Evaluating the removal of pigs from a group and subsequent floor space allowance on the growth performance of heavy-weight finishing pigs[1]

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ABSTRACT: A total of 1,092 finishing pigs (initially 36.3 kg) were used in a 117-d study to evaluate the impact of initial floor space allowance and removal strategy on the growth of pigs up to 140 kg BW. There were 4 experimental treatments with 14 pens per treatment. The first treatment provided 0.91 m² per pig (15 pigs/pen). The other 3 treatments initially provided 0.65 m² per pig (21 pigs/pen) with 3 different removal strategies. The second treatment (2:2:2) removed the 2 heaviest pigs from pens on d 64, 76, and 95 when floor space allowance was predicted to be limiting. Treatment 3 (2:4) removed the 2 heaviest pigs on d 76 and the 4 heaviest pigs on d 105. Treatment 4 (6) removed the heaviest 6 pigs on d 105. All pigs remaining in pens after removals were fed to d 117. Overall (d 0 to 117), pigs initially provided 0.91 m² of floor space had increased ($P < 0.05$) ADG compared to pigs in pens on the 2:4 or 6 removal strategy, but ADG was not different compared with pigs on the 2:2:2 removal strategy. Total BW gain per pen was greater ($P < 0.05$) for pens initially stocked at 0.65 m² compared to pens initially stocked at 0.91 m². Feed usage per pen was less ($P < 0.05$) for pens initially stocked at 0.91 m² compared to pens initially providing 0.65 m² of floor space and on removal strategies; however, feed usage per pig was greater ($P < 0.05$) for pigs initially stocked at 0.91 m² compared to pigs initially stocked at 0.65 m² and on removal strategies. Feed usage, on a pig or pen basis, was less ($P < 0.05$) for pigs on the 2:2:2 removal strategy compared to pigs on the 2:4 or the 6 removal strategy. Income over feed and facility cost (IOFFC) was less ($P < 0.05$) for pigs initially provided 0.91 m² compared to pigs initially provided 0.65 m² and on removal strategies. Also, IOFFC was less ($P < 0.05$) for pigs on the 2:2:2 compared to the 2:4 and 6 removal strategies. In conclusion, increasing the floor space allowance or the time points at which pigs are removed from the pen improved the growth of pigs remaining in the pen; however, IOFFC may be reduced because fewer pigs are marketed from each pen (pigs stocked at 0.91 m² throughout the study) or from reducing total weight produced (2:2:2 removal strategy).

INTRODUCTION

Reducing the variation in BW of pigs marketed to commercial abattoirs is a ubiquitous goal of swine producers because of the economic incentives tied to marketing animals within a specified weight range. One common practice is to market the heaviest pigs in a group prior to marketing the entire group. This provides additional time for lighter-weight pigs that remain to reach a more desirable BW.

Following the removal of pigs from a group, increased growth of the pigs remaining is typically observed (Woodworth et al., 2000; Jacela et al., 2009). DeDecker et al. (2005) concluded that the improved growth performance of pigs was the result of increased feed intake from increased pen resources that were provided after pigs within the group were removed. One resource that has clearly been shown to impact growth of finishing pigs is floor space allowance (Gehlbach et al., 1966; Jensen et al., 1973; Moser et

al., 1985). Gonyou et al. (2006) developed floor space prediction equations for ADG and ADFI on the basis of a review of published literature. A decade later it is still recognized as the most commonly used predictor of finishing pig growth based on floor space allowance because of its use of a percentage change in ADG and ADFI, which is easily translated across a wide variety of genetic, health, and environmental scenarios that can impact growth. Interestingly, these prediction equations were developed using previously published research that evaluated the influence of floor space allowance on pigs up to approximately 110 kg, which is well below current BW targets for finishing pigs.

The objectives of this study were to evaluate initial stocking density and marketing removal strategies on the growth of pigs remaining in the pen until market as well as the economic implications of the experimental treatments. Additionally, this study was designed to help validate whether the use of the prediction equations proposed by Gonyou et al. (2006) is applicable for heavier-weight finishing pigs.

MATERIALS AND METHODS

This experiment was conducted in a commercial wean-to-finish facility in central Iowa. This study was approved by and conducted in accordance with the guidelines of the Kansas State University Institutional Animal Care and Use Committee.

Experimental Design

The experiment was conducted as a generalized randomized design, with sex acting as a main factor and a total of 7 pens per experimental treatment randomly assigned within each sex, providing a total of 14 pens per experimental treatment. Four experimental treatments were compared: 1) initial floor space allowance of 0.91 m^2 (15 pigs/pen) with no pigs removed from pens, designed to provide enough space for pigs to be above their predicted requirement until 140 kg (control); 2) initial floor space allowance of 0.65 m^2, with the 2 heaviest pigs removed when average BW was high enough to drop the k coefficient below its predicted optimal threshold (0.0336; as calculated by the equation k = floor space, m^2/BW$^{0.67}$) proposed by Gonyou et al. (2006), with the average weights targeted being 83 kg (0.65 m^2), 97 kg (0.72 m^2), and 114 kg (0.80 m^2), respectively, which corresponded to removals conducted on d 64, 76, and 95 of the study (**2:2:2 strategy**); 3) initial floor space allowance of 0.65 m^2 with the 2 heaviest pigs removed at an average BW of 109 kg and the 4 heaviest pigs removed when average BW reached 127 kg with removals conducted on d 76 and 105 (**2:4 strategy**); and 4) initial floor space

Table 1. Removal strategies based on experimental treatments[1]

	Initial floor space, m^2			
	0.91	0.65	0.65	0.65
	Removal strategy[2]			
Day	None	2:2:2	2:4	6
d 0	0 (15)	0 (21)	0 (21)	0 (21)
d 64	0 (15)	2 (19)	0 (21)	0 (21)
d 76	0 (15)	2 (17)	2 (19)	0 (21)
d 95	0 (15)	2 (15)	0 (19)	0 (21)
d 105	0 (15)	0 (15)	4 (15)	6 (15)
d 117	15 (0)	15 (0)	15 (0)	15 (0)

[1]A total of 1,092 pigs (PIC 359 × Genetiporc F25 females; initial BW = 36.3 kg) were used in a 117-d study to determine the influence of initial floor space allowance and removal strategy on growth performance. There were either 15 or 21 pigs per pen and 14 pens (7 barrow and 7 gilt pens) per treatment.

[2]Pigs initially provided 0.65 m^2 of floor space were removed using 3 different strategies: 2:2:2 signifies pens where the 2 heaviest pigs on d 64, 76, and 95 were removed; 2:4 represents pens where the heaviest 2 pigs were removed on d 76 and the 4 heaviest pigs were removed on d 105; and 6 represents pens where the heaviest 6 pigs were removed on d 105. Values in parentheses represent the calculated number of pigs left following the experimental marketing strategies.

allowance of 0.65 m^2 with the 6 heaviest pigs removed when average BW reached 127 kg, which correlated to d 105 of the study (**6 strategy**). Table 1 provides a timeline of marketing events that occurred by experimental treatment throughout the length of the study. Prior to initiation of the study, all pens were stocked with 21 pigs (0.65 m^2). Pens were blocked by sex and were randomly allotted to treatments within each block. The number of pigs per pen was adjusted after allotment to experimental treatments to reflect the desired initial stocking density. Pigs were removed from pens assigned to treatment 1 to maintain similar initial BW and initial SD while adjusting group size down to 15 pigs per pen.

