Effects of space allowance and marketing strategy on growth performance of pigs raised to 165 kg

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ABSTRACT: A total of 976 pigs (PIC 327 × Camborough; PIC, Hendersonville, TN; initially 22.0 ± 1.53 kg body weight [BW]) were used in a 160-d growth study to evaluate the effects of increasing space allowance and varying marketing strategies on growth performance of pigs raised to market weights of ~165 kg. Pens of pigs were blocked by location within the barn and allotted to one of six treatments. Pen served as the experimental unit, and there were eight replicate pens per treatment. The first four treatments consisted of increased initial stocking density and did not utilize topping strategies: (1) 14 pigs/pen (1.17 m^2/pig), (2) 17 pigs/pen (0.97 m^2/pig), (3) 20 pigs/pen (0.82 m^2/pig), and (4) 23 pigs/pen (0.71 m^2/pig). The fifth treatment began with 25 pigs/pen (0.66 m^2/pig) and had four marketing events with the heaviest 3 pigs/pen removed on day 93, and additional pigs removed to a common inventory of 20 pigs/pen on day 122 and 17 pigs/pen on day 147 with final marketing on day 160. The final treatment began the experiment with 23 pigs/pen (0.71 m^2/pig) with three marketing events to achieve a common inventory of 20 pigs/pen on day 108 and 17 pigs/pen on day 147. Pens of pigs were weighed and feed disappearance measured on days 0, 55, 93, 108, 122, 135, 147, and 160. As space allowance decreased from 1.17 to 0.71 m^2/pig via increased initial pen inventory (treatments 1 to 4), overall average daily gain (ADG) and average daily feed intake (ADFI) decreased (linear, $P < 0.001$), while gain:feed ratio (G:F) did not differ ($P > 0.05$). The treatments with multiple marketing events were compared with each other and with the treatment that began with 0.71 m^2/pig and only marketed once at the end of the study. Overall ADG and ADFI were not different ($P > 0.05$) among these three treatments. Marketing pigs three or four times improved ($P < 0.05$) G:F compared with the treatment that began the study with 0.71 m^2/pig and marketed only once. Reducing floor space allowance for heavy weight pigs decreased intake, which resulted in lower growth rate and final BW, with these reductions occurring before the critical *k*-value was reached. Total weight gain per pen was maximized with the lowest space allowance and the multiple marketing treatments. Thus, strategic use of pig removals prior to final marketing may allow producers to maximize both number of pigs and total weight marketed through a barn when feeding to heavy weights.

Key words: growth, heavy pigs, market weight, pig removal, space requirements

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INTRODUCTION

In the United States, average pig market weight increased over the past several years and averaged 128 kg during 2019 (USDA, 2020). The long-term pattern of increased market weight is expected to continue in the future. Literature regarding the growth and management of heavy pigs is limited, especially that which evaluates pigs from modern genetic lines housed in a commercial environment. Wu et al. (2017) outlined the current understanding of raising pigs to heavier market weights and identified animal housing, specifically floor space allowance, as a critical area of future research.

Space allowance is an important production input that impacts pig performance, welfare, and producer profitability. Space requirements are often referenced in regard to the *k*-value established by Gonyou et al. (2006), where k is an allometric function expressed as k = area, m^2 /$BW^{0.67}$, kg. The authors estimated every decrease in k <0.0336, or the critical *k*-value, will result in decreased average daily gain (ADG) and average daily feed intake (ADFI) for grow-finish pigs (Gonyou et al., 2006). Flohr et al. (2016) concluded that the *k*-value defined by Gonyou et al. (2006) was a valid predictor of the impacts of space allowance on growth performance for pigs raised up to 140 kg. However, others have observed that growth performance is reduced and that the *k*-value may underestimate the space allowance (Potter et al., 2010; Thomas et al., 2017; Carpenter et al., 2018).

In addition to adjusting the initial stocking density of a pen, topping (or removal of the heaviest pigs from the pen prior to final marketing) can be implemented to provide finishing pigs increased floor space. The additional space in the pen and time before harvest allow the remaining pigs to reach target market weight and provide increased product consistency at the packing plant, resulting in fewer packer discounts due to variation (Woodworth et al., 2000). Further, these remaining pigs may demonstrate compensatory growth after the period of limited feed intake (FI) due to restricted feeder access caused by increased pen stocking density (Flohr et al., 2016). Ultimately, topping strategies are used to maximize facility space while minimizing reduced performance from high pen stocking rates.

Data demonstrating the impact of stocking density and marketing strategy are limited when pigs are fed to heavy weights. Therefore, the objective of this study was to examine the effects of floor space allowance and marketing strategy on the growth performance of pigs raised to 165 kg and evaluate growth performance at heavy weights.

MATERIALS AND METHODS

General

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The trial was conducted at a commercial research facility (Holden Farms, Inc., Northfield, MN). The barn was double-curtain sided with completely slatted concrete flooring and deep pits for manure storage. Each pen (3.05 × 5.48 m) was equipped with adjustable gates and contained a three-hole, dry feeder with each space being 38 cm wide (Thorp Equipment, Inc., Thorp, WI) and a double-sided pan waterer. The feeder and waterer are excluded from the floor space allowance calculation. Feed additions were delivered and recorded using a robotic feeding system (FeedPro; ComDel Innovation., Willmar, MN).

