Dietary energy level, feeder space, and group size on growth performance and carcass characteristics of growing-finishing barrows and gilts

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ABSTRACT: To benefit from feeding low net energy (NE) diets, growing-finishing pigs must be able to increase feed intake to compensate for lower caloric density, but this might be difficult in pens with a high stocking density. Access to the feeder, trough space, and(or) floor area may limit voluntary feed intake. The objective of this study was to clarify the relationships among dietary NE level, feeder space, group size, sex, and interactions in growing-finishing pigs. In a 2 × 2 × 2 × 2 factorial design, 1,920 pigs (33 kg) housed in 96 fully slatted floor pens (6.1 × 2.4 m) with 2 or 3 feeder spaces, and 18 or 22 barrows or gilts per pen, were fed either low (9.2 MJ/kg) or high (9.85 MJ/kg) NE diets over 5 growth phases (Grower 1: day [d] 0 to 20, Grower 2: d 21 to 41, Grower 3: d 42 to 62, Finisher 1: d 63 to 80, Finisher 2: d 81 to slaughter). Pen body weight (BW) and average daily feed disappearance (ADFD) were measured for each growth phase, biweekly from the start of shipping and at slaughter. Warm carcasses were weighed and graded (Destron). For the entire trial, pigs fed low versus (vs.) high NE diets had 0.119 kg/d greater ($P < 0.001$) ADFD, but 0.556 MJ/d lower ($P < 0.050$) average daily caloric disappearance (ADCD), and 0.017 kg/kg lower ($P < 0.001$) gain-to-feed (G:F). Pens with 18 vs. 22 pigs had 0.062 kg/d greater ($P < 0.001$) ADFD, 0.730 MJ/d greater ($P < 0.010$) ADCD, and 0.029 kg/d greater ($P < 0.001$) average daily weight gain (ADWG). Pigs in pens with 3 vs. 2 feeding spaces had 0.051 kg/d greater ($P < 0.010$) ADFD, 0.511 MJ/d greater ($P = 0.050$) ADCD but 0.004 kg/kg lower ($P < 0.050$) G:F. Pigs fed low vs. high NE diets had 0.6 kg lower ($P < 0.050$) carcass weight and 0.9 mm lower ($P < 0.050$) loin depth. Pens with 18 vs. 22 pigs took 2.8 days less ($P < 0.001$) to reach 130 kg slaughter BW. Pens with 18 vs. 22 pigs had a 0.4 %-point decrease ($P < 0.050$) in dressing percentage. Feeding low vs. high NE diets reduced ($P < 0.001$) feed cost by Can$21.87/tonne, $3.34/pig, $0.03/kg gain, and increased ($P < 0.05$) gross income subtracting feed cost by $1.82/pig. Housing 18 vs. 22 pigs per pen increased ($P < 0.010$) ISFC by $1.98 per pig. Lack of interactions between NE level, feeder space, and group size for ADFD indicate that low NE diets can be fed to pigs even if they have lower than recommended floor area allowance during part of the finishing phase.

Key words: feeder space, growth performance, net energy, pig, stocking density

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INTRODUCTION

Considering that feed is the largest cost of production and energy-yielding feedstuffs account for 85% to 90% of feed cost (Patience, 2013), previous research has evaluated decreasing dietary energy density to reduce feed cost. Our research indicated that feeding reduced net energy (NE) diets (≤9.6 MJ NE/kg) to growing-finishing pigs resulted in greater profit (revenue after subtracting feed cost) per pig than feeding traditional NE levels (≥10 MJ NE/kg; Smit et al., 2017, 2018), but pigs must have the ability to increase feed intake to make up for lower caloric density. In pens with high stocking density, where floor area allowance (Gonyou and Stricklin, 1998) may dip below the recommended value as pigs grow, there may be reduced access to the feeder, insufficient trough space, or both, that can limit feed intake and defeat the advantages of feeding low NE diets. Previous research has shown that pigs eat more and grow faster when pigs have more effective pen space (Brumm and Miller, 1996; Gonyou and Stricklin, 1998; Brumm et al., 2001, 2004; Potter et al., 2010), but it is not clear if this is due to a decrease in the number of pigs per feeder space, or because it is easier for pigs to access the feeder in less densely populated pens where pigs have more floor area. To clarify the relationships among dietary NE level, feeder space, group size, and sex, we studied the effects of these parameters and their interactions in growing-finishing pigs.

