Effects of wet/dry feeder and pen stocking density on grow-finish pig performance

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ABSTRACT: Three thousand one hundred and eighty-two terminal cross pigs (barrows and gilts) PIC line 359 sires × 1,050 dams were used from three consecutive grow-finish groups (initial BW of 21.51 ± 0.42 kg, 31.61 ± 1.18 kg, 29.41 ± 0.28 kg for replicates 1–3). Pigs were randomly assigned to each pen at the start of the trial and the research period continued for 106, 94, and 100 d for the first, second, and third replicates, respectively. The experimental treatments were designed as a two by three factorial (pen space of 0.65 or 0.78 m^2/pig with 10, 13, or 16 pigs per feeder space), each pen had an equal number of barrows and gilts with 20, 26, and 32 pigs per pen for the 10, 13, and 16 pigs per feeder space pens. Each pen was equipped with one double-sided wet/dry feeder, 37.5 cm wide, with one nipple drinker. All pigs had ad libitum access to feed and water supply during the trial period. Pigs for all the three replicates were fed with the same series of diets. Pigs were weighed by pen at the start of trial and at the end of the trial to calculate ADG. Feed was removed from the feeders and weighed to determine ADFI and G:F. To express floor space allowance, the k value was estimated by the equation: space per pig $(m^2) = k \times$ BW $(kg)^{0.67}$. No interactions ($P > 0.05$) of floor space allowance with pigs per feeder were observed. Pigs with less floor space allowance had reduced BW (128.8 vs. 129.5 kg, $P = 0.026$), ADG (1.00 vs. 1.02 kg/d, $P = 0.002$), and ADFI (2.52 vs. 2.61 kg/d, $P < 0.001$). However, G:F was improved (0.402 vs. 0.397, $P = 0.039$) with less floor space allowance per pig. Increased pigs per feeder space reduced final BW (129.7, 129.4, 128.4 kg, linear; $P = 0.001$). However, ADG had a quadratic relationship ($P = 0.005$) with pigs per feeder space with means of 1.03, 1.01, and 1.01 kg/d for 10, 13, and 16 pigs per feeder space. Overall, ADFI had a quadratic relationship ($P < 0.0001$) with number of pigs per feeder space with means of 2.62, 2.52, and 2.55 kg/d for 10, 13, and 16 pigs per feeder space. Gain efficiency had a quadratic relationship ($P = 0.005$) with number of pigs per feeder space with means of 0.395, 0.404, and 0.400 for 10, 13, and 16 pigs per feeder space. In conclusion, a floor space allowance of 0.65 m^2/pig in the grow-finish period reduced ADFI and ADG compared with 0.78 m^2/pig. Overall, with the type of wet/dry feeder used in this study, 10 pigs per feeder had the greatest ADG and ADFI, compared with 13 or 16 pigs per feeder space. However, G:F improved as the number of pigs per feeder space increased.

Key words: feeder space, floor space, k value, space allocation, swine

INTRODUCTION

The economic return of a pig production system is related to the housing capacity of the production sites as well as the technologies employed to increase pig growth performance and gain efficiency, considering it is important to diminish facility cost per pig (Thomas et al., 2017). Gain efficiency is very important, as approximately 60%–75% of the total postweaning pig production costs are associated with feed costs (Honeyman, 1991; Wade and Barkley, 1992). In modern swine production, the pork processing plants have targeted heavier market weights (Wu et al., 2017). With increased market weights, the pen space required for modern pigs and the feeder space per pig should be evaluated to balance building utilization and production efficiency.

A number of researchers have found that increased group sizes do not affect the pig performance when the pigs are given equal pen space and ad libitum access to feed (McConnell et al., 1987; Walker, 1991; Turner et al., 2003; Turner and Edwards, 2004). The majority of the production systems for pigs use fully or partially slatted floors, a liquid effluent system, with group sizes from 5 to 50 pigs and approximately 0.7 m^2 of floor space allowance per pig (Morrison et al., 2007).

