females were fed 0.91 kg twice daily until parturition, after which they were given *ad-libitum* access to feed until weaning. Parity 1 females in lactation were given a feed supplement which was top-dressed to supply extra energy.

Body Condition Score and Body Weight Measurements

All females were evaluated for body condition at approximately day 7, 35, 60, and 90 of gestation, and at farrowing and weaning. The body condition score scale used was from 2.5 to 3.5, with 0.25 increments between scores (Figure 2). A body condition score of 2.5 was considered thin, and 3.5 was considered fat. Body weights were recorded on a sub-sample of animals which consisted of females from four breeding groups per 20-week breeding cycle (1338 weight records in total, across the 6 parities). Weights were recorded at allotment on day 35 of gestation, on entry into farrowing, and at weaning. Sow weights at weaning were discontinued after October 19, 2015 due to farm management.

Farrowing Measurements

The date on which each sow farrowed was recorded, as well as if the sow was induced or assisted to farrow. Sows that had not farrowed by day 114 of gestation were induced by injecting the sow with 1 mL of Lutalyse® (Pfizer Animal Health US) at both 6:00 h and 12:00 h. The number of piglets born alive, born dead, and mummified for each sow were recorded and used to calculate the total number of piglets born per litter. After farrowing was complete, all piglets born alive were weighed together to obtain average born alive weights. All piglets born dead were weighed together to obtain average born dead weights. These born alive and born dead weights were added to calculate total born litter weight. Litters were weighed again at weaning to obtain a litter weaning weight, which was used to calculate average piglet weaning weight. The dates and causes of piglet deaths were recorded from birth until weaning. The date of weaning was also recorded, and used to calculate the average piglet weaning age.

Breeding and Sow Measurements

The date of insemination was recorded and the weaning to insemination interval was calculated. In addition, days from weaning to rebreeding was recorded for animals that returned to estrus following the first mating. The date and reason for death or removal were also recorded.

Statistical Analysis

Normality and homogeneity of variance was tested using the PROC UNIVARIATE procedure of SAS (SAS Inst. Inc., NC). Data that were normally distributed were analyzed using the PROC MIXED procedures of SAS (Littell et al., 1996). The experimental unit was individual female for all measures and the model accounted for the fixed effects of treatment and parity and random effect of replicate. Data that were not normally distributed were transformed using the PROC RANK procedures of SAS. Binary response data were analyzed using the PROC FREQ procedures of SAS, using the chi-square test to evaluate differences between treatment means. Least-square means were separated by using the PDIFF option of SAS with treatment means being different at $P \leq 0.05$.

RESULTS

The statistical analysis included the effects of parity. However, the effects of parity were generally in line with previous studies and, therefore, parity means are only presented and discussed in the results when there was a Gestation Housing by parity interaction. Parity means are presented in Appendix Tables 12-15.

Sow Body Condition Score

Means for the effect of Gestation Housing treatment on body condition score (BCS) are presented in Table 5. There was Gestation Housing treatment by Parity interaction (*P* < 0.05) for BCS at day 35 and 60 of gestation, and at farrowing. However, treatment differences were very small and not practically important.

With the exception of the interactions described above, there were no differences (*P* > 0.05) between the gestation housing systems for BCS at day 35, 60, and 90, and at farrowing. Sows housed in groups had a greater (*P* < 0.05) BCS at day 7 and at weaning compared to individually-housed sows; however, the differences between treatment means were small (Table 5). There was a significant (*P* < 0.05) effect of parity on BCS at all times of measurement (Appendix; Table 12).

Sow Body Weight

Least-squares means for the effect of Gestation Housing treatment on sow body weight are presented in Table 6. Body weights were measured on a sub-sample of animals from 4 blocks (weeks of allotment) from a total of 20 blocks. There were no significant (*P* > 0.05) interactions between Gestation Housing treatments and parity for body weight or body weight gain at any time during from allotment to weaning (Table 6).

Sows housed in groups had a greater (*P* < 0.05) body weight at allotment (219.1 kg) than those in individual crates (213.5 kg) (Table 6). There was no effect (*P* > 0.05) of Gestation Housing treatment on sow body weight at farrowing, and weaning, or body weight gain from allotment to farrowing or farrowing to weaning.

Litter Performance

Least-squares means for the effect of Gestation Housing treatment on litter performance are presented in Table 7. There were no significant (*P* > 0.05) interactions between Gestation Housing treatment and parity for any of the measurements (Table 7). The treatment by parity interaction for pre-weaning mortality could not be tested as the data were analyzed using the PROC FREQ procedure of SAS.

There was no effect (*P* > *0.05*) of housing treatment on the number of piglets born alive, mummified, total born, and weaned, or on piglet and litter weights (at birth and weaning) (Table 7). Sows housed in groups had a greater (*P* < 0.05) number of piglets born dead per litter and after cross-fostering compared to sows housed in individual crates. However, the differences between the treatments for these two variables were small and of limited practical importance. Pre-weaning mortality was greater (*P* < 0.05) for the Group (15.2%) compared to the Individual Gestation Housing treatment (14.2%).

Breeding Performance and Removal Rate

Least-squares means for the effect of Gestation Housing treatment on sow breeding performance and removal rates are presented in Table 8. There were no significant (*P* > 0.05) interactions between Gestation Housing treatment and parity for days to breeding or rebreeding (Table 8). The treatment interactions were not tested for the percentage of females removed, conception rate, farrowing rate, or percentage induced to farrow, as these data were analyzed using PROC FREQ procedure of SAS.

There was no significant (*P* > 0.05) effect of Gestation Housing treatment on days to breeding, conception rate, farrowing rate, or the percentage of sows induced to farrow (Table 8). Sows housed in groups had a lower (*P* < 0.05) number of days to rebreeding than those housed in stalls. In addition, the total percentage of sows removed from the study was greater (*P* < 0.05) for the Group than the Individual Gestation Housing treatment (Table 8). There were no differences (*P* > 0.05) between the Group and Individual housing treatments for the percentage of sows that were euthanized, died, or culled during the study. However, The Group housing treatment had a greater ($P < 0.05$) percentage of sows removed from treatment (16.3 %) compared to the Individual housing treatment (10.0 %). Sows could be removed from treatment between day 35 (at allotment to treatment) and day 112 (at movement to farrowing). Criteria for sow removal from treatment included sows found not pregnant, sows which aborted their litter, sows in pens found sick, lame, or injured that did not respond to treatment, or sows with a body condition score 0.5 units below the average of the pen.

DISCUSSION

Sow Body Condition Score

There were few differences between the gestation housing systems for BCS at any measurement times, and the differences found were numerically small and not practically important. The means for BCS that were statistically significant was most likely an effect of the high number of replicates rather than being due to any real differences between Gestation Housing treatments. These results differ from those of the study of Salak-Johnson et al. (2007), which showed that the average BCS which was greater for individually- than group-housed sows. However, in the study by Salak-Johnson et al. (2007) all females were fed a fixed amount of feed (2.5 kg per day) regardless of parity, BCS, or housing treatment. In the current study, the amount of feed that a sow received was based on parity and BCS, which could explain the different results found in the current study compared to Salak-Johnson et al. (2007). Seguin et al. (2006) found no difference in average BCS between individually- and group-housed sows, which is similar to the results of the present study.

Sow Body Weight

In the current study, sows housed in groups had a greater body weight at allotment than those in individual crates, however, this difference was numerically small and was most likely due to chance. There was no effect of Gestation Housing treatment on sow body weight at any other time. These results are generally in agreement with those of the studies of Hulbert et al. (2014), Li et al. (2014), and Zhao et al. (2013), which all found no effect of group compared to individual gestation housing on sow body weights. Other studies that have reported gestation housing effects on sow body weight found conflicting results. Johnston et al. (2013) reported that sows housed in small groups were lighter at allotment (at day 35 of gestation) than those housed in either large groups or individual stalls, and sows in either small or large groups were generally lighter at farrowing and weaning than those kept in individual stalls. Conversely, Salak-Johnson et al. (2007) found no differences between group and individually-housed sows at allotment (at day 28 of gestation), but group-housed sows were generally heavier than individually-housed sows at farrowing and weaning.

In the current study, there were no effects of Gestation Housing treatment on body weight changes from allotment to farrowing or farrowing to weaning. Similarly, Salak-Johnson et al. (2007) did not find an effect of housing system on body weight change during gestation. However, Johnston et al. (2013) reported a greater body weight gain in gestation for sows housed in individual crates and small groups than those housed in large groups, and a greater body weight loss in lactation for sows housed in individual crates in gestation compared to sows housed in large groups, with sows housed in small groups being intermediate. The reason for the difference in results between these studies is not clear, and suggests further study may be needed to understand the effects of group vs. individual housing and group size on sow body weights.