The objective of this study was to compare the growth performance, dressing percentage, and carcass characteristics of growing-finishing barrows and gilts fed low (9.2 MJ/kg) or high (9.85 MJ/kg) dietary NE levels, with 2 or 3 feeder spaces per pen, and housed in two group sizes (18 versus [vs.] 22 pigs).

MATERIAL AND METHODS

Study procedures were reviewed, and the number of animals involved in this experiment was approved (AUP0000122) by the University of Alberta Animal Care and Use Committee for Livestock and followed principles established by the Canadian Council on Animal Care in Science (CCAC, 2009). The study was conducted at a commercial pig farm that had a grower-finisher barn set up as a test facility (Lougheed, Alberta, Canada).

Animals and Housing

The experiment involved a total of 1,920 pigs over two barn turns. Per barn turn, 960 pigs (480 barrows and 480 gilts; PIC380 [PIC Canada, Winnipeg, MB, Canada] × Large White/Landrace [Line 277; Fast Genetics, Saskatoon, SK, Canada]) were randomly placed into 48 pens by sex, either 18 or 22 pigs per pen, with initial body weight (BW) of 33 ± 2.3 kg. The flooring of each pen (6.1 × 2.4 m) was fully slatted concrete, the siding was concrete panels with open slotting, and the front gate was made of polyvinyl chloride planking hinged at both ends. Each pen was equipped with one wet-dry feeder (0.38 × 0.56 m; model F1-115, Crystal Spring Hog Equipment, St. Agathe, Manitoba, Canada) with two opposing feeding places located halfway along a dividing wall between pens. An additional water bowl drinker was located toward the back of the pen. In half of the pens, an additional feeder (0.38 × 0.35 m; model F3-115, Crystal Spring Hog Equipment, St. Agathe, MB, Canada) with one feeding place was installed on the opposing sidewall with an extra nipple drinker nearby. In the first barn turn, the extra feeder did not have a water line installed making the extra feeder a dry feeder. In the second barn turn, the water line was installed providing a wet-dry feeder. For both consecutive barn turns (Winter [November to March]; Spring [April to July]), the room was ventilated using negative pressure and temperature was maintained within the thermo-neutral zone for pigs. Artificial light was provided for 14-h (0600 to 2000 h) followed by 10-h of darkness in the windowless barn.

Experimental Design and Diets

For the experiment, pens were blocked by area of the rectangular growout room. The trial was set up as a 2 × 2 × 2 × 2 factorial design with dietary NE level (9.2 or 9.85 MJ/kg), feeding spaces (2 or 3 feeder spaces), group size (18 or 22 pigs/pen), and sex (barrows or gilts) as factors. Each combination of factors occurred in 6 replicate pens. The test diets were fed to slaughter weight over five growth phases (Grower 1: day [d] 0 to 20, Grower 2: d 21 to 41, Grower 3: d 42 to 62, Finisher 1: d 63 to 80, Finisher 2: d 81 to slaughter). Low NE diets were based on barley grain whereas high NE diets were based on wheat grain and field pea or faba bean with added canola oil (Tables 1–3). Feedstuff NE levels were calculated using EvaPig based on chemical analysis of samples for that year's crop; standardized ileal digestibility (SID) of amino acids (AA) were taken from AminoDat. Diets were formulated to provide 1.10, 0.92, 0.78, 0.69, and 0.65 g SID lysine (Lys)/MJ NE per growth phase, respectively. Other AA ratios to Lys were set as per the ideal protein concept

Table 1. Ingredient composition and analyzed nutrient content (standardized to 12% moisture) of experimental Grower and Finisher diets fed in the first barn turn

