Title: Floor Space Requirements for Grow/Finish Pigs in Large Groups – **NPB #04-086**

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ABSTRACT

The effects of group size and floor space allowance on productivity, health and welfare were tested on 1728 grow-finish pigs (barrows) of PIC genetics. Group sizes were 18 (small) and 108 (large) pigs per pen, and space allowances were 0.52 m^2/pig (crowded) and 0.78 m^2/pig (uncrowded), creating four experimental treatments: small crowded, small uncrowded, large crowded, and large uncrowded.

Overall, average daily gain (ADG) was 1.032 kg/d versus 1.077 kg/d for crowded and uncrowded pigs, respectively, and differences were most evident during the final week of the trial. Final body weights differed by 2.1 % (92.62 and 94.65 kg for crowded and uncrowded, respectively). Overall feed efficiency (FE; gain:feed ratio) was also reduced in the crowded treatment pigs. Pigs in the crowded groups spent less time eating over the eight week trial, but overall feed intake, feeding patterns, postural behavior, carcass measurements, injuries, morbidity and mortality were unaffected by space allowance.

Overall, the ADG of large group pigs was 1.035 kg/d while small group pigs gained 1.073 kg/d. ADG differences were most evident during the first two weeks of the trial. Final body weights differed by 3.0 % (92.20 and 95.08 kg for large and small, respectively). FE over the entire eight-week trial also differed, with large groups being less efficient than small groups. Although large group pigs experienced more lameness and leg sores throughout the eight-week period, the number of animals requiring treatment with antibiotics or requiring removal from the trial did not differ between the group sizes. Minimal changes in postural behavior and feeding patterns were noted in large groups. Stress levels and carcass measurements did not differ.

Although some behavioral variables, such as lying postures, would suggest that pigs in large groups were able to use space more efficiently, overall production performance and health variables would indicate that pigs in large and small groups were similarly affected by the crowding imposed in this study. In fact, the broken line analysis of ADG suggests that large groups were affected by space restriction earlier in the study than were small groups. Little support was found for reducing space allowances for pigs in large groups.

INTRODUCTION

Traditionally pigs have been housed in group sizes of approximately 25 pigs per pen. However, the hog industry is beginning to shift towards housing grow-finish pigs in groups as large as 100 to 1000. Appropriate management practices have yet to be determined for this type of housing. Studies have indicated that ADG is depressed by approximately 2 % for pigs housed in large groups when compared with pigs housed in small groups (Wolter et al., 2001), and this usually only occurs within the first few days or weeks of the trial period (Schmolke, 2002; Samarakone and Gonyou, 2003). It has been suggested that pigs in large groups could perform better than pigs in small groups when space is restricted, as the free space available to pigs in large groups is greater (McGlone and Newby, 1994), but this has not been confirmed in production studies.

Past studies on space allowance have traditionally been empirical in nature, reporting the overall performance of pigs at different space allowances. Those studies often find that crowding does in fact reduce overall productivity, but they fail to determine the precise point at which crowding and growth depression begin (Harper and Kornegay, 1983; Meunier-Salaun et al., 1987; Brumm et al., 2001). An alternative approach, when studying crowding, is to express space allowance based on an allometric equation relating body weight to floor area. The equation used is $k = \text{Area} \div \text{BW}^{0.667}$, where area is in m^2 and body weight (BW) is in kilograms (Petherick and Baxter, 1981). This method allows the use of a broken line analysis to determine the critical point at which crowding begins, and the rate at which performance is depressed as further reductions in space allowance occur. The use of this equation is more effective for expressing pig space needs because it reflects a consistent space requirement that applies to a range of body weights.

According to Gonyou et al. (In Press), the critical value at which space allowance begins to negatively affect production is $k = 0.034$, and growth is depressed by approximately 0.5 % for every 1 % reduction in space beneath that value. So, at $k = 0.034$, pigs weighing 65 kg require 0.55 m^2 whereas pigs weighing 95 kg require 0.71 m^2 of space per pig to achieve maximum performance.

Similar data based on large groups is not yet available. This study was designed to determine the effects of crowding in both large and small groups on productivity, physiology, behavioral time budgets, carcass characteristics, and health of grow-finish pigs. As well, this study will determine the point of crowding at which production begins to decline and the rate of the decline in large and small groups using the allometric approach and the broken line analysis advocated.

OBJECTIVES

1. To determine the critical *k* value at which productivity (ADG) of pigs in large and small groups is affected by crowding.
2. To determine the rate of depression in production as space allowance is restricted below the critical value.
3. To determine similar effects of crowding in large and small groups on feed intake, postural behavior, injuries, and cortisol levels.