Animals

A total of 1,092 crossbred pigs (PIC 359 × Genetiporc F25; PIC, Hendersonville, TN; initial BW of 36.3 ± 1.2 kg) in 56 split-sex pens (barrows and gilts) were used in a 117-d study. Pigs were initially allotted to treatments approximately 10 wk postweaning.

Diets and Housing

The study was conducted in an insulated, tunnel-ventilated wean-to-finish barn. Pens contained fully slatted concrete floors and were 5.75 × 2.50 m (length × width). In the case of a pig removal due to illness or death, pen gates were adjusted to maintain the desired floor space allowance. The only changes in floor space that occurred were the changes consistent with the experimental removal strategies.

Table 2. Diet composition (as-fed basis)

Item	Dietary phase			
	1	2	3	4
BW range,	36 to 59	59 to 82	82 to 100	100 to 140
Ingredient, %				
Corn	55.22	59.62	61.54	63.39
Soybean meal, 46.5% CP	19.20	14.90	13.15	11.40
DDGS[1]	20.00	20.00	20.00	20.00
Fat[2]	3.50	3.50	3.43	3.35
Calcium carbonate	0.96	0.95	0.95	0.95
Sodium chloride	0.44	0.44	0.44	0.44
Lysine sulfate, 46.5% Lys	0.44	0.37	0.36	0.34
DL-Methionine	0.01	—	—	—
Phytase[3]	0.023	0.018	0.013	0.005
Copper sulfate	0.05	0.05	—	—
VTM premix[4]	0.15	0.15	0.12	0.12
Total	100.00	100.00	100.00	100.00
Calculated analysis				
SID AA,[5] %				
Lys	1.10	0.90	0.80	0.70
TSAA:Lys	58	58	58	58
Thr:Lys	62	62	64	68
Trp:Lys	18	18	18	18
NE, Mcal/kg	2.61	2.64	2.65	2.66
SID Lys:NE, g/Mcal	4.21	3.41	3.02	2.63
Ca, %	0.46	0.46	0.44	0.43
P, %	0.40	0.40	0.38	0.37
Available P, %	0.28	0.27	0.25	0.21

[1]Dried distillers grains with solubles.

[2]The source of fat was an animal vegetable blend.

[3]Optiphos (HuvePharma, St. Louis, Mo) provided 562, 438, 313, and 125 phytase units/kg of diet, releasing an estimated 0.11%, 0.10%, 0.07%, and 0.04% available P for phases 1, 2, 3, and 4, respectively.

[4]VTM = vitamin and trace mineral premix. The premix provided 14,595 mg Cu, 330 ppm I, 162,018 mg Fe, 44,555 mg Mn, 440 mg Se, 162,018 mg Zn, and 573 mg Co, 2,943,168 IU vitamin A, 738,548 IU vitamin D3, 14,698 IU vitamin E, 1,470 mg vitamin K, 2,205 mg riboflavin, 18,364 mg niacin, 11,023 mg pantothenic acid, and 14.70 mg B12 per kg of premix.

[5]SID = standardized ileal digestible.

Pigs were given ad libitum access to feed and water throughout the study. Pigs were fed common corn and soybean meal–based diets that contained 20% dried distillers grains with solubles and 3% added fat (Table 2). Diets were fed in 4 sequential phases from approximately 36 to 59, 59 to 82, 82 to 100, and 100 to 140 kg. Diets were formulated to meet or exceed NRC (2012) recommendations for the nutrient requirements of finishing pigs. The diets were formulated to contain 1.10%, 0.90%, 0.80%, and 0.70% standardized ileal digestible Lys in phases 1 through 4, respectively. Each pen was equipped with a 4-hole (SDI, Alexandria, SD) stainless-steel dry self-feeder with feed pan dimensions of 127 × 18 × 15 cm (length × width × height). To help maintain similar linear feeder space across initial floor space allowances, 1 feeder hole in pens stocked at 0.91 m^2 (15 pigs/pen; treatment 1) was blocked. This provided approximately 6.0 and 5.8 linear cm of trough space per pig for pens initially stocked at 0.91 and 0.65 m^2, respectively. All pens contained 1 pan waterer (53 × 20 cm).

Growth Measurements

All pigs were individually weighed at initiation of the study (d 0) and again on d 64, 76, 95, 105, and 117. Pen weights were also collected on the aforementioned days along with d 21 and 42. Individual weight information was used to identify the heaviest pigs in the pen to market on removal days, to calculate the variation of BW with pens throughout the study, and to evaluate ADG of pigs within pens when categorized into the light, medium, and heavy thirds of the pen. Pen weights along with feed disappearance were used to calculate ADG, ADFI, and G:F during each period.

Economic Calculations

Total weight gain per pen was calculated by subtracting the total pen weight on d 0 from the sum of BW from pigs marketed from the pen. The total weight gain per pig was calculated using the total weight gain per pen divided by the number of pigs marketed per pen. Revenue was calculated using a low ($0.99/kg) and high ($1.32 kg) base carcass price; then individual HCW for each pig marketed was calculated using a fixed yield percentage of 75%. To account for premiums and discounts associated with varying individual HCW, the following equation was used: $/Cwt, kg = (0.0001169532 × HCW, kg^3) − (0.0516996146 × HCW, kg^2) + (6.6397162094 × HCW, kg) − 257.58240, where Cwt is carcass weight. The premium/discount calculation was added to the base price to determine revenue per pig. The individual revenue per pig was summed for the number of pigs in a pen to calculate the revenue per pen. Low ($220.46/t) and high ($286.60/t) feed costs were used to calculate feed cost per pen and per pig on the basis of the observed feed intake. Finally, to calculate the income over feed and facility cost (**IOFFC**) the total feed cost and facility cost (assumed to be $0.11 per 0.69 m^2/d) were subtracted from the total revenue.

Statistical Analyses

Pig performance data were analyzed as a generalized randomized block design using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) with pen as the experimental unit and sex as the blocking factor. Growth performance within each time period was evaluated using the same statistical model design. Treatment means were analyzed using the LSMEANS statement, and protected pairwise comparisons were performed using the

Tukey-Kramer multiple-comparison adjustment. A pre-planned CONTRAST statement was used to compare the means of pigs initially provided 0.91 m^2 of floor space vs. pigs initially provided 0.65m^2 of floor space. Mortality and morbidity were not a normally distributed response; therefore, the GLIMMIX procedure with binomial distribution was used to evaluate treatment means. For BW categorization information, the RANK procedure of SAS was used to rank pigs within the pen into the lightest, medium, and heaviest thirds of the pen prior to each weigh period. The assigned rank was then used as a fixed effect in the model to evaluate the interactive and main effects of experimental treatment and BW category on ADG within each period. Results were considered significant at $P < 0.05$ and marginally significant at $P > 0.05$ and $P < 0.10$.