	Grower 1		Grower 2		Grower 3		Finisher 1		Finisher 2	
	Low NE[1]	High NE	Low NE	High NE	Low NE	High NE	Low NE	High NE	Low NE	High NE
Ingredient, %										
Wheat, ground	30.04	36.71	18.87	58.63	6.77	68.17	2.50	48.85	2.50	45.58
Barley, ground	14.69	0.00	43.42	0.00	67.89	9.93	81.04	36.19	83.37	41.79
Wheat DDGS[2]	30.00	29.41	21.55	18.83	13.75	5.86	7.73	2.14	5.27	0.00
Field pea, ground	22.57	28.37	13.62	18.76	9.27	13.64	6.59	10.17	6.83	10.04
Canola oil	0.00	2.70	0.00	1.21	0.98	0.92	0.00	0.50	0.00	0.50
Limestone	1.35	1.35	1.18	1.17	0.18	0.28	0.87	0.88	0.88	0.83
Salt	0.50	0.50	0.50	0.50	0.40	0.40	0.50	0.50	0.50	0.50
L-Lysine HCl	0.54	0.56	0.47	0.47	0.03	0.04	0.35	0.35	0.32	0.32
Mono-/di-calcium phosphate	0.00	0.00	0.11	0.12	0.50	0.50	0.21	0.17	0.15	0.21
Vitamin/trace mineral premix[3]	0.10	0.10	0.10	0.10	0.10	0.10	0.07	0.07	0.05	0.05
L-Threonine	0.11	0.14	0.09	0.11	0.07	0.11	0.10	0.13	0.09	0.12
DL-Methionine	0.05	0.07	0.03	0.04	0.07	0.11	0.02	0.03	0.02	0.03
$CuSO_4 \cdot 5H_2O$	0.04	0.04	0.04	0.04	0.04	0.04	0.00	0.00	0.00	0.00
Phytase[4]	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
L-Tryptophan	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Analyzed content, %										
Starch	33.92	29.12	35.91	37.56	42.35	49.49	40.6	50.52	44.98	54.62
Crude protein	20.72	20.28	17.77	18.20	16.03	14.92	15.72	14.92	12.66	13.00
NDF	14.19	13.60	14.95	12.09	13.5	10.64	16.73	11.38	14.79	12.27
ADF	9.28	9.28	9.06	7.13	6.91	5.23	8.43	5.54	6.73	5.97
Crude fibre	3.94	3.94	4.49	3.48	4.07	3.52	5.07	3.59	4.14	3.70
Ash	5.73	5.32	4.55	4.29	4.32	3.28	4.40	3.32	3.68	3.40
Crude fat	3.59	6.09	2.23	3.31	1.47	0.90	1.28	0.83	1.22	1.41
Lysine	1.14	1.08	0.99	1.06	0.91	0.97	0.94	0.82	0.77	0.83
Threonine	0.75	0.75	0.61	0.64	0.57	0.55	0.56	0.55	0.49	0.51
Methionine	0.30	0.30	0.28	0.27	0.27	0.25	0.26	0.23	0.21	0.24
Cysteine	0.36	0.39	0.34	0.35	0.35	0.32	0.34	0.32	0.28	0.31

Table 1. Continued

	Grower 1		Grower 2		Grower 3		Finisher 1		Finisher 2	
	Low NE[1]	High NE	Low NE	High NE	Low NE	High NE	Low NE	High NE	Low NE	High NE
Calculated levels										
DE[5] (MJ/kg)[6]	13.27	13.89	13.15	13.89	13.19	13.84	12.62	13.70	12.93	13.48
NE (MJ/kg)[7]	9.09	9.61	9.07	9.74	9.32	9.98	8.83	9.89	9.31	9.91
NE as fed basis (MJ/kg)[7]	9.35	9.87	9.14	9.89	9.33	9.96	8.81	9.73	9.31	9.88

[1]Net energy level.

[2]Distillers dried grain and solubles.