MATERIALS & METHODS

Animals and Feeding

One thousand seven hundred and twenty-eight PIC barrows were divided into six blocks consisting of 288 pigs each. The pigs entered the grow-finish area of the barn at approximately 10 to 11 weeks of age. Eight pigs from each treatment were randomly selected and individually identified as focal pigs by use of a colored, numbered ear tag on the day they entered the grow-finish room. They were then allowed a three or four day habituation period prior to the first weigh period. The pigs were put onto test at an average initial body weight of 37.4 kg.

Nutritionally balanced mash diets (three phases) were supplied via an automated feed system, and feed was weighed prior to entry into the feeder by means of calibrated weight-based dump scales (Brehmer Manufacturing, Lyons, NE). Feed and water were supplied ad libitum in two-space wet/dry feeders (Crystal Springs, St. Agathe, MN), which were provided at a rate of one space for every nine pigs. Water was not provided elsewhere. Environmental enrichment in the form of "Bite rite" toys (AM Warkup Ltd., Lisset, UK) was provided at a rate of one toy for every 18 pigs.

Experimental layout

In each block there were four small pens (18 pigs/pen) and two large pens (108 pigs/pen). Two small pens and one large pen in each block were reduced in size by means of a temporary partition to create the crowded treatment. Crowded pigs were provided with 0.52 m^2 of space per pig while uncrowded pigs were provided with 0.78 m^2/pig. Thus, four experimental treatments existed in a 2 x 2 factorial arrangement: small crowded (18 pigs at 0.52 m^2/pig), small uncrowded (18 pigs at 0.78 m^2/pig), large crowded (108 pigs at 0.52 m^2/pig), and large uncrowded (108 pigs at 0.78 m^2/pig). Although the *k* value decreased as the pigs grew, the floor space allowance for the uncrowded treatment remained above the critical value $k = 0.034$ established by Gonyou et al. (In Press) throughout the study. For the crowded treatment pigs the space allowance chosen provided $k = 0.035$ at an average body weight of 55 kg; $k = 0.028$ at a body weight of 75 kg; and $k = 0.025$ at a body weight of 95 kg. Previously established animal care guidelines were set to terminate the crowded treatment when the crowded $k = 0.025$.

Procedures

Pigs were weighed on a weekly basis and feed additions were recorded daily. On a bi-weekly basis and at the same time as weighing, the pigs were assessed for injuries, including tail bites, flank bites, leg lesions, and lameness. Twice daily walk-through health assessments were conducted in order to maintain accurate morbidity and mortality records.

Behavioral observations employed methodology described by Martin and Bateson (1993) and were carried out at bi-weekly intervals. Instantaneous scan sampling of each pen within 20-minute intervals throughout a 24-hour period was performed to determine the number of pigs that were lying laterally (on side), lying ventrally (sternum in contact with floor), sitting (supported by two legs; resting on rear end), standing (supported on four legs but not eating), and eating (head in the feeder). In order to examine the frequency and duration of feeding events, video cameras monitored groups of feeders continuously for a 24-hour period bi-weekly throughout the study. Only data for the focal pigs (eight per experimental treatment) were recorded. A bout criteria interval of six minutes was established to determine the number of meals a pig ate.

Saliva samples were taken from focal pigs at bi-weekly intervals throughout the study. Sampling took place between 1200 and 1400 hours to reduce diurnal variation in cortisol levels. Samples were collected using an absorbent cotton wad held close to the pigs mouth on a stick or manually. Samples from the first sampling period (week) were analyzed individually to determine whether there were differences in salivary cortisol concentrations that had been obtained in less versus more than five minutes of the technician entering the pen. Within the remaining sampling periods (weeks), all samples obtained in less than five minutes from each pen were combined (equal volumes) to obtain a single sample for analysis. Saliva samples were analyzed for salivary cortisol concentrations using the methodology described by Cook et al. (1997).

Adrenal glands were collected at slaughter from two randomly selected focal pigs from each treatment within a block. The glands were individually weighed then preserved in formalin solution. The left adrenal gland from each animal was sent to the Prairie Diagnostics Laboratory at the Western College of Veterinary Medicine where they were cross-sectioned in the mid-section of the gland, stained with a Grimelius stain so the areas of the cortex and medulla, as well as the total gland area, could be measured.

Carcass data were collected from the first half of pigs from each treatment within a block that went to slaughter. The carcass data recorded for data analysis included pig index score, yield class OR (on-rail) %, fat depth, and lean depth. The yield class OR % is calculated from the fat and lean depths while the index score is calculated from the fat depth, lean depth, and yield class OR %. Due to welfare standards set by the Animal Care Committee, crowding partitions were removed from the crowded treatment when $k = 0.025$ was reached. The time period required for the first half of the pigs to reach market weight after the crowding partitions had been removed was up to 41 days. The group size treatments, however, remained intact up until the pigs were marketed.

