EFFECT OF FLOOR SPACE IN THE NURSERY AND GROW-FINISH PERIODS ON THE GROWTH PERFORMANCE OF PIGS

BY

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THESIS

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ABSTRACT

Two studies were carried out over two 4-week periods (week 6 to 10 post-weaning in Study 1 and week 12 to 16 post-weaning in Study 2) to determine the effects of floor space in the nursery and grow-finish periods on the growth performance of pigs. In both studies, subsequent growth performance at an equal floor space across treatment levels was also evaluated over a 2-week period immediately following the floor space evaluation period. Both studies were conducted as randomized complete block designs (blocking factor = day of start of test) with 5 floor space treatment levels (0.21, 0.27, 0.33, 0.39, and 0.44 m^2/pig in Study 1; 0.35, 0.45, 0.54, 0.64, and 0.73 m^2/pig in Study 2). Treatment levels were selected to cover the range likely to be used under commercial conditions and were calculated to provide the same *k* values in both studies (i.e., 0.019, 0.025, 0.030, 0.035, and 0.041 $m^2/BW^{0.67}$). The estimated weight at the midpoint of the floor space evaluation period (end of week 8 in Study 1 and week 14 in Study 2) was used to calculate the respective *k* values. All adjustment gates were moved to the back of the pens during the subsequent period, resulting in floor spaces of 0.53 and 0.73 m^2/pig in Study 1 and 2, respectively. Study 1 consisted of 15 replicates with 40 pigs per pen for a total of 3,000 pigs. Pens of pigs in Study 1 were reduced to groups of 29 pigs and re-allotted to Study 2 for a total of 2,175 pigs in 15 replicates. During the floor space evaluation periods in Study 1 and 2, ADG was decreased ($P < 0.001$) by 17.9 and 42.1% and ADFI was decreased ($P < 0.001$) by 14.4 and 28.6%, respectively, from the highest to lowest floor space treatment levels. Feed efficiency was lower ($P < 0.001$) for the two lowest floor space treatment levels than the other three treatment levels in both studies. However, potential differences in environmental temperature between floor space treatment levels due to limited access to water misters and reduced air movement could have influenced the results. During the subsequent periods, feed

efficiency generally increased ($P < 0.001$) as previous floor space decreased in both studies. Morbidity and mortality levels differed ($P < 0.01$) between treatment levels during the floor space evaluation period in Study 1, but there was no clear pattern in the treatment means. There were no differences ($P > 0.05$) in morbidity and mortality levels in the subsequent period of Study 2 or either period in Study 1. The results of these studies suggest that decreasing floor space can cause significant reductions in ADG, ADFI, and feed efficiency; however, feed efficiency can be improved by providing increased floor space subsequent to a floor space restriction.

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CHAPTER 1: LITERATURE REVIEW.

Sustained profitability in a competitive swine industry can only be achieved if costs are minimized over time. A large portion of the costs incurred in swine production are fixed costs associated with necessary facilities and equipment. One method of reducing the fixed cost per pig produced is to improve the utilization of these assets by reducing the amount of floor space given to each pig. It has been reported that the growth rate of pigs declines as floor space per pig decreases below a certain level (Kornegay and Notter, 1984; Gonyou et al., 2006), however, the cost of a reduction in growth may be overcome by the economic advantage of increasing the production per unit area of building (Powell et al., 1993). The impact of floor space on feed efficiency and morbidity and mortality levels is typically more important than the effect on growth rate in determining the most economical floor space and, therefore, is critical to understand. Unfortunately, research studies have shown mixed results for the effects of floor space on both feed efficiency and morbidity and mortality. Some studies have reported a decrease in feed efficiency (NCR-89, 1993; Hyun et al., 1998a) and an increase in morbidity and mortality (Wolter et al., 2003b; Peterson, 2004) with decreasing floor space. In contrast, others have reported no change or a slight improvement in feed efficiency (Harper and Kornegay, 1983; Peterson, 2004) and morbidity and mortality levels (NCR-89, 1984; Street and Gonyou, 2008) as floor space decreased.

Housing pigs in a single facility from weaning to market has become common practice in the US swine industry. In such situations, pigs are typically stocked at a floor space which is large enough to accommodate market weight pigs. It is common knowledge that the floor space required for maximum growth performance changes as the pig increases in size. As a result, the space within a wean-to-finish facility is not fully utilized for a large portion of the growing period. Housing pigs at different floor spaces at different stages of the growth period is a possible strategy to increase the production per unit area of building and reduce the facility and equipment cost per pig. Furthermore, it has been reported that pigs will undergo growth compensation following a period of floor space restriction (Wolter et al., 2003b). Housing pigs at floor spaces that maximize profitability from weaning to market requires a thorough understanding of, firstly, the relationship between floor space and growth performance at all stages of growth and, secondly, the subsequent effects on growth performance after a floor space restriction has been removed.

Definition of Terms

Floor space: The amount of floor area provided to pigs, measured in m^2 per pig.

Body space: The amount of floor area occupied by the bodies of pigs within a pen, which varies with the posture of pigs and the amount of floor area occupied by more than one pig.

Dynamic space: The amount of floor area required by pigs to change posture, orientation, and position within a pen.

Social space: The amount of floor area within a pen of pigs required for social interactions.

Residual space: The amount of floor area within a pen of pigs that can never be used by pigs.

Activity space: The amount of floor area required for eating, drinking, defecating, urinating, and socializing activities.

Shared space: The amount of floor area occupied by more than one pig.

Unoccupied or "free" space: The amount of floor area within a pen not occupied by pigs, which can be calculated by subtracting the body space within a pen of pigs from the total available floor area.

k: The constant in the equation proposed by Petherick and Baxter (1981), which is equal to the floor area occupied by a pig divided by $BW^{0.67}$.

Floor space requirement: The minimum amount of floor area required for the maximization of production and efficiency of individual pigs or groups of pigs.

Floor space restriction: A condition created by housing pigs below the floor space requirement that results in a reduction in production or efficiency.

<u>*Floor Space Concepts*</u>

Pigs require floor space for resting and for activities such as eating, drinking, excreting, and socializing. Baxter (1985) suggested the total floor area required by a pig is the summation of body space, dynamic space, and social space, plus any residual space. The starting point for estimating the total floor space required by a pig, and the easiest to quantify, is body space. The first step to quantifying body space is to estimate the area of the pigs as they increase in size. To simplify this process, pigs can be considered to be a fixed physical object, normally a cube or, in some situations, a cylinder, which has fixed physical relationships between linear dimensions and the area and/or volume of the object. For example, the surface area of a cube increases in proportion to the square of its linear dimensions and, consequently, surface area increases in proportion to $volume^{0.67}$. If the density of the cube remains constant as it increases in size, the relationship between the weight and surface area of the cube would be equivalent to the relationship between the volume and surface area of the cube (i.e., $weight^{0.67}$). Similarly, it can be shown that the area of one side of a cube (which can be considered equivalent the area of the side of the pig) also increases in proportion to $weight^{0.67}$. Meeh (1879) was the first to suggest that this concept could be extended to animals when he proposed that the surface area of animals was equal to $BW^{0.67}$ multiplied by a constant of proportionality that varied between species.

Petherick and Baxter (1981) applied this concept to pigs and found that as the body weight of Large White x Landrace pigs increased, body length, width, and height each generally increased in proportion to $BW^{0.33}$ and the body area (i.e., surface area of the side of the pig) of a pig (l x w or l x h, depending on its posture) increased in proportion to the square of $BW^{0.33}$, which equals $BW^{0.67}$. Based on this relationship, they proposed the following equation: $A=k*BW^{0.67}$, where A is the floor area (m^2) occupied by a pig, which is equivalent to body area, BW is the body weight in kg, and *k* is a constant which depends on the posture of the pig.

Pastorelli et al. (2006) calculated the body area of a pig lying on its side for animals of live weights between 47 and 198 kg by multiplying linear measurements of body height and length and reported that the equation $A=0.041*BW^{0.67}$ explained 99.7% of the variation in the body area of a pig as it increased in size. However, this equation was based on much greater weights than used in most situations and there is a need to develop and validate equations to predict body area at lower, more conventional weights for modern genotypes of pigs. However, this area of research is outside of the scope of this thesis. Therefore, the equation proposed by Petherick and Baxter (1981) (i.e., $A = k*BW^{0.67}$) will be used throughout this thesis for estimating the body area of a pig.

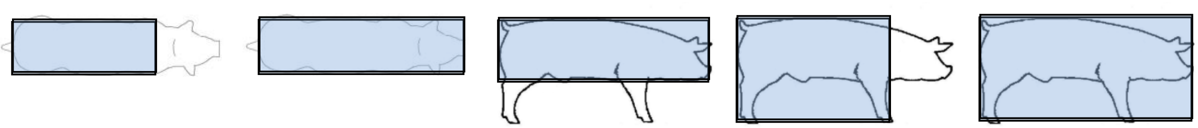
The use of equations to predict the body area of pigs of different weight is further complicated when they are used to predict the body space of a group of pigs because a number of other factors, such as the postures of pigs and the amount of floor area shared by pigs, become important for this estimation. Baxter (1985) suggests that the body space within a pen of pigs could be calculated by using the following equation: $S = N \sum k_i B_i$, where S is the total floor area required for body space, N is the number of pigs in the group, k_i is the proportion of pigs performing the i^{th} behavior, and B_i is the floor area required for the i^{th} behavior. However, it is likely that the body space of a group of pigs will range between a minimum floor area in which all pigs are lying on their sternum (which is equivalent to a standing pig), and a maximum floor area in which all pigs are lying on their side. Baxter (1985) provided estimations of the body area of a pig lying on its sternum and on its side using different measures and these are illustrated in Figure 1. He concluded that a rectangle drawn to fully encompass pigs lying on their sternum and side would occupy a floor area of 0.019 and 0.047 $m^2/BW^{0.67}$, respectively (pictures B and E in Figure 1, respectively). A rectangle drawn around a pig lying in the sternal position (picture B) would have little available space that could be shared by other pigs, outside of a pig resting its head on another pig and, therefore, would be a realistic estimate of the minimum body space requirement. However, a rectangle drawn around a pig lying on its side (picture E) may not be a realistic estimate of the maximum body space requirement. Ekkel et al. (2003) suggested that a portion of the area of the rectangle drawn to encompass a pig in this position was not physically occupied by the pig and was occupied by other pigs, which suggests that the body area of a pig lying on its side is less than 0.047 $m^2/BW^{0.67}$. Pastorelli et al. (2006) used digital image analysis to measure the actual body area of a pig lying on its side and found it to be equivalent to 0.028 $m^2/BW^{0.67}$. Furthermore, it has been suggested that pigs may lie in different postures (which would change body space) as they increase in size and as floor space is decreased (Ekkel et al., 2003; Averos et al., 2010). Unfortunately, there are no studies that have attempted to measure the relationship between body space and floor space within a group of pigs with increasing pig size and future research should focus on this area.