However, when less pen floor space allowance is provided per pig, pig growth rate is reduced, more markedly with pens for smaller groups as demonstrated by Thomas et al. (2017), which had nine pigs per pen. Besides the reduced growth performance, restricted pen floor space allowance can cause behavioral problems, increase plasma glucocorticoid levels, and reduce animal welfare (Randolph et al., 1981; Kornegay, 1986; Meunier-Salaun et al., 1987).

Feeder design and management can affect pig growth and the pigs' capacity to eat, so it is extremely important to evaluate the impact of the number of pigs per feeder space with each model of the commercial feeder. Past research has been done with dry feeders on the impact of the number of pigs per feeder space and has produced variable results, possibly due to different models of feeders and different levels of feeder adjustment.

Considering that feeder space per pig and pen floor space allowance per pig can affect pig growth performance, the objective of the trial was to evaluate the effects of different feeder stocking density and pen stocking density on the growth performance of grow-finish pigs fed with wet/dry feeders.

MATERIALS AND METHODS

Animal procedures were consistent with the Guide for the Care and Use of Animals in Agricultural Research and Teaching (FASS, 2010).

General

The trial was conducted at a commercial research finishing barn located in Southwest Minnesota from October 2015 to September 2016. The facility was double curtain sided with totally slatted floors and environmentally controlled with sprinklers to reduce summertime heat stress and heaters for winter time temperature control. Each building contained 44 pens. The pens had adjustable gating to provide the different floor space allowances, so each floor space allowance was arranged by moving the gates after measurement of the floor space. The experimental treatments were designed as a two by three factorial arrangement (pen space of 0.65 or 0.78 m^2/pig × 10, 13, or 16 pigs per feeder space). Each pen had an equal number of barrows and gilts with 20, 26, and 32 pigs per pen for the 10, 13, and 16 pigs per feeder space pens. Each pen was equipped with one Crystal Spring Wet/Dry single-space double-sided feeder model F1-115 (Ste. Agathe, MB), space of 37.5 cm of length, with one nipple drinker. The drinker of the feeder was the only provided in each pen. The feed was delivered by a robotic feeding system (FeedPro; Feedlogic Corp., Wilmar, MN), which recorded the daily individual pen feed additions.

Animals and Performance

Three thousand one hundred and eighty-two terminal cross pigs (PIC line 359 sires × 1,050 dams, barrows, and gilts) from three consecutive grow-finish groups (initial BW of 21.5 ± 0.42, 31.6 ± 1.18, and 29.4 ± 0.28 kg for replicate 1, 2, and 3, respectively) were used. Pigs were randomly assigned to each pen at the start of the trial, and the trial continued for 106, 94, and 100 d for the first, second, and third replicates, respectively, for each replicate pen group remained intact until the end of the experiment. No pigs were removed for marketing until after the experiment ended.

Initial BW was equalized for each pen, and the pens were randomly distributed to one of the six treatments with seven pens per treatment for each trial group. All pigs had ad libitum access to feed and water supply during the trial period. Pigs for all the three replicates were fed with the same

feeding program with a seven-phase corn-soybean meal base feed in mash form (Table 1). The diets were formulated to achieve or exceed NRC (2012) requirements for grow-finish pigs.

Pigs were weighed by pen at the start of trial, at approximately every 21 d of the trial, and at the end of the trial to calculate ADG, all the feed placed in the feeders was weighed and at the end of the trial the remaining feed in the feeders was weighed to determine ADFI and G:F.

Evaluation of k Value

To express floor space allowance, k value was used, as it describes pen space as a function of effective pig space requirements ($BW^{0.67}$). The k values were calculated using a formula reported by Whittemore (1998): space per pig $(m^2) = k \times BW \; (kg)^{0.67}$. According to Gonyou et al. (2006), a k value of 0.0336 is required for maximal feed intake and ADG for grow-finish pigs with fully slatted flooring, as k value lower than 0.0336 reduces feed intake and consequently ADG.