Live Animal Management

A total of 976 pigs (PIC 327 × Camborough; PIC, Hendersonville, TN; initially 22.0 ± 1.53 kg body weight [BW]) were used in the 160-d growth study. Pens were blocked by location within the barn and randomly assigned within block to one of six space allowance treatments. The first four treatments consisted of increased initial stocking density and did not utilize multiple marketing strategies: (1) 14 pigs/pen (1.17 m^2/pig), (2) 17 pigs/pen (0.97 m^2/pig), (3) 20 pigs/pen (0.82 m^2/pig), and (4) 23 pigs/pen (0.71 m^2/pig). The fifth treatment began with 25 pigs/pen (0.66 m^2/pig) and had four marketing events with the heaviest 3 pigs/pen removed on day 93, and additional pigs marketed to achieve common inventories of 20 and 17 pigs/pen on days 122 and 147, respectively. Final marketing occurred on day 160. The final treatment began the experiment with 23 pigs/pen (0.71 m^2/pig) with three marketing events to achieve a common inventory of 20 pigs/pen on day 108 and 17 pigs/pen on day 147 with final marketing on day 160. Marketing events were planned to correspond to when the weight of pigs in the pen would reach their respective *k*-value.

Pens of pigs were weighed and feed disappearance was measured approximately every 12 to 14 days to determine ADG, ADFI, and gain:feed ratio (G:F). In the case of a pig removal due to illness or death, pen gates were adjusted to maintain the desired floor space allowance. An additional response criteria of adjusted G:F was calculated to adjust to a common BW of 166 kg by using an adjustment of 0.005 for every 0.45 kg difference in BW on day 160 according to Gaines et al. (2012).

Pigs were given ad libitum access to feed and water throughout the study. Diets were corn- and soybean meal-based and included 30% to 40% corn distillers dried grains with solubles until the final dietary phase. Diets were fed in six sequential phases from ~21 to 32, 32 to 54, 54 to 83, 83 to 105, 105 to 122, and 122 kg BW until the end of the study (Table 1). Diets were formulated to meet or exceed NRC (2012) requirement estimates for finishing pigs and contained 1.18%, 1.03%, 0.88% and 0.78%, 0.76%, 0.77% standardized ileal digestible lysine in phases 1 through 6, respectively, based on a required SID Lys:net energy value. All diets were fed in meal form and manufactured at a commercial feed mill (Blooming Prairie, MN).

Statistical Analysis

Data were analyzed as a randomized complete block design using the PROC GLIMMIX procedure of SAS (version 9.4, SAS Institute, Inc., Cary, NC) with the fixed effect of treatment, random effect of block, and pen as the experimental unit. There were eight replicate pens per treatment. Linear and quadratic contrasts were applied for the four treatments without multiple marketing events, and PROC IML provided coefficients to account for unevenly spaced floor space allowances. Preplanned contrast statements were designed to compare the two multiple removal strategies to each other and to the treatment initially stocked at 0.71 m^2/pig with only one marketing event. Results were considered significant at $P \le 0.05$.

RESULTS

Adjusting Floor Space Via Initial Pen Stocking Inventory

The four treatments that utilized fixed pen inventories to decrease floor space per pig were evaluated using linear and quadratic contrast statements (Table 2). There was no evidence for floor space differences on days 0 or 55 BW ($P > 0.192$); however, BW was decreased as floor space was reduced (linear, $P < 0.008$) on days 93, 108, 122, 135, 147, and 160.

As floor space allowance was decreased from 1.17 to 0.71 m^2/pig, ADG was also reduced (linear, $P < 0.028$) during days 0 to 55, 55 to 93, 108 to 122, 122 to 135, and for the overall period. ADFI decreased (linear, $P < 0.027$) as floor space allowance was reduced during all growth periods and for the overall experimental period. This occurred prior to many treatments reaching the critical *k*-value (Table 3). There was no evidence that decreasing floor space allowance impacted G:F during any intermediate growth period ($P > 0.080$); however, G:F and adjusted G:F were improved with decreasing space allowance during the overall period (quadratic, $P = 0.042$).

Although removals numerically increased with decreasing floor space, high variation resulted in no evidence ($P > 0.131$) for differences in removals with the static inventory treatments. Furthermore, total weight gain was increased ($P = 0.001$) on a pen basis and decreased ($P = 0.001$) on a per pig basis as stocking density increased.

Adjusting Floor Space Via Pig Removal

There was no evidence that BW ($P > 0.05$) was different on day 0, 93, 122, 135, 147, or 160 among the treatments that incorporated multiple marketing events in comparison to each other and to the treatment that was stocked at 0.71 m^2/ pig with only one marketing event. However, on day 108, pigs initially allowed 0.71 m^2/pig with only one marketing event were heavier ($P < 0.05$) than pigs initially allowed 0.66 m^2/pig with multiple marketing events, with pens initially stocked at 0.71 m^2/pig with multiple marketing events intermediate.