Several researchers have suggested that the equation proposed by Petherick and Baxter (1981) (i.e., $A=k*BW^{0.67}$) can be used across a range of body weights to determine the floor space required for maximum growth rate (Edmonds et al., 1988; Gonyou and Stricklin, 1998;

Gonyou et al., 2006). However, there has been no research carried out to validate that the floor space required for maximum growth rate increases proportionately with $BW^{0.67}$. Nevertheless, the proposed equation may be the best available equation for expressing the degree of floor space restrictions. Therefore, the floor space treatment levels (A) and the overall average end of study live weight (BW) will be used to calculate *k* values for each floor space treatment level in the historical floor space studies discussed in this thesis.

Figure 1. Estimated floor area occupied by Large White x Landrace pigs (Baxter, 1985).

Standing or Lying on Sternum		Lying on Side		
A.	B.	C.	D.	E.



$A = 0.012*BW^{0.67}$	$A = 0.019*BW^{0.67}$	$A = 0.024*BW^{0.67}$	$A = 0.029*BW^{0.67}$	$A = 0.047*BW^{0.67}$

Complexity of Floor Space Studies

The first layer of complexity with floor space research is that the body space increases and conversely the unoccupied space within the pen decreases as pigs increase in size. For this reason, it is difficult to compare floor space studies unless they evaluated similar floor spaces over the same range of body weight. Further complicating the matter is that procedures and conditions in many of the studies were different. For example, some studies have created different floor spaces by adjusting the pen dimensions and others have maintained a constant pen dimension and adjusted group size to form the different floor spaces. Increasing group size to create the reduced floor spaces confounds the effects of floor space with those of group size and, also, in many studies, with feeder space and the number of pigs per water point, unless these were adjusted in line with changes in floor space. Confounding the effects of floor space with any of these factors makes it impossible to determine the impact that floor space alone had on the study results. Furthermore, it is possible that interactions may exist between floor space and factors such as group size, temperature and humidity, genotype, and gender for growth performance, which would make it even more difficult to compare the results of historical floor space studies.

In terms of group size, most historical studies were conducted with less than 20 pigs per pen and many used less than 10 pigs per pen, whereas more recent floor space research has been conducted with much larger group sizes (25 to 200 pigs per pen). McGlone and Newby (1994) monitored the number of pigs standing or lying on their side and sternum and suggested that pigs adopted postures that occupied less space as group size increased from 10 to 40 pigs, resulting in more unoccupied or “free space” with increasing group size. Street and Gonyou (2008) evaluated two group sizes (18 and 108 pigs) and two floor spaces (0.52 and 0.78 m^2/pig) over a 12-week period with an initial weight of 34.7 kg and found no significant group size × floor space interactions for any growth performance measure. Gonyou and Stricklin (1998) reported significant floor space × group size interactions for ADG and ADFI using much smaller group sizes (ranging from 3 to 15 pigs) and three different floor space treatments (floor space was adjusted at 2-week intervals to provide floor spaces with calculated *k* values equal to 0.030, 0.039, and 0.048), but there were no clear patterns in the interaction means. Therefore, the possibility of an interaction between floor space and group size for growth performance does exist when small (<15 pigs) and large group sizes are compared, but this has not been evaluated.

The existence of a temperature and humidity × floor space interaction for growth performance has also been hypothesized (Gehlbach et al., 1966). Hyun et al. (1998b) conducted a factorial study evaluating the effects of two floor spaces (0.25 or 0.56 m^2/pig; 8 pigs/pen), two temperature regimes (constant 24 °C or cycling between 28 and 34 °C; relative humidity was the same for all treatments), and two regrouping approaches (static group or mixed at the start of week 1 and 3) over a 4-week study period from an initial live weight of ~35 kg and found no significant floor space × temperature regime interactions for growth performance. However, for pigs that remained in a static group, which would be typical of commercial production, the numerical differences in ADG and G:F between the floor space and temperature treatment combinations suggest a possible interaction between floor space and temperature (23.2 and 16.2% reductions in ADG at the lower floor space for the high and thermal neutral temperatures, respectively; 15.0 and 7.5% reductions in G:F at the lower floor space for the high and thermal neutral temperatures, respectively; Table 1). These results need to be viewed with caution, however, because there were only 4 replicates of pigs housed in a static group. Therefore, further research including larger numbers of pigs and a wider range of temperatures may be required to determine if temperature × floor space interactions exist.

Pig genotype and gender could also influence the response of pigs to different floor spaces. Several studies have reported the existence of a genotype × environment interaction related to aspects of the environment other than floor space (Merks, 1989; Bidanel and Ducos, 1996). More recently, Hamilton et al. (2003) investigated the performance of the progeny of two sire lines housed at two floor spaces (restricted = 0.37 and 0.56 m^2/pig in the grower and finisher phases, respectively; unrestricted = 0.93 m^2/pig in both the grower and finisher phases) from 40 to 120 kg live weight. No genotype × floor space interactions were reported in that study. Further research is needed to establish if there are important differences between genotypes in their response to low floor spaces. It has also been speculated that there may be an interaction between gender and floor space. Hugh and Reimer (1967) suggested that genders responded differently to reductions in floor space, but showed no significant gender × floor space interaction in their study. Several others have shown no gender × floor space interaction for growth performance (Jensen et al., 1973; Hamilton et al., 2003; Peterson, 2004).

In addition to specific factors and conditions during the studies, the procedures in which studies are terminated could impact their results. The two options for study termination are to end the study at a fixed time or at a fixed weight. All of the historical floor space studies carried out in the nursery period and many of the studies carried out in the grow-finish period have been terminated at a fixed time, resulting in significant differences in end body weight between the floor space treatment levels. In such studies, overall ADG, ADFI, and G:F could be influenced by end body weight, which would not allow for accurate comparison between the floor space treatment levels. Therefore, studies evaluating floor space should be terminated at a fixed weight rather than a fixed time.

Also, there is considerable variation in the procedures for removing pigs from studies at the end of the experimental period or when pigs are removed from test due to morbidity or mortality which could impact the results of floor space studies. It is important to establish whether pens of pigs or individual pigs are removed from the study at the fixed weight. Removing individual pigs from pens during a floor space study would result in the remaining pigs having greater floor space, which could potentially confound the results. Additionally, some studies have not adjusted the dimensions of the pen when mortality occurs or when a morbid pig is removed, which again would result in floor spaces greater than those actually reported. Therefore, it is important to consider the specific procedures used in each floor space study.

Understanding the animals used and the conditions employed during each floor space study is critical for correct interpretation of the results. Therefore, specific details of certain studies that may influence the effects of floor space on growth performance and carcass characteristics will be noted throughout this thesis. Floor space studies carried out using intact males, outdoor facilities, facilities with solid concrete and straw bedding, or individual pig housing will not be included in the discussion. Additionally, floor space studies with inconsistencies in the procedures and/or results will not be discussed.

Table 1. Interaction means for the effects of temperature and floor space (Hyun et al., 1998b).

	Temperature, °C	
Item	24	28-34
Average daily gain, g		
Static group		
0.25 m^2/pig	734	608
0.56 m^2/pig	876	792
Mixed group		
0.25 m^2/pig	657	606
0.56 m^2/pig	777	676
Gain:feed ratio		
Static group		
0.25 m^2/pig	0.37	0.34
0.56 m^2/pig	0.40	0.40
Mixed group		
0.25 m^2/pig	0.35	0.33
0.56 m^2/pig	0.39	0.37

Impact of Nursery Floor Space on Growth Performance

A summary of 16 floor space studies that have been carried out during the nursery period is presented in Table 2. However, only 5 of these studies used the same group size and feeder space across the floor space treatment levels. Among these studies, Yen and Pond (1987) evaluated two floor spaces (0.13 and 0.25 m^2/pig; equivalent to *k* values of 0.020 and 0.038, respectively) and reported a 12.8% reduction in ADG for pigs housed at the lower floor space. Kornegay et al. (1993a) evaluated similar floor spaces to Yen and Pond (1987) (0.14 and 0.28 m^2/pig; equivalent to *k* values of 0.019 and 0.039, respectively) and reported a 12.1% reduction in ADG for pigs on the lower floor space treatment level. Kornegay et al. (1993b) evaluated the same floor spaces (0.14 and 0.28 m^2/pig), but had a heavier end of study live weight than the previous two studies, so these treatments were equivalent to k values of 0.016 and 0.032, respectively, and reported that the growth rate of pigs on the lower floor space treatment level was reduced by 18.0%. However, all of these studies were carried out using small group sizes (<10 pigs). Two additional studies that did not confound the effects of floor space with group size were carried out using larger group sizes (≥20 pigs), which are more representative of commercial conditions. Wolter et al. (2000) housed pigs in large (100 pigs) and small (20 pigs) groups at either 0.17 m^2/pig (k = 0.028) or 0.17 m^2/pig minus 50% of the unoccupied space or "free space" (0.13 and 0.15 m^2/pig for the large and small groups, respectively; k = 0.021 and 0.025, respectively). Pigs on the reduced floor space treatment had 3.9% lower ADG than pigs housed at the base floor space from weaning to week 4 post-weaning. In addition, Wolter et al. (2003b) evaluated two floor spaces (0.315 and 0.630 m^2/pig; equivalent to k values of 0.021 and 0.043, respectively) from weaning to either 12 or 14 weeks post weaning, and reported a 6.8% reduction ($P < 0.05$) in ADG for pigs housed at the lower floor space. Unfortunately, the range of floor spaces evaluated in the study of Wolter et al. (2000) and the range in body weight over which the study of Wolter et al. (2003b) was conducted makes it difficult to compare the results of these studies with the results of the previously discussed studies.