Statistical Analysis

All variables measured were tested for normality by the Shapiro–Wilk test before analysis with $P < 0.05$, and any variable that failed to follow a normal distribution was transformed through the RANK procedure of SAS (SAS Inst. Inc., Cary, NC). The PROC RANK statement with the NORMAL option was used to produce a normalized transformed variable. All data were analyzed using the MIXED procedure of SAS (SAS Institute Inc., Cary, NC) as a randomized complete block design (replicate) in a factorial scheme with floor space allowance (0.65 or 0.78 m^2/pig) and pigs per feeder space (10, 13, or 16 pigs per feeder space). Pen was considered as the experimental unit. Initial analyses found no significant interactions and thus were deleted from the model. The pigs per feeder space treatments were analyzed as linear and quadratic orthogonal contrasts. The effects of floor space allowance per pig were compared by F test. All data are reported as least squares means, and

Table 1. Composition of the trial feeds (as-fed basis)

Ingredient, %	Phase[1]						
	1	2	3	4	5	6	7
Corn	42.62	42.55	45.02	48.06	52.77	61.12	66.76
Soybean meal, 46.5% CP	10.44	5.63	3.15	0.12	0.49	2.28	1.72
DDGS[2]	40.00	45.00	45.00	45.00	40.00	30.00	25.00
Tallow	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Salt	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Calcium carbonate, 38% Ca	1.27	1.30	1.28	1.27	1.19	1.05	0.97
Mono dicalcium P, 21% P	0.22	0.07	0.00	0.00	0.00	0.00	0.00
Potassium chloride	0.00	0.00	0.10	0.10	0.10	0.10	0.10
Premix[3]	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis							
Crude protein, %	19.4	18.5	17.5	16.3	15.4	14	12.7
ME, kcal/kg	2970	2964	2953	2968	2984	2991	3003
Fat, %	8.11	8.11	7.98	8.15	8.09	7.49	7.29
Crude fiber, %	3.55	3.69	3.65	3.60	3.39	2.99	2.76
Calcium, %	0.58	0.55	0.53	0.51	0.48	0.43	0.4
Phosphorus, %	0.52	0.5	0.48	0.47	0.44	0.4	0.37
Lys (total), %	1.31	1.22	1.12	1.02	0.95	0.87	0.79
Met (total), %	0.37	0.35	0.34	0.32	0.30	0.27	0.25
Thr (total), %	0.82	0.77	0.73	0.67	0.64	0.58	0.53
Trp (total), %	0.24	0.23	0.21	0.19	0.18	0.16	0.15

[1]Phase 1–7 diets were fed from 25 to 34 kg, 34 to 43 kg, 43 to 61 kg, 61 to 75 kg, 75 to 86 kg, 86 to 98 kg, and 98 to slaughter, respectively.

[2]DDGS = dried distillers grains with solubles.

[3]Mineral and vitamin premix provided per kilogram of diet: 4,412,200 IU vitamin A, 551,200 IU vitamin D, 17,700 IU vitamin E, 1,782 mg vitamin K, 15.5 mg vitamin B12, 19,876 mg niacin, 11,065 mg pantothenic acid, 3,318 mg riboflavin, 1,106 mg Zn, 1,100 mg Fe, 313 mg Mn, 107 mg Cu, 2 mg I, and 2 mg Se. Amino acid premix provided per kilogram of diet: Phase 1: 11.74 g lysine, 0.43 g methionine, 2.83 g threonine, and 1.29 g tryptophan; Phase 2: 11.91 g lysine, 2.47 g threonine, and 1.39 g tryptophan; Phase 3: 11.23 g lysine, 2.42 g threonine, and 1.34 g tryptophan; Phase 4: 10.86 g lysine, 2.08 g threonine, and 1.33 g tryptophan; Phase 5: 9.84 g lysine, 2.12 g threonine, and 1.19 g tryptophan; Phase 6: 8.57 g lysine, 1.98 g threonine, and 1.01 g tryptophan; Phase 7: 7.77 g lysine, 1.88 g threonine, and 0.92 g tryptophan.

the greatest standard errors (SEM) were reported. Results are considered significant if $P < 0.05$.