Litter Performance

In the present study, there was no effect of Gestation Housing treatment on the number of piglets born alive per litter which is in agreement with the results of 13 of the 16 studies summarized in the literature review (Table 1). The other 3 studies which found effects of gestation housing on numbers born alive showed conflicting results. Broom et al. (1995) reported that sows housed in individual crates had a greater number of piglets born alive compared to those housed in both small and large groups. Conversely, Seguin et al. (2006) and Oliviero et al. (2009) reported that sows housed in groups had a greater number of piglets born alive than sows housed in individual crates.

In the current study, sows housed in groups had a greater number of piglets born dead than those housed individually, however, the difference between treatments was small and of limited practical importance. In 10 of the 12 studies summarized in the literature review, there was no effect of gestation housing on the number of piglets born dead (Table 1). Contrary to the results of the current study, Bates et al. (2003) and Oliviero et al. (2009) found that individually-housed sows had a greater number of piglets born dead per litter than group-housed sows.

In the current study, there was also no effect of gestation housing treatment on the number of piglets born mummified per litter. This result is in agreement with 6 of the 7 studies summarized in the literature review which reported this measurement (Table 1). However, Broom et al. (1995) reported that sows housed in small pens had a greater number of mummified piglets per litter than those housed in either large pens or individual crates.

In the current study, there was no effect of Gestation Housing treatment on the total number of piglets born per litter which is in agreement with 11 of the 12 studies summarized in the literature review (Table 1). In contrast, Salak-Johnson et al. (2007) found that group-housed sows kept at a floor space of 3.3 m^2/sow had a greater total number of piglets born per litter compared to sows kept in individual crates. However, in the study of Salak-Johnson et al. (2007) sows housed in groups at a floor space of 2.3 or 1.4 m^2/sow had a similar total number of pigltes born per litter to those kept in individual crates.

There was no effect of Gestation Housing treatment on the number of piglets weaned per litter in the current study which is in agreement with 6 of the 7 studies summarized in the literature review (Table 1). However, Karlen et al. (2007) reported a greater number of piglets weaned per litter for group-housed sows compared to those kept in individual crates.

In the current study, pre-weaning mortality was greater for the Group compared to the Individual Gestation Housing treatment. This result was contrary to 4 studies that reported pre-weaning mortality levels (Bates et al., 2003; Harris et al., 2006; Hulbert et al., 2006; Li et al., 2014), that all found no effect of gestation housing system. The reason for the difference in pre-weaning mortality between housing systems found in the present study is not clear, which, although it is relatively small, it would be commercially important. Further research would be required to clarify any effect of gestation housing on pre-weaning mortality levels.

There was no effect of Gestation Housing treatment on piglet birth weights in the current study which is in agreement with 7 of the 9 studies reporting litter birth weights that were summarized in the literature review (Table 1) that also found no effect of gestation housing treatment. Conversely, Bates et al. (2003) and Seguin et al (2006) both reported higher litter birth weights for group-housed sows compared to individually-housed sows. Seguin et al. (2006) also found group-housed sows had a greater number of piglets born alive per litter, which suggests this effect on birth weight may be due to litter size. However, Bates et al. (2003) found no effect of gestation housing on the number of piglets born alive or total born per litter, suggesting that there may have been an effect in that study on the average piglet birth weight.

In the current study, there was no effect of Gestation Housing treatment on litter weaning weights which is in agreement with 5 of the 7 studies summarized in the literature review (Table 1) that reported this measure. In contrast, Salak-Johnson et al. (2007) reported that sows housed in individual crates had the highest litter weaning weight compared to sows housed in groups at a floor space of 2.3 m^2/ sow, and sows housed in groups at floor spaces of 1.4 and 3.3 m^2 were intermediate to these 2 treatments. However, Bates et al. (2003) reported higher litter weaning weights for sows housed in groups compared to individually during gestation.

Breeding Performance and Removal Rate

In the current study, there was no effect of Gestation Housing treatment on days from weaning to breeding, however, sows housed in groups had a lower number of days from weaning to rebreeding than those housed in stalls Table 8). Weaning to breeding interval was reported in 4 of the studies that were summarized in the literature review (Table 2; Jansen et al., 2007; Johnston et al., 2013; Knox et al., 2014; Munsterhjelm et al., 2008) and all of these studies also showed no difference between group and individual-housing systems. There were no studies found that presented the effects of gestation housing treatment on days from weaning to rebreeding.

In the current study, there was no effect of Gestation Housing treatment on conception rate or farrowing rate (Table 8). Five of the 8 studies summarized in the literature review (Table 2) reported a higher farrowing rate for sows in individual crates compared to those housed in groups (Bates et al., 2003; Hulbert et al., 2006; Johnston et al., 2013; Karlen et al., 2007). Knox et al. (2014) found sows mixed in groups at 3 days post-insemination had a lower farrowing rate than those mixed at day 14 or 35, or those housed in individual crates. There were 3 studies that found no effect of housing treatment on farrowing rate (Jansen et al., 2007; Cassar et al., 2008;

McGlone et al., 2004). The differences in results between these studies suggests that group housing design and management may have an effect on conception and farrowing rates, and this warrants further study.

In the current study, the total percentage of sows removed from the study was greater for the Group than the Individual Gestation Housing treatment (Table 8). However, there were no differences between the Group and Individual housing treatments for the percentage of sows that were euthanized, died, or culled during the study. The treatment difference in overall removal rate was due to the Group Housing treatment having a greater percentage of sows removed from treatment in gestation compared to the Individual housing treatment. Only 2 of the studies summarized in the literature review (Table 2) evaluated the effect of gestation housing system on sow removal rates. In these studies, sow removal rate was calculated as the percentage of sows assigned to the study that were culled, euthanized, or died during the study period. Similar to the results of the current study, neither of the studies reviewed reported any difference between individual and group-housing treatments (Karlen et al., 2007; Li et al., 2014).

Conclusion

In conclusion, most measures of sow reproductive performance did not differ significantly or practically between Gestation Housing treatments. However, females housed in groups had greater piglet pre-weaning mortality, and a greater number of sows removed from treatment in gestation than those housed in individual crates. The effects on pre-weaning mortality, although relatively small, are of commercial relevance and differed from the results of other published studies. Further research is needed to validate this result and to establish the causes of any differences between individual and group housing systems for pre-weaning mortality. The overall sow removal rate was also greater for the Group housing treatment compared to the Individual housing treatment. However, this difference was due to a greater number of sows removed from treatment in gestation for the Group treatment, rather than differences in the number of sows which were culled, euthanized, or died during the study period. Overall, the results of this study suggest that converting individual stalls to small pens is a potential approach to allow group-housing of sows during gestation for use in commercial practice with limited negative effects on reproductive performance.

TABLES

Table 5. Means for the Effect of Gestation Housing Treatment on Sow Body Condition Score (BCS)[1].

	Number of Observations		Means				*P*-value[4]		
Item	Individual	Group	Individual	Group	Parity	SEM	Treatment	Parity	Trt*Parity
BCS Day 7[2,3]	2776	2794	3.36	3.37	-	-	0.02	<0.0001	0.51
BCS Day 35[2]	3398	3404	3.40	3.42	-	-	0.07	<0.0001	0.001
Parity 1	814	856	3.44	3.44	3.44	-	0.47	-	-
Parity 2	816	791	3.42	3.43	3.43	-	0.56	-	-
Parity 3	639	645	3.39	3.42	3.41	-	<0.0001	-	-
Parity 4	511	512	3.36	3.40	3.38	-	<0.0001	-	-
Parity 5	393	383	3.36	3.40	3.38	-	0.0002	-	-
Parity 6	225	217	3.38	3.41	3.40	-	0.07	-	-
BCS Day 60[2]	3145	3116	3.42	3.42	-	-	0.42	<0.0001	0.02
Parity 1	622	669	3.44	3.43	3.44	-	0.15	-	-
Parity 2	801	766	3.45	3.44	3.44	-	0.14	-	-
Parity 3	633	608	3.43	3.42	3.43	-	0.27	-	-
Parity 4	493	488	3.37	3.38	3.38	-	0.67	-	-
Parity 5	382	370	3.39	3.39	3.39	-	0.42	-	-
Parity 6	214	215	3.40	3.44	3.42	-	0.001	-	-
BCS Day 90[2]	3260	3216	3.43	3.42	-	-	0.10	<0.0001	0.40
BCS Farrowing	3093	3034	3.34	3.35	-	-	0.10	<0.0001	0.01
Parity 1	771	805	3.34	3.36	3.35	-	0.10	-	-
Parity 2	767	711	3.38	3.37	3.37	-	0.30	-	-
Parity 3	602	575	3.32	3.31	3.31	-	0.22	-	-
Parity 4	457	451	3.25	3.27	3.26	-	0.05	-	-
Parity 5	340	335	3.36	3.39	3.37	-	0.01	-	-
Parity 6	156	157	3.45	3.45	3.45	-	0.99	-	-
BCS Weaning	2908	2854	3.25	3.27	-	-	0.0001	0.01	0.42

[1]Sow body condition score (BCS) on a 2.5 (extremely thin) to 3.5 (fat) scale.