From days 0 to 93 (premarketing period), there was no evidence ($P > 0.05$) that ADG, ADFI, or

Table 1. Diet composition, as-fed

	BW range, kg					
Item	21 to 32	32 to 54	54 to 82	82 to 105	105 to 122	122 to 167
Ingredient, %						
Corn	39.39	47.08	55.49	60.74	60.52	82.76
Soybean meal, 46.5% crude protein	17.40	9.80	6.58	6.52	6.92	14.62
Corn distillers dried grains with solubles	40.00	40.00	35.00	30.00	30.00	---
Monocalcium phosphate, 21% P	0.20	0.15	0.10	0.10	0.09	0.50
Limestone	1.30	1.25	1.20	1.20	1.15	0.78
Salt	0.50	0.50	0.50	0.50	0.50	0.50
Copper sulfate	0.03	0.03	0.03	—	—	—
L-Lysine HCl	0.58	0.63	0.55	0.45	0.40	0.30
DL-Methionine	0.02	—	—	—	--	0.05
L-Threonine	0.09	0.09	0.07	0.05	0.04	0.12
L-Tryptophan	0.04	0.05	0.04	0.04	0.04	0.03
Vitamin and trace mineral premix[1]	0.25	0.20	0.20	0.15	0.10	0.10
Phytase[2]	0.08	0.08	0.10	0.10	0.10	0.10
Sodium metabisulfite	0.15	0.15	0.15	0.15	0.15	0.15
Total	100	100	100	100	100	100
Calculated analysis						
Standardized ileal digestible (SID) AA, %						
Lysine	1.18	1.03	0.88	0.78	0.76	0.77
Isoleucine:lysine, %	63	59	60	64	67	61
Leucine:lysine, %	166	172	183	194	203	149
Methionine:lysine, %	31	30	32	34	36	34
Methionine + cystine:lysine, %	56	56	60	64	67	61
Threonine:lysine, %	62.0	60.7	60.7	63.0	64.9	67.6
Tryptophan:lysine, %	18.3	18.3	17.8	19.3	19.7	19.7
Val:lysine, %	74	72	75	80	84	70
Net energy[3], kcal/kg	2,385	2,434	2,469	2,487	2,487	2,533
SID lysine:net energy ratio, g/mcal	4.94	4.24	3.56	3.15	3.04	3.06
Crude protein, %	22.9	20.1	17.8	16.7	16.9	14.0
Ca, %	0.63	0.58	0.54	0.53	0.51	0.45
P, %	0.50	0.46	0.42	0.40	0.40	0.42
Available P, %	0.40	0.37	0.35	0.33	0.32	0.29

[1]Provided 1,543,220 IU vitamin A from vitamin A acetate; 440,920 IU vitamin D from vitamin D3; 8,047 IU vitamin E from DL-α-tocophorol acetate; 882 mg menadione from menadione nicotinamide bisulfite; 8 mg B12 from cyanocobalamin; 14,991 mg niacin from niacinamide; 6614 pantothenic acid from d-calcium panthothenate; 1,984 mg riboflavin from crystalline riboflavin; 3 g Cu from copper sulfate; 160 mg I from calcium iodate; 31 mg Fe from ferrous sulfate; 3 g Mn from manganese sulfate; 120 mg Se from sodium selenite; and 31 g Zn from zinc sulfate per kilogram of premix.

[2] Ronozyme HiPhos (GT) 2700 (DSM Nutritional Products, Parsippany, NJ) provided 1,102,300 phytase units (FTU)/kg of product with a release of 0.10% available P.

[3] NRC (2012).

G:F was different between the two treatments with multiple marketing events or compared with the pens stocked at 0.71 m^2/pig.

From days 93 to 108, after pens originally stocked at 0.66 m^2/pig had their first marketing event, there was no evidence for differences in ADG or ADFI ($P > 0.05$) between the two treatments with multiple marketing events or compared with the pens initially stocked at 0.71 m^2/pig. However, after the heaviest pigs were marketed from the pens initially stocked at 0.66 m^2/pig, these pigs demonstrated improved ($P < 0.05$) G:F compared with both treatments initially stocked at 0.71 m^2/pig, regardless of marketing strategy, which were not different from each other ($P > 0.05$).

The treatment originally stocked at 0.71 m^2/pig with three marketing events was topped to 20 pigs for the first time on day 108, yet there was no evidence for differences ($P > 0.05$) in ADG, ADFI, or G:F from days 108 to 122 compared with other multiple marketing treatments.

The next marketing event occurred for the pens initially allowed 0.66 m^2/pig, which were marketed for the second time to 20 pigs/pen on day 122. From days 122 to 135, both treatments with multiple marketing events had similar ($P > 0.05$) ADG, but both

Table 2. Effects of space allowance and marketing strategy on growth performance of pigs raised to 160 kg[1]