An experimental paradigm was developed that paired the crowded pens with the uncrowded pens to allow each crowded pen to yield data over a wide range of *k* values. For each observation (week), the ADG for each crowded treatment was expressed as a proportion of that for the corresponding uncrowded treatment (ex. ADG large crowded/ADG large uncrowded). A *k* value based on the final average body weight for each week was calculated for each pen as well. The change in each variable from that of the uncrowded treatment was plotted against the *k* value for that interval and, within pen, analyzed using a broken line procedure to yield the break point and slope of the line below that point.

The SAS statistical software system for Windows (SAS Inst., Inc., Cary, NC) was used for data analysis. Residuals were tested for normality and transformed when necessary. The following statistical model was used for analysis of raw data:

Block	df	5	
Group size	df	1	
Space allowance	df	1	
Space x Group	df	1	
Block (Space x Group)	df	15	(main plot error)
Week (analyzed as a sub-plot)			
Time period (analyzed as a sub-plot)			

RESULTS

Productivity

Overall ADG and FE were affected by space allowance, but ADFI was not. Crowded pigs gained less (1.035 kg/day) than uncrowded pigs (1.077 kg/day, SEM = 0.015, $P = 0.02$), and crowded pigs were less efficient (0.3697) than uncrowded pigs (0.3958, SEM = 0.0055, $P = 0.002$). Final body weights were lower among crowded pigs (92.62 kg) than uncrowded pigs as well (94.65 kg, SEM = 0.41, $P = 0.002$). ADG and FE were most affected by space allowance during the final weeks of the study when the pigs were most crowded.

Overall, pigs in the small group (1.073 kg/day) gained more than those in large groups (1.035 kg/day, SEM = 0.015, $P = 0.04$). Resulting final body weights differed by 3.0 % (95.08 vs. 92.20 kg for small and large group pigs, respectively, SEM = 0.41, $P < 0.0001$). Overall, pigs in small groups also had a higher FE (0.3945) than large group pigs (0.3710, SEM = 0.0055, $P = 0.005$). ADG was most affected by group size early on in the study.

Interactions of group size and space allowance were not evident for performance parameters (ADG, ADFI, FE). The broken line analysis showed that small groups began showing signs of growth depression at $k = 0.035$ (approximately 57 kg BW) and the large group housed pigs were showing signs of growth depression at $k = 0.042$ (approximately 43 kg BW). However, the rate of depression in gain differed for the two group sizes. In the large group, the rate of depression in gain was gradual, declining by 0.2 % for every 1 % reduction in space below the critical value ($k = 0.042$). In the small group, the rate of depression in gain was 0.5 % for every 1 % reduction in space below the critical value ($k = 0.035$). Although the critical values and rates of growth depression in the two group sizes differed, the net effect was such that, at the end of the trial, average daily gain of the crowded large and small group pigs was similar (0.963 vs. 0.962 for large crowded and small crowded groups respectively, SEM = 0.046, $P = 0.13$). The broken line analyses graphs are illustrated in Figure 1.