[2]Number of days after breeding.

[3]Previously allotted sows that were weaned and scored 7 days post-breeding.

[4]Data were analyzed using PROC RANK of SAS.

Table 6. Least-Squares Means for the Effect of Gestation Housing Treatment on Sow Body Weight.

Item	Number of Observations		Means		SEM	*P*-value		
	Individual	Group	Individual	Group		Treatment	Parity	Trt*Parity
Body weight at allotment (kg)[2]	651	662	213.5	219.1	2.05	0.004	<0.0001	0.19
Body weight at farrowing (kg)[3,4]	537	531	244.2	249.3	2.44	0.06	<0.0001	0.14
Body weight at weaning (kg)[4]	201	192	200.4	197.4	2.58	0.19	<0.0001	0.23
Body weight gain-allotment to farrowing (kg)[4]	504	507	36.9	35.2	2.08	0.46	0.37	0.39
Body weight gain-farrowing to weaning (kg)[4]	191	184	-34.6	-32.6	1.74	0.38	<0.0001	0.81

[1]Weights taken over 4 weeks of allotments per 20 week cycle.

[2]Allotments carried out at approximately day 35.

[3]Sow body weight at farrowing was taken at movement into the farrowing room.

[4]Same sows weighed at farrowing and weaning as were weighed at allotment.

Table 7. Least-Squares Means for the Effect of Sow Gestation Housing Treatment on Litter Performance.

	Number of Observations		Means			*P*-value		
Item	Individual	Group	Individual	Group	SEM	Treatment	Parity	Trt*Parity
Number of piglets:	-	-	-	-	-	-	-	-
Born alive	2817	2752	12.8	12.8	0.08	0.86	<0.0001	0.76
Born dead[5]	3084	3029	0.8	0.9	-	0.03	<0.0001	0.13
Born mummified[5]	3074	3021	0.5	0.5	-	0.33	<0.0001	0.53
Total born[1]	2721	2665	14.4	14.5	0.08	0.37	<0.0001	0.63
After cross-fostering	2819	2755	12.6	12.7	0.07	0.05	<0.0001	0.73
Weaned	2872	2805	10.7	10.7	0.08	0.49	<0.0001	0.98
Pre-weaning mortality (%)[2,6]	2737	2661	14.2	15.2	-	0.002	-	-
Birth weight (kg):	-	-	-	-	-	-	-	-
Average piglet[3]	1518	1458	1.5	1.5	0.01	0.58	<0.0001	0.94
Total litter[4]	1518	1458	15.8	15.6	0.22	0.85	<0.0001	0.77
Weaning weight (kg):	-	-	-	-	-	-	-	-
Average piglet	1518	1454	6.5	6.5	0.05	0.54	<0.0001	0.07
Total litter	1518	1454	73.7	73.0	0.67	0.30	<0.0001	0.39

[1]Total number of piglets born alive, dead, and mummified.

[2]Preweaning mortality calculated as the percentage of piglets per sow after cross-fostering that died before weaning, within treatment.

[3]Average weight of piglets born alive and dead, before cross-fostering.

[4]Total weight of piglets born alive and born dead, before cross-fostering.

[5]Data were analyzed using PROC RANK of SAS.

[6]Data were analyzed using PROC FREQ of SAS.

Table 8. Least-Squares Means for the Effect of Gestation Housing Treatment on Sow Breeding Performance and Removal Rate.

	Number of Observations		Means			*P*-value		
Item	Individual	Group	Individual	Group	SEM	Treatment	Parity	Trt*Parity
Days to breeding[1,8]	2681	2687	8.1	7.8	-	0.92	<0.0001	0.46
Days to rebreeding[1,8]	143	154	51.3	48.3	-	0.05	0.22	0.20
Conception rate (%)[2,7]	2681	2687	94.7	94.3	-	0.52	-	-
Induced to farrow (%)[3,7]	3136	3129	89.3	88.4	-	0.30	-	-
Farrowed rate (%)[4,7]	3127	3088	97.0	96.9	-	0.98	-	-
Sows removed from the study (%):[5,7]	-	-	-	-	-	-	-	-
Total	412	486	12.1	14.3	-	0.02	-	-
Euthanized	72	82	17.5	16.9	-	0.84	-	-
Died	81	78	19.7	16.0	-	0.24	-	-
Removed from treatment (%)[6]	41	79	10.0	16.3	-	0.02	-	-
Culled	218	247	52.9	50.8	-	0.73	-	-

[1]Days from weaning to breeding or rebreeding.
[2]Percentage of total sows allotted to the study that were not removed for 2 negative pregnancy checks, within treatment.
[3]Percentage of sows induced to farrow, within treatment.
[4]Percentage of total sows allotted to the study that farrowed, within treatment.
[5]Percentage of total sows allotted to the study, within treatment.
[6]Percentage of total sows allotted to the study that were removed from the study, within treatment.
[7]Data were analyzed using PROC FREQ procedure of SAS.
[8]Data were analyzed using PROC RANK procedure of SAS.

Table 9. Feeding levels for gilts	
Gilt body weight at breeding (kg)	Total daily amount (kg/day)
118-127	4.54
128-136	4.10
137-145	3.64
146-155	3.64
156-164	3.18

Table 10. Feeding levels for sows (kg/day)					
	Body condition score (BCS)				
Parity	2.50	2.75	3.00	3.25	≥3.50
P 2-3	2.50	2.28	2.04	1.82	1.60
P ≥ 4	2.96	2.50	2.28	2.04	1.60

FIGURES

Figure 1. Layout of breeding and gestation facility at South Ridge illustrating the animal flow.

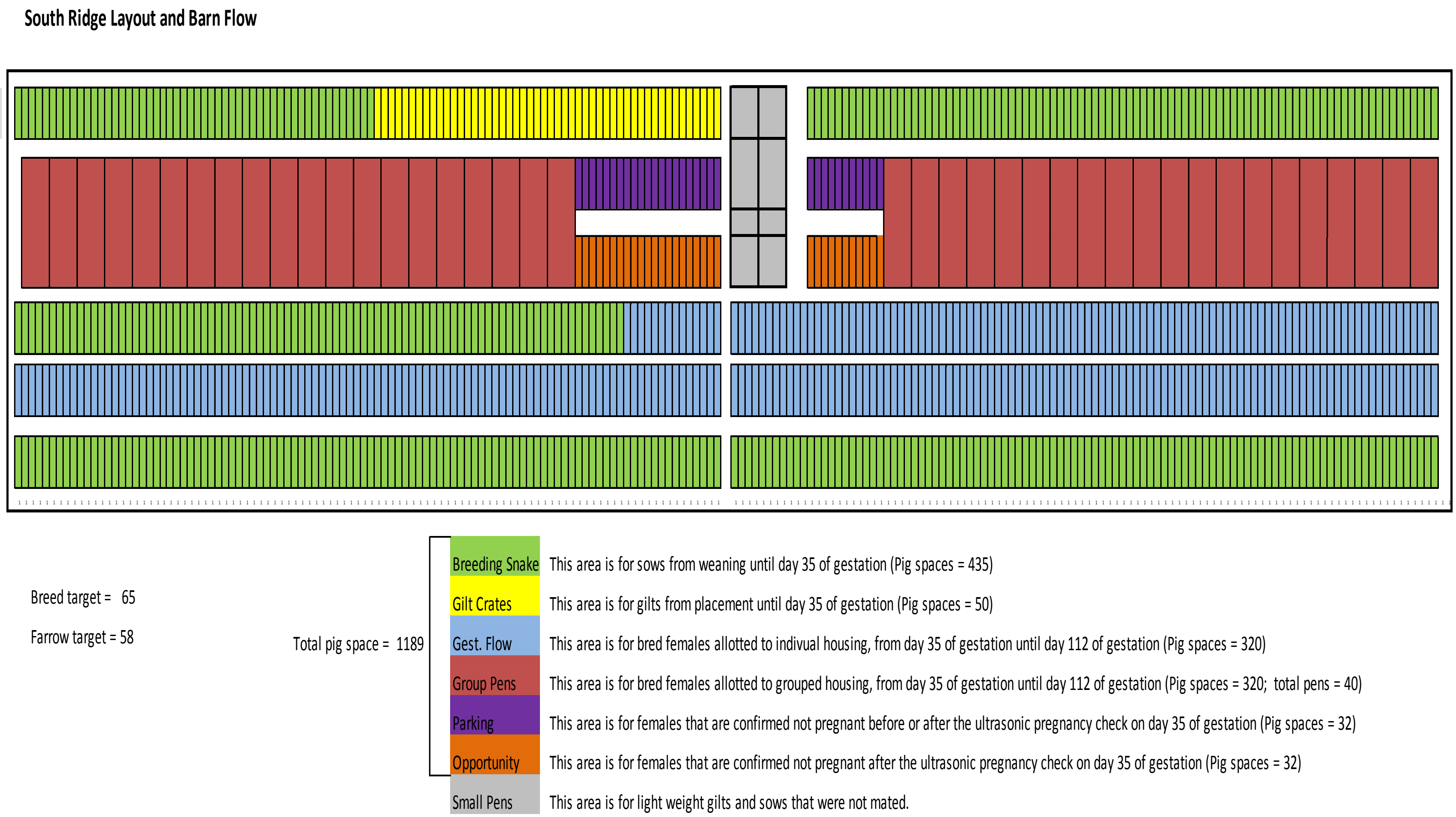


Figure 2. The Maschhoff body condition scoring.