RESULTS

No interactions ($P > 0.05$) of floor space allowance with pigs per feeder space were observed. Pigs allocated in pens with 0.65 m²/pig had reduced ADG during the growing phase (Table 2, 1.00 vs. 1.02 kg/d, $P < 0.001$), finishing phase (1.03 vs. 1.05 kg/d, $P = 0.033$), and the overall period (1.00 vs. 1.02 kg/d, $P = 0.002$).

As suggested by previous studies with dry feeders, these pigs had lower BW at 70 d (97.7 vs. 99.4 kg, $P < 0.001$) and final BW (128.8 vs. 129.5 kg, $P = 0.026$) and reduced ADFI (2.52 vs. 2.61 kg/d, $P < 0.001$) than pigs with 0.78 m²/pig floor space allowance. However, the overall G:F was improved (0.402 vs. 0.397, $P = 0.039$) for pigs with less pen space. Floor space allowance had no effect for the percentage of dead or removed pigs.

It was estimated that the BW in which pen space became limiting ($k = 0.0336$) for the floor space allowance of 0.65 m²/pig was 85.0 kg and at 111.7 kg BW for the floor space allowance of 0.78 m²/pig (Table 3). At 70 d, the BWs for pigs allocated in pens with 0.65 and 0.78 m²/pig were 97.7 and 99.4 with estimated k values of 0.0306 and 0.0363, respectively. The final BWs were 128.8 and 129.5 kg with estimated k values of 0.0255 and 0.0304 for pigs assigned to 0.65 and 0.78 m²/pig.

The number of pigs per feeder space did not affect ADG (Table 4, $P > 0.14$) during the growing phase. Average daily gain during the finishing phase had a quadratic ($P = 0.010$) relationship with the number of the pigs per feeder. In the same way, the overall ADG had a quadratic relationship ($P = 0.005$) with the number of pigs per feeder space with the maximal ADG at 10 pigs per feeder space. Final BW was reduced with increased number of pigs per feeder space (linear $P = 0.001$).

Daily feed intake had a quadratic relationship ($P < 0.001$) with the number of pigs per feeder space. Gain efficiency had a quadratic relationship ($P = 0.005$) with the number of pigs per feeder space. The number of pigs per feeder space had no effect for the percentage of dead or removed pigs.

DISCUSSION

Reduction of the floor space allowance by increasing the number of pigs per space unit reduces the housing cost per pig (Brumm and Gonyou, 2001); however, with reduction of floor space allowance, pigs have reduced ADFI, ADG, and consequently reduced BW (Brumm and Miller, 1996; Gonyou and Stricklin, 1998; Jensen et al., 2012; Thomas et al., 2017). It is common for crowded pigs to eat fewer meals; however, pigs spend more time eating each meal (Meunier-Salaun et al., 1987; Hyun et al., 1998).

Johnston et al. (2017) conducted a series of trials and established the ideal floor space allowance for pigs weighing 130 kg is 0.89 m²/pig as they did not observe any improvement in final BW and ADG beyond this floor space allowance, the group

Table 2. Effects of floor space allocation on growing-finishing pig performance

Item	Space allocation per pig, m²		SEM	P value
	0.65	0.78		
Growing phase				
Day 0 weight, kg	27.5	27.5	3.060	0.566
ADG, kg	1.00	1.02	0.016	<0.001
Dead/removed, %	1.7	1.7	0.943	0.704
Finishing phase				
Day 70 weight, kg	97.7	99.4	2.154	<0.001
ADG, kg	1.03	1.05	0.035	0.033
Day 100 final weight, kg	128.8	129.5	0.242	0.026
Dead/removed, %	1.2	1.2	0.921	0.758
Overall				
ADG, kg	1.01	1.03	0.009	0.002
ADFI, kg	2.52	2.61	0.155	<0.001
G:F	0.402	0.397	0.029	0.039
Dead/removed, %	2.9	2.9	0.913	0.743

Sixty-three replicates per treatment with 1,591 pigs per treatment was used.

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

Item	Space allocation per pig, m²		k value[2,3]	
	0.65	0.78	0.65 m²	0.78 m²
Day 0 weight, kg	27.5	27.5	0.0724	0.0869
Day 70 weight, kg	97.7	99.4	0.0306	0.0363
Day 100 final weight, kg	128.8	129.5	0.0255	0.0304
BW when $k = 0.0336$, kg[4]	85.0	111.7		

[1]Average pig weight reported for each space allocation and weigh day.