RESULTS AND DISCUSSION

Growth Performance

There were no sex by treatment interactions; therefore, only the main effects of sex and treatment will be discussed. The lack of interaction agrees with results of other researchers (Hugh and Reimer, 1967; Jensen et al., 1973; Hamilton et al., 2003; Peterson, 2004), who have also tested the potential for a sex × floor space interaction and did not observe a difference in response to floor space allowances between barrows and gilts.

From d 0 to 64, barrows had increased ($P < 0.001$; Table 3) ADG and ADFI compared to gilts, but G:F were similar. Barrows and gilts had similar ADG from d 64 to 76; however, barrows had increased ($P < 0.001$) ADFI and poorer ($P < 0.001$) G:F during this period. From d 76 to 95, barrows tended ($P < 0.098$) to have lower ADG and increased ($P = 0.068$) ADFI compared to gilts, which resulted in poorer ($P = 0.007$) G:F. Barrows had increased ($P = 0.018$) ADFI from d 95 to 105; however, ADG and G:F were similar between sexes. During the final period (d 105 to 117), barrows had lower ($P < 0.001$) ADG and ($P < 0.001$) G:F than gilts, but ADFI were not different. Overall (d 0 to 117), barrows had increased ($P < 0.002$) ADG and ADFI and poorer ($P < 0.001$) G:F compared to gilts. The differences in performance of gilts and barrows are similar to the differences in lean tissue deposition and maturity curves among sexes discussed by Cline and Richert (2001).

Initial BW on d 0 was similar across treatments (Table 4). One objective of this study was to use the information to validate whether the ADG and ADFI prediction equations developed by Gonyou et al. (2006) were applicable to heavy-weight finishing pigs. The allometric principle of these equations suggests that as BW increases, the pig's space requirement increases

Table 3. Main effects of sex on the growth of finishing pigs[1]

Period	Sex		SEM	Probability P
	Barrow	Gilt		
d 0 to 64				
ADG, kg	0.90	0.83	0.007	<0.001
ADFI, kg	2.16	1.95	0.020	<0.001
G:F	0.419	0.425	0.003	<0.138
d 64 to 76				
ADG, kg	0.99	1.01	0.013	<0.309
ADFI, kg	3.07	2.84	0.023	<0.001
G:F	0.322	0.356	0.004	<0.001
d 76 to 95				
ADG, kg	0.94	0.98	0.019	<0.098
ADFI, kg	2.99	2.93	0.026	<0.068
G:F	0.314	0.340	0.006	<0.007
d 95 to 105				
ADG, kg	0.85	0.86	0.032	<0.849
ADFI, kg	2.99	2.88	0.033	<0.018
G:F	0.283	0.298	0.010	<0.294
d 105 to 117				
ADG, kg	0.85	0.95	0.020	<0.001
ADFI, kg	3.12	3.01	0.046	<0.103
G:F	0.273	0.319	0.006	<0.001
d 0 to 117				
ADG, kg	0.91	0.88	0.005	<0.002
ADFI, kg	2.52	2.35	0.016	<0.001
G:F	0.360	0.375	0.002	<0.001

[1]A total of 1,092 pigs (PIC 359 × Genetiporc F25 females; initial BW = 36.3 kg) were used in a 117-d study to determine the influence of initial floor space allowance and marketing strategy on growth performance. There were either 15 or 21 pigs per pen and 28 pens per sex. No treatment × sex interactions were observed for growth performance.

at a rate of BW$^{0.67}$. This geometric principle was first applied to swine by Petherick and Baxter (1981), who found that as Large White × Landrace pigs grew, their length and height increased at a rate of BW0.33, thereby increasing the animal's surface area by the proportion of BW$^{0.67}$. Gonyou et al. (2006) predicted a broken-line requirement for space (on the basis of the allometric measurement of k = floor space, m^2/BW, kg0.67), where k = 0.0336 and is the optimal point where maximum ADG and ADFI are achieved, but when space is provided below that value, pigs have reduced ADG and ADFI. The treatments in the current study were designed to test this hypothesis. In treatment 1, pigs initially stocked at 0.91 m^2 should not have been limited on space on the basis of the prediction equations, up to 140 kg. Additionally, for pigs stocked at 0.65 m^2, if the 2 heaviest pigs are marketed when average BW reaches 83, 97, and 114 kg (2:2:2), then the pigs remaining in the pen should also achieve maximum ADG and ADFI. Meanwhile, the pigs initially stocked at 0.65 m^2 and marketed using more common industry practices of 2 removal points (2:4 removal strategy) or a single removal point (6 removal

Table 4. The effects of initial floor space and removal strategy on BW of finishing pigs[1]

	Initial floor space, m^2					
	0.91	0.65	0.65	0.65		Probability P, initial
	Marketing strategy[2]					
Item	None	2:2:2	2:4	6	SEM	floor space[3]
Avg BW of pen prior to removals, kg						
d 0	36.4	36.3	36.3	36.3	0.32	<0.835
d 64	93.7^a	92.0^{a,b}	91.3^b	91.6^{a,b}	0.62	<0.007
d 76	105.6^a	102.9^b	102.8^b	103.4^{a,b}	0.68	<0.002
d 95	125.5^a	119.9^b	118.7^b	121.3^b	0.79	<0.001
d 105	134.1^a	127.5^b	127.8^b	129.0^b	0.80	<0.001
d 117	144.8^a	138.4^b	135.5^b	135.0^b	1.00	<0.001
Avg BW of pigs removed, kg						
d 0	—	—	—	—	—	—
d 64	—	107.1	—	—	—	—
d 76	—	115.0	120.2	—	0.79	—
d 95	—	131.0	—	—	—	—
d 105	—	—	139.9	140.4	0.81	—
d 117	144.8^a	138.4^b	135.5^b	135.0^b	1.00	<0.001
Avg BW of pigs remaining in pen after removals, kg						
d 0	—	—	—	—	—	—
d 64	—	90.3	—	—	—	—
d 76	—	100.9	101.4	—	0.63	—
d 95	—	118.3	—	—	—	—
d 105	—	—	124.4	124.1	0.89	—
d 117	—	—	—	—	—	—
Avg BW of pigs at time of removal, kg	144.8^a	132.3^c	134.9^{b,c}	136.6^b	0.87	<0.001

$^{a–c}$Means without a common superscript letter differ ($P < 0.05$).

[1]A total of 1,092 pigs (PIC 359 × Genetiporc F25 females; initial BW = 36.3 kg) were used in a 117-d study to determine the influence of initial floor space allowance and removal strategy on growth performance. There were either 15 or 21 pigs per pen and 14 pens (7 barrow and 7 gilt pens) per treatment at the start of the trial.

[2]Pigs initially provided 0.65 m^2 of floor space were removed using 3 different strategies: 2:2:2 signifies pens where the 2 heaviest pigs on d 64, 76, and 95 were removed; 2:4 represents pens where the heaviest 2 pigs were removed on d 76 and the 4 heaviest pigs were removed on d 105; and 6 represents pens where the heaviest 6 pigs were removed on d 105.

[3]Initial floor space compares the mean of pigs initially provided 0.91 or 0.65 m^2.

strategy) will still have limited ADG and ADFI until the final marketing event occurs. Then for the final period (d 105 to 117), after all removal events have taken place, pigs remaining in pens initially provided 0.65 m^2 (2:2:2, 2:4, 6) should have enough space for ADG and ADFI to be similar to pigs initially stocked at 0.91 m^2.