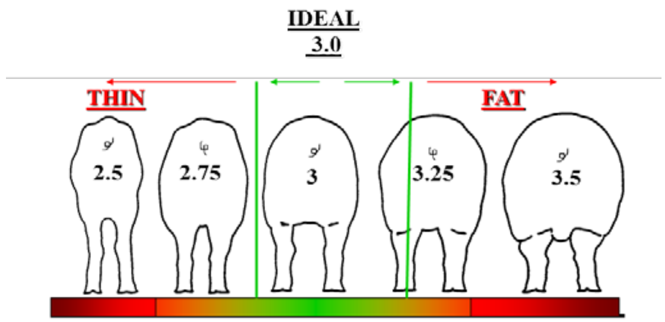
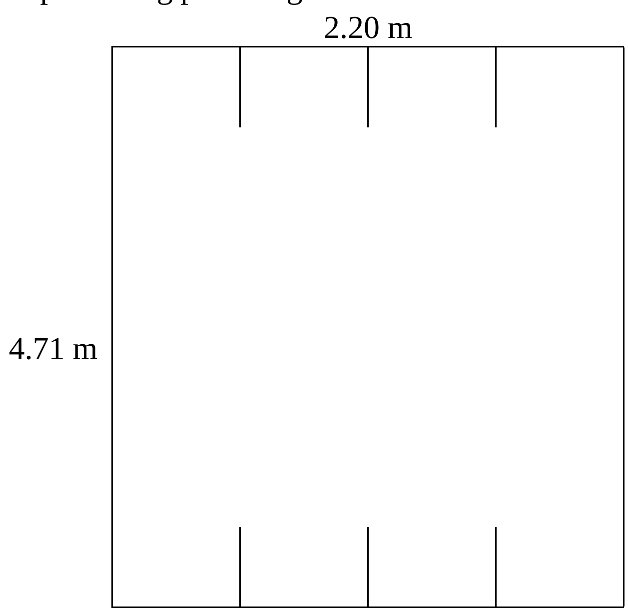


Figure 3. Group Housing pen design.



	Group Housing
-Floor area/female	1.30 m²
-Feeder	Drop type, dropping into trough.
- Waterer	Trough waterer.

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CHAPTER 3: EFFECT OF FARROWING PEN SIZE ON PRE-WEANING MORTALITY

INTRODUCTION

The use of crates in farrowing pens has been established as a means to reduce pre-weaning mortality. As a result, most commercial facilities house sows and litters in farrowing pens with a sow crate. However, in the last 20 years it has been estimated that litter size has increased by approximately 2 piglets, whereas the farrowing pen size has not increased. The most common cause of piglet mortality is due to crushing by the sow. Increasing pen size would give more space for piglets, and may piglet reduce mortality. There has been no published research that has evaluated the effect of farrowing pen size in current commercial production on piglet pre-weaning mortality.

Therefore, the objective of this study is to compare the effect of standard-width to increased sized farrowing pens on the pre-weaning mortality of piglets.

MATERIALS AND METHODS

This study was conducted at South Ridge Sow Farm, a breed-to-wean facility located near Pittsfield, IL, owned and operated by The Maschhoffs LLC (Carlyle, IL). The experimental protocol was approved by the University of Illinois Institutional Animal Care and Use Committee. This study utilized females from the Gestation Housing System study, and was carried out during the time that these females were in the farrowing facility (from day 112 when they were moved to the farrowing facility until weaning). Results for the performance of the sows for the first two parities (parities 1 and 2) of this study were presented by Laudwig at al. (2015); the results reported in this thesis are a continuation of this study with sows taken to parity 6.

Experimental Design and Treatments

This study was carried out as a Randomized Complete Block Design, with farrowing room as the blocking factor. Two farrowing pen size treatments were compared: 1) Standard (pen width = 1.52 m), 2) Increased (pen width = 1.68 m).

Animals and Allotment to Study

The animals used in this study were housed during gestation in either individual crates or small group pens (8 pigs/pen; see Sow Housing System Animal Housing and Management section). A total of 1816 bred females were used. Animals were allotted to farrowing pen size treatments at placement in farrowing rooms on approximately day 112 of gestation. All of the farrowing pens in the rooms used for this study had pens of the Increased pen width (1.68 m). For the Standard pen width treatment, half of the pens in each room had a divider fitted to reduce the pen width to 1.52 m. For allotment to the study, females within a farrowing room were formed into outcome groups of 2 of the same sow housing treatment, with similar parity (±1 parity), and similar breeding date (± 2 days). Females were then randomly allotted from within outcome group to each of the farrowing pen width treatments. After allotment, the sows on the Standard pen size treatment had a divider inserted into the pen, and sows on the Increased pen size treatment were left without a divider.

Animal Housing and Management

Animals in this study were housed and managed as previously described in the Sow Housing System Study (Animal Housing and Management section). The farrowing facility consisted of 9 rooms with either 24 or 26 farrowing pens per room. Farrowing rooms used in this study had different farrowing pen lengths of 2.07 m (rooms 1 and 2) and 2.20 m (rooms 8 and 9). The different crate lengths led to different total pen areas: the Standard treatment had a total pen area of 1.99 m^2 and 2.14 m^2; the Increased treatment of 2.20 m^2 and 2.47, by crate lengths respectively. Crates were equipped with a trickle-type feeder that dropped into a feed trough and a cup-type drinker. The thermostat in each room was set at 22.5° C until all sows in the room had farrowed, then decreased by 0.25° C per day for 10 days to 20.0° C, then decreased over the next 5 days to 19° C, remaining this temperature until weaning. Each sow and litter had one heat lamp, held in place by a metal bar attached to the crate, suspending the heat lamp over the center of the creep space. An additional heat lamp was provided during the winter (November-May) for the first few days after farrowing, and was suspended similarly to the first, on the opposite side of the farrowing pen. The farrowing crate in the Standard width pens width was located in the center of the pen, providing equal amounts of piglet space on either side. The farrowing crate in the Increased width pens was off-centered, with the additional creep space on the side of the primary heat lamp.

Management in the farrowing facility was generally in accordance with standard unit procedures. For the first 6.5 months of the study period, cross-fostering of piglets between litters was only carried out between sows of the same housing treatment. However, due to practical problems with this approach, from April 5, 2015 onwards the protocol was amended to allow cross-fostering between sows of either treatment. On December 31, 2015, South Ridge Sow Farm was tested for and confirmed as having a PRRSv infection. Upon veterinary recommendation, no cross-fostering or piglet weights were performed until the farm was no longer under an active infection. The 4-day old and weaned piglets were tested weekly, and when both groups tested negative for 4 consecutive weeks (July 8, 2016), the farm was declared as no longer under an active PRRSv infection and cross-fostering was resumed.

Farrowing Measurements

The date on which each sow farrowed was recorded, as well as if the sow was induced or assisted to farrow. Sows that had not farrowed by day 114 of gestation were induced by injecting the sow with 1 mL of Lutalyse® (Pfizer Animal Health US) at both 6:00 h and 12:00 h. The number of piglets born alive, born dead, and mummified for each sow were recorded and used to calculate the total number of piglets born per litter. After farrowing was complete, all piglets born alive were weighed together to obtain average born alive weights. All piglets born dead were weighed together to obtain average born dead weights. These born alive and born dead weights were added to calculate total born litter weight. Litters were weighed again at weaning to obtain a litter weaning weight, which was used to calculate average piglet weaning weight. The dates and causes of piglet deaths were recorded from birth until weaning. The date of weaning was also recorded, and used to calculate the average piglet weaning age.