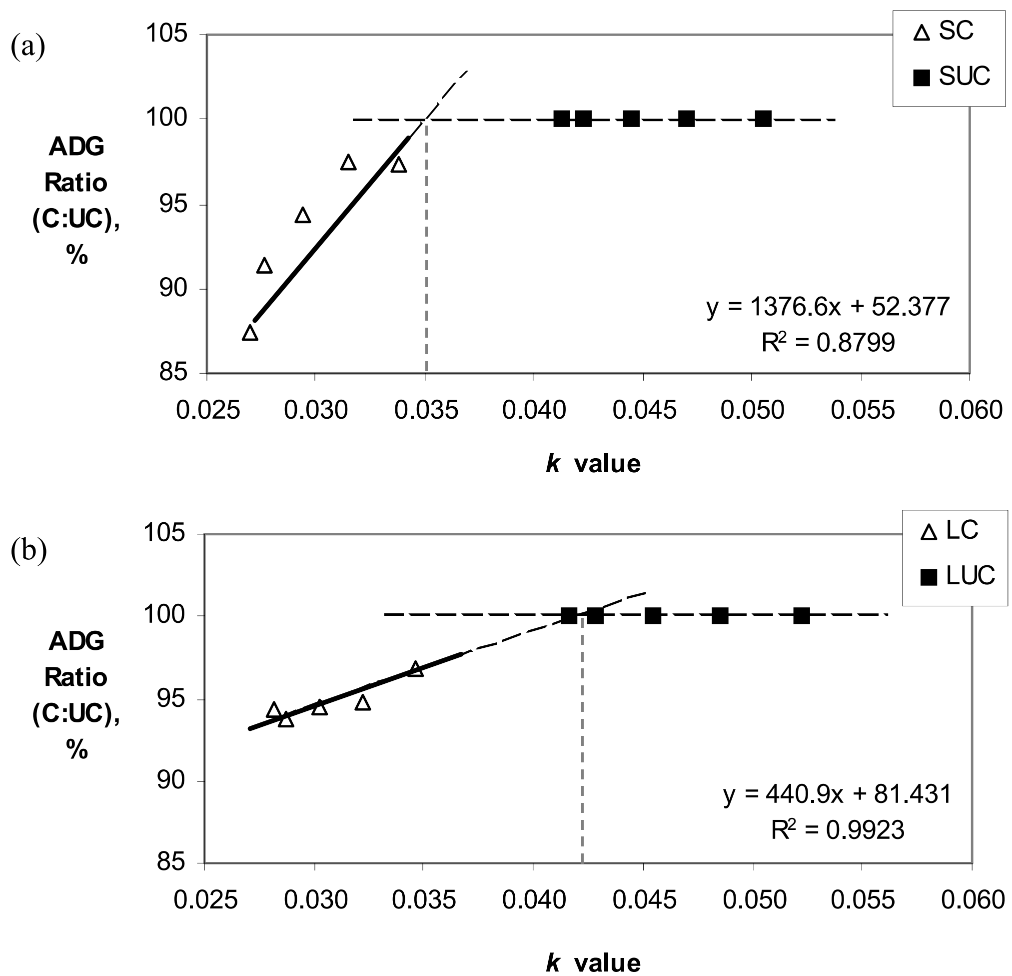

FIGURE 1. The broken line analysis showing the ratio of average daily gain in the crowded treatment to average daily gain in the uncrowded treatment for both (a) small and (b) large groups of grower-finisher pigs over time. The solid line is the trendline to which the crowded treatment R^2 values apply. The dark-colored dashed lines indicate the intersection of the crowded and uncrowded trendlines, and the light-colored dashed line (vertical) indicates the k value at which this intersection occurs ($k = 0.035$ for small groups and $k = 0.042$ for large groups).

Injuries & Health

Overall injury scores were not affected by space allowance, although the occurrence of leg lesions had increased among the crowded group pigs at the final scoring period when the pigs were most crowded. Group size was found to influence overall lameness and leg lesion scores. Pigs housed in large groups experienced more lameness than pigs in small groups (0.019 vs 0.030; SEM = 0.0088, $P = 0.01$), and had a higher overall incidence of leg lesions (0.166 vs 0.128; SEM = 0.056, $P = 0.02$).

No statistically significant effects of space allowance or group size were found on the proportion of animals receiving antibiotic treatment, or the proportion of animals that had to be removed from the trial due to illness or death. The total mortality rate within the study was 0.9 %. Mortality incidences were too low to differentiate between the treatments.

Interactions of group size and space allowance were evident for lameness. Pigs in the large crowded groups had the highest overall lameness scores, followed by pigs in small uncrowded groups, then pigs in large uncrowded groups (SEM = 0.011, $P = 0.04$). Pigs in the large crowded groups had the highest scores at the final scoring period. There were no interaction effects on the proportion of animals receiving antibiotic treatment or the number of animals removed from the trial due to death or illness.

Behavior

Pigs that were crowded spent less time eating (5.38 % of time) than pigs that were not crowded (6.04 %, SEM = 0.23, $P = 0.003$). Space allowance did not affect overall meal patterns. However, during the final weeks of the trial, when the pigs were most crowded ($k = 0.025$), the number of meals and the total meal duration of crowded group pigs decreased, and the latency between meals for crowded pigs increased. Restricting the amount of space provided to the pigs did not affect the proportion of time the pigs spent sitting, standing, lying ventrally or lying laterally.

Group size had many effects on the daily feeding pattern of pigs. The overall number of meals was greater in small groups (11.70) than in large groups (9.15, SEM = 0.71, $P = 0.002$), and the overall mean meal durations were lower among small group pigs (5.26 min) than large group pigs (7.35 min, SEM = 0.54, $P = 0.0003$). Overall mean latencies to the next meal were lower among small group pigs (120.1 min) than large group pigs (159.0 min, SEM = 8.6, $P = 0.001$). Pigs housed in large groups spent less time sitting than pigs in small groups (2.48 % vs 3.27 %, respectively, SEM = 0.16, $P = 0.003$), they spent less time lying ventrally than the pigs housed in small groups (21.06 % vs. 23.52 %, respectively, SEM = 0.75, $P = 0.002$), and they spent more time lying laterally than the pigs housed in small groups (62.4 % vs. 59.9 %, respectively, SEM = 1.3, $P = 0.01$).