From d 0 to 64, pigs initially provided 0.91 m^2 of floor space had greater ($P < 0.003$; Table 5) ADG and ADFI compared to pigs initially provided 0.65 m^2 of floor space, regardless of removal strategy, but G:F was not different between treatments. On d 64, the mean BW of pigs provided 0.91 m^2 of floor space was heavier ($P = 0.007$) than that of pigs initially provided 0.65 m^2 of floor space and on the 2:4 removal strategy.

The objective was to remove the first 2 heaviest pigs from pens on the 2:2:2 removal strategy when BW reached 83 kg. However, pigs were not removed until d 64 when average BW was 92 kg; therefore, a depression in ADG and ADFI was expected for pigs from 83 to 92 kg, and that is illustrated by the calculated k coefficients

listed in Table 6. The predicted reduction by Gonyou et al. (2006) in ADG and ADFI for this period was 1.4% and 4.9%, respectively. However, the observed reduction in ADG and ADFI between treatment pigs provided 0.91 and 0.65 m^2 was 3.4% and 5.1%, respectively. This suggests that the predicted outcomes were underestimated for ADG. Potter et al. (2010) reported similar findings when finishing pigs were stocked at 22, 24, 26, or 28 pigs per pen. However, the authors attributed the larger than predicted reduction in ADG to be from reduced trough space, which was confounded by the different group sizes. However, Thomas et al. (2015) concluded the same findings when evaluating floor space allowance effects on finishing pigs. The researchers controlled feeder space by adjusting gates to achieve floor space treatments, rather than group size. In both the aforementioned studies, reductions occurred prior to pigs reaching the calculated BW needed to reduce the coefficient k below the critical threshold expected to reduce ADG. That would suggest the breakpoint estimated

Table 5. The effects of initial floor space and removal strategy on the growth of finishing pigs[1]

	Initial floor space, m²					Probability P, Initial floor space[3]
	0.91	0.65	0.65	0.65		
	Marketing strategy[2]					
Item	None	2:2:2	2:4	6	SEM	
d 0 to 64						
Pigs per pen, n	15	21	21	21		
ADG, kg	0.89[a]	0.86[a,b]	0.85[b]	0.85[b]	0.010	<0.003
ADFI, kg	2.14[a]	2.03[b]	2.02[b]	2.03[b]	0.028	<0.001
G:F	0.418	0.426	0.424	0.419	0.004	<0.178
d 64 to 76						
Pigs per pen, n	15	19	21	21		
ADG, kg	1.03[a]	1.04[a]	0.94[b]	0.98[a,b]	0.019	<0.040
ADFI, kg	3.10[a]	2.96[b]	2.84[c]	2.91[b,c]	0.032	<0.001
G:F	0.334[a,b]	0.352[b]	0.332[a]	0.337[a,b]	0.005	<0.310
d 76 to 95						
Pigs per pen, n	15	17	19	21		
ADG, kg	1.03[a]	0.97[a,b]	0.93[b]	0.92[b]	0.027	<0.005
ADFI, kg	3.16[a]	2.94[b]	2.87[b]	2.88[b]	0.037	<0.001
G:F	0.326	0.332	0.323	0.320	0.008	<0.938
d 95 to 105						
Pigs per pen, n	15	15	19	21		
ADG, kg	0.86	0.92	0.89	0.75	0.046	0.890
ADFI, kg	3.03[a]	3.02[a]	2.93[a,b]	2.76[b]	0.046	0.024
G:F	0.283	0.305	0.305	0.270	0.014	0.545
d 105 to 117						
Pigs per pen, n	15	15	15	15		
ADG, kg	0.88	0.90	0.92	0.91	0.028	<0.340
ADFI, kg	3.20	3.04	3.03	2.98	0.066	<0.022
G:F	0.275	0.299	0.305	0.304	0.008	<0.005
d 0 to 117						
ADG, kg	0.92[a]	0.90[a,b]	0.88[b,c]	0.87[c]	0.008	<0.001
ADFI, kg	2.58[a]	2.40[b]	2.39[b]	2.39[b]	0.022	<0.001
G:F	0.358[c]	0.377[a]	0.370[a,b]	0.364[b,c]	0.002	<0.001

[a–c]Means without a common superscript letter differ ($P < 0.05$).

[1]A total of 1,092 pigs (PIC 359 × Genetiporc F25 females; initial BW = 36.3 kg) were used in a 117-d study to determine the influence of initial floor space allowance and removal strategy on growth performance. There were either 15 or 21 pigs per pen and 14 pens (7 barrow and 7 gilt pens) per treatment at the start of the trial.

[2]Pigs initially provided 0.65 m² of floor space were removed using 3 different strategies: 2:2:2 signifies pens where the 2 heaviest pigs on d 64, 76, and 95 were removed; 2:4 represents pens where the heaviest 2 pigs were removed on d 76 and the 4 heaviest pigs were removed on d 105; and 6 represents pens where the heaviest 6 pigs were removed on d 105.

[3]Initial floor space compares the mean of pigs initially provided 0.91 or 0.65 m².

by Gonyou et al. (2006) needed for maximal ADG is underestimated at $k = 0.0336$. The results reported from d 0 to 64 herein support the same conclusion; however, since the heaviest pigs on the 2:2:2 marketing strategy were removed and marketed after the time point when average BW was 83 kg (needed to keep $k \geq 0.0336$), it is unclear whether the higher than expected reduction in ADG is due to the critical threshold of 0.0336 underestimating the true threshold of the pig's space requirement or if the slope associated with the linear reduction in ADG, below the critical point, is underestimating the reduction in ADG when pigs were limited on floor space.

From d 64 to 76, pigs on the 2:4 removal strategy had decreased ($P < 0.006$) ADG compared to pigs initially

provided 0.91 m² of floor space and pigs initially provided 0.65 m² of floor space on the 2:2:2 removal strategy. This was expected since pigs on the 2:4 and 6 removal strategies were still stocked at 0.65 m², which was below their predicted space requirement. Additionally, ADFI was higher ($P < 0.019$) for pigs initially provided 0.91 m² of floor space compared to pigs initially provided 0.65 m² of floor space regardless of removal strategy. Pigs remaining in pens on the 2:2:2 removal strategy had increased ($P = 0.049$) ADFI compared to pigs on the 2:4 removal strategy. Feed efficiency was also increased ($P = 0.035$) for pigs on the 2:2:2 removal strategy compared to pigs on the 2:4 removal strategy. On d 76, mean BW of pigs provided 0.91 m² of floor space was heavier ($P < 0.033$)

Table 6. Calculated *k* coefficients based on floor space and removal strategy[1]