Statistical Analysis

Normality and homogeneity of variance was tested using the PROC UNIVARIATE procedure of SAS (SAS Inst. Inc., NC). Data that was normally distributed were analyzed using the PROC MIXED procedures of SAS (Littell et al., 1996). Data that was not normally distributed were transformed using the PROC RANK procedures of SAS. Binary response data were analyzed using the PROC FREQ procedures of SAS, using the chi-square test to evaluate differences between treatment means. The experimental unit was individual sow and litter for all measures, and the model accounted for the fixed effects of treatment and random effects of replicate. Least-square means were separated by using the PDIFF option of SAS with treatment means being different at a $P \leq 0.05$.

RESULTS

The statistical analysis included the effects of parity. However, the parity effects were generally in line with previous studies and, therefore, parity means are only presented and discussed in the results when there was a Farrowing Pen Size treatment by parity interaction. Parity means are presented in the Appendix (Table 18).

Least-squares means for the effect of Farrowing Pen Size treatment on litter performance are presented in Table 11. There were no significant ($P > 0.05$) interactions between Farrowing Pen Size treatment and parity for any of the measurements (Table 11). The treatment by parity interactions were not tested for pre-weaning mortality as the data were analyzed using PROC FREQ procedure of SAS.

Total litter birth and weaning weights were greater ($P < 0.05$) for the Increased compared to the Standard Farrowing Pen Size treatment. There were no significant ($P > 0.05$) effects of farrowing pen size on any of the other measures reported here (Table 11).

DISCUSSION

In the current study, there were no commercially important effects of the larger farrowing pen size on any of the measures reported. A total of 10 studies were discussed in the literature review that evaluated the effects of farrowing crate design or compared farrowing pens with or without crates with respect to sow litter performance (Table 4). However, only the study by Cronin et al. (1998) compared farrowing pens of varying size and width (large/wide, large/narrow, small/wide, and small/narrow). Cronin et al. (1998) also found no significant effects on any measures reported. However, in that study there were large numerical differences in pre-weaning mortality that were not statistically significant due to the low number of sows used in the study (9/treatment for weaning data; Table 4). Fels et al. (2016) suggested that with continuously increasing litter sizes, current commercial farrowing creep area should be increased for piglets in litters of 12 or more, though no effects of farrowing pen size were studied. With such limited research in the area of farrowing pen size, it is difficult to compare the results of the current study. Further research is necessary to validate the results of this study, and to determine the effects of farrowing pen size and design as litter sizes continue to increase.

Conclusion

The larger farrowing pen size did not impact pre-weaning mortality, despite the fact that average litter sizes were relatively high (> 12 piglets). As commercial litter sizes continue to increase, further research into the effects farrowing pen size and design on pre-weaning mortality are necessary.

TABLE

Table 11. Least-Squares Means for the Effect of Farrowing Pen Size Treatment on Litter Performance.

	Treatment			*P*-value		
Item	Standard	Increased	SEM	Treatment	Parity	Trt*Parity
Number of litters	805	808	-	-	-	-
Number of piglets:	-	-	-	-	-	-
Born alive	13.0	13.3	0.15	0.19	<0.0001	0.86
Born dead[5]	0.7	0.8	-	0.78	<0.0001	0.41
Born mummified[5]	0.3	0.3	-	0.98	<0.0001	0.12
Total born[1]	14.1	14.4	0.19	0.11	<0.0001	0.59
After cross-fostering	12.8	13.1	0.10	0.09	<0.0001	0.07
Weaned	10.9	11.0	0.11	0.23	<0.0001	0.58
Pre-weaning mortality (%)[2,6]	15.2	14.6	-	0.39	-	-
Birth weight (kg):	-	-	-	-	-	-
Average piglet[3]	1.5	1.5	0.01	0.58	<0.0001	0.09
Total litter[4]	19.7	20.2	0.18	0.04	<0.0001	0.94
Weaning weight (kg):	-	-	-	-	-	-
Average piglet	6.4	6.5	0.05	0.19	<0.0001	0.81
Total litter	72.8	74.5	0.65	0.03	<0.0001	0.86
Piglet age at weaning (days)	21.3	21.3	0.09	0.51	<0.0001	0.40

[1]Total number of piglets born alive, dead, and mummified.

[2]Preweaning mortality calculated as the percentage of the number of piglets per sow after cross-fostering that died before weaning, within treatment.

[3]Average weight of piglets born alive and dead, before cross-fostering.

[4]Total weight of piglets born alive and born dead, before cross-fostering.

[5]Data were analyzed using PROC RANK of SAS.

[6]Data were analyzed using PROC FREQ of SAS.

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APPENDIX

Table 12. Means for the Effect of Gestation Housing Treatment and Parity on Sow Body Condition Score (BCS)[1].

	Number of Observations		Means				*P*-value[4]		
Item	Individual	Group	Individual	Group	Parity	SEM	Trt	Parity	Trt*Parity
BCS Day 7[2,3]	2776	2794	3.36	3.37	-	-	0.02	<0.0001	0.51
Parity 1	662	688	3.39	3.40	3.40^{a}	-	0.92	-	-
Parity 2	688	674	3.37	3.38	3.38^{b}	-	0.26	-	-
Parity 3	545	563	3.33	3.34	3.34^{c}	-	0.31	-	-
Parity 4	450	435	3.33	3.36	3.35^{bc}	-	0.01	-	-
Parity 5	323	313	3.35	3.36	3.35^{bc}	-	0.51	-	-
Parity 6	108	121	3.33	3.35	3.34^{c}	-	0.49	-	-
BCS Day 35[2]	3398	3404	3.40	3.42	-	-	0.07	<0.0001	0.001
Parity 1	814	856	3.44	3.44	3.44^{a}	-	0.47	-	-
Parity 2	816	791	3.42	3.43	3.43^{b}	-	0.56	-	-
Parity 3	639	645	3.39	3.42	3.41^{c}	-	<0.0001	-	-
Parity 4	511	512	3.36	3.40	3.38^{c}	-	<0.0001	-	-
Parity 5	393	383	3.36	3.40	3.38^{c}	-	0.0002	-	-
Parity 6	225	217	3.38	3.41	3.40^{c}	-	0.07	-	-
BCS Day 60[2]	3145	3116	3.42	3.42	-	-	0.42	<0.0001	0.02
Parity 1	622	669	3.44	3.43	3.44^{a}	-	0.15	-	-
Parity 2	801	766	3.45	3.44	3.44^{a}	-	0.14	-	-
Parity 3	633	608	3.43	3.42	3.43^{b}	-	0.27	-	-
Parity 4	493	488	3.37	3.38	3.38^{b}	-	0.67	-	-
Parity 5	382	370	3.39	3.39	3.39^{b}	-	0.42	-	-
Parity 6	214	215	3.40	3.44	3.42^{b}	-	0.001	-	-
BCS Day 90[2]	3260	3216	3.43	3.42	-	-	0.10	<0.0001	0.40
Parity 1	3260	3216	3.43	3.42	3.43^{ab}	-	0.10	-	-
Parity 2	744	788	3.45	3.45	3.45^{a}	-	0.30	-	-
Parity 3	799	760	3.45	3.45	3.45^{c}	-	0.23	-	-
Parity 4	632	608	3.44	3.43	3.33^{e}	-	0.20	-	-
Parity 5	491	479	3.37	3.36	3.37^{de}	-	0.22	-	-
Parity 6	380	367	3.39	3.40	3.39^{bcd}	-	0.78	-	-
BCS Farrowing	3093	3034	3.34	3.35	-	-	0.10	<0.0001	0.01
Parity 1	771	805	3.34	3.36	3.35^{c}	-	0.10	-	-
Parity 2	767	711	3.38	3.37	3.37^{b}	-	0.30	-	-
Parity 3	602	575	3.32	3.31	3.31^{d}	-	0.22	-	-
Parity 4	457	451	3.25	3.27	3.26^{d}	-	0.05	-	-
Parity 5	340	335	3.36	3.39	3.37^{bc}	-	0.01	-	-
Parity 6	156	157	3.45	3.45	3.45^{a}	-	0.99	-	-
BCS Weaning	2908	2854	3.25	3.27	-	-	0.0001	0.01	0.42
Parity 1	719	729	3.24	3.25	3.25^{a}	-	0.78	-	-
Parity 2	725	678	3.26	3.28	3.27^{a}	-	0.21	-	-
Parity 3	579	556	3.27	3.30	3.28^{ab}	-	0.01	-	-
Parity 4	434	431	3.19	3.21	3.20^{b}	-	0.03	-	-
Parity 5	320	323	3.26	3.28	3.27^{a}	-	0.09	-	-
Parity 6	131	137	3.28	3.32	3.30^{a}	-	0.09	-	-

^{a,b,c,d,e}Parity means, within measurement, with different superscripts differ ($P \leq 0.05$).

