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Summary

A total of 405 pigs (PIC 327 × 1050) from 2 consecutive finishing groups (group 1 initially 145 ± 3.9 lb, group 2 initially 134 ± 5.5 lb) were used to examine the effects of stocking density on finishing pig growth performance and carcass characteristics. Pigs were randomly allotted to pens upon entry into the finishing facility. Pens of pigs were balanced by initial BW and randomly allotted to 1 of 3 treatments with either 7 or 8 replications per treatment (group 1 and 2, respectively). Pens were stocked with 9 pigs, and adjustable gates provided treatments that allowed for 9, 8, or 7 ft² per pig. All pigs were fed the same diets in 3 phases. There was a two-hole feeder in each pen providing 1.56 in. of feeder space per pig.

In both studies, as stocking density decreased, ADG and ADFI increased (linear; $P < 0.019$), but there was no difference in F/G. In group 1, these effects were evident when pigs reached approximately 238 lb; however in group 2, decreases in ADG and ADFI were already observed when pigs averaged 163 lb. As a result, final weight was 8.5 and 11.7 lb lower (linear; $P \leq 0.005$) in groups 1 and 2, respectively, when comparing the lowest and highest stocking density treatments. In group 1, there were no differences in carcass characteristics with the exception of an increase in BF (linear; $P = 0.051$) as stocking density decreased. In group 2, HCW and BF increased (linear; $P \leq 0.007$) and carcass yield decreased (linear; $P = 0.004$) as stocking density decreased. The k -value for each body weight was calculated at each of the three space allocations using the formula reported by Whittemore². When comparing growth performance to a suggested required k -value of 0.0336, performance should have been affected above 267.2, 224.1, and 183.6 lb at 9, 8, and 7 ft² per pig, respectively. In group 1, these pen weights were not reached until after d 42 (239.8 lb), d 28 (206.9 lb), and d 14 (176.7 lb) for the 9, 8, and 7 ft² per pig treatments, respectively. However, even after d 14 negative effects of increased stocking density were observed on ADFI (linear, $P < 0.08$). In group 2, performance should not have been affected until after d 56 (258.9 lb), d 27 (190.5 lb)

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² Whittemore, C. T. 1998. The science and practice of pig production. 2nd ed. Blackwell Science, Oxford; Malden, MA

and d 14 (162.7 lb) for the 9, 8, and 7 sq ft² per pig treatments. Similar to group 1, feed consumption, and consequently ADG, decreased linearly (linear; $P \leq 0.033$) after d 14 as stocking density increased, before pigs reached the k -value that should have influenced performance. The data suggest that the accepted k -value of 0.0336 might underestimate the impact of increased stocking density on ADG and ADFI. Overall, this study indicates that increasing stocking density resulted in poorer ADG driven by a reduction in ADFI.

Key words: finishing pig, space allowance, stocking density

Introduction

The relationship between pen space and pig performance has been a subject of interest dating back to the early 1960s. Pork producers are faced with a trade-off between allowing sufficient space to minimize facility cost per pig yet maximize performance and overall efficiency of facility utilization to provide optimum economic return. Previous research has demonstrated that when grower-finisher pigs are provided decreasing amounts of pen space, feed intake decreases, resulting in a reduction in ADG, with variable effects on feed efficiency. Gonyou³ et al. (2006) reported a critical k -value of 0.0336, below which ADFI is reduced. The k -value is calculated based on a relationship between BW and floor area, generating an expression that can be used to determine when performance will be affected based on space and animal weight. Valuable knowledge can be obtained from understanding the effects of different stocking densities on performance as producers constantly make decisions on pig flow and facility availability. The objective of this experiment is to evaluate the effects of stocking density on growth performance and carcass characteristics of finishing pigs.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The study was conducted at the Kansas State University Swine Teaching and Research Center in Manhattan, KS. The facility was totally enclosed and environmentally regulated, containing 36 pens. The experiment was designed with 3 treatments providing 9, 8, or 7 ft²/pig and 9 pigs per pen (5 barrows and 4 gilts). The pens were equipped with adjustable gates to allow different space allowances per pig. If a pig died or was removed from a pen during the experiment, pen size was adjusted to maintain the correct space allocation per pig. Each pen was equipped with a dry single-sided feeder (Farmweld, Teutopolis, IL) with two 14.0 in. × 4.5 in. (length × width) feeder spaces and a 1-cup waterer. All pens contained 9 pigs, yielding 1.56 in. feeder space per pig. All pigs were provided ad libitum access to feed and water. Pens were located over a completely slatted concrete floor with a 4-ft pit underneath for manure storage. A robotic feeding system (FeedPro; Feedlogic Corp., Wilmar, MN) was used to deliver and record daily feed additions to each individual pen.