Initial floor space, m^2/pig	1.17	0.97	0.82	0.71	0.66	0.71			
Final floor space, m^2/pig	1.17	0.97	0.82	0.71	0.97	0.97		*P*-value	
Initial pigs/pen	14	17	20	23	25	23		Floor space[4]	
Marketing events	1	1	1	1	4[2]	3[3]	SEM	Linear	Quadratic
Item									
BW, kg									
Day 0	22.2	22.1	22.2	22.2	21.8	21.9	0.57	0.994	0.926
Day 55	69.2	67.9	67.4	67.8	66.3	66.1	1.06	0.192	0.464
Day 93	108.7	106.2	105.5	104.7	103.3	103.5	1.49	0.008	0.610
Day 108[a]	120.2	116.6	116.1	115.6	111.9	113.9	1.40	0.005	0.276
Day 122	134.5	130.4	129.8	128.6	125.7	125.1	1.45	0.002	0.397
Day 135	147.7	143.1	142.1	140.2	137.7	137.8	1.34	0.001	0.527
Day 147	159.5	155.1	154.2	151.5	150.8	149.8	1.46	0.001	0.814
Day 160	171.1	167.2	165.5	162.6	160.3	161.7	1.59	0.001	0.925
Days 0 to 55									
ADG, kg	0.85	0.83	0.82	0.83	0.81	0.80	0.011	0.028	0.138
ADFI, kg	1.93	1.86	1.83	1.86	1.80	1.79	0.031	0.022	0.108
G:F	0.443	0.447	0.448	0.446	0.450	0.446	0.0039	0.452	0.467
Days 55 to 93									
ADG, kg	1.02	1.01	1.00	0.98	0.97	0.98	0.019	0.006	0.474
ADFI, kg	3.00	2.91	2.89	2.85	2.78	2.83	0.035	0.001	0.543
G:F	0.341	0.346	0.347	0.342	0.349	0.346	0.0048	0.614	0.108
Days 93 to 108									
ADG, kg	0.75	0.67	0.69	0.71	0.77	0.69	0.031	0.231	0.057
ADFI, kg	2.66	2.51	2.50	2.53	2.47	2.44	0.050	0.027	0.086
G:F[a,c]	0.283	0.268	0.275	0.281	0.311	0.280	0.0111	0.893	0.141
Days 108 to 122									
ADG, kg	1.02	0.95	0.94	0.93	0.97	0.95	0.023	0.005	0.342
ADFI, kg	3.59	3.26	3.26	3.19	3.24	3.25	0.059	0.001	0.054
G:F	0.285	0.291	0.289	0.290	0.299	0.293	0.0064	0.520	0.654
Days 122 to 135									
ADG, kg[a,b]	1.02	0.97	0.90	0.88	0.96	0.96	0.033	0.001	0.918
ADFI, kg	3.63	3.42	3.35	3.28	3.38	3.36	0.050	0.001	0.459
G:F	0.282	0.284	0.269	0.269	0.285	0.287	0.0079	0.080	0.496
Days 135 to 147									
ADG, kg[a,b,c]	0.98	1.00	1.00	0.91	1.09	1.00	0.028	0.165	0.052
ADFI, kg[a,b]	3.68	3.57	3.43	3.30	3.57	3.53	0.052	0.001	0.297
G:F[a,c]	0.267	0.280	0.291	0.277	0.306	0.284	0.0067	0.095	0.084
Days 147 to 160									
ADG, kg	0.90	0.93	0.87	0.84	0.86	0.98	0.047	0.145	0.183
ADFI, kg[b]	3.81	3.71	3.56	3.47	3.63	3.77	0.116	0.001	0.583
G:F	0.235	0.249	0.245	0.240	0.237	0.259	0.0076	0.588	0.138
Days 0 to 160									
ADG, kg	0.93	0.90	0.89	0.87	0.89	0.88	0.008	0.001	0.713
ADFI, kg	2.81	2.68	2.64	2.62	2.56	2.59	0.031	0.001	0.169
G:F[a,b,c]	0.329	0.335	0.336	0.333	0.348	0.340	0.0023	0.096	0.042
Adjusted G:F[5,a,b,c]	0.332	0.336	0.336	0.332	0.345	0.338	0.0021	0.907	0.034
Marketing period (Days 93 to 160)									
ADG, kg[a,b]	0.93	0.89	0.87	0.85	0.92	0.90	0.013	0.001	0.941
ADFI, kg	3.45	3.26	3.19	3.13	3.21	3.20	0.038	0.001	0.314
G:F[a,b]	0.270	0.275	0.274	0.271	0.288	0.281	0.0033	0.637	0.159

Table 2. Continued

Initial floor space, m²/pig	1.17	0.97	0.82	0.71	0.66	0.71			
Final floor space, m²/pig	1.17	0.97	0.82	0.71	0.97	0.97		*P*-value	
Initial pigs/pen	14	17	20	23	25	23		Floor space[4]	
Marketing events	1	1	1	1	4[2]	3[3]	SEM	Linear	Quadratic
Item									
Removals, %	2.6	7.2	7.3	5.8	7.8	7.4	2.4	0.182	0.131
Total weight gain, kg/pen	2,022	2,258	2,621	2,985	2,986	2,870	95.4	0.001	0.080
Total weight gain, kg/pig[a,b,c]	148	143	141	139	131	135	1.4	0.001	0.691

[a]Pigs stocked at 0.71 m²/pig with one marketing event vs. pigs initially stocked at 0.66 m²/pig with four marketing events are different ($P < 0.05$).

[b]Pigs stocked at 0.71 m²/pig with one marketing event vs. pigs initially stocked at 0.71 m²/pig with three marketing events are different ($P < 0.05$).

[c]Pigs stocked at 0.66 m²/pig with four marketing events vs. pigs initially stocked at 0.71 m²/pig three marketing events are different ($P < 0.05$).