Interactions of space allowance and group size were only evident for eating and sitting. The small uncrowded pigs spent more time eating than the small crowded, large crowded, and large uncrowded groups (6.33 %, 5.04 %, 5.71 %, 5.71 %, respectively, SEM = 0.27, $P = 0.005$). Eating behavior did not differ between the two large groups. Overall mean meal durations differed between the treatments and were 8.25, 6.45, 5.71, and 4.81 minutes for large uncrowded, large crowded, small crowded, and small uncrowded treatments, respectively (SEM = 0.66, $P = 0.01$). The small groups did not differ from each other, nor did the crowded treatments. Overall total meal durations also differed and were 67.0, 56.5, 54.8, and 53.9 minutes for large uncrowded, small crowded, small uncrowded, and large crowded treatments, respectively (SEM = 4.2, $P = 0.03$). The large uncrowded group differed significantly from all other treatments, but the other treatments did not differ from each other. Pigs in the small uncrowded group sat more than pigs in either of the large groups. The proportion of time spent sitting by small crowded pigs exceeded that of large uncrowded pigs only. There were no differences in sitting behavior between either small group or between either large group. Overall proportion of time spent sitting for small uncrowded, small crowded, large crowded, and large uncrowded were 3.54 %, 3.00 %, 2.71 %, and 2.25 %, respectively (SEM = 0.23, $P = 0.04$).

Physiology

Overall, there were no differences in salivary cortisol concentrations. Space allowance did not affect any of the measurements taken from the adrenal glands analyzed. Group size only affected the gland weight:100 kg body weight ratio. Pigs housed in small groups had a smaller ratio than pigs housed in large groups (2.358 vs. 2.578 g/100 kg BW, respectively, SEM = 0.064, $P = 0.03$). There were no interactions of group size and space allowance for the physiological parameters assessed.

Carcass measurements

Overall, neither space allowance nor group size had any effects on carcass measurements. However, there were interactions of space allowance and group size for some of the carcass measurements, namely index score, yield class on-rail (OR) percentage, and fat depth. The small uncrowded and large crowded groups had the highest index score, and they did not differ from each other, while the small crowded and large uncrowded groups had the lowest score, also not differing from each other. Index scores were 113.01, 112.95, 112.37, and 112.19 for the small uncrowded, large crowded, small crowded, and large uncrowded groups, respectively (SEM = 0.22, $P = 0.01$). Yield class OR % was the highest in the small uncrowded pigs (SEM = 0.12, $P = 0.02$) while fat depth was highest among the large uncrowded pigs (SEM = 0.25, $P = 0.03$).

DISCUSSION

Productivity

Crowding pigs results in reduced productivity. The pigs do not gain as well and become less efficient at achieving high gains from the feed they eat. In the current study, overall ADG of crowded pigs was 4.2 % less than that of uncrowded pigs, and FE was 7.5 % poorer. During the final week when the pigs were severely restricted (95 kg BW, 0.52 m^2/pig, $k = 0.025$), gains among crowded pigs were 9.8 % less than that of uncrowded pigs ($k = 0.037$), and FE was 11 % poorer. These findings were not unexpected. Space restriction ($k < 0.034$) has been proven to cause reduced gains (Brumm and NCR-89 Committee on Swine Management, 1996; Brumm and Miller, 1996; Eisemann and Argenzio, 1999), reduced feed intake (Hanrahan, 1981), and reduced feed efficiency in the past (Brumm and NCR-89 Committee on Swine Management, 1996; Brumm and Miller, 1996; Goihl, 1996).

Samarakone and Gonyou (2003) found that ADG was reduced among pigs housed in large groups (108 pigs) by 2 % when compared with pigs in small groups (18 pigs). The current study indicated the same effects, with the difference being 3.5 % overall. The 3.3 % difference in initial body weights indicates that set backs may have occurred as soon as the large groups were formed. Examination of ADG in the first week provided further evidence that this theory was true. Pigs housed in small groups were outperforming their large group housed counterparts by 5.4 % during the first week of the test period, but performance was similar thereafter.

The broken line analyses suggested differences in the responses of large and small group pigs to crowding. Small groups experienced reduced gains at $k = 0.035$, which is near the critical value pinpointed by Gonyou et al. (In Press). The break point for large group pigs was at $k = 0.042$. Therefore, it may suffice to say that large group pigs were not able to maintain maximum growth rates under crowded conditions any better than pigs in small groups. However, the rate of depression in gain in the large crowded group was more gradual than in the small crowded group. Thus, the net effect was such that, at the end of the trial, average daily gain of the crowded large and small group pigs was similar.