Among the floor space studies that confounded the effects of floor space with group size, several had floor space treatment levels within a similar range as the studies previously discussed (i.e., 0.13 to 0.25 m^2/pig; equivalent to k values of between 0.019 to 0.038; Kornegay et al., 1980; NCR-89, 1984; Yen and Pond, 1987; Brumm et al., 2001). Across these studies, ADG was reduced by between 8.0 to 12.0% per 0.1 m^2/pig reduction in floor space (equivalent to a reduction in ADG of 0.62 to 0.89% per 0.001 $m^2/BW^{0.67}$). Despite the fact that group size effects on ADG are typically small (Turner et al., 2003), it is not possible to separate the effects of group size and floor space on growth rate when they are confounded. These studies do, however, generally support the results of studies which maintained the same group size across all floor space treatment levels.

Studies investigating the effects of floor space in the nursery period on feed intake and feed efficiency have shown inconsistent results. Of the studies that did not confound the effects of floor space with group size, some suggested that the reduction in ADG for pigs housed at reduced floor spaces was a result of reduced feed intake, with no effect of floor space on feed efficiency (Kornegay et al., 1993a and 1993b). However, other studies have reported no effect of floor space on feed intake and that the reduction in ADG at the lower floor spaces were due to reductions in feed efficiency (Yen and Pond, 1987; Wolter et al., 2000). Wolter et al. (2003b) reported a reduction in both feed intake and feed efficiency when pigs were housed at reduced floor spaces. The reason for these conflicting results remains unclear and will be discussed in more detail later on in this review. In addition, most of the studies reviewed above only had two treatments and, consequently, it is not possible to determine the floor space required for maximum growth performance in this stage of growth.

Table 2. Summary of floor space literature in the nursery period.[3]

							Confounded (Y or N)				Absolute change, units/0.1 m^2*			Percentage change, %/0.1 m^2*		
Study	Floor space treatments (m^2/pig)	BW range (kg)	k ($m^2/BW^{0.667}$)	Group size	Min reps[4]	Flooring type[2]	Floor space[5]	Group size[6]	Feeder space[1]	Water space[1]	ADG (kg)	ADFI (kg)	G:F	ADG	ADFI	G:F
Brumm et al. (2001) Exp 1	0.16, 0.25	6 to 20	0.022, 0.034	12, 18	8	FS	Y	Y	N	N	0.05	0.08	NS	11.98	12.04	NS
Brumm et al. (2001) Exp 2	0.16, 0.23	5 to 22	0.020, 0.029	6 to 18	24	FS	N	Y	N	N	0.04	0.06	NS	8.97	9.17	NS
Harper and Kornegay (1983)	0.12, 0.24	6 to 19	0.017, 0.034	6, 12	26	PS	N	Y	Y	N	0.03	0.03	0.01	7.70	5.30	2.77
Kornegay et al. (1980)	0.15, 0.18, 0.25	6 to 22	0.019, 0.023, 0.032	6 to 10	16	FS	NA	Y	N	N	0.03	0.06	NS	8.00	9.15	NS
Kornegay et al. (1981)	0.12, 0.17, 0.25	6 to 21	0.016, 0.023, 0.033	6 to 12	15	FS	NA	Y	N	Y	0.05	0.07	NS	12.26	10.34	NS
Kornegay et al. (1993a)	0.14, 0.28	7 to 20	0.019, 0.039	4	36	FS	N	N	N	N	0.03	0.06	NS	8.62	8.25	NS
Kornegay et al. (1993b)	0.14, 0.28	8 to 26	0.016, 0.032	4	12	FS	NA	N	N	N	0.07	0.16	NS	12.85	14.77	NS
Lindvall (1981)	0.13, 0.17, 0.25	8 to 23	0.016, 0.021, 0.031	8 to 16	4	FS & PS	NA	Y	N	Y	0.07	NA	NS	15.75	NA	NS
NCR-89 (1984)	0.14, 0.23	8 to 17	0.021, 0.035	NA	45	FS & PS	Y	Y	N	NA	0.04	0.05	0.02	10.61	7.56	4.04
Wolter et al. (2000)	0.13 or 0.15, 0.17	5 to 15	0.021 or 0.025, 0.028	20, 100	16	FS	NA	N	N	N	0.07	NS	0.10	19.66	NS	13.51
Wolter et al. (2002a) Exp 1	0.33, 0.65	6 to 41	0.027, 0.055	52, 104	10	FS	NA	Y	Y	N	0.01	0.02	NS	2.37	2.09	NS
Wolter et al. (2002a) Exp 2	0.33, 0.65	5 to 43	0.026, 0.053	27, 54	18	FS	NA	Y	Y	N	0.01	NS	NS	2.42	NS	NS
Wolter et al. (2003a)	0.21, 0.63	5 to 28	0.023, 0.068	54	16	FS	NA	N	Y	N	0.01	0.01	NS	1.89	1.63	NS
Wolter et al. (2003b)	0.32, 0.63	6 to 57	0.021, 0.043	54	16	FS	NA	N	N	N	0.01	0.02	0.00	2.15	1.66	0.56
Yen and Pond (1987) Exp 1	0.13, 0.25	7 to 17	0.020, 0.038	8, 16	9	FS	NA	Y	N	Y	0.04	0.09	NS	10.94	13.01	NS
Yen and Pond (1987) Exp 2	0.13, 0.25	7 to 17	0.020, 0.038	8	9	FS	NA	N	N	N	0.04	NS	0.03	10.70	NS	6.83

[1] The number of pigs per feeder hole or per water source. The study was only considered to be confounded by feeder or water space if the number of pigs per space was different between treatments and at least one of the treatments had >10 pigs per feeder or water space.
[2] FS = fully slatted flooring; PS = partially slatted flooring.
[3] NA = not available.
[4] The minimum number of replicates among all floor space treatment levels.
[5] Floor space was not adjusted when mortality occurred or when morbid pigs were removed from the study.
[6] Group size was different between floor space treatments levels.
* NS = not significant ($P \geq 0.05$).

Impact of Grow-Finish Floor Space on Growth Performance

A summary of 36 floor space studies that were carried out in the grow-finish period is presented in Table 3. Twenty of these studies did not confound the effects of floor space with group size and of these, 9 studies adjusted the floor space as the pigs increased in size and could not be accurately compared with other studies because of the potential interaction between previous and subsequent floor space. Of the remaining 11 studies, only 8 maintained intact pens until the end of the study. These 8 studies will be used in the discussion of the effects of floor space on growth performance.

Among the 8 studies, NCR-89 (1993) and Anil et al. (2007) were the only two studies that were carried out over a fixed weight range. This ensures that differences in live weight do not influence overall ADG, ADFI, or G:F. NCR-89 (1993) evaluated three floor spaces (0.56, 0.74, and 0.93 m^2/pig; equivalent to k values of 0.024, 0.031, and 0.040, respectively) and reported a linear reduction in ADG as floor space was reduced with an 11.1% difference between the 0.56 and 0.93 m^2/pig treatment levels. Anil et al. (2007) evaluated four floor spaces with a narrower range than the previous study (0.64, 0.74, 0.81, and 0.88 m^2/pig; equivalent to k values of 0.027, 0.031, 0.034, and 0.037) and found that ADG was reduced by 8.2% for pigs housed at 0.64 compared to 0.88 m^2/pig. The remaining 6 studies were all terminated after a fixed time on test. Harper and Kornegay (1983) housed pigs in pens of 5 at either 0.43 (k = 0.021) or 0.78 (k = 0.038) m^2/pig from an initial live weight of 23 kg over a fixed time period until the pigs on the 0.78 m^2/pig treatment level reached an average live weight of 98 kg and reported an 8.3% reduction in ADG for pigs housed at the lower floor space. Hyun et al. (1998a) and Hyun et al. (1998b) evaluated two floor spaces [0.25 (k = 0.017 in both studies) and 0.56 (k = 0.038 and 0.039, respectively) m^2/pig] over a 4-week period with 8 pigs per pen and reported a 15.7 and

16.4% reduction in ADG for pigs housed at 0.25 m^2/pig, respectively. More recently, two studies have been carried out with larger group sizes, which are more typical of current commercial practice. Peterson (2004) kept pigs in groups of 29 at three different floor spaces (0.61, 0.68, and 0.74 m^2/pig; k = 0.026, 0.029, and 0.031, respectively) from week 8 post-weaning (34 kg) to week 20 post-weaning (~115 kg) and reported a 4.4% reduction in ADG for pigs housed at the lowest floor space compared to the highest floor space. Street and Gonyou (2008) used group sizes of either 18 or 108 pigs at either 0.52 m^2/pig (k = 0.025) or 0.78 m^2/pig (k = 0.038) for 8 weeks from an initial live weight of 37 kg and reported that pigs on the 0.52 m^2/pig treatment level grew 4.2% slower than pigs on the 0.78 m^2/pig treatment level. In that study, no group size × floor space interaction was reported for growth performance (ADG, ADFI, or G:F). Contrary to the previous studies, Brumm and NCR-89 (1996), in a 99-day study starting from an initial live weight of 20 kg, reported that pigs housed at a higher floor space [1.02 m^2/pig (k = 0.046)] had a lower ADG when compared to pigs housed at two lower floor spaces [0.65 (k = 0.029) and 0.84 (k = 0.038) m^2/pig]. There is no explanation to why these results conflict with those of previous studies. Ignoring the results of Brumm and NCR-89 (1996), these 8 studies suggest that daily gain is reduced by 1.6 to 5.3% per 0.1 m^2/pig reduction in floor space (equivalent to a reduction in ADG of 0.33 to 0.80% per 0.001 $m^2/BW^{0.67}$).

Similar to the nursery period, the reason for this reduction in ADG is unclear. Among the 8 studies previously discussed, two reported a significant reduction in feed intake with no reduction in feed efficiency as floor space was reduced (Harper and Kornegay, 1983; Peterson, 2004), two reported a reduction in both ADFI and G:F (Hyun et al., 1998b; NCR-89, 1993), and two reported a reduction in G:F with no decline in ADFI (Hyun et al., 1998a; Street and Gonyou, 2008). Anil et al. (2007) did not measure feed intake and the feed intake results of Brumm and

NCR-89 (1996) provide no understanding of the effect of floor space on feed intake and feed efficiency as the highest floor space had the lowest growth rate. There is no clear explanation for the inconsistency in these results.