[3]Provided the following per kilogram of diet: In grower-diets, 100 mg Zn, 100 mg Fe, 15 mg Cu, 40 mg Mn, 1 mg I, 0.3 mg Se, 8,000 IU vitamin A, 1,500 IU vitamin D, 30 IU vitamin E, 20 mg niacin, 12 mg D-pantothenic acid, 4 mg riboflavin, 2 mg menadione, 2 mg pyridoxine, 0.5 mg folic acid, 1 mg thiamine, 0.1 mg D-biotin, and 0.02 mg vitamin B12; in finisher 1 diets, 70 mg Zn, 70 mg Fe, 10.5 mg Cu, 28 mg Mn, 0.7 mg I, 0.2 mg Se, 5,600 IU vitamin A, 1,050 IU vitamin D, 21 IU vitamin E, 14 mg niacin, 8.4 mg D-pantothenic acid, 2.8 mg riboflavin, 1.4 mg menadione, 1.4 mg pyridoxine, 0.35 mg folic acid, 0.7 mg thiamine, 0.07 mg D-biotin, and 0.01 mg vitamin B12; in finisher 2 diets, 50 mg Zn, 50 mg Fe, 7.5 mg Cu, 20 mg Mn, 0.5 mg I, 0.15 mg Se, 4,000 IU vitamin A, 750 IU vitamin D, 15 IU vitamin E, 10 mg niacin, 6 mg D-pantothenic acid, 2 mg riboflavin, 1 mg menadione, 1 mg pyridoxine, 0.25 mg folic acid, 0.5 mg thiamine, 0.05 mg D-biotin, and 0.01 mg vitamin B12.

[4]Ronozyme P-(M) 200; DSM Nutritional Products Canada Inc., Ayr, ON, Canada.

[5]Digestible energy level.

[6]Calculated using equations 1–3 from NRC (2012).

[7]Calculated using equations 1–8 from NRC (2012).

Table 2. Ingredient composition and analyzed nutrient content (standardized to 12% moisture) of experimental Grower and Finisher diets fed in the second barn turn

	Grower 1		Grower 2		Grower 3		Finisher 1		Finisher 2	
	Low NE[1]	High NE	Low NE	High NE	Low NE	High NE	Low NE	High NE	Low NE	High NE
Ingredient, %										
Wheat, ground	30.04	36.71	26.83	51.49	19.66	64.14	12.04	74.32	4.23	75.96
Barley, ground	14.69	0.00	34.44	0.00	52.99	0.00	69.84	0.00	82.88	3.98
Wheat DDGS[2]	30.00	29.41	22.28	22.53	18.01	18.49	13.44	14.11	8.33	9.09
Faba bean, ground	0.00	0.00	13.78	21.27	6.93	13.81	2.43	8.94	2.41	8.85
Field pea, ground	22.57	28.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Canola oil	0.00	2.70	0.30	2.31	0.30	1.47	0.30	0.71	0.30	0.30
Limestone	1.35	1.35	1.14	1.13	1.00	0.99	0.95	0.94	0.90	0.88
Salt	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
L-Lysine HCl	0.54	0.56	0.40	0.40	0.40	0.40	0.35	0.35	0.32	0.32
Vitamin/trace mineral premix[3]	0.10	0.10	0.10	0.10	0.10	0.10	0.07	0.07	0.05	0.05
L-Threonine	0.11	0.14	0.05	0.05	0.05	0.05	0.04	0.04	0.06	0.05
DL-Methionine	0.05	0.07	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00
$CuSO_4 \cdot 5H_2O$	0.04	0.04	0.04	0.04	0.04	0.04	0.00	0.00	0.00	0.00

Table 2. Continued

	Grower 1		Grower 2		Grower 3		Finisher 1		Finisher 2	
	Low NE[1]	High NE	Low NE	High NE	Low NE	High NE	Low NE	High NE	Low NE	High NE
Phytase[4]	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
L-Tryptophan	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Analyzed content, %										
Starch	36.08	35.82	36.12	36.77	44.96	44.37	48.24	47.57	45.08	53.41
Crude protein	19.93	21.07	18.38	20.28	16.62	18.59	15.14	16.30	12.17	13.38
NDF	13.62	13.62	12.58	13.72	13.23	11.37	12.76	10.81	14.06	10.82
ADF	9.20	9.35	7.25	8.13	6.56	5.96	5.83	5.32	5.61	3.82
Crude fibre	4.24	4.50	3.61	4.35	3.65	3.59	3.43	2.97	4.11	2.97
Ash	4.58	3.85	4.18	3.85	3.65	3.55	3.24	3.43	3.41	3.03
Crude fat	2.57	4.37	2.74	4.44	2.16	3.17	2.28	2.37	1.07	0.95
Lysine	1.22	0.99	0.98	0.92	0.93	0.96	0.75	0.83	0.79	0.70
Threonine	0.75	0.75	0.66	0.67	0.55	0.57	0.48	0.55	0.47	0.49
Methionine	0.35	0.31	0.26	0.32	0.25	0.27	0.24	0.24	0.19	0.22
Cysteine	0.45	0.40	0.38	0.42	0.37	0.37	0.33	0.36	0.26	0.29
Calculated levels										
DE[5] (MJ/kg)[6]	13.56	14.23	13.78	14.16	13.65	14.29	13.78	14.10	13.08	13.79
NE (MJ/kg)[7]	9.30	9.83	9.59	9.88	9.73	10.18	9.98	10.17	9.47	10.14
NE as fed basis (MJ/kg)[7]	9.31	10.01	9.71	10.02	9.72	10.17	9.95	10.12	9.41	10.02