Injuries & Health

Crowded pigs have restricted mobility, so one would assume that this would cause a whole host of problems. Reduced mobility may cause limb stiffness leading to lameness. Lengthened contact with concrete flooring would presumably cause chaffing, resulting in a greater severity of leg lesions. However, minimal differences were found until the final scoring period, at which time the pigs were most crowded. Then, only the leg lesion scores of crowded pigs were higher than that of uncrowded pigs. These results were likely an artefact of increased lateral lying behavior over time and a reduction of other postures, such a ventral lying, which would be more likely than lateral lying to cause limb stiffness if assumed frequently. Overall, space allowance did not affect the severity of any injury assessed, suggesting that the degree of restriction in the current study may not have been sufficient to cause increased injury levels.

It was also presumed that tail biting would occur more frequently in crowded groups since crowded pigs are often more stressed than uncrowded pigs (Meunier-Salaun et al., 1987; Pearce and Paterson, 1993), and intolerable stress levels have been shown to influence the prevalence of tail biting (Schroder-Petersen et al., 2004). However, this was not the case. Tail biting scores were not affected by space restriction. Perhaps this is because the pigs in this study were not stressed. Another possibility is that the provision of environmental enrichment devices in the current study was able to reduce the prevalence of tail biting, as it has been shown to reduce harmful social behavior in past research (Beattie et al., 1996). Since the causes of tail biting are still relatively obscure, one can say that perhaps space restriction does not actually influence the behavior.

The occurrence of non-aggression related injuries has not been well documented in large groups of pigs. In the current study, higher leg lesion scores were recorded among large group housed pigs. Pigs in large groups may have experienced a higher score for these injuries because they spent more time lying laterally than pigs in small groups, which would have allowed their legs to rub on the concrete more frequently. Pigs in large groups also had higher lameness scores. An explanation may be that pigs in the large groups spent more time sitting, lying ventrally, and lying laterally than small group pigs. This may have increased the occurrence of lameness. Another possibility lies in the fact that large group housing allows more space for running. If the pigs' feet were to get caught in the slats while running, injury to the limb would be more likely. Casual observations of pigs running through a large group indicate that they run into walls and other pigs often, likely because they are traveling too fast to stop in time. This may also contribute to the higher incidence of lameness in such groups. Leg injuries to 'non-runners' may be a result of being stepped on or tripped over by 'runners'. The literature provided no possible explanation or previous findings on lameness within large groups of pigs.

The prevalence of tail biting within large groups has been more frequently documented. Studies comparing groups of 40 or more pigs found no differences in the prevalence of tail biting (Spoolder et al., 1999; Wolter et al., 2000b; Schmolke, 2002). The current study agrees with the findings of the other large group studies. Tail biting scores did not differ among the group sizes.

Pigs in the large crowded groups had the highest overall lameness scores of all four treatment groups. A compounding effect of increased lying behavior preferred by pigs in large groups and forced immobility imposed on pigs in a restricted space environment may be to blame.

Although there were significant differences in leg lesion and lameness injury scores, the severity of the injuries did not justify antibiotic treatment or an animal's removal from the trial. It is possible that the higher overall injury scores were due to a large number of non-severe lesions or lameness incidences that would not justify treatment or removal from the trial, rather than a minimal number of severe injuries that would justify treatment or removal. These findings agree with reviewed literature (Wolter and Ellis, 2002; Samarakone and Gonyou, 2003; Schmolke et al., 2003).

Behavior

Literature has indicated that pigs spend more time eating when housed under restricted space allowances (Bryant and Ewbank, 1974). However, the results of the current study disagreed with that found in the literature. The overall time spent eating was less for crowded pigs than it was for uncrowded pigs, although the proportion of time spent eating did not differ during any particular observation period. The degree of physical restriction imposed upon the pigs near the end of the trial may have been responsible for these results. This hypothesis is supported by videotape data, which showed that crowded pigs ate fewer meals and had a significantly higher latency to their next meal than uncrowded pigs when they were the most crowded (k = 0.025). The increased total meal duration seen during that time period was not sufficient to make up for the reduced number of meals and increased latency times.

Literature has indicated that pigs are observed sitting or standing motionless more often when housed under restricted space allowances; behaviors thought to be a strategy for coping with the stress of crowding (Pearce and Paterson, 1993). The behavior of the crowded pigs in the current study did not indicate they were experiencing a higher level of stress than uncrowded pigs, as overall sitting and standing behaviors were unaffected by the space allowance provided.

Using equations based on pig body dimensions of height, breadth, and length, the space occupied by a pig resting on its sternum (ventrally) and resting fully recumbent (laterally) can be estimated (Petherick, 1983). For a pig weighing 40 kg, 0.22 m^2 of space is needed to lie ventrally, while 0.54 m^2 of space is needed to lie laterally. To compare, a 95 kg pig would require 0.38 m^2 of space to lie ventrally and 0.95 m^2 of space to lie laterally. Although it should be noted that the value for lateral lying is likely high as it assumes no sharing of the space between a pig's front and back legs.