Gonyou (1999) suggested limited feeder access as a possible reason for the reduction in feed intake of pigs housed at reduced floor spaces. Feeder access is a vaguely defined term, but the amount of feeder space and the location of the feeders are likely to impact the ability of pigs to access the feeders when floor space is restricted. Reducing floor space increases the likelihood of pigs standing or lying in front of the feeder. For this reason, it could be argued that the feeder space required for maximum growth rate would increase as floor space decreases. In addition, the space available for walking to and from the feeding area is also decreased when floor space is reduced. Feeders located in multiple locations would decrease the distance between the resting and feeding areas. Unfortunately, the interaction between floor space and feeder space and location has not been investigated. However, many of the historical floor space studies have been conducted using small group sizes (<20 pigs) with less than 10 pigs per feeder space, which is less than the number of pigs per feeder space recommended for maximum growth rate (Nielsen et al., 1996; Gonyou and Lou, 2000). Under these study conditions, feeder access would not be expected to be an issue. This suggests that factors other than reduced feeder access are contributing to the reductions in feed intake observed in some studies when floor space is restricted.

A second potential explanation of a reduction in feed intake when a floor space restriction is present is that it is due to the effects of stress on the pigs. McEwan (2000) defined stress as a "real or interpreted threat to the physiological or psychological integrity of an individual that results in physiological and/or behavioral responses". Stress in pigs has been shown to cause reduced feed intake (McGlone et al., 1993; Hyun et al., 1998b). Street and Gonyou (2008) attempted to determine if decreasing floor space induced stress by measuring salivary cortisol levels and adrenal gland weights (measures of acute and chronic stress, respectively), but failed to detect a significant difference between floor space treatment levels. Other studies have attempted to determine effects of floor space on stress by evaluating pig behavior and have found little evidence of changes in behavior due to floor space (Anil et al., 2007; Street and Gonyou, 2008). Future research should focus on the behavioral and physiological responses to reductions in floor space as they may prove critical to determining the effect of floor space on pig welfare, which is an increasing concern.

Possible explanations of a reduction in feed efficiency for pigs housed at reduced floor spaces include an increase in feed wastage and an increase in energy expenditures during daily activities. Historical floor space studies have not actually measured feed intake, but rather feed disappearance. Therefore, it is possible that an increase in feed wastage when floor space is reduced is the cause of the reduction in feed efficiency. If this were true, the reductions in actual feed intake due to reduced floor space would be larger than what was reported in historical literature, as part of the reported feed intake would be feed wastage. Reducing floor space could potentially increase the number of interruptions during feeding, resulting in an increase in feed wastage. Feed wastage has not been measured in any of the previous floor space studies and, therefore, warrants further research.

Additionally, feed efficiency will be negatively impacted if energy is diverted from growth to other activities. An increase in the amount of energy expended during daily activities such as feeding, drinking, and socializing when pigs are housed at reduced floor spaces could explain the reduction in feed efficiency. Anil et al. (2007) reported an increase in the number of aggressive interactions for pigs housed at reduced floor spaces. This is somewhat expected as contact between pigs is likely to increase when floor space is restricted. Nevertheless, little is known about the energy expenditures of pigs kept at different floor spaces as this is difficult to measure.

The stage of growth could also impact the effect of floor space on feed efficiency. Hamilton et al. (2003) showed that for pigs in the grow-finish period, the ratio of protein accretion to lipid accretion is significantly decreased as pigs increase in size. As a result, lean growth would be expected to decline at a greater proportion in a growing pig than in a finishing pig when feed intake is reduced due to a floor space restriction. The ratio of nutrients used for lean growth to nutrients used for maintenance decreases as lean growth is reduced. Consequently, a reduction in feed efficiency would be expected. Milgen and Noblet (2003) suggested that a reduction in the feed intake of finishing pigs typically impacts lipid accretion before protein accretion. Therefore, a small reduction in feed intake in a finishing pig might actually improve feed efficiency. However, once the reduction in feed intake is large enough to reduce protein accretion significantly, feed efficiency would decline.

Another factor that could influence both feed intake and feed efficiency is temperature. Elevated environmental temperatures have been shown to reduce feed intake (Becker et al., 1992; Hyun et al., 1998b; Collin et al., 2001a; Bellego et al., 2002), and in some cases reduce both feed intake and feed efficiency (Collin et al., 2001b; White et al., 2008). Decreasing floor space results in a greater number of pigs per unit of floor area, which would increase the heat production per unit of floor area. The increase in heat production per unit of floor area would likely result in elevated temperatures at the pig level. The effect of floor space on the temperature and humidity at the pig level is difficult to measure, but warrants further research.

Nevertheless, the impact of possible elevated temperatures at the pig level when floor space is reduced on feed efficiency may be dependent on the amount of active heat dissipation (e.g., panting) that is required to regulate body temperature. Furthermore, the environmental temperature (i.e., season) would also impact the effect of increased temperatures at the pig level associated with reduced floor spaces on feed intake and efficiency.

Despite the extensive amount of research during the grow-finish period, very few studies have been designed in a manner that allows for interpretation of the floor space required for maximum growth performance. NCR-89 (1993) is one of the few studies that evaluated floor space over a wide enough range to make inferences about the floor space requirement of pigs. In the second of two experiments, four floor spaces (0.56, 0.74, 0.93, and 1.11 m^2/pig; equivalent *k* values of 0.026, 0.034, 0.043, and 0.052, respectively) were evaluated from an initial weight of 54 kg to the time at which the first pig in the pen reached 113.6 kg. Two of the 12 replicates were carried out with unequal group sizes between floor space treatment levels. In this study, a linear reduction in ADG was reported as floor space was reduced, but there were only small numerical differences between the 0.93 and 1.11 m^2/pig treatment levels. From these results, they concluded that 0.93 m^2/pig ($k = 0.043$) is sufficient for maximum growth rate for pigs in the grow-finish period. However, no other studies have been carried out with multiple floor space treatment levels near the floor space required for maximum growth rate suggested by NCR-89 (1993). Therefore, additional research with a greater number of treatments above and below the projected floor space requirement of pigs would be required to accurately determine the floor space requirement.

Table 3. Summary of floor space literature in the grow-finish period.[3]

Study	Floor space treatments (m^2/pig)	Body weight range (kg)	Equivalent *k* value ($m^2/BW^{0.667}$)	Group size	Min reps[8]	Flooring type[2]	Study end[4]	Marketing strategy[5]	Confounded (Y or N) Floor space[6]	Group size[7]	Feeder[1]	Water[1]	Absolute change, units/0.1 m^2* ADG (kg)	ADFI (kg)	G:F	Percentage change, %/0.1 m^2* ADG	ADFI	G:F
Anil. et al. (2007)	0.64, 0.74, 0.81, 0.88	31 to 116	0.027, 0.031, 0.034, 0.037	19	8	FS	FW	EG	N	N	N	N	0.03	NA	NA	3.33	NA	NA
Brumm (2004) Exp 2	0.58, 0.74	5 to 124	0.023, 0.030	14,18	8	FS	FT	EG	Y	Y	N	Y	0.01	NS	NS	1.74	NS	NS
Brumm and Miller (1996) Exp 1	0.56, 0.78	20 to 111	NA	10,14	32	PS	FW	IP	N	Y	N	Y	0.02	0.07	NS	2.18	2.81	NS
Brumm and Miller (1996) Exp 2	0.56, 0.78	23 to 107	NA	10,14	12	PS	FW	IP	N	Y	N	Y	0.01	NS	0.00	1.72	NS	1.18
Brumm and Miller (1996) Exp 3	0.56, 0.78	21 to 106	NA	10,14	12	PS	FW	IP	N	Y	N	Y	0.01	NS	NS	1.94	NS	NS
Brumm and NCR-89 (1996) Exp 1	0.65, 0.84, 1.02	20 to 107	0.029, 0.038, 0.046	12	7	FS	FT	EG	N	N	N	N	-0.01	0.00	NS	-0.65	-0.16	NS
Brumm and NCR-89 (1996) Exp 2	0.65, 0.93, 1.20	56 to 137	NA	12	7	FS	FW	IP	N	N	N	N	NS	NS	NS	NS	NS	NS
Brumm et al. (2001) Exp 1	0.56, 0.78	20 to 110	NA	12,18	12	PS	FW	IP	Y	Y	N	Y	0.03	0.06	NS	3.13	2.21	NS
Brumm et al. (2001) Exp 2	0.60, 0.74	22 to 110	NA	6 to 18	24	FS & PS	FW	IP	N	N	N	N	NS	NS	NS	NS	NS	NS
Brumm et al. (2004)	0.55, 0.74	30 to 108	0.024, 0.033	14,19	8	FS	FW	EG	N	Y	N	Y	0.03	NS	NS	2.84	NS	NS
Edmonds et al. (1998) Exp 1	varied	18 to 127	NA	6 to 16	4	FS	FW	IP	N	Y	N	Y	NA	NA	NA	NA	NA	NA
Edmonds et al. (1998) Exp 2	0.37, 0.60	55 to 91	0.018, 0.030	6,12	6	FS	FW	EG	N	Y	N	Y	0.05	NS	0.01	7.04	NS	4.66
Ford and Teague (1978)	varied	23 to 99	NA	8,12	6	PS	NA	NA	N	N	N	N	NA	NA	NA	NA	NA	NA
Gehlbach et al. (1966) Exp 1	varied	14 to 90	NA	7	4	FS & PS	NA	NA	NA	N	N	N	NA	NA	NA	NA	NA	NA
Gehlbach et al. (1966) Exp 2	varied	34 to 90	NA	7	4	FS & PS	NA	NA	NA	N	N	N	NA	NA	NA	NA	NA	NA
Gonyou and Stricklin (1998)	varied	25 to 97	NA	3 to 15	6	FS	FT	EG	N	N	N	N	NA	NA	NA	NA	NA	NA
Hale and Utley (1985)	varied	18 to 100	NA	8	8	FS	FT	EG	NA	N	N	N	NA	NA	NA	NA	NA	NA
Hamilton et al. (2003)	varied	40 to 120	NA	4,12	46	PS	FW	EG	NA	Y	N	NA	NA	NA	NA	NA	NA	NA
Handlin et al. (1972)	0.79, 1.06, 1.28	35 to 91	0.039, 0.052, 0.063	10,12,16	6	PS	FW	EG	NA	Y	NA	NA	NS	NA	NS	NS	NA	NS
Harper and Kornegay (1983)	0.43, 0.78	23 to 94	0.021, 0.038	5	12	PS	FT	EG	NA	N	N	N	0.02	0.04	NS	2.36	1.83	NS
Hyun et al. (1998a)	0.25, 0.56	36 to 56	0.017, 0.038	8	16	PS	FT	EG	NA	N	N	N	0.04	NS	0.01	5.07	NS	3.23
Hyun et al. (1998b)	0.25, 0.56	35 to 55	0.017, 0.039	8	16	PS	FT	EG	NA	N	N	N	0.04	0.04	0.01	5.29	1.94	3.31
Jensen et al. (1973)	varied	21 to 100	NA	6	4	FS & PS	NA	NA	NA	N	N	N	NA	NA	NA	NA	NA	NA
Krider et al. (1975) Exp 2	0.43, 0.63	19 to 102	0.020, 0.029	10,15	8	FS	FW	EG	N	Y	N	Y	0.04	NS	NS	5.80	NS	NS
Libal et al. (1981)	varied	30 to 100	NA	6 to 20	2	FS	FW	EG	NA	Y	N	N	NA	NA	NA	NA	NA	NA
Matthews et al. (2001)	varied	51 to 109	NA	4	10	FS	FW	EG	N	N	N	N	NA	NA	NA	NA	NA	NA
McGlone and Newby (1994)	0.56, 0.65, 0.74	59 to 106+	NA	20	4	FS	FW	IP	NA	N	N	N	0.06	NS	NS	7.94	NS	NS
Moser et al. (1985)	varied	23 to 100	NA	9	10	FS	FW	EG	NA	N	N	N	NA	NA	NA	NA	NA	NA
NCR-89 (1993) Exp 1	0.56, 0.74, 0.93	53 to 114	0.024, 0.031, 0.040	10 to 18	12	PS	FW	EG	N	N	N	N	0.02	0.05	0.00	3.00	1.76	1.44
NCR-89 (1993) Exp 2	0.56, 0.74, 0.93, 1.11	54 to 99	0.026, 0.034, 0.043, 0.052	Varied	12	PS	FT	EG	N	Y	N	Y	0.02	0.04	0.00	2.28	1.38	0.90
Peterson (2004) Exp 2	0.61, 0.68, 0.74	34 to 115	0.026, 0.029, 0.031	29	36	FS	FT	EG	N	N	N	N	0.03	0.05	NS	3.40	2.41	NS
Peterson (2004) Exp 3	0.61, 0.68, 0.74	5 to 108	0.027, 0.030, 0.033	29 to 36	36	FS	FT	EG	Y	Y	Y	Y	0.01	NA	NA	1.35	NA	NA
Randolph et al. (1981) Exp 2	0.33, 0.66	16 to 42	0.027, 0.055	5,10	6	PS	FT	EG	NA	Y	N	N	NS	NS	NS	NS	NS	NS
Street and Gonyou (2008)	0.52, 0.78	37 to 94	0.025, 0.038	18,108	16	FS	FT	EG	NA	N	N	N	0.02	NS	0.01	1.61	NS	2.54
Ward et al. (1997)	varied	27 to 104	NA	4	16	FS	FW	EG	N	N	N	N	NA	NA	NA	NA	NA	NA
White et al. (2008)	0.66, 0.93	88 to 108	0.029, 0.041	5, 7	20	NA	FT	EG	NA	Y	N	N	0.05	0.11	0.01	6.61	4.04	2.69