[2]k values were calculated using a formula reported by Whittemore (1998): space per pig (m²) $= k \times BW$ (kg)$^{0.67}$.

[3]Shaded background indicates k values below 0.0336, critical k value for adequate feed intake as defined by Gonyou et al. (2006).

[4]Estimated body weight for space allocation when $k = 0.0336$, the critical k value for adequate feed intake for grow-finish, fully slatted flooring and equal group sizes (Gonyou et al., 2006).

Table 4. Effects of pigs per feeder space on growing-finishing pig performance

	Pigs per feeder space				P value	
Item	10	13	16	SEM	Linear	Quadratic
Growing phase						
Day 0 weight, kg	27.5	27.5	27.5	3.061	0.877	0.829
ADG, kg	1.02	1.01	1.01	0.016	0.156	0.142
Dead/removed, %	1.6	1.9	1.6	0.987	0.848	0.793
Finishing phase						
Day 70 weight, kg	99.0	98.5	98.1	2.041	0.244	0.158
ADG, kg	1.07	1.02	1.03	0.035	0.488	0.010
Day 100 final weight, kg	129.7	129.4	128.4	0.326	0.001	0.028
Dead/removed, %	1.1	1.3	1.3	0.865	0.799	0.575
Overall						
ADG, kg/d	1.03	1.01	1.01	0.010	0.152	0.005
ADFI, kg/d	2.62	2.52	2.55	0.156	0.385	<0.0001
G:F	0.395	0.404	0.400	0.029	0.877	0.005
Dead/removed, %	2.6	3.2	2.9	1.000	0.950	0.568

Forty-two replicates per treatment with 816, 1,062, and 1,304 pigs, respectively, for the treatments with 10, 13, or 16 pigs per feeder space was used.

size was constant across treatments however varied across trials, varying from 6 to 19 pigs per pen.

Increased pen density could cause welfare problems because crowded pigs tend to have more aggressive behavior and higher lesion scores (Fu et al., 2016). Also, increased stocking density reduces the area available for lying so pigs tend to disturb each other more often (Bulens et al., 2017).

However, the results of this trial contradict some past research that found G:F was unchanged (Brumm and Miller, 1996; Gonyou and Stricklin, 1998; Jensen et al., 2012; Thomas et al., 2017) or decreased (Street and Gonyou, 2008; Flohr et al., 2016) with decreased floor space allowance per pig. In this trial, G:F was greater for pigs with less floor space allowance. This observation is in agreement with a meta-analysis (Averós et al., 2012) that suggested that the pig floor space required for maximal G:F is reduced if the pigs are housed on fully slatted floors compared with pens with nonslatted floor. Despite the small lower ADG (20 g/d) and ADFI (90 g/d) of pigs with the floor space allowance of 0.65 m², the pigs had a small improvement of G:F for overall grow-finish period.

These findings are important considering the final BW difference of 0.7 kg represents less than 1 d of ADG for the overall period; however, the difference on ADFI represents 9.00 kg of feed for the overall period of 100 d, being economically more representative.

The percentage of dead or removed pigs were the same for the both floor space allowances treatments during the grower, finishing phase and consequently the overall period and it was lower than

4.44% (Metafarms Analytics Team, 2017) observed in commercial US pig farms. This suggests suggested that problems associated with welfare were not present in this trial.

Floor space allowance was expressed using the allometric approach suggested by Gonyou et al. (2006); the minimum k value of 0.0336 represents the best value for pigs to have an ideal ADFI and ADG, associated with floor space allowance. For this study, both floor space allowance treatments exceeded the minimum value of 0.0336 for k value for maximal ADFI and ADG for most of the finish period. Most likely, pigs that were allocated with 0.65 m²/pig had restricted ADFI after they reached 85.0 kg BW and resulted in the lower DFI for this group of pigs.