Calculated k coefficient[2]	Initial floor space, m²			
	0.91	0.65	0.65	0.65
	Marketing strategy[3]			
	None	2:2:2	2:4	6
d 0	0.0819 (0.91)	0.0586 (0.65)	0.0586 (0.65)	0.0586 (0.65)
d 64				
Prior to removals	0.0434 (0.91)	0.0314 (0.65)	0.0316 (0.65)	0.0315 (0.65)
After removals	—	0.0352 (0.72)	—	—
d 76				
Prior to removals	0.0401 (0.91)	0.0323 (0.72)	0.0292 (0.65)	0.0291 (0.65)
After removals	—	0.0363 (0.80)	0.0326 (0.72)	—
d 95				
Prior to removals	0.0357 (0.91)	0.0324 (0.80)	0.0293 (0.72)	0.0261 (0.65)
After removals	—	0.0372 (0.91)	—	—
d 105				
Prior to removals	0.0342 (0.91)	0.0353 (0.91)	0.0279 (0.72)	0.0251 (0.65)
After removals	—	—	0.0359 (0.91)	0.0360 (0.91)
d 117	0.0325 (0.91)	0.0335 (0.91)	0.0339 (0.91)	0.0340 (0.91)

[1]A total of 1,092 pigs (PIC 359 × Genetiporc F25 females; initial BW = 36.3 kg) were used in a 117-d study to determine the influence of initial floor space allowance and removal strategy on growth performance. There were either 15 or 21 pigs per pen and 14 pens (7 barrow and 7 gilt pens) per treatment at the start of the trial.

[2]The constant coefficient *k* is calculated as $k = $ floor space, $m^2/BW^{0.67}$. Coefficients in bold represent values below the predicted critical threshold of $k = 0.0336$ predicted by Gonyou et al. (2006) as the required amount of space needed to maximize ADG and ADFI.

[3]Pigs initially provided 0.65 m² of floor space were removed using 3 different strategies: 2:2:2 signifies pens where the 2 heaviest pigs on d 64, 76, and 95 were removed; 2:4 represents pens where the heaviest 2 pigs were removed on d 76 and the 4 heaviest pigs were removed on d 105; and 6 represents pens where the heaviest 6 pigs were removed on d 105. Values in parentheses represent the floor space allowance (m²) pigs remaining in pens were provided based on initial floor space and marketing strategy.

than that of pigs on the 2:2:2 and 2:4 removal strategies. The fact that pigs remaining in pens on the 2:2:2 removal strategy had similar ADG during this period as pigs provided 0.91 m² of floor space suggests that relieving stocking pressure and providing additional floor space resulted in improvements in gain. Interestingly, by the end of the period their calculated *k* coefficient (0.0323) was still below their predicted need, but it did not seem to affect their gain. Also, ADFI of pigs remaining in pens on the 2:2:2 removal strategy was improved compared that of pigs on the 2:4 removal strategy, suggesting that providing additional floor space to the pigs remaining in the pen changed their feeding behavior. This has previously been reported by Augspurger et al. (2000), who found that removing pigs from pens caused changes in feeding behavior to be more like that of pigs in intact pens of the same group size. But in the current study, pigs remaining in pens on the 2:2:2 removal strategy did not consume as much as pigs initially provided 0.91 m² of floor space. This may be because the heaviest pigs were removed from the pen on d 64, which reduced the voluntary feed intake of the pigs remaining below that of pigs in intact pens provided 0.91 m² of floor space.

From d 76 to 95, pigs initially provided 0.91 m² of floor space had increased (*P* < 0.046) ADG compared to pigs on the 2:4 and 6 removal strategies. Additionally, pigs provided 0.91 m² of floor space had increased

(*P* < 0.001) ADFI compared to pigs initially provided 0.65 m² regardless of the removal strategy. Feed efficiency was similar regardless of treatment. During this period, it was expected that pigs remaining in pens on the 2:4 removal strategy would have improved ADG and ADFI compared to pigs on the 6 removal strategy, but that was not observed. Although they were still below their predicted space requirement to reach maximal ADG and ADFI, these pigs performed similarly to those on the 6 removal strategy who had less space (*k* coefficient 0.0326 vs. 0.0291 for pigs on the 2:4 and 6 removal strategies, respectively). On d 95, pigs provided 0.91 m² had heavier (*P* < 0.002) mean BW compared to pigs initially provided 0.65 m², regardless of removal strategy.

From d 95 to 105, pigs remaining in pens on the 2:2:2 removal strategy had marginally significantly increased ADG (*P* = 0.054) compared to pigs on the 6 removal strategy. Average daily feed intake was greater (*P* < 0.001) for pigs initially provided 0.91 m² or on the 2:2:2 removal strategy compared to pigs on the 6 removal strategy. Feed efficiency was similar regardless of experimental treatment. The importance of space for late finishing pigs was most evident during this period where pigs on the 6 removal strategy, who were still stocked at 0.65 m² and had greatly decreased ADG and ADFI compared to the other treatments. On d 105, average BW of pigs provided 0.91 m² of floor

space was heavier ($P < 0.001$) than that of pigs initially provided 0.65 m^2, regardless of removal strategy.

During the final period from d 105 to 117, after all removal strategies were completed, ADG and ADFI were similar regardless of treatment. This suggests that removing pigs and providing additional floor space was useful in recapturing ADG and ADFI back to levels similar to that of pigs maintained with adequate floor space. Feed efficiency was marginally significantly ($P < 0.070$) higher for pigs remaining in pens on the 2:4 and 6 removal strategies compared to pigs initially provided 0.91 m^2 of floor space. That is not surprising considering that the mean BW of pigs provided 0.91 m^2 of floor space was heavier ($P < 0.001$) on d 117 than that of pigs initially provided 0.65 m^2 of floor space, regardless of removal strategy.

Over the entire length of the study, from d 0 to 117, pigs provided 0.91 m^2 of floor space had greater ($P < 0.002$) ADG compared to pigs on the 2:4 and 6 removal strategies. Also, pigs on the 2:2:2 removal strategy had increased ($P = 0.018$) ADG compared to pigs on the 6 removal strategy. Pigs provided 0.91 m^2 had greater ($P < 0.001$) ADFI compared to pigs initially provided 0.65 m^2, regardless of removal strategy. Pigs on the 2:2:2 removal strategy had improved ($P < 0.001$) G:F compared to pigs initially provided 0.91 m^2 of floor space or pigs on the 6 removal strategy. Additionally, pigs on the 2:4 removal strategy had improved ($P = 0.029$) G:F compared to pigs initially provided 0.91 m^2 of floor space. Pigs initially provided 0.91 m^2 of floor space had heavier ($P < 0.001$) average BW at removal compared to pigs initially provided 0.65 m^2, regardless of removal strategy. Also, pigs on the 2:2:2 removal strategy had lighter ($P < 0.005$) average BW at removal compared to pigs on the 6 removal strategy.