[1] The number of pigs per feeder hole or per water source. The study was only considered to be confounded by feeder or water space if the number of pigs per space was different between treatments and at least one of the treatments had >10 pigs per feeder or water space.
[2] FS = fully slatted flooring; PS = partially slatted flooring.
[3] NA = not available.
[4] FW = fixed weight; FT = fixed time.
[5] EG = entire pens of pigs were taken off study at once; IP = individual pigs were taken off study.
[6] Floor space was not adjusted when mortality occurred or when morbid pigs were removed from the study.
[7] Group size was different between floor space treatments levels.
[8] The minimum number of replicates among all floor space treatment levels.
* NS = not significant ($P \geq 0.05$).

Impact of Floor Space on Morbidity and Mortality

The effect of floor space on morbidity and mortality also has major implications in determining which floor space is most profitable to the producer. Morbidity and mortality typically occur at low frequencies and, as a result, very few studies have been large enough to detect commercially important differences between treatments. In studies carried out in the nursery period, NCR-89 (1984) compared 0.14 m^2/pig (k = 0.021) to 0.23 m^2/pig (k = 0.035) and Brumm et al. (2001) compared 0.16 m^2/pig (k = 0.022) to 0.25 m^2/pig (k = 0.034) and reported no differences in the number of pigs removed from the study. Conversely, Wolter et al. (2003b) reported a higher removal rate when pigs were housed at 0.315 m^2/pig (k = 0.021) compared to 0.630 m^2/pig (k = 0.043) from weaning to either 12 or 14 weeks post-weaning, and Wolter et al. (2003a) reported higher levels of morbidity and mortality in pigs when both floor and feeder space were restricted (0.21 m^2/pig and 2 cm/pig vs. 0.63 m^2/pig and 4 cm/pig, respectively; equivalent to k values of 0.023 and 0.068, respectively) from weaning to week 8 post-weaning. Some grow-finish studies have shown no effect of floor space on morbidity and mortality (Brumm et al., 2001; Street and Gonyou, 2008). Hamilton et al. (2003), however, reported an increase in morbidity and mortality for pigs housed at 0.37 m^2/pig from 40 to 80 kg and 0.56 m^2/pig from 80 to 120 kg compared to 0.93 m^2/pig for the entire period. Similarly, Peterson (2004) reported an increase in morbidity and mortality when pigs were housed at 0.61 m^2/pig compared to 0.68 and 0.74 m^2/pig. Due to these inconsistent results, it is difficult to draw conclusions on the impact of floor space on morbidity and mortality levels. Future research should be carried out with larger numbers of pigs in each treatment level in order to more accurately determine the effects of floor space on morbidity and mortality.

Impact of Floor Space on Carcass Characteristics

Contrary to the impact of floor space on growth performance, carcass characteristics may actually be improved by decreasing floor space, especially in the finishing period. It has been suggested that housing pigs with restricted floor space during the finishing period lowers feed intake during a time when energy intake is greater than that which is required for maximum lean growth and, as a result, the lipid accretion rate is reduced (Holck et al., 1997; Schinckel, 1999). This is supported by the study of Hamilton et al. (2003) which reported a decrease in lipid accretion rate for pigs housed with restricted compared to unrestricted floor space from 40 to 120 kg. Other researchers have reported a reduction in 10^{th} rib backfat depth (Matthews et al., 2001) and increased predicted carcass lean content (Ward et al., 1997; Brumm et al., 2001) for pigs housed at reduced compared to higher floor spaces. Conversely, Peterson (2004) reported minimal effects of floor space on carcass measures. Future research should be aimed at determining the effects of floor space on lipid and protein accretion rates in a wean-to-finish system.

Floor Space Meta-Analyses

Several meta-analyses have been performed in an attempt to quantify the effect of floor space on the growth, feed intake, and feed efficiency of growing pigs. This has typically been carried out by performing regression analysis of the treatment means for growth and feed intake from historical studies (Kornegay and Notter, 1984; Wellock et al., 2003; Gonyou et al., 2006). However, there are many potential limitations to the approaches and studies used in these analyses and these are discussed below.

In a classic paper by Kornegay and Notter (1984), the effect of floor space on ADG, ADFI, and G:F ratio was estimated by regressing the treatment means for ADG, ADFI, and G:F ratio from a number of studies against the actual floor spaces compared. However, the studies used in this regression analysis differed in terms of the location of the study, the study time period, the weight range used, and the genetics of the pigs. Therefore, overall actual growth performance levels differed substantially between studies, even at common floor spaces. The studies used in this analysis were also carried out with different ranges in floor space. As a result, the intercept and slope of the regression line could have been influenced by these differences between studies.

A more recent meta-analysis transformed actual performance values reported in historical studies into relative values by dividing the performance values of all floor space treatment levels within a study by the performance values reported for the highest floor space treatment level (Wellock et al., 2003). However, the use of relative values for ADG, ADFI, and G:F ratio is only effective in floor space regression analysis if all of the studies used in the analysis had either a common floor space treatment level or at least one floor space treatment level above the floor space requirement.

Using this same approach to transform historical data, Gonyou et al. (2006) used broken-line regression analysis to determine the floor space requirement of pigs in the nursery and grow-finish periods. In these analyses, which were based on 20 published studies, *k* values were calculated for each treatment level and regressed against both relative and actual values of ADG, ADFI, and G:F. For inclusion in the analysis, a study needed to have one floor space treatment level above and one below an equivalent *k* value of 0.030. However, floor spaces with an equivalent *k* value of 0.030 are well below the floor space required for maximum growth rate suggested by NCR-89 (1993) (0.93 m^2/pig; equivalent to a *k* value of 0.043). Of the 20 experiments included in the meta-analyses of Gonyou et al. (2006), 12 had a maximum floor space treatment at or below an equivalent *k* value of 0.035. As a result, the relative values used in these analyses were not relative to the floor space requirement, but rather, relative to the highest floor space treatment levels in each study. Not surprisingly, Gonyou et al. (2006) reported that the floor space required for maximum growth rate for pigs on fully slatted flooring in the grow-finish period to be equivalent to a *k* value of 0.034, which was near to the maximum *k* values used in the majority of the studies included in the analyses. By using studies with maximum floor space treatment levels below the floor space required for maximum growth rate and calculating relative values, an inaccurate breakpoint (i.e., floor space requirement) was generated. Additionally, an inaccurate breakpoint could also impact the slope of the line below the breakpoint. Therefore, the equations in Gonyou et al. (2006) could potentially have significant errors in the prediction of the floor space required for maximum growth performance and the growth performance response to floor spaces below the requirement.