[1]A total of 976 finishing pigs (initially 22.1 ± 1.53 kg) were used in a 160-day experiment to evaluate the effects of pig space allowance and marketing strategy on finishing pigs raised to heavier weights.

[2]Three of the heaviest pigs per pen were removed on day 93. The heaviest pigs in each pen were also removed to achieve a common pen inventory of 20 pigs/pen on day 122 and 17 pigs/pen on day 147.

[3]The heaviest pigs in each pen were removed on to reach a common pen inventory of 20 pigs/pen on day 108 and 17 pigs/pen on day 147.

[4] Treatments 1 through 4 were evaluated using the linear and quadratic contrasts.

[5] Calculated as adjusted G:F = 1/[(observed G:F) + ((22.7 − initial BW)× 0.005) + ((165.5 − final BW) × 0.005) according to an equation by Gaines et al. (2012).

demonstrated increased ($P < 0.05$) ADG compared with the treatment that allowed 0.71 m²/pig with only one marketing event at the end of the study. There was no evidence ($P > 0.05$) that ADFI or G:F differed from days 122 to 135 between these treatments.

There were no marketing events on day 135; however, pens initially stocked at 0.66 m²/pig that had two marketing events prior to that point in time demonstrated increased ($P < 0.05$) ADG from days 135 to 147 compared with both treatments that began with 0.71 m²/pig, regardless of marketing strategy. Pens that began with 0.71 m²/pig and had been marketed once up to this point also had increased ($P < 0.05$) ADG compared with their counterparts that were only marketed once at the end of the study. Although this response was not exhibited directly after the removal of the heaviest pigs for market, this appears to be a compensatory gain response. During days 135 to 147, both treatments with multiple marketing events had increased ($P < 0.05$) ADFI compared with the treatment with 0.71 m²/pig that had no pigs removed prior to the final marketing event, yet were not different from each other ($P > 0.05$). G:F was improved ($P < 0.05$) for pens of pigs initially stocked at 0.66 m²/pig that had been marketed twice compared with both pens initially stocked at 0.71 m²/pig, which were not different from each other ($P > 0.05$).

The last marketing events occurred for both multiple marketing treatments on day 147, at which point both treatments had 17 pigs/pen remaining. From days 147 to 160, there was no evidence of difference in ADG and G:F ($P > 0.05$). ADFI was increased ($P < 0.05$) for pens of pigs stocked at 0.71 m²/pig and marketed multiple times compared with pens of pigs only marketed once at the end of the study, yet similar ($P > 0.05$) to the other multiple marketing treatment. There was no evidence ($P > 0.05$) that pens of pigs allowed 0.71 m²/pig with no previous marketing events had different ADFI than those allowed 0.66 m²/pig but were marketed three times.

There was no evidence that overall ADG or ADFI differed among these three treatments ($P > 0.05$). G:F and adjusted G:F were improved ($P < 0.05$) for pigs initially stocked at 0.66 m²/pig and marketed four times compared with both treatments initially stocked at 0.71 m²/pig, regardless of marketing strategy. Additionally, overall G:F and adjusted G:F were improved ($P < 0.05$) for pigs that began at 0.71 m²/pig and were marketed three times compared with the treatment that also began at 0.71 m²/pig but only marketed at the end of the study.

Once marketing began on day 93, ADG and G:F were improved ($P < 0.05$) for the remainder of the trial (days 93 to 160) for both multiple marketing treatments compared with the 0.71 m²/pig allowance with only one marketing event at the end of the study, but were not different ($P > 0.05$) from each other.

Removals and total weight gain per pen did not differ between these three treatments ($P > 0.05$). However, total weight gain per pig was greater ($P < 0.05$) for pigs originally stocked at 0.71 m²/pig with only one marketing event at the end of the

Table 3. Determination of *k*-values for different space allocations and pig weights[1,2]