³ Gonyou, H. W., M. C. Brumm, E. Bush, J. Deen, S. A. Edwards, T. Fangman, J. J. McGlone, M. Meunier-Salaun, R. B. Morrison, H. Spolder, P. L. Sundberg, and A. K. Johnson. 2006. Application of broken-line analysis to assess floor space requirements of nursery and grower-finisher pigs expressed on an allometric basis. *J. Anim. Sci.* 84: 229-235.

A total of 405 pigs (PIC 327 × 1050) from 2 consecutive finishing groups (group 1 initially 145 ± 3.9 lb, group 2 initially 134 ± 5.5 lb) were used. Pigs were allotted randomly to pens upon entry into the finisher, and the experiments lasted 66 and 77 d for groups 1 and 2, respectively. Pens of pigs were balanced by initial BW and randomly allotted to 1 of the 3 treatments with 7 and 8 replications per treatment for groups 1 and 2, respectively. Feed was manufactured at the O. H. Kruse Feed Technology Innovation Center. Pigs were fed a common 3-phase corn-soybean meal-based diet in meal form (Table 1). Feed samples were taken at the feeder during each phase. Feed was analyzed for moisture, CP, ADF, NDF, crude fiber, ether extract, Ca, and P (Table 2, Ward Laboratories, Inc., Kearney, NE).

Pigs and feeders were weighed approximately every 2 wk to calculate ADG, ADFI, and F/G. Prior to marketing, all pigs were individually weighed and tattooed for carcass data collection. They were transported approximately 2.5 h to a commercial packing plant (Triumph Foods LLC, St. Joseph, MO). Standard carcass characteristics were measured, and jowl fat samples were collected and analyzed at the plant by near-infrared analysis for iodine value.

Data were analyzed as a generalized blocked design with stocking density as a fixed effect and block as a random effect using PROC MIXED in SAS (SAS Institute, Inc., Cary, NC), with pen serving as the experimental unit.

Results and Discussion

In group 1, stocking density had no effect on ADG, ADFI, or F/G up to a mean BW of 238 lb (Table 3). Thereafter, increasing stocking density decreased ADFI (linear, $P = 0.017$), leading to a tendency for a decrease (linear; $P < 0.063$) in ADG. Stocking density did not affect feed efficiency. Overall, as stocking density increased, ADG and ADFI decreased (linear; $P < 0.019$) and F/G was not affected (linear; $P = 0.727$). Final BW decreased (linear; $P = 0.005$) as stocking density increased, which resulted in an 8.5-lb difference in pig weight between the 7 and 9 ft²/pig treatments. There were no significant differences in carcass characteristics with the exception of a tendency for a decrease in BF (linear; $P = 0.051$; Table 3) as stocking density increased (Table 3).

In group 2, stocking density had no effect on ADG, ADFI, or F/G up to a mean BW of 163 lb. In all subsequent periods, ADFI decreased (linear, $P \leq 0.033$; Table 4) as stocking density increased, which led to a decrease (linear; $P \leq 0.029$) or tendency for a decrease (linear; $P \leq 0.068$) in ADG in all remaining phases. Stocking density did not influence feed efficiency. Overall, as stocking density increased, ADG and ADFI decreased (linear; $P \leq 0.005$) and F/G was not affected (linear; $P = 0.42$). Final body weight decreased ($P \leq 0.004$) as stocking density increased, which resulted in an 11.7-lb difference in pig weight between the 7 and 9 ft²/pig treatments. In group 2, HCW and BF decreased (linear; $P \leq 0.007$) and carcass yield increased (linear; $P = 0.004$) as stocking density increased (Table 4).

Allometry is used to define the relationship between BW and floor area requirement, generating an expression in the form of $A = k \times BW^{0.67}$, where A represents floor space allowance and k represents a space allowance coefficient. Gonyou¹ et al. (2006) reported a critical k -value of $0.0336 \text{ m}^2/\text{BW}^{0.67}$ below which ADFI was reduced for finisher pigs

on full slats with equal group sizes. Thus, the critical k -value of $0.0336 \text{ m}^2/\text{BW}^{0.67}$ acts as a threshold below which feed intake and performance should be reduced due to inadequate space allowance per pig.