Growth performance results from the current study agree with previous research examining the impact of removals on finishing pig growth performance (Woodworth et al., 2000; DeDecker et al., 2005; Jacela et al., 2009) in the sense that removing heavy-weight pen mates from a pen results in the remaining pigs having increased ADG and ADFI compared to pigs in intact pens. Interestingly, Bates and Newcomb (1997) and Woodworth et al. (2000) observed no impact of pig removal on the G:F of those animals remaining. Alternatively, DeDecker et al. (2005) observed an improvement in feed efficiency for pigs remaining in pens after the removals were conducted. Also, Jacela et al. (2009) observed improved feed efficiency for pigs remaining in pens after removals occurred compared to intact pens. Chapple (1993) hypothesized that the improvements in performance of pigs in smaller group sizes may be due to biological and hormonal changes that increase protein deposition and correspondingly

feed efficiency compared to commercially reared pigs in larger group environments. However, in the case of most removal studies, the heaviest pigs are the animals removed, suggesting that the difference in BW of the pigs remaining in the pen after removals occur may be the driver of the differences in feed efficiency that are observed. In the present study, overall G:F was poorer for pens initially provided 0.91 m^2 of floor space compared to pens on the 2:2:2 removal strategy. This difference could be attributed to the lower average BW of the pigs remaining in pens on the 2:2:2 removal strategy after removals occurred. If the feed efficiency values are adjusted to account for differences in final BW using the G:F adjustments proposed by Gonçalves et al. (2016), then there is a marginally significant ($P = 0.072$) improvement in G:F for pigs on the 2:2:2 removal strategy (treatment mean of 0.364) compared to pigs on the 6 marketing strategy (treatment mean of 0.356), but no other significant differences are observed, with treatment means of 0.357 and 0.360 for pigs initially provided 0.91m^2 of space and pigs on the 2:4 removal strategy, respectively.

The specific source of the improvements in ADG and ADFI following pig removals is still debatable. It has been said that the additional resources that become present after pig removals may be the leading factor. The most notable resources that increase are floor space, feeder space, and water space. On the basis of previous research, floor space appears to be the most definite factor that affects growth rate (Moser et al., 1985; Hamilton et al., 2003; Potter et al., 2010). However, some studies have confounded the effects of floor space and feeder space because they alter group size to achieve the desired floor space treatments rather than pen size, and the feeder or trough space is not controlled with the varying number of pigs within a pen. Therefore, it makes it harder to interpret the results and attribute the response to a single source. However, the current study reduced feeder space for pigs initially provided 0.91 m^2 of floor space to more closely mimic the trough space in pens initially provided 0.65 m^2. The available trough space in the current trial was between 5.8 and 6.0 cm/pig, which was higher than in previous research by Myers et al. (2012) that found trough space of 4.45 cm/pig was adequate for maximum growth; therefore, the trough space in the current study should have been enough to mitigate a trough space effect on the growth performance of the pigs across initial floor space treatments. Research examining the effects of water space (pigs per waterer) on growth is limited. In the current study, water space was not adjusted, but water pans were used that may have allowed more than 1 pig access to water at a time.

The available resources for the pigs within the study and the previous literature suggest that the increased floor

Table 7. The effects of initial floor space allowance and removal strategy on the within-pen BW variation of finishing pigs[1]

	Initial floor space, m^2					Probability P, initial floor space[3]
	0.91	0.65	0.65	0.65		
	Marketing strategy[2]				SEM	
Item	None	2:2:2	2:4	6		
CV of within-pen BW						
d 0	15.5	14.8	15.2	14.1	0.67	<0.295
d 64						
Prior to removals	12.6	11.1	11.6	11.8	0.56	<0.107
After removals	12.6[b]	10.0[a]	11.6[a,b]	11.8[a,b]	0.57	<0.041
d 76						
Prior to removals	11.5[b]	9.1[a]	10.8[a,b]	11.1[a,b]	0.56	<0.067
After removals	11.5[b]	8.5[a]	9.7[a,b]	11.1[b]	0.67	<0.012
d 95						
Prior to removals	9.8[b]	7.7[a]	9.0[a,b]	9.3[b]	0.42	<0.022
After removals	9.8[b]	7.1[a]	9.0[b]	9.3[b]	0.43	<0.007
d 105						
Prior to removals	9.3[b]	6.9[a]	8.2[a,b]	8.7[b]	0.40	<0.004
After removals	9.3[b]	6.9[a]	6.7[a]	7.0[a]	0.50	<0.001
d 117	9.0[b]	6.5[a]	6.5[a]	6.8[a]	0.40	<0.001
Morbidity and mortality,[4] %	2.86	2.89	3.61	5.40	1.324	<0.503

[a,b]Means without a common superscript letter differ ($P < 0.05$).

[1]A total of 1,092 pigs (PIC 359 × Genetiporc F25 females; initial BW = 36.3 kg) were used in a 117-d study to determine the influence of initial floor space allowance and removal strategy on growth performance. There were either 15 or 21 pigs per pen and 14 pens (7 barrow and 7 gilt pens) per treatment.

[2]Pigs initially provided 0.65 m^2 of floor space were removed using 3 different strategies: 2:2:2 signifies pens where the 2 heaviest pigs on d 64, 76, and 95 were removed; 2:4 represents pens where the heaviest 2 pigs were removed on d 76 and the 4 heaviest pigs were removed on d 105; and 6 represents pens where the heaviest 6 pigs were removed on d 105.

[3]Initial floor space compares the mean of pigs initially provided 0.91 or 0.65 m^2.

[4]Morbidity and mortality were analyzed as a binomial distribution and were based on the actual number of pigs marketed divided by initial pen inventories.

space for pigs remaining after removals is the most important source of the improved growth rates. Additionally, Scroggs et al. (2002) measured physiological and behavioral responses among pigs in pens that remained intact compared to pigs in pens after removals occurred and found no detectable differences among responses. This result suggests that physiological and biological differences did not result from the removal process, which also strengthens the argument that floor space is the dominant contributor to growth improvements.

On the basis of the current study and the growth data from d 0 to 64, it appeared that prediction equations for ADG and ADFI developed by Gonyou et al. (2006) for varying group sizes of finishing pigs on slatted floors slightly underestimated either the threshold of k needed to achieve maximum ADG and ADFI or the slope of the linear reduction in ADG and ADFI when the animal is below its critical space threshold. This result would support the conclusions of Potter et al. (2010) and Thomas et al. (2015), who observed reductions in ADG and ADFI prior to $k = 0.0336$. However, because the performance of pigs initially provided 0.91 m^2 and those pigs on the 2:2:2 removal strategy were similar over the entire study (d 0 to 117) and because growth was similar from d 105

to 117 across all treatments, it appears that the concept of an allometric requirement is valid and useful as a predictor of floor space needs of heavier-BW pigs.

Within-Pen BW Variation

On d 0, the within-pen BW variation was similar (Table 7) across treatments. On d 64, prior to removing the heaviest 2 pigs from treatment 2, within-pen BW variation was similar across treatments, but after the removals occurred, the within-pen BW variation of pigs remaining in pens on the 2:2:2 removal strategy was less ($P = 0.029$) than that of pigs in pens initially provided 0.91 m^2 of floor space. On d 76, prior to removing the 2 heaviest pigs from pens on the 2:2:2 and the 2:4 removal strategies, within-pen BW variation was less ($P = 0.030$) for pens on the 2:2:2 removal strategy compared to pens initially providing 0.91 m^2 of floor space. After the removals occurred, BW CV numerically decreased for pigs remaining in pens on the 2:2:2 and 2:4 removal strategies, but only the 2:2:2 removal strategy CV was significantly less ($P = 0.004$) than that of pigs in pens initially provided 0.91 m^2 of floor space. On d 95 prior to removals, the 2:2:2 removal strategy pigs had less ($P <$

Table 8. The effects of initial floor space and removal strategy on ADG of BW groups (light, medium, or heavy pigs within pens)[1]