The key issues with each of these meta-analyses that attempted to use regression analysis of historical studies to predict the floor space requirement for maximum growth rate and the growth performance response below the requirement is the lack of floor space studies with a sufficient number of treatment levels above and below the likely floor space requirement. In addition, combining studies in a regression analysis is also challenging because of the large number of potential factors that could influence the effects of floor space on growth performance. As a result, the application of historical floor space studies to current production systems may be limited to specific studies carried out under similar conditions.

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CHAPTER 2: EFFECT OF FLOOR SPACE IN THE NURSERY AND GROW-FINISH PERIODS ON THE GROWTH PERFORMANCE OF PIGS.

INTRODUCTION

Management strategies, such as manipulating floor space, can have a significant impact on the profitability of a commercial production system. Reducing floor space has been consistently shown to reduce the growth rate of pigs (Wolter et al., 2003; Peterson, 2004; Anil et al., 2007). However, reducing floor space typically increases the production per unit area from a facility and reduces the fixed cost per pig. In many cases, the economic advantages associated with reducing floor space are greater than the cost of reduced growth rate (Powell et al., 1993). Housing pigs at the economically optimum floor space requires an understanding of the effects of floor space on growth performance from weaning to market.

The floor space required for maximum growth rate increases as pigs increase in size. For this reason, an equation proposed by Petherick and Baxter (1981) (i.e., $A = k*BW^{0.67}$) relating body weight to the floor area occupied by an individual pig has been used to predict the floor space required for maximum growth rate of pigs in the nursery and grow-finish periods (Gonyou et al., 2006). However, no research has been carried out to validate that the floor space required for maximum growth rate increases proportionately with $BW^{0.67}$ as pigs increase in size. Furthermore, it has been reported that pigs will undergo growth compensation following a period of floor space restriction (Wolter et al., 2003). A compensatory growth response following a period of floor space restriction could provide even more incentive for producers to house pigs at reduced floor spaces, particularly at lighter weights.

Therefore, the objectives of this research were to: 1) determine the relationship between floor space and growth performance during the nursery and grow-finish periods using floor spaces with the same range of equivalent *k* values in each period and, 2) determine the subsequent effects of a previous floor space restriction on the growth performance of pigs after the floor space restriction has been removed.

MATERIALS AND METHODS

Two studies were conducted at the The Maschhoffs' Georgia Technology Center located near New Minden, IL. The experimental protocols were approved by the University of Illinois Institutional Animal Care and Use Committee (IACUC #09061).

Experimental Design and Treatments. Both Study 1 and 2 were conducted as randomized complete block designs with 5 floor space treatments and 15 replicates. The floor space treatment levels in both studies were selected to cover the range likely to be used under commercial conditions and were calculated to be equivalent to the same values of k in both studies (i.e., 0.019, 0.025, 0.030, 0.035, 0.041 $m^2/BW^{0.67}$). The actual floor spaces used in Study 1 were 0.21, 0.27, 0.33, 0.39, and 0.44 m^2/pig and in Study 2 were 0.35, 0.45, 0.54, 0.64, and 0.73 m^2/pig. The body weight used to calculate the floor space treatment levels in each study was the projected average body weights at the end of week 2 of each study (36.3 and 77.1 kg for Study 1 and 2, respectively), which were selected to represent the average degree of floor space restriction over the two floor space evaluation periods. Pen was the experimental unit and day of start of test was the blocking factor. Pigs used in Study 1 were re-allotted to Study 2.

Study 1. This study was carried out from week 6 to week 12 post-weaning from an initial live weight of 24.2 ± 1.29 kg. The effects of floor space were evaluated over a 4-week period (week 6 to week 10 post-weaning) with 5 treatment levels (0.21, 0.27, 0.33, 0.39, and 0.44 m^2/pig) and the subsequent effects of previous floor space were evaluated from week 10 to week 12 post-weaning, during which time all treatments were provided the same floor space (0.53 m^2/pig).

Study 2. This study was carried out from week 12 to week 18 post-weaning from an initial live weight of 60.9 ± 2.11 kg. The effects of floor space were evaluated over a 4-week study period (week 12 to week 16 post-weaning) with 5 treatment levels (0.35, 0.45, 0.54, 0.64, and 0.73 m^2/pig) and the subsequent effects of previous floor space were evaluated from week 16 to week 18 post-weaning, during which time all treatments were provided the same floor space (0.73 m^2/pig).

Animals and Allotment. The same group of pigs was used for the two studies. Animals were the progeny of PIC 337 or PIC 359 sires mated to PIC C22 or PIC C29 dams (PIC, Hendersonville, KY). Immediately following weaning, pigs were individually weighed, tagged, and sorted into outcome groups of 5 pigs of similar body weight within each gender. Pigs were randomly allotted to pens from within outcome groups until there were 43 pigs per pen (22 barrows and 21 gilts).

Study 1. At week 6 post-weaning, pigs were individually weighed and group sizes were reduced to 40 pigs/pen. Any injured pigs or pigs with poor health were removed first and any remaining extra pigs were selected for removal in order to achieve the same mean weight and variation in weight within each pen within a block (day of start of test). Pens of pigs within a block were weighed and assigned to groups of 5 pens (a replicate) on the basis of similar average body weight and were randomly assigned to one of the 5 floor space levels. There were 15 pens of each floor space level for a total of 3,000 pigs.

Study 2. After completion of Study 1, pigs were individually weighed and group sizes were reduced to 29 pigs/pen. All injured pigs or pigs with poor health were removed first and the remaining extra pigs were selected for removal from weight ranges around the mean in order to maintain the variation within the pen prior reducing the group size. An equal gender ratio (15 barrows and 14 gilts) was maintained across all pens. Pens of pigs within a block (day of start of test) were weighed and randomly allotted to one of the 5 floor space levels on the basis of average body weight and previous floor space treatment level. Each block consisted of 5 replicates from Study 1, which resulted in 5 pens of each previous floor space treatment level. The 5 pens within a previous floor space treatment level were equally represented by the 5 floor space treatment levels in Study 2. There were 15 pens of each floor space level for a total of 2,175 pigs.

Diets and Housing. In both studies, pigs were housed in two rooms of a tunnel ventilated wean-to-finish building with fully slatted concrete flooring. Pen divisions consisted of gates with horizontal steel rods and adjustment gates were located in the back of each pen in order to create different pen dimensions. The floor area occupied by the feeder was taken into account when calculating the floor space treatment levels. In the event of pig death or removal, pen size was adjusted using a moveable partition to maintain the correct floor space. Each pen was equipped with one 5-hole wet/dry box feeder (Feed Ease Wet/Dry Feeder, A. J. O'Mara Group, Lyons, NE) mounted in the fence line with one feeder hole covered to provide 4 holes with 142.2 cm of feeder trough space (3.56 cm/pig in Study 1 and 4.90 cm/pig in Study 2). An additional water cup was provided for a total of 5 drinking locations in both studies. Pigs had ad libitum access to feed and water. Diets were formulated to meet or exceed NRC (1998) recommendations for nutrient requirements.

Air temperature was maintained using thermostatically controlled heaters and fan ventilation. Water sprinklers were provided to the pigs when the temperature reached 29.4 °C. However, water sprinklers were located in the back half of the pens and, as a result, pigs housed at 0.21 and 0.27 m^2/pig in Study 1 and 0.35 m^2/pig in Study 2 had no access to the water mist, and pigs housed at 0.33 m^2/pig in Study 1 and 0.45 m^2/pig in Study 2 were only able to access approximately half of pen area that was covered by the water mist. Water sprinklers were in use for only 1 day during Study 1 and for 19 days during Study 2. In addition, box feeders were located in the fence line towards the front half of the pen and could have significantly restricted the movement of air in that portion of the pen, which was the majority of the pen area in the lower floor space treatment levels in both studies.

Study 1. Pen dimensions (length x width) during the 4-week floor space evaluation period (week 6 to week 10 post-weaning) were 2.99 x 3.05 m, 3.75 x 3.05 m, 4.48 x 3.05 m, 5.24 x 3.05 m, and 6.00 x 3.05 m for the 0.21, 0.27, 0.33, 0.39, and 0.44 m^2/pig floor space treatment levels, respectively. During the subsequent period (week 10 to week 12 post-weaning), pigs on all previous floor space treatment levels were provided full access to the pen (7.16 x 3.05 m), which gave a floor space of 0.53 m^2/pig for all treatment levels.

Study 2. Pen dimensions (length x width) during the 4-week floor space evaluation period (week 12 to week 16 post-weaning) were 3.54 x 3.05 m, 4.45 x 3.05 m, 5.36 x 3.05 m, 6.25 x 3.05 m, and 7.16 x 3.05 m for the 0.35, 0.45, 0.54, 0.64, and 0.73 m^2/pig floor space treatment levels, respectively. During the subsequent period (week 16 to week 18 post-weaning), pigs on all previous floor space treatment levels were provided full access to the pen (7.16 x 3.05 m), which gave a floor space of 0.73 m^2/pig for all treatment levels.

Growth Measurements. In Study 1, pigs were individually weighed at the start (week 6 post-weaning) and end (week 10 post-weaning) of the floor space evaluation period and pen weights were collected at the start, week 2, and end of the floor space evaluation period and at the end of the subsequent period (week 12 post-weaning). In Study 2, pigs were individually weighed at the start (week 12 post-weaning) and end (week 16 post-weaning) of the floor space evaluation period and pen weights were collected at the start, week 2, and end of the floor space evaluation period and at the end of the subsequent period (week 18 post-weaning). For both studies, feed data were collected using a computerized feed-mixing (L.O.M.A.N. Systmetechovik, Bremerhaven, Germany) and feed delivery (ASA International, Medolago, Italy) system that recorded the weight of feed delivered to each feeder. The amount of feed left in the feeder was also recorded for each pen every time the pigs were weighed to calculate feed intake and gain:feed ratio. Pigs experiencing health problems or injuries that did not respond to treatment were removed from the study and the date of, pig weight at, and reason for removal were recorded and used in the calculation of growth rate and gain:feed ratio.

Statistical Analysis. All data were tested for normality using the PROC UNIVARIATE procedure of SAS (SAS Inst. Inc., Cary, NC). Morbidity and mortality data were not normally distributed and were analyzed using a Chi-square rank-based test (Steel and Torrie, 1980) using the PROC RANKS procedure of SAS. Data meeting the criteria for normality were analyzed using the PROC MIXED procedure of SAS. Data from both studies were analyzed as randomized complete block designs with pen as the experimental unit. The models included the effects of floor space, room, block, and replicate nested within block. Least-squares means were compared using the PDIFF and STDERR options of SAS.