[1]Net energy level.

[2]Distillers dried grain and solubles.

[3]Provided the following per kilogram of diet: In grower-diets, 100 mg Zn, 100 mg Fe, 15 mg Cu, 40 mg Mn, 1 mg I, 0.3 mg Se, 8,000 IU vitamin A, 1,500 IU vitamin D, 30 IU vitamin E, 20 mg niacin, 12 mg D-pantothenic acid, 4 mg riboflavin, 2 mg menadione, 2 mg pyridoxine, 0.5 mg folic acid, 1 mg thiamine, 0.1 mg D-biotin, and 0.02 mg vitamin B12; in finisher 1 diets, 70 mg Zn, 70 mg Fe, 10.5 mg Cu, 28 mg Mn, 0.7 mg I, 0.2 mg Se, 5,600 IU vitamin A, 1,050 IU vitamin D, 21 IU vitamin E, 14 mg niacin, 8.4 mg D-pantothenic acid, 2.8 mg riboflavin, 1.4 mg menadione, 1.4 mg pyridoxine, 0.35 mg folic acid, 0.7 mg thiamine, 0.07 mg D-biotin, and 0.01 mg vitamin B12; in finisher 2 diets, 50 mg Zn, 50 mg Fe, 7.5 mg Cu, 20 mg Mn, 0.5 mg I, 0.15 mg Se, 4,000 IU vitamin A, 750 IU vitamin D, 15 IU vitamin E, 10 mg niacin, 6 mg D-pantothenic acid, 2 mg riboflavin, 1 mg menadione, 1 mg pyridoxine, 0.25 mg folic acid, 0.5 mg thiamine, 0.05 mg D-biotin, and 0.01 mg vitamin B12.

[4]Ronozyme P-(M) 200; DSM Nutritional Products Canada Inc., Ayr, ON, Canada.

[5]Digestible energy level.

[6]Calculated using equations 1–3 from NRC (2012).

[7]Calculated using equations 1–8 from NRC (2012).

Table 3. Analyzed nutrient content of feedstuffs fed in the trial (as-is basis)

	Wheat		Barley		Wheat DDGS[1]		Field pea		Faba bean	
	First turn	Second turn	First turn	Second turn	First turn	Second turn	First turn	Second turn	First turn	Second turn
Nutrient, %										
Moisture	12.77	11.61	12.52	11.52	9.18	10.12	11.99	9.87	11.80	11.09
Starch	55.74	51.44	49.44	53.39	3.14	0.98	36.67	44.08	36.03	40.02
Crude protein	12.01	12.87	11.46	11.26	35.57	36.51	20.43	21.37	23.97	27.17
NDF	9.68	9.35	12.87	13.36	20.65	23.63	9.51	9.99	12.95	9.38
ADF	3.04	3.18	4.73	5.17	17.27	18.12	6.66	5.78	9.83	7.61
Crude fibre	2.10	2.47	3.81	4.05	6.58	6.17	4.67	4.59	9.10	6.26
Ash	1.34	1.52	2.19	2.06	4.77	4.93	4.00	3.15	3.37	2.99
Crude fat	0.85	1.00	1.48	0.95	5.89	5.83	0.63	0.63	0.31	0.58
Lysine	0.35	0.36	0.43	0.41	0.76	0.84	1.58	1.62	1.61	1.68
Threonine	0.33	0.36	0.37	0.36	1.07	1.13	0.77	0.79	0.85	0.93
Methionine	0.19	0.20	0.19	0.18	0.52	0.57	0.19	0.20	0.18	0.18
Cysteine	0.29	0.29	0.26	0.25	0.73	0.79	0.31	0.29	0.32	0.35

[1]Distillers dried grain and solubles.