Initial floor space, m^2/pig	1.17	0.97	0.82	0.71	0.66	0.71
Final floor space, m^2/pig	1.17	0.97	0.82	0.71	0.97	0.97
Initial pigs/pen	14	17	20	23	25	23
Marketing events	1	1	1	1	4	3
Item						
Day 0						
BW, kg	22.2	22.1	22.2	22.1	21.8	21.9
m^2/pig	1.17	0.97	0.82	0.71	0.66	0.71
k-value[5]	0.1471	0.1215	0.1028	0.0896	0.0834	0.0903
Day 55						
BW, kg	69.2	67.9	67.4	67.8	66.3	66.1
m^2/pig	1.17	0.97	0.82	0.71	0.66	0.71
k-value	0.0686	0.0572	0.0489	0.0424	0.0403	0.0440
Day 93						
BW, kg	108.7	106.2	105.6	104.7	103.2	103.5
m^2/pig	1.17	0.97	0.82	0.71	0.66	0.71
k-value	0.0507	0.0424	0.0362	**0.0316**	**0.0300**	**0.0326**
m^2/pig after marketing	—	—	—	—	0.81	—
k-value after marketing	—	—	—	—	0.0364	—
Inventory after marketing	—	—	—	—	20.2	—
Day 108						
BW, kg	120.2	116.6	116.1	115.6	111.9	113.9
m^2/pig	1.17	0.97	0.82	0.71	0.81	0.71
k-value	0.0474	0.0398	0.0340	**0.0296**	0.0345	**0.0306**
m^2/pig after marketing	—	—	—	—	—	0.82
k-value after marketing	—	—	—	—	—	**0.0344**
Inventory after marketing	—	—	—	—	—	20
Day 122						
BW, kg	134.4	130.4	129.8	128.6	125.7	125.1
m^2/pig	1.17	0.97	0.82	0.71	0.81	0.82
k-value	0.0440	0.0370	**0.0315**	**0.0276**	**0.0319**	**0.0323**
m^2/pig after marketing	—	—	—	—	0.82	—
k-value after marketing	—	—	—	—	**0.0322**	—
Inventory after marketing	—	—	—	—	20	—
Day 135						
BW, kg	147.7	143.1	142.1	140.2	137.7	137.8
m^2/pig	1.17	0.97	0.82	0.71	0.82	0.82
k-value	0.0413	0.0347	**0.0297**	**0.0260**	**0.0303**	**0.0303**
Day 147						
BW, kg	159.4	155.1	154.2	151.5	150.7	149.8
m^2/pig	1.17	0.97	0.82	0.71	0.82	0.82
k-value	0.0392	**0.0329**	**0.0281**	**0.0247**	**0.0285**	**0.0286**
m^2/pig after marketing	—	—	—	—	0.97	0.97
k-value after marketing	—	—	—	—	**0.0335**	0.0337
Inventory after marketing	—	—	—	—	17	17
Day 160						
BW, kg	171.1	167.2	165.5	162.6	160.3	161.7
m^2, pig	1.17	0.97	0.82	0.71	0.97	0.97
k-value	0.0374	**0.0313**	**0.0268**	**0.0236**	**0.0322**	**0.0320**

[1]A total of 976 finishing pigs (22.1 ± 1.53 kg) were used in a 160-day experiment to evaluate the effects of pig space allowance and marketing strategy on growth performance of finishing pigs raised to heavy market weights.

[2]Values in bold represent *k*-values below the critical value of 0.0336 as described by Gonyou et al. (2006).

[3]Three of the heaviest pigs/pen were removed on day 93. The heaviest pigs were also removed to achieve a common pen inventory of 20 pigs/pen on day 122 and 17 pigs/pen on day 147.

[4]The heaviest pigs were removed to reach a common pen inventory of 20 pigs/pen on day 108 and 17 pigs/pen on day 147.

[5]Defined as A, $m^2 = k \times (BW^{0.67}, kg)$ as defined by Gonyou et al. (2006).

study compared with both multiple marketing treatments. Furthermore, marketing three times with initial stocking density of 0.71 m^2/pig increased ($P < 0.05$) total weight gain per pig compared with marketing four times.

Feed Intake and Growth Rate to 160 kg

Figures 1 and 2 depict BW and cumulative FI by day of experiment. Slight reductions in projected BW and FI observed at day 108 correspond to a porcine reproductive and respiratory syndrome virus outbreak. However, growth rate past current market weights and capacity for feed consumption was noteworthy. At ~155 kg, pigs were gaining 0.92 kg/d. From 22 to 160 kg, pigs consumed over 400 kg of feed per pig, with intake still increasing at the end of the experiment. Figures 3 and 4 depict ADG and ADFI by body weight, respectively. Growth rate appears to be maximized between 95 and 100 kg BW, but ADFI continued to increase through 165 kg.

DISCUSSION

Live market weights for swine increased over the past several decades and averaged 128 kg in 2019 (USDA, 2020). If historical trends continue, market weights in the United States could exceed 150 kg by 2050. Growth rate has also increased over time due to genetic selection and greater understanding of nutritional requirements (Tokach et al., 2016). Producers are motivated to increase market weight to dilute fixed facilities cost (Park and Lee, 2011).

Floor space allowance is an important metric to consider when raising pigs to heavy weights. Space is a complex parameter in swine production due to the inverse relationship between profitability and growth performance (Gonyou et al., 2006).

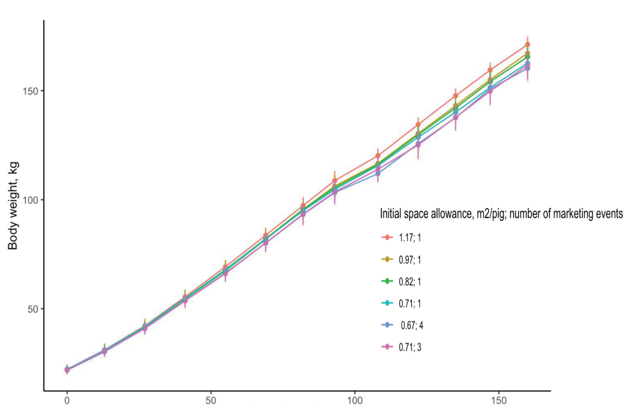

Figure 1. Body weight by day of experiment for six treatments differing in initial space allowance and marketing strategy. A total of 976 finishing pigs (22.1 ± 1.53 kg) were used in a 160-day experiment to evaluate the effects of pig space allowance and marketing strategy on growth performance of finishing pigs raised to heavy market weights.