In a crowded environment, it is likely that one would see a shift from the preferred lateral lying posture to ventral lying or another posture simply because space restriction would allow for fewer pigs to lie fully recumbent at once, and pigs over 50 kg BW will not tolerate overlying (Pearce and Paterson, 1993). However, the proportion of time spent lying laterally did not differ among the space treatments. Therefore, either there was some space sharing occurring (i.e. the space between the front and back legs), or there was some degree of overlying tolerated in order to compensate for the reduction in space.

The hypothesis that increasing group size encourages feeding behavior (Spoolder et al., 1999) was not proven in the current study. Pigs in large groups actually ate 22 % fewer meals overall than small group housed pigs, and overall latency to the next meal was longer for large group pigs by 25 %. A hypothesis put forward by Wolter and Ellis (2002) suggested that placing the feeders in a single central location, as was done in the large groups in the current study, would increase competition for access to the feeder. Competition at the feeder was not assessed in the present study, but the differences in feeding patterns seen could be attributed to increased competition at the feeder. Large group pigs ate fewer meals, took longer to eat a meal, and had increased latencies between their meals compared with small group pigs. The fact that the overall proportion of time spent eating did not change further indicated that there may have been increased competition at the feeder in large groups because the pigs were ingesting similar amounts of feed as pigs in small groups, but in fewer meals. Perhaps if the feeders had been spread out in the large pens, group size differences in feeding patterns would have been non-existent. Another possibility is that we would have seen increased feeding behavior in the large group, as was predicted by Spoolder et al. (1999).

McGlone and Newby (1994) proposed that a direct relationship existed between group size and the amount of free space available in a pen. Pigs in larger groups might have access to more free or unused space suggesting that, if group size is increased, total space allowance could be reduced without changing the free space available. In other words, provided similar space allowances, pigs in large groups would be able to make a more efficient use of space than pigs in small groups. The fact that large group housed pigs in the present study dedicated more time to lying in a fully recumbent, more space consuming posture than small group housed pigs provides support for this hypothesis. Since other research did not find differences in the resting behavior of pigs in large and small groups (Spoolder et al., 1999; Schmolke et al., 2004), perhaps this suggests that pigs housed in large groups were able to use space more efficiently than pigs housed in small groups.

Examination of group size x space allowance interactions for eating behavior also provided useful insight into space use of large and small groups. Eating behavior occurred more frequently in the large crowded groups than in the small crowded groups. These findings imply that large group pigs may have been able to maneuver around a space-restricted environment more easily than small group pigs. Furthermore, the proportion of time spent eating did not differ between the two large group treatments. Perhaps this means that space restriction imposed on a large group would have to be more intense than restriction imposed on a small group in order to alter behavior. However, productivity was equally depressed by crowding in both large and small groups.

Physiology

When an animal is stressed it more actively secretes cortisol from the cortex of the adrenal gland (Freedman, 1975). Salivary cortisol reflects circulating levels of free cortisol in the body, and is indicative of the level of acute stress the animal is experiencing. A stressed animal more actively secretes cortisol from the adrenal gland, and levels of the hormone become apparent in the blood, urine and saliva of that animal. Under prolonged periods of stress, the adrenal cortex would increase in size in attempt to keep up with the body's requirement for cortisol. Increased cortisol levels would be apparent in the blood and saliva until the animal was stressed to the point that its glands could not keep up with the cortisol requirement of the body. At that point, the glands would become fatigued and blood and salivary cortisol levels would decrease. Therefore, animals experiencing prolonged (chronic) stress may not necessarily have high levels of cortisol present in their saliva, but would still have larger and heavier adrenal glands (Freedman, 1975).

According to results obtained from the salivary cortisol concentration analysis in the current study, neither space allowance nor group size affected the level of stress the animal experienced. Past studies examining the effects of space allowance (Pearce and Paterson, 1993) and group size (Samarakone, Unpublished) on cortisol concentrations agree with these findings. Furthermore, analysis on individual samples within the first sampling week did not indicate differences between the stress levels of pigs sampled in more versus less than five minutes of the technician entering the pen.

In the current study, space allowance did not affect any of the measurements taken from the adrenal glands. This suggests that crowded pigs were not chronically stressed. The effects of group size were limited to the gland weight:100 kg BW ratio, with the large group pigs having the higher ratio. These findings disagreed with that of Samarakone (Unpublished data) who found no difference in the gland weight:100 kg BW ratio of pigs in large and small groups. In our study, the tendency ($p < 0.10$) of pigs in the large groups to have and heavier gland weights than small group pigs (likely due to greater cortex area and larger total gland area; $P < 0.10$), in conjunction with the insignificant differences in live off-test body weights in the two groups may have been sufficient to cause the large group pigs to have a greater gland weight:100 kg BW ratio. However, these findings are not sufficient to conclude that pigs in large groups were chronically stressed.