RESULTS AND DISCUSSION

Floor Space Evaluation Periods. Growth performance data for the floor space evaluation periods of Study 1 and 2 are presented in Table 4. Live weight at the end of the floor space evaluation period was generally increased ($P < 0.05$) as floor space increased in Study 1 and 2. However, the within-pen coefficient of variation in live weight at the end of this period was not affected ($P > 0.05$) by floor space in either study, which suggests that floor space impacted every pig in the pen to a similar degree. The results of studies carried out in the nursery and grow-finish periods have also shown no impact of floor space on within-pen variation in live weight (Kornegay et al., 1985; Wolter et al., 2003; Peterson, 2004; Street and Gonyou, 2008). There was no effect ($P > 0.05$) of floor space on morbidity and mortality in Study 1. The incidence of morbidity and mortality was affected ($P < 0.05$) by floor space in Study 2, but there was no clear pattern to this relationship. A number of other studies have shown no effect of floor space on morbidity and mortality (NRC-89, 1984; Street and Gonyou, 2008) whilst others have shown an increase in morbidity and mortality as floor space decreased (Wolter et al., 2003; Peterson, 2004). Nevertheless, many floor space studies have not been large enough to detect commercially significant differences between floor space treatment levels.

In Study 1, overall ADG and ADFI increased as floor space increased (17.9 and 14.4% difference between the highest and lowest floor space treatment levels, respectively), and the difference between treatment levels was greatest between the lowest two treatment levels. In Study 2, there was a quadratic relationship ($P < 0.05$) between floor space and overall ADG and ADFI. As floor space increased, overall ADG and ADFI increased (42.1 and 28.6% difference in ADG and ADFI between the highest and lowest floor space treatment levels, respectively). In both studies, G:F was reduced ($P < 0.05$) for the lowest two treatment levels compared to the other three, however, the differences between treatment levels were much larger in Study 2 than Study 1 (18.2 and 4.0% difference in G:F between the highest and lowest floor space treatment level in Study 1 and 2, respectively).

Comparing the growth performance results of these studies to results of historical studies is difficult due to the short time period (i.e., 4-week study period) over which the current studies were carried out. Most historical studies have been carried out over several weeks (typically a minimum of 8 weeks) using floor spaces based on body weight at the end of the study period. Therefore, floor spaces were less restricting at the start than at the end of the study. The floor spaces in the current studies were selected to cover the range typically used in commercial production and were calculated to have the same equivalent *k* values at the end of week 2 of each 4-week study period. As a result, the lowest 3 or 4 treatment levels in these studies could have been restricting growth at the start of the study. Equivalent *k* values for the lowest to highest floor space treatment levels at the start of the study were 0.025, 0.032, 0.039, 0.046, and 0.052 in Study 1 and 0.023, 0.029, 0.034, 0.041, and 0.047 in Study 2. Thus, these studies would be expected to have larger decreases in performance with reducing floor space than studies with longer study periods that did not restrict growth until much later in the study period. Two other studies have been conducted over a 4-week period and compared pigs housed at 0.25 and 0.56 m^2/pig with initial live weights of ~35 kg (Hyun et al., 1998a; Hyun et al., 1998b). Hyun et al. (1998a) reported a 15.7 and 10.0% reduction in ADG and G:F ratio, respectively, for pigs housed at 0.25 m^2/pig (k = 0.017) compared to 0.56 m^2/pig (k = 0.038), with no difference in ADFI between treatment levels. Hyun et al. (1998b) reported a 16.4, 6.0, and 10.3% reduction in ADG, ADFI, and G:F ratio for pigs housed at 0.25 m^2/pig (k = 0.017) compared to 0.56 m^2/pig (k = 0.039), respectively. These results are comparable to Study 1, but the reduction in ADG, ADFI, and G:F ratio reported in Study 2 are much larger. All other studies carried out in the grow-finish period were carried out over longer study periods (Table 3) and, therefore, are difficult to compare to the current studies. It is also unclear if imposing immediate floor space restrictions, as in some of the treatment levels in the current studies, and not allowing the pigs to grow into the floor space restriction has an effect on the growth performance response to floor space. Future research should be aimed at determining the effect of the degree of initial floor space restriction on the growth performance response to floor space.

The current studies were designed to evaluate floor space treatment levels with similar *k* values across studies. This was done using the projected average live weight at the end of week 2 of each study in order to have a similar floor space restriction at the midpoint of the floor space evaluation periods. However, most other studies have calculated *k* values using the end of study live weight in order to represent the greatest degree of floor space restriction. Using the average live weight at the end of the floor space evaluation period, equivalent *k* values of the lowest to highest floor space treatment levels were 0.016, 0.020, 0.025, 0.029, and 0.033 in Study 1 and 0.018, 0.023, 0.028, 0.033, and 0.038 in Study 2. The larger reductions in ADG, ADFI, and G:F ratio as floor space decreased in Study 2 compared to Study 1 suggest that a single *k* value cannot be used to predict the floor space required for maximum growth rate from weaning to market. However, pigs from Study 1 were re-allotted to Study 2. Therefore, many of the pigs used in Study 2 had already experienced a floor space restriction. It is possible that a previous floor space restriction would cause pigs to have a larger response to a subsequent floor space restriction, which would explain some of the differences in the results of Study 1 and Study 2. Conversely, a previous floor space restriction could lessen the growth performance response to subsequent floor space restrictions. Brumm et al. (2001) investigated the interaction of nursery and grow-finish floor space and reported no significant interactions, which suggests that previous floor space does not affect the growth performance response to subsequent floor space. However, additional research should be carried out to validate these findings.

Another factor that was different between Study 1 and Study 2 that could have influenced the results was environmental temperature. Over the 4-week study periods, the high in room temperature was over 29.4 °C (temperature at which water misters were activated) on 19 days during Study 2 and only on 1 day during Study 1. In addition, pen dimensions were adjusted to create the floor space treatment levels in both studies by moving adjustment gates off of the back wall towards the front of the pen. However, box feeders were located in the fence line towards the front half of the pen and could have significantly blocked the movement of air. As a result, pigs on the lower floor space treatment levels could have experienced reduced air flow. Also, water sprinklers were located in the back half of the pens. As a result, pigs housed at the lower floor spaces (0.21 and 0.27 m^2/pig in Study 1 and 0.35 m^2/pig in Study 2) had no access to the water mist, and pigs housed at 0.33 m^2/pig in Study 1 and 0.45 m^2/pig in Study 2 were only able to access approximately half of the area covered by the water misters. Combining all of these factors, the effective environmental temperatures at pig level could have been significantly different between floor space treatment levels. Collin et al. (2001a) housed individual pigs at temperatures ranging from 19 to 35 °C from an initial live weight of 15.5 kg over a 17-day period and concluded that growth rate and voluntary feed intake was generally reduced for pigs housed at temperatures above 25 °C. Several other studies have evaluated environmental temperature and have reported significant reductions in ADG and ADFI, with no effect on G:F ratio (Becker et al., 1992; Hyun et al., 1998b; Bellego et al., 2002). Other studies have shown a decline in G:F ratio as environmental temperatures increased (Collin et al., 2001b; White et al., 2008). Conversely, Witte et al. (2000) showed an improvement in G:F ratio when finishing pigs were housed at 32 compared to 18 °C . The effect of environmental temperature on feed efficiency probably depends on the amount of active heat dissipation (e.g., panting) required by pigs to regulate body temperature. Gehlbach et al. (1966) suggested that a temperature × floor space interaction for growth performance exists, but further research is needed to determine if a floor space × temperature interaction exists in a commercial production setting.

Subsequent Periods. Growth performance data for the subsequent periods of Study 1 and 2 are presented in Table 5. In Study 1, ADG did not differ ($P > 0.05$), ADFI generally increased ($P < 0.001$), and G:F ratio generally decreased ($P < 0.001$) as the previous floor space treatment level increased. In Study 2, ADG and G:F ratio were greater ($P < 0.05$) for the two lowest previous floor space levels than the other three treatment levels. ADFI increased linearly ($P < 0.001$) as previous floor space treatment level increased.

Compensatory growth has been defined as a period of "catch-up growth" in which an animal accelerates its growth following a period of restricted growth, usually due to reduced feed intake, in an attempt to reach the weight of animals whose growth was never reduced (Hornick et al., 2000; Lawrence and Fowler, 2002). By this definition, pigs on the lowest two floor space treatment levels in Study 2 experienced compensatory growth. Limited research has been carried out evaluating the effects of previous floor space on subsequent growth performance. Wolter et al. (2003) housed pigs at two floor spaces (0.315 and 0.630 m^2/pig) from weaning to either 12 or 14 weeks post-weaning and allowed all pigs 0.630 m^2/pig from the end of the floor space treatment to the end of test (~119 kg). Subsequent to the removal of the floor space treatments to the end of test, ADFI was not affected by previous floor space, but ADG and G:F ratio were increased for the lower initial floor space (0.315 m^2/pig). Interestingly, in the current studies and in that of Wolter et al. (2003), feed intake was not increased but feed efficiency was improved following a period of floor space restriction. Additional research should be conducted to further understand the effects of previous floor space on subsequent growth performance and carcass characteristics.

A number of other studies have evaluated the effects of a feed restriction on subsequent growth performance. Several studies have shown compensatory growth in pigs following a period of feed restriction, but the reason for the increase in growth is not clear. For pigs fed ad libitum following a period of feed restriction, some studies have reported an increase in feed intake with no difference in feed efficiency (Donker et al., 1986; Therkildsen et al., 2002), others have reported an increase in feed efficiency with no difference in feed intake (Prince et al., 1983; Kristensen et al., 2004), and one study has reported an increase in both feed intake and efficiency (Heyer and Lebret, 2007). Some research has suggested that the timing, duration, and intensity of feed restriction and the timing and duration of the subsequent period could impact growth performance (Prince et al., 1983; Therkildsen et al., 2002). This could explain some of the inconsistency in the results of previous studies. In addition, Mersmann et al. (1987) and Heyer and Lebret (2007) reported that restricted fed pigs had lower empty stomach weights than pigs fed ad libitum, however, the empty stomach weight of the restricted fed pigs increased at a faster rate in subsequent periods when they were fed ad libitum than pigs fed ad libitum the entire period. Consequently, gut capacity could also play a role in determining the feed intake during the subsequent period following a period of feed restriction. Thus, compensatory growth is a complex phenomenon that could be influenced by multiple factors.