[1]Sow body condition score (BCS) on a 2.5 (extremely thin) to 3.5 (fat) scale.

[2]Number of days after breeding.

[3]Previously allotted sows that were weaned and scored 7 days post-breeding.

[4]Data were analyzed using PROC RANK of SAS.

Table 13. Least-Squares Means for the Effect of Gestation Housing Treatment and Parity on Sow Body Weight[1].

	Number of Observations		Means				*P*-value		
Item	Individual	Group	Individual	Group	Parity	SEM	Trt	Parity	Trt*Parity
Body weight at allotment (kg)[2]	651	662	213.5	219.1	-	2.05	0.004	<0.0001	0.19
Parity 1	159	168	182.0	184.1	183.1[f]	1.96	0.29	-	-
Parity 2	162	163	193.8	194.5	194.2[e]	1.81	0.72	-	-
Parity 3	114	112	204.8	210.4	207.6[d]	2.14	0.02	-	-
Parity 4	107	109	219.4	219.6	219.5[c]	2.27	0.94	-	-
Parity 5	78	75	226.1	233.0	229.5[b]	2.62	0.02	-	-
Parity 6	31	35	235.1	245.3	240.2[a]	4.25	0.03	-	-
Body weight at farrowing (kg)[3,4]	537	531	244.2	249.3	-	2.44	0.06	<0.0001	0.14
Parity 1	143	147	224.3	220.5	222.4[d]	2.06	0.17	-	-
Parity 2	141	129	232.9	234.7	233.8[c]	2.02	0.53	-	-
Parity 3	108	111	241.3	247.4	244.3[b]	2.31	0.05	-	-
Parity 4	80	80	255.9	260.0	258.0[a]	2.60	0.27	-	-
Parity 5	58	60	260.2	261.1	260.7[a]	3.12	0.83	-	-
Parity 6	7	4	250.7	271.9	261.3[ab]	10.49	0.14	-	-
Body weight at weaning (kg)[4]	201	192	200.4	197.4	-	2.58	0.19	<0.0001	0.23
Parity 1	89	94	191.1	188.6	189.8[b]	2.49	0.29	-	-
Parity 2	97	85	204.4	205.9	205.2[a]	2.42	0.50	-	-
Parity 3	15	13	205.9	197.8	201.8[a]	5.39	0.18	-	-
Parity 4	0	0	-	-	-	-	-	-	-
Parity 5	0	0	-	-	-	-	-	-	-
Parity 6	0	0	-	-	-	-	-	-	-
Body weight gain-allotment to farrowing (kg)[4]	504	507	36.9	35.2	-	2.08	0.46	0.37	0.39
Body weight gain-farrowing to weaning (kg)[4]	191	184	-34.6	-32.6	-	1.74	0.38	<0.0001	0.81
Parity 1	87	93	-42.1	-40.6	-41.3[b]	1.39	0.52	-	-
Parity 2	90	78	-27.9	-27.6	-27.7[a]	1.43	0.95	-	-
Parity 3	14	13	-33.7	-29.6	-31.7[a]	3.41	0.50	-	-
Parity 4	0	0	-	-	-	-	-	-	-
Parity 5	0	0	-	-	-	-	-	-	-
Parity 6	0	0	-	-	-	-	-	-	-

[a,b,c,d,e,f]Parity means, within measurement, with different superscripts differ ($P \leq 0.05$).

[1]Weights taken over 4 weeks of allotments per 20 week cycle.

[2]Allotments carried out at approximately day 35.

[3]Sow body weight at farrowing was taken at movement into the farrowing room.

[4]Same sows weighed at farrowing and weaning as were weighed at allotment.

Table 14. Least-Squares Means for the Effect of Sow Gestation Housing Treatment on Litter Performance.

	Number of Observations		Means				*P*-value		
Item	Individual	Group	Individual	Group	Parity	SEM	Trt	Parity	Trt*Parity
Number of Piglets:	-	-	-	-	-	-	-	-	-
Born alive	2817	2752	12.8	12.8	-	0.08	0.86	<0.0001	0.76
Parity 1	696	711	11.4	11.4	11.4[c]	0.11	0.78	-	-
Parity 2	684	644	12.7	12.6	12.6[b]	0.11	0.44	-	-
Parity 3	568	538	13.6	13.3	13.4[a]	0.12	0.26	-	-
Parity 4	432	420	13.3	13.5	13.4[a]	0.14	0.55	-	-
Parity 5	301	301	12.8	12.8	12.8[b]	0.16	0.89	-	-
Parity 6	136	138	12.9	13.1	13.0[ab]	0.25	0.53	-	-
Born dead[5]	3084	3029	0.8	0.9	-	-	0.03	<0.0001	0.13
Parity 1	770	803	0.8	0.7	0.8[c]	-	0.27	-	-
Parity 2	763	711	0.6	0.7	0.6[d]	-	0.24	-	-
Parity 3	600	577	0.8	0.8	0.8[c]	-	0.71	-	-
Parity 4	457	451	0.9	1.2	1.1[b]	-	0.04	-	-
Parity 5	338	330	1.3	1.3	1.3[a]	-	0.87	-	-
Parity 6	156	157	1.2	1.5	1.3[a]	-	0.05	-	-
Born mummified[5]	3074	3021	0.5	0.5	-	-	0.33	<0.0001	0.53
Parity 1	771	805	0.3	0.3	0.3[d]	-	0.42	-	-
Parity 2	762	711	0.3	0.4	0.4[c]	-	0.45	-	-
Parity 3	599	572	0.5	0.6	0.5[b]	-	0.12	-	-
Parity 4	451	449	1.0	0.9	0.9[a]	-	0.69	-	-
Parity 5	335	327	0.8	0.7	0.7[b]	-	0.62	-	-
Parity 6	156	157	0.4	0.5	0.4[bc]	-	0.38	-	-
Total born[1]	2721	2665	14.4	14.5	-	0.08	0.37	<0.0001	0.63
Parity 1	681	694	12.4	12.4	12.4[d]	0.10	0.96	-	-
Parity 2	621	592	13.7	13.6	13.7[c]	0.11	0.64	-	-
Parity 3	561	531	15.0	14.9	14.9[b]	0.12	0.51	-	-
Parity 4	424	417	15.3	15.6	15.5[a]	0.13	0.24	-	-
Parity 5	298	293	15.1	15.1	15.1[ab]	0.16	0.89	-	-
Parity 6	136	138	14.5	15.0	14.8[b]	0.23	0.23	-	-
After cross-fostering	2819	2755	12.6	12.7	-	0.07	0.05	<0.0001	0.73
Parity 1	700	713	11.8	12.0	11.9[c]	0.09	0.15	-	-
Parity 2	683	644	12.7	12.6	12.7[b]	0.09	0.83	-	-
Parity 3	567	538	13.0	13.1	13.1[a]	0.10	0.31	-	-
Parity 4	432	421	13.0	13.1	13.1[a]	0.12	0.92	-	-
Parity 5	301	301	12.5	12.7	12.6[b]	0.14	0.28	-	-
Parity 6	136	138	12.5	12.9	12.7[ab]	0.21	0.21	-	-
Weaned	2872	2805	10.7	10.7	-	0.08	0.49	<0.0001	0.98
Parity 1	710	717	10.5	10.5	10.5[b]	0.11	0.99	-	-
Parity 2	698	651	11.0	11.0	11.0[a]	0.11	0.99	-	-
Parity 3	566	540	11.1	11.1	11.1[a]	0.12	0.87	-	-
Parity 4	439	429	10.7	10.6	10.7[b]	0.13	0.52	-	-
Parity 5	327	329	10.3	10.3	10.3[b]	0.16	0.78	-	-

Table 14 (cont.). Least-Squares Means for the Effect of Sow Gestation Housing Treatment on Litter Performance.