Initial floor space, m²	Marketing strategy[2]	BW group[3]	d 0 to 64	d 64 to 76	d 76 to 95	d 95 to 105	d 105 to 117
0.91	None	Light	0.82	0.98	1.00	0.88	0.81
0.91	None	Medium	0.88	1.03	0.98	0.93	0.94
0.91	None	Heavy	0.97	1.02	1.02	0.87	0.87
0.91, no. of pigs per pen			15	15	15	15	15
0.65	2:2:2	Light	0.81	1.03	0.98	0.90	0.92
0.65	2:2:2	Medium	0.87	1.02	1.00	0.93	0.93
0.65	2:2:2	Heavy	0.91	1.06	0.99	0.95	0.90
0.65, no. of pigs per pen			21	19	17	15	15
0.65	2:4	Light	0.82	0.89	0.88	0.84	0.92
0.65	2:4	Medium	0.84	0.94	0.94	0.86	0.94
0.65	2:4	Heavy	0.91	0.97	0.96	0.87	0.94
0.65, no. of pigs per pen			21	21	19	19	15
0.65	6	Light	0.80	0.91	0.93	0.76	0.94
0.65	6	Medium	0.86	0.96	0.95	0.74	0.94
0.65	6	Heavy	0.92	0.98	0.92	0.75	0.84
0.65, no. of pigs per pen			21	21	21	21	15
SEM			0.04	0.027	0.045	0.057	0.085
Interaction					Probability P		
Treatment × BW group			<0.048	<0.347	<0.085	<0.511	<0.099
Main effects							
Treatment			<0.022	<0.001	<0.064	<0.085	<0.602
BW group			<0.001	<0.001	<0.055	<0.665	<0.026

[1]A total of 1,092 pigs (PIC 359 × Genetiporc F25 females; initial BW = 36.3 kg) were used in a 117-d study to determine the influence of initial floor space allowance and removal strategy on growth performance. There were either 15 or 21 pigs per pen and 14 pens (7 barrow and 7 gilt pens) per treatment.

[2]Pigs initially provided 0.65 m² of floor space were removed using 3 different strategies: 2:2:2 signifies pens where the 2 heaviest pigs on d 64, 76, and 95 were removed; 2:4 represents pens where the heaviest 2 pigs were removed on d 76 and the 4 heaviest pigs were removed on d 105; and 6 represents pens where the heaviest 6 pigs were removed on d 105.

[3]Pigs were ranked within pen as either light, medium, or heavy weight prior to each growth period for evaluation.

0.040) within-pen BW variation compared to pigs on the 6 removal strategy and pigs initially provided 0.91 m² of floor space. After removals occurred on d 95, pigs remaining in pens on the 2:2:2 removal strategy had less ($P < 0.024$) within-pen BW variation than pigs initially provided 0.91 m² of floor space or pigs on the 2:4 and 6 removal strategies. By d 105, prior to removals, pigs remaining in pens on the 2:2:2 removal strategy had less ($P < 0.016$) within-pen BW variation than pigs initially provided 0.91 m² of floor space or pigs on the 6 removal strategy. After removals occurred, all pigs in treatments initially providing 0.65 m² had less ($P < 0.005$) within-pen BW variation compared to pigs initially provided 0.91 m² of floor space. This was still evident on d 117, when within-pen variation was greater ($P < 0.003$) for pens initially providing 0.91 m² of floor space compared to pens initially providing 0.65 m² of floor space.

DeDecker et al. (2005) concluded that BW variation within pen was reduced with the removal of the heaviest pigs, but the rate of reduction was dependent on the number of pigs removed and the time of measure after removals. Previous work by DeDecker et al. (2002) concluded that removing the heaviest 25% of the pen reduced within-pen BW variation, but by 21 d postremoval the BW variation was similar regardless of removal strategy. In the current study, it appeared that removing 2 pigs per pen, or approximately 10% of the pen, was successful at reducing within-pen BW variation, and the reductions in variation were still evident up to 19 d after the removals occurred. Interestingly, after removing 2 pigs from pens on the 2:4 removal strategy on d 76, within-pen variation was not reduced enough to be different from that of pens initially providing 0.91 m² of floor space or pens on the 6 removal strategy (treatments without removals); this suggests that as BW increases, more pigs must be removed to significantly decrease the weight variation. Regardless, after all 6 pigs were removed from pens (approximately 30% of the pen) on treatments initially providing 0.65 m² of floor space, the BW variation within the pen was reduced below that of

intact pens initially providing 0.91 m². This information agrees with the previous reports of DeDecker et al. (2005) that within-pen BW variation is reduced when the heaviest pigs in a pen are removed but the degree of reduction is dependent on the number of pigs removed and their BW at time of removal.

BW Categories within Pen

From d 0 to 64, there was a BW category × treatment interaction ($P = 0.048$; Table 8) for ADG. This was due to a greater ADG in the heavy-weight pigs initially provided 0.91 m² of floor space compared to heavy-weight pigs initially provided 0.65 m² of floor space, whereas growth rates of the light- and medium-BW pigs were similar across initial floor space treatments. From a space standpoint it would be sensible to hypothesize that the heavier pigs in the pen would become limited on floor space before the lighter-weight pigs. The data set from the first growth period (d 0 to 64) supports that hypothesis; however, this warrants further investigation to understand if BW rank interacts with floor space allowance. From d 64 to 76, individual pig weights suggested no BW category × treatment interaction; however, light-weight pigs had lower ($P < 0.001$) ADG compared to medium- and heavy-weight pigs. From d 76 to 95, there was a marginally significant BW group × treatment interaction ($P = 0.085$) that was mainly the result of light-weight pigs in pens on the 2:4 removal strategy having lower ADG than light-weight pigs initially provided 0.91 m² of floor space or light-weight pigs on the 2:2:2 removal strategy. No interaction of BW group × treatment or main effect of BW group was observed from d 95 to 105, but from d 105 to 117 there was a marginally significant BW group × treatment interaction ($P = 0.099$) because light-weight pigs provided 0.91 m² of initial floor space had lower ADG compared to light-weight pigs on other floor space and removal strategy treatments. Also, there was a BW group effect ($P = 0.026$) from d 105 to 117 because medium-BW pigs had the greatest ADG compared to light- and heavy-weight pigs within pens regardless of treatment.