It has been suggested that values proposed by Gonyou et al. (2006) may underestimate the requirement of floor space allowance for heavy pigs (over 120 kg of BW), and it should be revaluated for heavy pigs (Potter et al., 2010; Flohr et al., 2016; Johnston et al., 2017). If the density increases in a reasonable manner, the total BW produced per unit of fixed building assets increase, generating a greater net revenue over facility costs (Powell and Brumm, 1993; Flohr et al., 2016).

According to NRC (2012), when the pigs are crowded with k values lower than 0.0336, the ADFI is reduced and consequently growth rate is worsened. If adequate floor space allowance is not provided, the impact of reduce floor space allowance on pig performance depends on the magnitude of the restriction. Flohr et al. (2015) conducted a meta-analysis and established equations to predict

ADG, ADFI, and G:F based on the BW of pigs. From this meta-analysis, for each 0.001 below, the critical value of k (0.0336), ADG, ADFI, and G:F should decrease by 0.88%, 0.58%, and 0.31%, respectively, for pigs with more than 125 kg of BW, contradictory for the present trial G:F was improved with lower floor space allocation.

Another factor that could impair the real evaluation of the ideal value proposed by Gonyou et al. (2006) is that his trials were made with dry feeders and it can impact the speed of which the animals eat, so these values must be re-established to ensure which would be the ideal k value that does not harm the ADFI.

The group size of the pigs was adjusted with 20, 26, and 32 pigs per pen to achieve the 10, 13, and 16 pigs per feeder space. When pigs were housed in groups of 18 or 108 pigs, the size of the group did not affect ADG (Street and Gonyou, 2008). Schmolke et al. (2003) evaluated groups of 10, 20, 40, and 80 pigs and verified that housing growing-finishing pigs in groups of up to 80 pigs was not detrimental to productivity and health. These findings are important to ensure that the group size did not have effect over the performance variables of the present trial.

Restricted feeder space in grow-finish pigs increases ingestion rate, reduces the duration of visits to the feeder as well as the time spent eating (Hsia and Wood-Gush, 1984; Brumm and Gonyou, 2001). In this trial, pigs with the greatest feeder space had a greater ADFI, in agreement with Averós et al. (2012) that reported when the feeder places per pig are increased, the pigs spend more time eating.

However, with more feeder places per pig, ADFI can be associated with an increase in feed wastage. With more restricted feeder space pigs tend to reduce feed wastage, something that may have occurred in this trial, as the pigs with the least number of pigs per feeder space had a poorer G:F, in disagreement with previous research (Spoolder et al., 1999; Gonyou and Lou, 2000) both treatments 13 and 16 pigs per feeder space had a better feed conversion than 10 pigs per feeder space in the present trial.

Gonyou and Lou (2000) demonstrated that pigs fed with wet/dry feeders usually have greater ADFI and ADG than dry feeders; similarly, Walker (1990) verified pigs fed from wet/dry feeders tend to have a greater feed intake. The increase in weight gain would be a consequence of greater feed intake (Maton and Daelemans, 1992). Pigs fed from wet/dry feeders have shorter feeder visits and have higher

ingestion rates compared with dry feeders (Averós et al., 2012), although pigs fed wet/dry feeders eat more feed and gain more weight than those fed conventional feeders, feed conversion does not change (Gonyou and Lou, 2000). Wet/dry feeders have the ability to accommodate more pigs per feeder space, without harming the performance of the pigs, as wet feed is eaten faster than dry feed (Gonyou and Lou, 2000).

According to Bates et al. (1995), the traditional recommendation of pigs per feeder space with dry feeders was five; however, the same researcher conducted a trial and found that 10 pigs per feeder space do not have any detrimental effect on pig performance. The results in our study showed that there was not a detrimental effect on pig performance with 13 pigs per wet/dry feeder space. In conclusion, a floor space allowance of 0.65 m²/pig marginally reduced the ADFI and ADG during the finisher phase and overall. Overall, with the type of wet/dry feeder used in this study, 10 pigs per feeder had the greatest ADG and ADFI, compared with 13 or 16 pigs per feeder space. However, G:F improved as the number of pigs per feeder space increased.

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