	Number of Observations		Means				*P*-value		
Item	Individual	Group	Individual	Group	Parity	SEM	Trt	Parity	Trt*Parity
Pre-weaning mortality (%)[2,6]	2737	2661	14.2	15.2	-	-	0.002	-	-
Birth weight (kg)	-	-	-	-	-	-	-	-	-
Average piglet[3]	1518	1458	1.5	1.5	-	0.01	0.58	<0.0001	0.94
Parity 1	397	415	1.5	1.5	1.5^{b}	0.01	0.82	-	-
Parity 2	532	495	1.5	1.5	1.5^{a}	0.01	0.77	-	-
Parity 3	422	391	1.5	1.5	1.5^{b}	0.01	0.69	-	-
Parity 4	167	157	1.4	1.4	1.4^{c}	0.02	0.60	-	-
Parity 5	0	0	-	-	-	-	-	-	-
Parity 6	0	0	-	-	-	-	-	-	-
Total litter[4]	1518	1458	15.8	15.6	-	0.22	0.85	<0.0001	0.77
Parity 1	397	415	18.1	17.6	17.9^{c}	0.20	0.10	-	-
Parity 2	532	495	19.9	19.8	19.8^{b}	0.17	0.73	-	-
Parity 3	422	391	20.8	20.4	20.6^{a}	0.20	0.16	-	-
Parity 4	167	157	20.1	20.1	20.1^{ab}	0.32	0.89	-	-
Parity 5	0	0	-	-	-	-	-	-	-
Parity 6	0	0	-	-	-	-	-	-	-
Weaning weight (kg)	-	-	-	-	-	-	-	-	-
Average piglet	1518	1454	6.5	6.5	-	0.05	0.54	<0.0001	0.07
Parity 1	413	434	6.5	6.3	6.4^{c}	0.06	0.04	-	-
Parity 2	566	525	6.8	6.8	6.8^{a}	0.05	0.37	-	-
Parity 3	403	375	6.6	6.7	6.6^{b}	0.06	0.92	-	-
Parity 4	136	120	6.2	6.4	6.3^{c}	0.11	0.14	-	-
Parity 5	0	0	-	-	-	-	-	-	-
Parity 6	0	0	-	-	-	-	-	-	-
Total litter	1518	1454	73.7	73.0	-	0.67	0.30	<0.0001	0.39
Parity 1	413	434	70.8	69.0	69.9^{b}	0.84	0.09	-	-
Parity 2	566	525	76.1	76.4	76.3^{a}	0.73	0.77	-	-
Parity 3	403	375	77.3	77.7	77.5^{a}	0.89	0.75	-	-
Parity 4	136	120	70.3	68.8	69.5^{b}	1.60	0.41	-	-
Parity 5	0	0	-	-	-	-	-	-	-
Parity 6	0	0	-	-	-	-	-	-	-

[a,b,c]Parity means, within measurement, with different superscripts differ ($P \leq 0.05$).

[1]Total number of piglets born alive, dead, and mummified.

[2]Preweaning mortality calculated as the percentage of piglets per sow after cross-fostering that died before weaning, within

[3]Average weight of piglets born alive and dead, before cross-fostering.

[4]Total weight of piglets born alive and born dead, before cross-fostering.

[5]Data were analyzed using PROC RANK of SAS.

[6]Data were analyzed using PROC FREQ of SAS.

Table 15. Least-Squares Means for the Effect of Gestation Housing Treatment and Parity on Sow Breeding Performance and Removal Rate.

	Number of Observations		Means				*P*-value		
Item	Individual	Group	Individual	Group	Parity	SEM	Trt	Parity	Trt*Parity
Days to breeding[1,8]	2681	2687	8.1	7.8	-	-	0.92	<0.0001	0.46
Parity 2	650	663	11.7	10.5	11.1[a]	-	0.37	-	-
Parity 3	623	613	6.8	6.7	6.8[b]	-	0.73	-	-
Parity 4	541	553	7.0	7.3	7.1[b]	-	0.46	-	-
Parity 5	441	427	7.6	7.1	7.3[bc]	-	0.17	-	-
Parity 6	319	311	6.7	7.1	6.9[b]	-	0.26	-	-
Parity 7	107	120	4.9	4.8	4.9[c]	-	0.82	-	-
Days to rebreeding[1,8]	143	154	51.3	48.3	-	-	0.05	0.22	0.20
Conception rate (%)[2,7]	2681	2687	94.7	94.3	-	-	0.52	-	-
Induced to farrow (%)[3,7]	3136	3129	89.3	88.4	-	-	0.30	-	-
Farrowed rate (%)[4,7]	3127	3088	97.0	96.9	-	-	0.98	-	-
Sows removed from the study (%):[5,7]	412	486	12.1	14.3	-	-	0.02	-	-
Total	72	82	17.5	16.9	-	-	0.84	-	-
Euthanized	81	78	19.7	16.0	-	-	0.24	-	-
Died	41	79	10.0	16.3	-	-	0.02	-	-
Removed from treatment (%)[6]	218	247	52.9	50.8	-	-	0.73	-	-

[a,b,c]Parity means, within measurement, with different superscripts differ ($P \leq 0.05$).

[1]Days from weaning to breeding or rebreeding.

[2]Percentage of total sows allotted to the study that were not removed for 2 negative pregnancy checks, within treatment.

[3]Percentage of sows induced to farrow, within treatment.

[4]Percentage of total sows allotted to the study that farrowed, within treatment.

[5]Percentage of total sows allotted to the study, within treatment.

[6]Percentage of total sows allotted to the study that were removed from the study, within treatment.

[7]Data were analyzed using PROC FREQ procedure of SAS.

[8]Data were analyzed using PROC RANK procedure of SAS.

Table 16. Means for the Effect of Gestation Housing Treatment on the Causes of Piglet Mortality.

	Number of Deaths		% of Total Deaths[1]		*P*-value[2]
Item	Individual	Group	Individual	Group	Treatment
Number of litters	2817	2752	-	-	-
Low Viability	742	742	13.7	12.8	0.20
Laid On	3094	3443	57.1	59.2	0.25
Starvation	167	212	3.1	3.6	0.11
Scours	59	61	1.1	1.0	0.84
Spraddle Leg	16	17	0.3	0.3	0.98
Savaged	16	24	0.3	0.4	0.30
Deformed	26	22	0.5	0.4	0.41
Shaker	29	42	0.5	0.7	0.21
Injury	72	67	1.3	1.2	0.40
Greasy Pig	5	12	0.1	0.2	0.12
Swollen Joints	12	20	0.2	0.3	0.23
Unknown	196	214	3.6	3.7	0.87
Euthanized	901	862	16.6	14.8	0.02
Ruptures- Scrotal	48	28	0.9	0.5	0.01
Ruptures- Other	35	50	0.6	0.9	0.19
Total	5418	5816	100.0	100.0	-

[1] Calculated as a percent of totals within treatment.

[2]Data were analyzed using PROC FREQ procedure of SAS.

Table 17. Means for the Effect of Gestation Housing System on Mortality and Removals.

	Housing treatment		
Item.	Individual	Group	*P*-value[2]
Euthanized	72	82	0.84
Percentage of total	17.5	16.9	-
Body condition score	7	12	-
Enteric Disease	2	0	-
Farrowing difficulty	14	6	-
Feet and legs	27	41	-
Heat Stress	2	1	-
Injury or trauma	2	11	-
Productivity	0	2	-
Prolapse	15	8	-
Ulcer	1	0	-
Unknown	2	1	-
Died	81	78	0.24
Percentage of total	19.7	16.0	-
Body condition score	1	3	-
Enteric Disease	2	0	-
Farrowing difficulty	22	17	-
Feet and legs	5	3	-
Heat Stress	2	4	-
Injury or trauma	5	5	-
Prolapse	4	2	-
Respiratory	5	1	-
Ulcer	3	6	-
Unknown	32	37	-
Removed from treatment[1]	41	79	0.02
Percentage of total	10.0	16.3	-
Abortion	5	0	-
Body condition score	3	27	-
Feet and legs	0	8	-
Found not pregnant	7	9	-
Injury or trauma	0	8	-
Respiratory	0	1	-
No Estrus	21	17	-
Return to Estrus	1	0	-
Unknown	3	9	-
Culled	218	247	0.73
Percentage of total	52.9	50.8	-
Abortion	16	8	-
Body condition score	10	11	-
Farrowing difficulty	0	2	-
Feet and legs	4	6	-
Genetics	21	20	-
Injury or trauma	2	3	-
Milking Ability	2	4	-
No Estrus	86	96	-
Not pregnant	34	45	-
Productivity	11	15	-
Return to Estrus	30	35	-
Unknown	2	2	-
Total	412	486	-

[1]Removed was females that out of assigned treatment location between day 35 and 112 of gestation.
[2]Data were analyzed using PROC FREQ procedure of SAS.

Table 18. Least-Squares Means for the Effect of Farrowing Pen Size and Parity on Litter Performance.