Body weight corresponding to a k -value of 0.0336 was calculated (Tables 5 and 6), using the formula reported by Whittemore⁴, at each of the three space allocations for each group of finishing pigs. Based on this critical k -value, the negative effects on feed intake should have been observed as pigs reached the projected average body weights of 267.2, 224.1, and 183.6 lb for 9, 8, and 7 sq. ft per pig, respectively. In group 1, these pen weights were not reached until after d 42 (239.8 lb), d 28 (206.9 lb), and d 14 (176.7 lb) for the 9, 8, and 7 ft² per pig treatments, respectively. However, even after d 14, a trend was observed for negative effects of increased stocking density on ADFI (linear, $P < 0.08$), which suggests that the commonly accepted k -value threshold of 0.0336 might be underestimating the impact of increased stocking density. In group 2, using the k -value of 0.0336, performance should not have been affected until after d 56 (258.9 lb), d 27 (190.5 lb) and d 14 (162.7 lb) for the 9, 8, and 7 ft² per pig treatments. Similar to group 1, feed consumption and, consequently, ADG decreased linearly (linear, $P \leq 0.033$) after d 14 as stocking density increased, before pigs reached the k -value that should have influenced performance.

In this study, increasing stocking density resulted in decreased ADG driven by a reduction in ADFI. One concern expressed in published reviews evaluating stocking density is the maintenance of adequate feeder space per pig when stocking density is increased. Based on a study done by Wolter⁵ et al. (2003), the 1.56 in. per pig of feeder space provided in this study is considered unrestrictive and should not have negatively affected performance. Furthermore, the ability to manipulate stocking density by utilizing adjustable gates allowed a change in stocking density without impacting the feeder space per pig, which is typically done when more pigs are added to pens to increase stocking density. Consequently, the trial was successful in determining the effects of stocking density on pig performance without affecting the results by restricting feeder space per pig. The differences in trial performance compared with expected outcomes from published reviews may have been attributable to group size, behavior, or other physiological variables. It is unknown whether these variables contributed to the negative effects on performance as stocking density increased. Additional research should be conducted to further determine the effects of stocking density on pig performance, especially considering the heavier market weights for pigs today.

⁴ Whittemore, C. T. 1998. The science and practice of pig production. 2nd ed. Blackwell Science, Oxford; Malden, MA.

⁵ Wolter, B. F., M. Ellis, B. P. Corrigan, J. M. DeDecker, S. E. Curtis, E. N. Parr, and D. M. Webel. 2003. Effect of restricted postweaning growth resulting from reduced floor and feeder-through space on pig growth to slaughter weight in a wean-to-finish production system. *Journal of Animal Science* 81:836-842.

Table 1. Composition of experimental diets (as-fed basis)

Item	Phase ¹		
	1	2	3
Ingredient, %			
Corn	78.45	82.85	85.25
Soybean meal, 46.5% CP	19.20	14.95	12.70
Monocalcium P, 21% P	0.33	0.30	0.30
Limestone	1.10	1.08	0.01
Salt	0.35	0.35	0.35
L-Lysine HCl	0.25	0.22	0.20
DL- Methionine	0.02	-	-
L-Threonine	0.05	0.05	0.05
Vitamin premix	0.13	0.10	0.075
Trace mineral premix	0.13	0.10	0.075
Phytase ²	0.015	0.015	0.015
Total	100.0	100.0	100.0
Calculated analysis			
Standard ileal digestible (SID) amino acids, %			
Lys	0.85	0.72	0.65
Ile:lys	64	66	67
Leu:lys	149	162	172
Met:lys	29	30	31
Thr:lys	61	64	67
Trp:lys	18	18	18
Val:lys	73	76	79
SID lys NE, g/Mcal	2.57	2.17	1.96
ME, kcal/lb	1,501	1,504	1,507
NE, kcal/lb	1,122	1,135	1,143
Total lysine, %	0.96	0.82	0.75
CP, %	15.9	14.2	13.3
Ca, %	0.53	0.50	0.47
P, %	0.41	0.39	0.38
Available P, %	0.27	0.26	0.26

¹ Phase 1, 2, and 3 diets were fed from d 0 to 28, d 28 to 56, and d 56 to slaughter, respectively.

² HiPhos (DSM Inc, Parsippany, NJ) provided phytase units 1,228,503 (FTU)/lb of product and released 0.10% P available P.

Table 2. Chemical analysis of diets (as-fed basis)

Item, % ²	Phase ¹		
	1	2	3
DM	91.57	91.15	91.05
CP	17.1	14.8	14.1
ADF	3.6	3.2	4.5
NDF	6.9	5.2	10.7
Crude fiber	2.9	1.9	3.1
Ca	0.41	0.46	0.50
P	0.40	0.38	0.39
Ash	3.29	2.83	3.28
Starch	45.2	52.0	47.0

¹ Phase 1, 2, and 3 diets were fed from d 0 to 28, d 28 to 56, and d 56 to slaughter, respectively.