Economic Implications

Total BW gain per pen was less ($P < 0.001$; Table 9) for pens initially providing 0.91 m² of floor space per pig compared to pens initially providing 0.65 m² of floor space per pig. This was expected because there were fewer pigs per pen in pens initially providing 0.91 m² of floor space. Alternatively, total weight gain per pig was greater ($P < 0.001$) for pigs initially provided 0.91 m² of floor space compared to pigs initially provided 0.65 m² of floor space. Additionally, weight gain per pig was less ($P = 0.003$) for pigs on the 2:2:2 removal strategy com-

pared to pigs on the 6 removal strategy. Similar to total BW gain per pen, revenue expressed on a pen basis was less ($P < 0.05$) for pens initially providing 0.91 m² of floor space because there were fewer pigs in the pen; however, when expressing the revenue on a pig basis, it was greater for pigs initially provided 0.91 m² of floor space compared to pigs initially provided 0.65 m² of floor space. Pigs on the 2:2:2 removal strategy had less ($P < 0.001$) revenue, either on a pen or pig basis, than pigs on the 2:4 and 6 removal strategies. Feed usage and feed cost per pen were less ($P < 0.001$) for pens initially providing 0.91 m² of floor space compared to pens initially providing 0.65 m² of floor space; however, per pig feed usage and feed cost were greater ($P < 0.001$) for pigs initially provided 0.91 m² of floor space compared to pigs initially provided 0.65 m² of floor space. Pigs in pens on the 2:2:2 removal strategy had less ($P < 0.015$) feed usage and reduced feed cost, either on a pen or pig basis, than pigs on the 2:4 and 6 removal strategies. Income over feed and facility cost was the least ($P < 0.001$), either on a pen or pig basis, for pigs initially provided 0.91 m² of floor space. Pigs on the 2:2:2 removal strategy had less ($P < 0.021$) IOFFC when revenue was high and feed cost was low compared to pigs on the 6 removal strategy.

Powell et al. (1993) developed an economic model to determine the optimal stocking density for growing and finishing pigs and concluded that providing floor space below the requirement of pigs needed to achieve maximal ADG and ADFI was the most economic. The current study agrees with the previous work of Powell et al. (1993) indicating that providing enough space for pigs to achieve their maximum ADG was not the most economic. However, using removal strategies is beneficial to increase profitability. DeDecker et al. (2005) and Jacela et al. (2009) observed reductions in feed usage when removal strategies were utilized, and the same conclusion was derived in the present trial. Additionally, utilizing removal strategies reduces weight discounts associated with marketing pigs outside the specified packer weight range (Jacela et al., 2009). The study herein also illustrates that performing removals to provide the floor space allowance needed to reach maximum ADG (2:2:2) is still not economical because the weight of pigs that were removed is lighter than the specified packer weight range. The economic scenarios conclude that using the 2:4 and 6 marketing strategies is the most economic and that as feed cost increases and revenue decreases, the feed savings from the 2:4 marketing strategy are more profitable; alternatively, if revenue increases, keeping pigs within pens longer is more cost-effective. Therefore, this study concludes that improvements in ADG and ADFI can be achieved by pigs remaining in the pen following planned removals; however, it is important to consider the economic

Table 9. The effects of initial floor space and removal strategy on economic parameters[1]

	Initial floor space, m²					Probability P, initial floor space[3]
	0.91	0.65	0.65	0.65		
	Marketing strategy[2]					
Item	None	2:2:2	2:4	6	SEM	
Total weight gain, kg/pen	1,603[b]	2,032[a]	2,077[a]	2,083[a]	27.4	<0.001
Total weight gain,[4] kg/pig	110.1[a]	99.8[c]	103.1[b,c]	104.7[b]	0.93	<0.001
Revenue[5]						
Low, $/pen	1,705[c]	2,177[b]	2,247[a]	2,281[a]	10.6	<0.001
High, $/pen	2,243[c]	2,844[b]	2,931[a]	2,977[a]	15.2	<0.001
Low,[6] $/pig	113.69[a]	103.65[c]	106.98[b]	108.64[b]	0.51	<0.001
High,[6] $/pig	149.55[a]	135.45[c]	139.57[b]	141.78[b]	0.74	<0.001
Feed usage, kg/pen	4,537[c]	5,349[a]	5,566[b]	5,730[b]	46.1	<0.001
Feed usage, kg/pig	307.7[a]	269.5[c]	282.8[b]	292.4[b]	2.75	<0.001
Feed cost[7]						
Low, $/pen	1,000[c]	1,179[b]	1,227[a]	1,263[a]	10.2	<0.001
High, $/pen	1,300[c]	1,533[b]	1,595[a]	1,642[a]	13.2	<0.001
Low,[8] $/pig	66.69[a]	56.16[c]	58.43[b]	60.16[b]	0.51	<0.001
High,[8] $/pig	86.70[a]	73.01[c]	75.97[b]	78.21[b]	0.67	<0.001
IOFFC,[9] $/pen						
Low Rev-High Feed	152.15[b]	390.75[a]	398.57[a]	386.45[a]	10.51	<0.001
Low Rev-Low Feed	452.25[b]	744.50[a]	766.71[a]	765.45[a]	8.94	<0.001
High Rev-High Feed	690.15[b]	1058.59[a]	1083.06[a]	1082.37[a]	11.93	<0.001
High Rev-Low Feed	990.15[c]	1412.38[b]	1451.19[a,b]	1461.37[a]	11.48	<0.001
IOFFC,[9] $/pig						
Low Rev-High Feed	10.14[b]	18.60[a]	18.98[a]	18.40[a]	0.56	<0.001
Low Rev-Low Feed	30.15[b]	35.45[a]	36.51[a]	36.45[a]	0.47	<0.001
High Rev-High Feed	46.00[b]	50.41[a]	51.57[a]	51.54[a]	0.62	<0.001
High Rev-Low Feed	66.01[c]	67.26[b,c]	69.10[a,b]	69.59[a]	0.58	<0.001

[a–c]Means without a common superscript letter differ ($P < 0.05$).

[1]A total of 1,092 pigs (PIC 359 × Genetiporc F25 females; initial BW = 36.3 kg) were used in a 117-d study to determine the influence of initial floor space allowance and removal strategy on growth performance. There were either 15 or 21 pigs per pen and 14 pens (7 barrow and 7 gilt pens) per treatment.

[2]Pigs initially provided 0.65 m² of floor space were removed using 3 different strategies: 2:2:2 signifies pens where the 2 heaviest pigs on d 64, 76, and 95 were removed; 2:4 represents pens where the heaviest 2 pigs were removed on d 76 and the 4 heaviest pigs were removed on d 105; and 6 represents pens where the heaviest 6 pigs were removed on d 105.

[3]Initial floor space compares the mean of pigs initially provided 0.91 or 0.65 m².

[4]Total weight gain per pig marketed.

[5]Revenue was based on a low ($0.99/kg) or high ($1.32/kg) base price. To mimic premium and discounts associated with specific carcass weights (Cwt), a fixed yield of 75% was used to calculate HCW of pigs marketed, and the following regression equation was used to adjust premiums and discounts for varying HCW: premium/discount, $/Cwt, kg = $0.0001169532 \times HCW^3 - 0.0516996146 \times HCW^2 + 6.6397162094 \times HCW - 257.58240$.

[6]Revenue per pen divided by the initial placement of either 15 or 21 pigs per pen for pens initially stocked at 0.91 or 0.65 m², respectively.

[7]Based on average diet costs of $220.46/t for Low and $286.60/t for High.

[8]Feed cost per pen divided by the initial placement of either 15 or 21 pigs per pen for pens initially stocked at 0.91 or 0.65 m², respectively.

[9]Income over feed and facility costs: calculated as revenue − feed cost − facility cost. A fixed facility cost of $0.11 per 0.69 m²/d was used to calculate facility costs.

implications of removal strategies to determine the most profitable strategy. In addition, the current study illustrates that the prediction equations developed by Gonyou et al. (2006) are useful predictors of the impact of floor space allowance on growth of finishing pigs but may underestimate the true impact of space restriction.

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