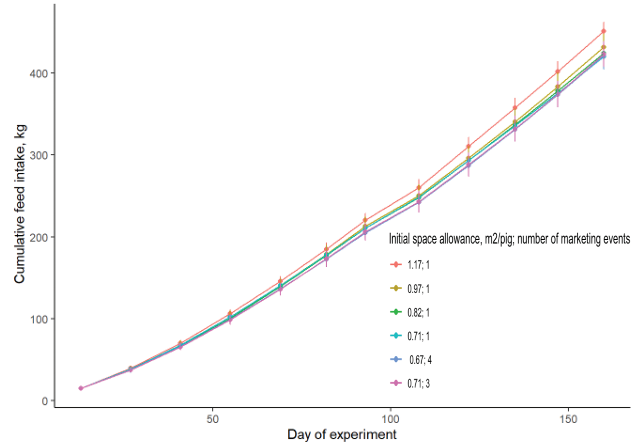

Figure 2. Cumulative feed intake by day of experiment for six treatments differing in initial space allowance and marketing strategy. A total of 976 finishing pigs (22.1 ± 1.53 kg) were used in a 160-day experiment to evaluate the effects of pig space allowance and marketing strategy on growth performance of finishing pigs raised to heavy market weights.

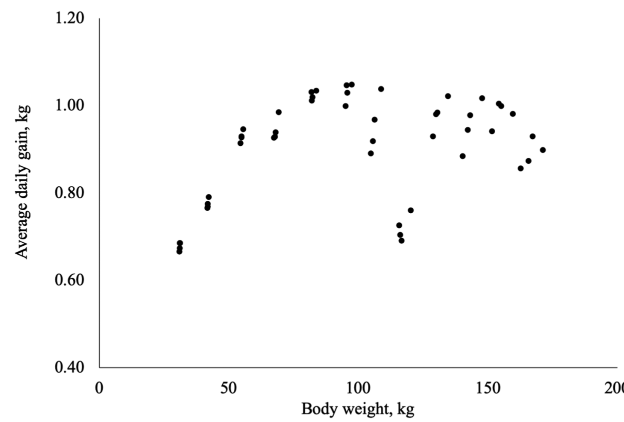

Figure 3. Average daily gain from 22 to 160 kg. Data represent the mean from the four treatments with static pen inventory (provided 0.71 to 1.17 m^2/pig).

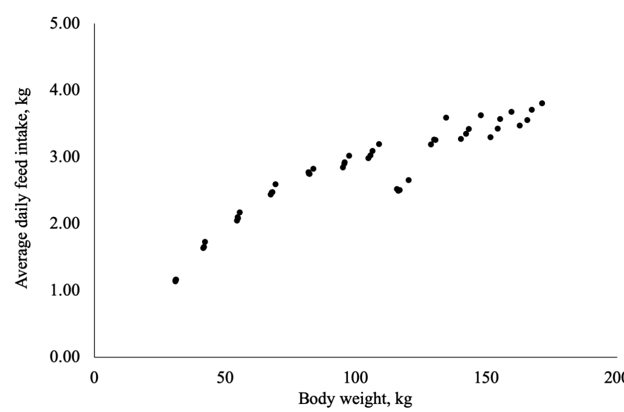

Figure 4. Average daily feed intake from 22 to 160 kg. Data represent the mean from the four treatments with static pen inventory (provided 0.71 to 1.21 m^2/pig).

A majority of the fundamental research regarding space requirements for grow-finish pigs was conducted several decades ago with different genetics and lighter market weights than modern production standards. The consistent finding from this literature is that floor space restriction decreases ADFI, which drives a reduction in ADG (NCR-89 Committee on Confinement Management of Swine, 1993; Brumm, 1996; Gonyou and Stricklin, 1998).

Using available literature, Gonyou et al. (2006) performed a meta-analysis to establish an equation (A, $m^2 = k \times [BW^{0.67}$, kg]) that describes pig BW as an allometric function by which ADG and ADFI may be reduced if the k-value is <0.0336, or the critical k-value. This equation is a useful tool for understanding the impact of space allowance on the growth performance of pigs raised in commercial environments. However, final BW in Gonyou et al. (2006) did not exceed 110 kg and, thus, the application of this equation may become limited as market weights continue to increase.

Recent research evaluating space allowance (either by changing pen inventory or adjustable gating) for pigs raised to modern market weights continues to report decreased growth rate as a consequence of reduced FI (Johnston et al., 2017; Thomas et al., 2017; Carpenter et al., 2018). Thomas et al. (2017) and Carpenter et al. (2018) reduced floor space in pens with fixed inventories and observed decreased ADG and ADFI, with these reductions occurring from ~70 kg BW, or prior to reaching the critical k-value. Body weight was used to calculate k-value for all weigh days in the present study (Table 3). Interestingly, ADG was decreased among static inventory treatments as early as d 55 (~67 kg BW) due to reduced FI as floor space decreased. This immediate impact was not anticipated given the k-value was >0.0336 for all treatments, with the exception of the pens providing 0.71 m^2/pig, which only would have been limited near the end of this period. The treatment that allowed 1.17 m^2 per pig was never below the critical k-value even at 171 kg. Treatments that provided 0.97, 0.82, or 0.71 m^2 for the entire experiment became limiting at 155, 130, and 105 kg, respectively. However, growth was impaired compared with the treatment with the greatest space allowance prior to reaching 105 kg during days 0 to 93. Thus, these results align with the aforementioned experiments (Thomas et al., 2017; Carpenter et al., 2018) and indicate the k-value may underestimate the point at which growth performance is compromised.