² Values represent the mean of one composite sample of each diet.

Table 3. Effects of space allocation on finishing pig performance (Group 1)¹

Item	Space allocation per pig, sq ft ²			SEM	Probability, P<	
	9	8	7		Linear	Quadratic
No. of pens	7	7	6	---	---	---
d 0 to 14						
ADG, lb	2.31	2.21	2.20	0.066	0.238	0.538
ADFI, lb	5.88	5.80	5.67	0.098	0.081	0.780
F/G	2.56	2.63	2.59	0.059	0.572	0.313
d 14 to 28						
ADG, lb	2.36	2.16	2.25	0.063	0.180	0.057
ADFI, lb	6.31	6.12	6.06	0.117	0.072	0.533
F/G	2.67	2.85	2.71	0.080	0.752	0.110
d 28 to 42						
ADG, lb	2.03	2.13	2.01	0.089	0.874	0.292
ADFI, lb	6.27	6.15	6.19	0.154	0.597	0.577
F/G	3.12	2.92	3.08	0.093	0.804	0.109
d 42 to 55						
ADG, lb	2.12	2.02	2.00	0.050	0.063	0.414
ADFI, lb	6.72	6.57	6.16	0.163	0.017	0.454
F/G	3.18	3.26	3.10	0.083	0.508	0.249
d 55 to 66						
ADG, lb	2.34	2.27	2.12	0.071	0.043	0.636
ADFI, lb	6.97	6.86	6.53	0.101	0.001	0.215
F/G	2.98	3.06	3.08	0.103	0.493	0.817

continued

Table 3. Effects of space allocation on finishing pig performance (Group 1)¹

Item	Space allocation per pig, sq ft ²			SEM	Probability, P<	
	9	8	7		Linear	Quadratic
d 0 to 66						
ADG, lb	2.23	2.15	2.12	0.034	0.019	0.568
ADFI, lb	6.40	6.27	6.11	0.099	0.009	0.805
F/G	2.87	2.91	2.89	0.028	0.727	0.292
BW, lb						
d 0	145.79	145.78	145.83	1.604	0.953	0.944
d 14	178.10	176.65	176.65	1.637	0.317	0.543
d 28	211.40	206.87	208.07	7.905	0.078	0.071
d 42	239.79	236.65	236.32	2.449	0.163	0.486
d 55	267.31	262.86	262.35	2.727	0.064	0.347
d 66	294.19	287.83	285.66	2.564	0.005	0.323
Carcass traits						
HCW, lb	217.4	207.7	210.0	3.399	0.128	0.124
Yield, %	73.4	73.1	73.8	0.003	0.236	0.072
BF, in.	0.74	0.69	0.66	0.687	0.051	0.698
Loin depth, in.	2.53	2.54	2.52	1.746	0.894	0.859
Lean, %	53.4	54.2	54.3	0.004	0.101	0.439
Iodine value, mg/100g	69.1	69.2	69.6	0.285	0.178	0.604

¹ A total of 189 finishing pigs (PIC 327 × 1050, initially 145.85 lb) were used in a 66-d study.

² Each pen contained 9 pigs, and space allocation was manipulated by utilizing adjustable gates.