Carcass measurements

Since ADG and FE were affected by both space allowance and group size, one would expect that fat and lean depth would also be affected. However, this was not the case. Past studies have found that crowded pigs ($k = 0.030$) achieved only 70 % of the fat and lean gain that uncrowded pigs achieved (Holck et al., 1998). Crowded pigs also had lower back fat levels in studies carried out by Burnham et al. (1995) and Brumm and NCR-89 Committee on Management of Swine (1996). Back fat differences among large and small group sizes were nonexistent (Wolter et al., 2001; Samarakone, Unpublished data), as were differences in lean depth (Samarakone, Unpublished data). Since the crowding partitions had been removed for up to 41 days before the pigs went to slaughter, results may differ from that of pigs that were crowded right up until slaughter. Since the group sizes did remain intact until the pigs went to slaughter, the adequacy of those results has not been questioned.

Implications

The biggest concern raised in this study was the use of space in large groups, and whether it differed from that of small groups. It was hypothesized that the performance of small groups would be more affected by space restriction than large groups, and that large groups would be able to more efficiently use the space provided to them. Behavior adaptations of pigs in large groups would support this hypothesis, yet resulting performance would not. Pigs in large crowded groups exhibited depressed gains much earlier on than pigs in small groups. However, the effect of space restriction on pigs in large crowded groups was more gradual over time, and the net effect of crowding on gains at the end of the trial was similar among pigs in large and small crowded groups.

Welfare concerns for pigs housed in large groups are not warranted. Although gains of pigs in large groups were somewhat depressed compared with pigs in small groups, morbidity levels remained unaffected. Furthermore, effects of large group housing on stress levels were non-existent, as evidenced by salivary cortisol, adrenal gland, behavior (sitting), and injury score (tail bites) analyses.

Further studies should increase focus on the prevalence of lameness in large groups of pigs, especially when space allowance is restricted. Perhaps probing into the importance of environmental enrichment in such housing, and into the effects of such housing on levels of aggression, would be useful. The swine industry is encouraged to adopt the k value system for space provision since it reflects consistent space requirements applying to pigs over a range of body weights.

LAY INTERPRETATION

The effects of group size and floor space allowance on productivity, health and welfare were tested on 1728 grow-finish pigs (barrows) of PIC genetics. Group sizes were 18 (small) and 108 (large) pigs per pen, and space allowances were 0.52 m^2/pig (crowded) and 0.78 m^2/pig (uncrowded), creating four experimental treatments: small crowded, small uncrowded, large crowded, and large uncrowded.

Pigs housed in crowded groups had poorer performance than uncrowded pigs. Overall, average daily gain (ADG) was 4.2 % lower for crowded pigs than uncrowded pigs. During the final week of the trial, when the pigs were most crowded, the difference was 9.8 %. Final body weights differed by 2.1 %. Although crowded pigs spent less time at the feeder, had fewer meals, and had longer latencies between their meals than uncrowded pigs, average daily feed intake (ADFI) values did not differ. Overall feed efficiency was reduced by 6.6 % in the crowded treatment pigs.

Measurement of cortisol concentrations in the saliva, which are indicative of the level of stress a pig is experiencing, indicated that neither the group sizes nor space allowances used in the current study affected the stress level of the pigs. Postural behavior, carcass measurements, injuries, morbidity and mortality were unaffected by space allowance as well.

Pigs housed in large groups had poorer performance than pigs housed in small groups. Overall, the ADG of large group pigs was 3.5 % less than that of small group pigs and final body weights differed by 3.0 %. ADG differences were most evident during the first two weeks of the trial, at which time the difference was 5.4 %. The 3.3 % difference in initial body weights indicated that setbacks may have been occurring at group formation. FE also differed, with pigs in large groups being 6.0 % less efficient than pigs in small groups.

Although large group pigs experienced more lameness and leg sores throughout the trial, the number of animals requiring treatment with antibiotics or requiring removal from the trial did not differ between the group sizes. Stress levels and carcass measurements did not differ.

Large group housing for grow-finish pigs is not as detrimental to pig performance and vitality as once presumed. Pigs in large groups do not seem to suffer reduced welfare as long as regular and thorough health checks are performed. Deleterious effects of large groups were generally confined to the initial adaptation period. Marginal losses occurring at that time are most likely to be recovered through reduced input and labor costs associated with large group housing.

Under restricted space allowances, the gains of pigs in large groups were negatively affected much earlier on than for pigs in small groups. However, the effect of space restriction on gains of pigs in large groups is much more gradual over time, and the net effect of crowding at the end of the trial was similar among pigs in large and small groups. There was limited evidence, and none related to productivity, that pigs in large groups were able to use space more efficiently under crowded conditions than were pigs in small groups.

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