Economic response criteria were not evaluated in the current experiment due to the pigs being heavier than current packer specifications, yet total weight gain per pen was maximized at the lowest space allowance and the treatments with multiple marketing events. This response demonstrates that having more pigs in the pen or barn will consistently yield increased gross revenue strictly due to the quantity of pork produced, which is in agreement with findings by Flohr et al. (2016). They observed that income over fixed facilities cost was increased with increased stocking density. However, multiple marketing strategies can help reduce market weight variation (Flohr et al., 2016).

Unlike growth rate and FI, the effects of space allowance on gain efficiency in the literature are more variable. Several have reported no evidence for differences (Johnston et al., 2017; Thomas et al., 2017; Carpenter et al., 2018), while others observed decreased G:F as floor space becomes restricted (NCR-89 Committee on Confinement Management of Swine, 1993; M. C. Brumm and NCR-89 Committee on Management of Swine, 1996; Street and Gonyou, 2008). Possible mechanisms for decreased G:F accompanying floor space restriction include decreased protein deposition (Chapple, 1993), increased activity, and increased trips to the feeder in crowded pens (Shull, 2010). Further, G:F can be confounded with increased BW for pigs provided ample floor space. In the present study, there were negligible G:F effects observed during intermediate periods, yet overall G:F improved slightly with decreasing floor space. This was likely due to lower ending BW in crowded pens because G:F adjusted for BW was not different. When adjusted to a final body weight of 166 kg, G:F also improved slightly with restricted space allowance.

Johnston et al. (2017) conducted an experiment to evaluate the space requirement for heavy weight pigs and suggest that 0.98 m^2/pig is necessary for pigs weighing 130 kg due to little evidence of improved growth performance beyond this space allowance. The current data displayed continued linear improvement in ADG and ADFI up to 1.17 m^2/pig, suggesting the point at which floor space would no longer improve performance was not reached.

Other authors have studied increasing space allowance in late finishing with pig removal strategies, commonly referred to as topping (DeDecker et al., 2005; Jacela et al., 2009; Flohr et al., 2016). Topping involves removal of the heaviest pigs one or more times prior to marketing of the entire pen or barn as they reach the optimal market weight, which allows the remaining pigs extra time and space to reach market weights. Woodworth et al. (2000) and Carpenter et al. (2018) demonstrated pigs remaining in the pen after the heaviest are removed have increased rate of gain. This improvement in growth rate may be attributed to decreased competition for resources such as feeder space, waterer space, and resting area within the pen, as well as improved social hierarchy with the removal of large pigs (Flohr et al., 2016; Johnston et al., 2017). Similarly, DeDecker et al. (2005) removed varying proportions of pen inventory during the final 19 day of the finishing period and concluded removing 25% or 50% of the pen resulted in increased performance of remaining pigs compared with pens with no removal. Flohr et al. (2016) increased floor space allowance via one, two, or three marketing events prior to the final marketing event and observed similar results. In the current experiment, during the marketing period (days 93 to 160) G:F ratio of pigs remaining in the pen after topping occurred was increased, which agrees with the aforementioned literature and an indicator of increased efficiency of gain associated with compensatory growth (DeDecker et al., 2005; Jacela et al., 2009; Flohr et al., 2016).

Recently, Flohr et al. (2018) reviewed available literature and developed multivariate equations to predict ADG and ADFI as a function of initial BW, final BW, and *k*-value. According to this model, increasing floor space among the static inventory treatments used in this experiment yields a 7% and 6% improvement in ADG and ADFI, respectively (Flohr et al., 2018). The actual improvements observed in this experiment were 7% for ADG and 7% for ADFI when increasing floor space from 0.71 to 1.17 m^2/pig. The equations of Flohr et al. (2018) appear to be robust indicators of expected growth outcomes when providing space allowance for pigs at heavy market weights.

Pigs are typically marketed as they approach the inflection point of their growth curve, or the point at which their growth rate begins to plateau (Shull, 2013). However, intensive selection for lean genetic lines has likely extended this growth curve and increased the capacity for lean growth at heavy weights. Shull (2013) developed growth curves for modern-type pigs raised to 170 kg in a commercial setting and observed that ADG and ADFI peaked at 76 and 118 kg, respectively. Pigs in the current experiment did not plateau until ~95 to 100 kg for ADG, which is a heavier BW than other researchers have reported (Schinckel et al., 2006; Shull, 2013). This observation reiterates the progress made via genetic selection and the potential for efficient protein deposition at weights exceeding current production practices.

In conclusion, these results demonstrate that floor space restriction reduces intake and, consequently, growth rate. The impact of reducing floor space allowance for pigs raised to heavy market weights is seen as early as 100 kg, or before reaching the critical *k*-value (0.0336). However, utilization of multiple marketing events provides producers a mean to maximize stocking density while mediating reduced performance. Finally, efficient rates of gain appear to be achievable at weights heavier than current market standards, highlighting the progress made via continued genetic selection for lean-type pigs.

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