CONCLUSIONS

Growth rate and feed intake generally increased as floor space was increased. Feed efficiency was reduced for pigs on the lowest two floor space treatment levels in each study. However, limited access to water sprinklers and restricted air flow for pigs on the lower floor space treatment levels could have influenced the results. Following a period of floor space restriction, feed efficiency improved for the lowest two floor space treatment levels in each study. These studies could not validate whether or not the floor space required for maximum growth rate increased proportionately with $BW^{0.67}$ as pigs increased in size and, therefore, this area should be a focus of future research.

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TABLES

Table 4. Least-squares means for the effect of floor space on the growth performance of pigs.

	Floor space level[1]						*P* - value			
Item	1	2	3	4	5	SEM	FS	Linear	Quad	Cubic
Number of pens	15	15	15	15	15					
Study 1										
Live weight, kg										
Start (week 6)	24.2	24.2	24.2	24.2	24.2	0.34	0.96	0.70	0.69	0.57
Week 8	34.5^{d}	35.4^{c}	35.7^{bc}	35.9^{ab}	36.2^{a}	0.35	0.001	0.001	0.01	0.08
End of test (week 10)	45.1^{e}	47.3^{d}	48.3^{c}	49.1^{b}	49.6^{a}	0.37	0.001	0.001	0.001	0.05
Coefficient of variation (within pen), %										
Start (week 6)	16.8	17.2	16.4	17.3	16.4	0.56	0.58	0.64	0.59	0.63
End of test (week 10)	12.6	12.8	12.3	12.9	12.7	0.46	0.91	0.83	0.90	0.99
Average daily gain, kg										
Start (week 6) to week 8	0.74^{d}	0.80^{c}	0.82^{bc}	0.84^{ab}	0.86^{a}	0.008	0.001	0.001	0.003	0.08
Week 8 to week 10	0.75^{e}	0.84^{d}	0.90^{c}	0.94^{b}	0.96^{a}	0.011	0.001	0.001	0.001	0.31
Overall (week 6 to week 10)	0.75^{e}	0.83^{d}	0.86^{c}	0.89^{b}	0.91^{a}	0.008	0.001	0.001	0.001	0.05
Average daily feed intake, kg										
Start (week 6) to week 8	1.35^{c}	1.42^{b}	1.42^{b}	1.43^{b}	1.48^{a}	0.023	0.001	0.001	0.68	0.02
Week 8 to week 10	1.57^{e}	1.73^{d}	1.79^{c}	1.84^{b}	1.91^{a}	0.044	0.001	0.001	0.001	0.03
Overall (week 6 to week 10)	1.45^{d}	1.58^{c}	1.61^{bc}	1.64^{b}	1.70^{a}	0.018	0.001	0.001	0.02	0.004
Gain:feed										
Start (week 6) to week 8	0.558^{c}	0.566^{bc}	0.577^{ab}	0.582^{a}	0.579^{ab}	0.0101	0.01	0.001	0.15	0.56
Week 8 to week 10	0.482^{b}	0.487^{b}	0.503^{a}	0.502^{a}	0.501^{a}	0.0075	0.001	0.001	0.07	0.41
Overall (week 6 to week 10)	0.513^{c}	0.523^{b}	0.535^{a}	0.537^{a}	0.535^{a}	0.0046	0.001	0.001	0.002	0.50
Morbidity and mortality, %	1.00	0.50	0.50	0.33	0.50	-	0.61	-	-	-
Study 2										
Live weight, kg										
Start (week 12)	60.8	60.8	60.9	60.9	60.8	0.56	1.00	0.86	0.85	0.83
Week 14	71.2^{c}	73.6^{b}	74.4^{b}	75.3^{a}	75.7^{a}	0.52	0.001	0.001	0.001	0.22
End of test (week 16)	77.4^{e}	82.3^{d}	85.9^{c}	87.6^{b}	89.4^{a}	0.69	0.001	0.001	0.001	0.26
Coefficient of variation (within pen), %										
Start (week 12)	9.9	9.6	11.0	9.6	10.0	0.46	0.07	0.79	0.34	1.00
End of test (week 16)	8.8	8.1	8.9	8.7	8.9	0.38	0.45	0.44	0.62	0.33
Average daily gain, kg										
Start (week 12) to week 14	0.74^{d}	0.91^{c}	0.97^{b}	1.03^{a}	1.06^{a}	0.021	0.001	0.001	0.001	0.10
Week 14 to week 16	0.44^{d}	0.62^{c}	0.82^{b}	0.87^{b}	0.97^{a}	0.044	0.001	0.001	0.001	0.72
Overall (week 6 to week 10)	0.59^{e}	0.77^{d}	0.89^{c}	0.95^{b}	1.02^{a}	0.019	0.001	0.001	0.001	0.21
Average daily feed intake, kg										
Start (week 12) to week 14	2.06^{c}	2.27^{b}	2.33^{b}	2.43^{a}	2.49^{a}	0.040	0.001	0.001	0.003	0.09
Week 14 to week 16	1.63^{e}	1.93^{d}	2.28^{c}	2.44^{b}	2.68^{a}	0.093	0.001	0.001	0.03	0.79
Overall (week 6 to week 10)	1.85^{e}	2.11^{d}	2.32^{c}	2.44^{b}	2.59^{a}	0.097	0.001	0.001	0.005	0.37
Gain:feed										
Start (week 12) to week 14	0.364^{c}	0.401^{b}	0.414^{ab}	0.425^{a}	0.428^{a}	0.0111	0.001	0.001	0.001	0.34
Week 14 to week 16	0.269^{c}	0.321^{b}	0.362^{a}	0.358^{a}	0.363^{a}	0.0180	0.001	0.001	0.001	0.31
Overall (week 6 to week 10)	0.322^{c}	0.364^{b}	0.387^{a}	0.391^{a}	0.394^{a}	0.0059	0.001	0.001	0.001	0.12
Morbidity and mortality, %	1.61^{a}	0.23^{ab}	0.00^{b}	0.00^{b}	1.15^{a}	-	0.003	-	-	-

[a,b,c,d,e] Means within a row with differing superscripts are significantly different ($P < 0.05$).

[1] Level 1 = 0.0195 $m^2/BW^{0.67}$; Level 2 = 0.0248 $m^2/BW^{0.67}$; Level 3 = 0.0301 $m^2/BW^{0.67}$; Level 4 = 0.0352$m^2/BW^{0.67}$; Level 5 = 0.0405 $m^2/BW^{0.67}$. Floor space levels were equivalent to 0.21, 0.27, 0.33, 0.39, and 0.44 m^2 in Study 1 and 0.35, 0.45, 0.54, 0.64, and 0.73 m^2 in Study 2 for levels 1, 2, 3, 4 and 5, respectively.

[2] Average live weights were calculated from a pen weight.

Table 5. Least-squares means for the effect of previous floor space on the subsequent growth performance of pigs.

	Previous floor space level[1,2]						*P* - value			
Item	1	2	3	4	5	SEM	FS	Linear	Quad	Cubic
Number of pens	15	15	15	15	15					
Study 1 (week 10 to week 12)										
Start live weight, kg[3]	45.1^{e}	47.3^{d}	48.3^{c}	49.1^{b}	49.6^{a}	0.37	0.001	0.001	0.001	0.05
End live weight, kg[3]	57.9^{d}	60.2^{c}	60.8^{b}	61.7^{a}	62.3^{a}	0.35	0.001	0.001	0.001	0.05
Overall average daily gain, kg	0.91	0.93	0.90	0.90	0.91	0.013	0.24	0.39	0.59	0.08
Overall average daily feed intake, kg	1.98^{c}	2.09^{b}	2.11^{b}	2.12^{ab}	2.16^{a}	0.035	0.001	0.001	0.02	0.02
Overall gain:feed ratio	0.459^{a}	0.445^{b}	0.430^{c}	0.428^{cd}	0.420^{d}	0.0091	0.001	0.001	0.05	0.68
Morbidity and mortality, %	0.34	0.33	0.00	0.17	0.34	-	0.68	-	-	-
Study 2 (week 16 to week 18)										
Start live weight, kg[3]	77.4^{e}	82.3^{d}	85.9^{c}	87.6^{b}	89.4^{a}	0.69	0.001	0.001	0.001	0.26
End live weight, kg[3]	91.1^{e}	95.9^{d}	98.6^{c}	100.4^{b}	102.2^{a}	1.63	0.001	0.001	0.001	0.16
Overall average daily gain, kg	1.09^{a}	1.08^{a}	1.02^{b}	1.02^{b}	1.03^{b}	0.026	0.001	0.001	0.08	0.22
Overall average daily feed intake, kg	2.47^{d}	2.58^{c}	2.62^{bc}	2.66^{ab}	2.72^{a}	0.158	0.001	0.001	0.27	0.24
Overall gain:feed ratio	0.446^{a}	0.423^{b}	0.390^{c}	0.386^{c}	0.380^{c}	0.0063	0.001	0.001	0.002	0.66
Morbidity and mortality, %	0.23	0.00	0.23	0.23	0.23	-	0.91	-	-	-

[a,b,c,d,e] Means within a row with differing superscripts are significantly different ($P < 0.05$).

[1] Level 1 = 0.0195 $m^2/BW^{0.67}$; Level 2 = 0.0248 $m^2/BW^{0.67}$; Level 3 = 0.0301 $m^2/BW^{0.67}$; Level 4 = 0.0352$m^2/BW^{0.67}$; Level 5 = 0.0405 $m^2/BW^{0.67}$. Floor space levels were equivalent to 0.21, 0.27, 0.33, 0.39, and 0.44 m^2 in Study 1 and 0.35, 0.45, 0.54, 0.64, and 0.73 m^2 in Study 2 for levels 1, 2, 3, 4 and 5, respectively.

[2] All pens had equal floor space from week 10 to week 12 post-weaning (0.53 m^2/pig) and from week 16 to week 18 post-weaning (0.73 m^2/pig).

[3] Average live weights were calculated from a pen weight.