Table 4. Effects of space allocation on finishing pig performance (group 2)¹

Item	Space allocation per pig, sq ft ²			SEM	Probability, P<	
	9	8	7		Linear	Quadratic
Pens, no.	8	8	8	---	---	---
d 0 to 14						
ADG, lb	2.14	2.08	2.06	0.058	0.322	0.817
ADFI, lb	5.08	4.98	5.03	0.071	0.623	0.418
F/G	2.38	2.39	2.46	0.062	0.337	0.690
d 14 to 27						
ADG, lb	2.25	2.10	2.06	0.059	0.029	0.428
ADFI, lb	6.40	6.15	6.02	0.115	0.033	0.696
F/G	2.84	2.94	2.92	0.053	0.197	0.329
d 27 to 42						
ADG, lb	2.27	2.18	2.15	0.040	0.068	0.615
ADFI, lb	6.46	6.18	6.06	0.083	0.004	0.426
F/G	2.86	2.84	2.82	0.048	0.579	0.989
d 42 to 56						
ADG, lb	2.14	2.08	2.01	0.029	0.002	0.797
ADFI, lb	6.82	6.44	6.17	0.087	<0.001	0.626
F/G	3.19	3.09	3.08	0.087	0.071	0.451
d 56 to 77						
ADG, lb	2.15	2.14	1.98	0.032	0.002	0.105
ADFI, lb	7.05	6.80	6.30	0.102	<0.001	0.318
F/G	3.28	3.19	3.18	0.055	0.180	0.533
d 0 to 77						
ADG, lb	2.19	2.12	2.05	0.029	0.005	0.949
ADFI, lb	6.42	6.17	5.94	0.071	<0.001	0.899
F/G	2.93	2.91	2.90	0.028	0.416	0.814
BW, lb						
d 0	133.9	134.0	133.9	2.069	0.956	0.899
d 14	163.9	163.2	162.7	2.044	0.513	0.941
d 27	193.2	190.5	189.7	2.282	0.142	0.638
d 42	228.3	224.4	222.1	2.147	0.015	0.707
d 56	258.9	253.6	250.2	2.188	0.005	0.688
d 77	304.1	298.7	292.4	2.558	0.004	0.902
Carcass traits						
HCW, lb	226.6	220.1	212.6	2.444	0.001	0.879
Yield, %	77.6	77.9	77.3	0.012	0.631	0.471
BF, in.	0.81	0.78	0.71	0.628	0.007	0.463
Loin depth, in.	2.56	2.53	2.55	1.376	0.915	0.687
Lean, %	52.7	52.9	54.0	0.003	0.004	0.262
Iodine value, mg/100g	68.6	69.2	69.1	0.262	0.209	0.225

¹ A total of 215 finishing pigs (PIC 327 × 1050, initially 133.9 lb) were used in a 77-d study.² Each pen contained 9 pigs, and space allocation was manipulated by utilizing adjustable gates.

Table 5. Determination of k -values for different stocking densities and pig weights (group 1)¹

Item	Space allocation per pig, sq ft ²			k -value ^{3,4}		
	9	8	7	9 sq ft	8 sq ft	7 sq ft
BW when $k = 0.0336$, lb ⁵	267.2	224.1	183.6	---	---	---
Weight, lb						
d 0	145.8	145.8	145.8	0.0504	0.0448	0.0392
d 14	178.1	176.7	176.7	0.0441	0.0394	0.0345
d 28	211.4	206.9	208.1	0.0393	0.0354	0.0309
d 42	239.8	236.7	236.3	0.0361	0.0324	0.0284
d 55	267.3	262.9	262.4	0.0336	0.0302	0.0265
d 66	294.2	287.8	285.7	0.0315	0.0284	0.0250

¹ Average pig weight reported for each stocking density and weigh day.² Each pen contained 9 pigs, and space allocation was manipulated by utilizing adjustable gates.³ k -values calculated using a formula reported by Whittemore (1998): space per pig (m²) = $k \times \text{BW (kg)}^{0.67}$ or space per pig (ft²)/10.7639 = $k \times \text{BW (lb)}/2.2046^{0.67}$.⁴ Bold type with shaded background indicate k -values below 0.0336, the critical k -value for adequate feed intake as defined by Gonyou et al. (2006).⁵ Calculated body weight for each stocking density when $k = 0.0336$, the critical k -value for adequate feed intake for grow-finish, full slat, equal group sizes (Gonyou et al., 2006).**Table 6. Determination of k -values for different stocking densities and pig weights (group 2)¹**

Item	Space allocation per pig, sq ft ²			k -value ^{3,4}		
	9	8	7	9 sq ft	8 sq ft	7 sq ft
BW when $k = 0.0336$, lb ⁵	267.2	224.1	183.6	---	---	---
Weight, lb						
d 0	133.9	134.0	133.9	0.0534	0.0474	0.0415
d 14	163.9	163.2	162.7	0.0466	0.0416	0.0364
d 27	193.2	190.5	189.7	0.0418	0.0375	0.0329
d 42	228.3	224.4	222.1	0.0373	0.0336	0.0296
d 56	258.9	253.6	250.2	0.0343	0.0309	0.0273
d 77	304.1	298.7	292.4	0.0308	0.0277	0.0246

¹ Average pig weight reported for each stocking density and weigh day.² Each pen contained 9 pigs, and space allocation was manipulated by utilizing adjustable gates.³ k -values calculated using a formula reported by Whittemore (1998): space per pig (m²) = $k \times \text{BW (kg)}^{0.67}$ or space per pig (ft²)/10.7639 = $k \times \text{BW (lb)}/2.2046^{0.67}$.⁴ Bold type with shaded background indicate k -values below 0.0336, the critical k -value for adequate feed intake as described by Gonyou et al. (2006).⁵ Calculated body weight for each stocking density when $k = 0.0336$, the critical k -value for adequate feed intake for grow-finish, full slat, equal group sizes (Gonyou et al., 2006).