Item	Means			SEM	*P*-value		
	Standard	Increased	Parity		Trt	Parity	Trt*Parity
Number of litters	805	808	-	-	-	-	-
Parity 1	179	176	-	-	-	-	-
Parity 2	248	251	-	-	-	-	-
Parity 3	187	182	-	-	-	-	-
Parity 4	105	113	-	-	-	-	-
Parity 5	26	26	-	-	-	-	-
Parity 6	60	60	-	-	-	-	-
Born alive	13.0	13.3	-	0.15	0.19	<0.0001	0.86
Parity 1	11.5	11.9	11.7[c]	0.17	0.30	-	-
Parity 2	12.8	12.8	12.8[b]	0.15	0.88	-	-
Parity 3	13.8	13.9	13.9[a]	0.17	0.64	-	-
Parity 4	13.9	14.3	14.1[a]	0.22	0.40	-	-
Parity 5	13.2	13.1	13.2[ab]	0.45	0.93	-	-
Parity 6	12.7	13.5	13.1[b]	0.30	0.16	-	-
Born dead[5]	0.7	0.8	-	-	0.78	<0.0001	0.41
Parity 1	0.6	0.8	0.8[d]	-	0.12	-	-
Parity 2	0.5	0.7	0.6[d]	-	0.06	-	-
Parity 3	0.8	0.7	0.7[cd]	-	0.78	-	-
Parity 4	0.8	0.9	0.8[bc]	-	0.66	-	-
Parity 5	1.1	1.4	1.2[ab]	-	0.78	-	-
Parity 6	1.5	1.2	1.4[a]	-	0.34	-	-
Born mummified[5]	0.3	0.3	-	-	0.98	<0.0001	0.12
Parity 1	0.2	0.2	0.2[c]	-	0.96	-	-
Parity 2	0.3	0.2	0.3[c]	-	0.08	-	-
Parity 3	0.3	0.5	0.4[b]	-	0.09	-	-
Parity 4	0.6	0.5	0.6[a]	-	0.32	-	-
Parity 5	0.4	0.5	0.5[ab]	-	0.30	-	-
Parity 6	0.4	0.4	0.4[b]	-	0.28	-	-
Total born[1]	14.1	14.4	-	0.19	0.11	<0.0001	0.59
Parity 1	12.1	12.9	12.5[b]	0.24	0.03	-	-
Parity 2	12.7	12.6	12.7[b]	0.20	0.72	-	-
Parity 3	14.9	15.1	15.0[a]	0.23	0.49	-	-
Parity 4	15.3	15.5	15.4[a]	0.31	0.55	-	-
Parity 5	14.9	15.2	15.0[a]	0.60	0.76	-	-
Parity 6	14.5	15.1	14.8[a]	0.41	0.29	-	-

Table 18 (cont.). Least-Squares Means for the Effect of Farrowing Pen Size and Parity on Litter Performance.

	Means				*P*-value		
Item	Standard	Increased	Parity	SEM	Trt	Parity	Trt*Parity
Number of piglets:	-	-	-	-	-	-	-
After cross-fostering	12.8	13.1	-	0.10	0.09	<0.0001	0.07
Parity 1	12.1	12.3	12.2[d]	0.12	0.29	-	-
Parity 2	12.7	12.9	12.8[c]	0.10	0.27	-	-
Parity 3	13.4	13.2	13.3[b]	0.12	0.20	-	-
Parity 4	13.8	13.5	13.7[a]	0.15	0.24	-	-
Parity 5	12.4	13.3	12.8[bcd]	0.31	0.11	-	-
Parity 6	12.7	13.3	13.0[bc]	0.21	0.09	-	-
Weaned	10.9	11.0	-	0.11	0.23	<0.0001	0.58
Parity 1	10.8	11.0	10.9[c]	0.13	0.39	-	-
Parity 2	11.2	11.5	11.3[a]	0.11	0.08	-	-
Parity 3	11.3	11.3	11.3[ab]	0.13	0.75	-	-
Parity 4	10.5	10.3	10.4[d]	0.17	0.33	-	-
Parity 5	10.7	11.3	11.2[abcd]	0.37	0.37	-	-
Parity 6	10.7	10.9	10.8[bcd]	0.24	0.67	-	-
Pre-weaning mortality (%)[2,6]	15.2	14.6	-	-	0.39	-	-
Parity 1	13.4	14.0	-	-	0.64	-	-
Parity 2	14.2	11.2	-	-	0.01	-	-
Parity 3	13.6	13.8	-	-	0.88	-	-
Parity 4	21.5	23.5	-	-	0.34	-	-
Parity 5	18.6	12.4	-	-	0.10	-	-
Parity 6	15.5	16.5	-	-	0.69	-	-
Birth weight (kg):	-	-	-	-	-	-	-
Average piglet[3]	1.5	1.5	-	0.01	0.58	<0.0001	0.09
Parity 1	1.5	1.4	1.5[b]	0.01	0.06	-	-
Parity 2	1.5	1.5	1.5[a]	0.01	0.19	-	-
Parity 3	1.5	1.5	1.5[b]	0.01	0.45	-	-
Parity 4	1.4	1.4	1.4[c]	0.02	0.37	-	-
Parity 5	-	-	-	-	-	-	-
Parity 6	-	-	-	-	-	-	-
Total litter[4]	19.7	20.2	-	0.18	0.04	<0.0001	0.94
Parity 1	17.6	17.9	17.8[c]	0.23	0.56	-	-
Parity 2	19.9	20.4	20.1[b]	0.20	0.21	-	-
Parity 3	20.5	21.1	20.8[a]	0.24	0.24	-	-
Parity 4	20.6	21.4	21.0[a]	0.34	0.27	-	-
Parity 5	-	-	-	-	-	-	-
Parity 6	-	-	-	-	-	-	-

Table 18 (cont.). Least-Squares Means for the Effect of Farrowing Pen Size and Parity on Litter Performance.

	Means				*P*-value		
Item	Standard	Increased	Parity	SEM	Trt	Parity	Trt*Parity
Weaning weight (kg):	-	-	-	-	-	-	-
Average piglet	6.4	6.5	-	0.05	0.19	<0.0001	0.81
Parity 1	6.4	6.4	6.4[b]	0.06	0.96	-	-
Parity 2	6.6	6.7	6.7[a]	0.05	0.50	-	-
Parity 3	6.5	6.6	6.6[ab]	0.06	0.49	-	-
Parity 4	6.1	6.3	6.2[c]	0.10	0.27	-	-
Parity 5	-	-	-	-	-	-	-
Parity 6	-	-	-	-	-	-	-
Total litter	72.8	74.5	-	0.65	0.03	<0.0001	0.86
Parity 1	70.8	71.7	71.2[b]	0.86	0.48	-	-
Parity 2	75.9	77.8	76.8[a]	0.74	0.10	-	-
Parity 3	75.6	76.7	76.1[a]	0.92	0.44	-	-
Parity 4	69.0	71.8	70.4[b]	1.42	0.19	-	-
Parity 5	-	-	-	-	-	-	-
Parity 6	-	-	-	-	-	-	-
Piglet Age at Weaning	21.3	21.3	-	0.09	0.51	<0.0001	0.40
Parity 1	22.0	22.0	22.0[a]	0.12	0.84	-	-
Parity 2	21.1	21.3	21.2[bc]	0.10	0.09	-	-
Parity 3	21.3	21.5	21.4[b]	0.12	0.23	-	-
Parity 4	21.0	20.9	21.0[c]	0.16	0.63	-	-
Parity 5	20.9	21.3	21.1[bc]	0.31	0.37	-	-
Parity 6	21.2	21.0	21.1[bc]	0.23	0.30	-	-

[a,b,c,d]Parity means, within measurement, with different superscripts differ ($P \leq 0.05$).

[1]Total number of piglets born alive, dead, and mummified.

[2]Preweaning mortality calculated as the percentage of the number of piglets per sow after cross-fostering that died before weaning, within treatment.

[3]Average weight of piglets born alive and dead, before cross-fostering.

[4]Total weight of piglets born alive and born dead, before cross-fostering.

[5]Data were analyzed using PROC RANK of SAS.

[6]Data were analyzed using PROC FREQ of SAS.

Table 19. Means for the Effect of Farrowing Pen Size Treatment on the Causes of Piglet Mortality.

	Number of Deaths		% of Total Deaths[1]		*P*-value[2]
Item	Standard	Increased	Standard	Increased	Trt
Number of litters	805	808	-	-	-
Low Viability	200	202	14.3	14.7	0.82
Laid On	826	792	59.2	57.6	0.66
Starvation	67	62	4.8	4.5	0.73
Scours	13	12	0.9	0.9	0.87
Spraddle Leg	4	6	0.3	0.4	0.51
Savaged	5	7	0.4	0.5	0.55
Deformed	6	4	0.4	0.3	0.54
Shaker	12	15	0.9	1.1	0.54
Injury	22	20	1.6	1.5	0.79
Greasy Pig	1	2	0.1	0.1	0.56
Swollen Joints	9	4	0.6	0.3	0.17
Unknown	72	83	5.2	6.0	0.34
Euthanized	147	144	10.5	10.5	0.96
Ruptures- Scrotal	5	16	0.4	1.2	0.02
Ruptures- Other	7	7	0.5	0.5	0.98
Total	1396	1376	100.0	100.0	-

[1] Calculated as a percent of totals within treatment.

[2]Data were analyzed using PROC FREQ procedure of SAS.