(NRC, 2012). Premixes were added to exceed vitamins and trace mineral requirements (NRC, 2012) per growth phase. Pigs had free access to water and the assigned phase test diet in mash form.

Measurements and Calculations

A robotic feeding system (Feed Logic, Feed Logic Co., Willmar, MN, USA) delivered and electronically recorded the amount of assigned test diet fed to each pen. Pigs were group-weighed at the initiation of feeding the experimental diets (d 0) and on d 20, 41, 62, 80, 88, and 98, and individually at target slaughter BW (130 kg). Feed remaining in the pen feeder on weigh days was determined by leveling the feed, measuring to the top of the feeder hopper, and estimating the leftover feed weight using an equation that accounted for measured diet bulk density (maximum weight error 0.1%; Seneviratne et al., 2010). Collected data were used to calculate pen average daily feed disappearance (ADFD), average daily weight gain (ADWG), and feed efficiency expressed as ADWG/ADFD (gain-to-feed ratio [G:F]). Average daily caloric disappearance (ADCD) was calculated multiplying ADFD by calculated diet NE level and dividing by number of days in each growth phase corrected for removals and mortality.

Pigs were fed the assigned test regimen until the attainment of target slaughter BW (130 kg). As pigs grew near target market BW, several pigs from each pen were individually weighed and used as reference size pigs to select other pigs to be sent for slaughter that week. Pigs were shipped for slaughter over 6 weeks starting on day 82. Pigs were slaughtered at a commercial abattoir (Maple Leaf, Brandon, MB, Canada) following typical commercial procedures. Warm carcasses were weighed including head, kidneys, omental fat, and feet, and were graded for backfat and loin depth using a light-reflectance probe (Destron PG-100, Destron Technologies, Markham, ON, Canada) inserted between the third and fourth last ribs, 7 cm off the midline (Pomar and Marcoux, 2003). Lean yield was estimated using an established equation (lean, % = 68.1863 − 0.7833 × backfat + 0.0689 × loin + 0.0008 × backfat × backfat − 0.0002 × loin × loin + 0.0006 × backfat × loin, [backfat and loin depth measurements in mm]; AAFC et al., 1994). Carcass index was determined using the packer's grid that interpolated warm carcass weight and estimated lean yield. Carcass dressing percentage was calculated as carcass weight divided by farm live BW at the time of shipping.

Chemical Analyses

Samples of the diets and main feedstuffs were ground through a 1 mm screen in a centrifugal mill (Retsch GmbH, Haan, Germany) prior to chemical analysis. Diets and ingredients were analyzed for moisture (method 934.01), crude protein (CP; method 990.03), crude fat (method 920.39 [A]), ash (method 942.05), crude fiber (method 978.10), acid detergent fiber (ADF; method 973.18 [A-D]), neutral detergent fiber (NDF; Holst, 1973), starch (assay kit STA-20; Sigma, St. Louis, MO, USA) and AA (method 982.30 E [a, b, c]) content using the Association of Official Analytical Chemists (AOAC, 2006) methods at the Agricultural Experiment Station Chemical Laboratories (University of Missouri, Columbia, MO, USA).

Statistical Analyses

Growth performance and carcass data were analyzed using the MIXED procedure of SAS Ver. 9.3. Pen was the experimental unit for all variables. Models included the fixed effects of dietary NE level, feeder space, group size, sex, and interactions. Area block and barn turn were random terms in the model. Initial BW was tested as covariate for ADFD, ADCD, ADWG, and G:F, and was included if it improved the fit of the model. Overall ADFD, ADCD, ADWG, and G:F were analyzed using barn turn ending (closeout) data. Body weight, ADFD, ADWG, G:F, and ADCD were also analyzed as repeated measures including growth phase as repeated term. An appropriate covariance structure was selected by comparing the goodness-of-fit measures of different structures. The Kenward-Roger correction was used for the denominator degrees of freedom. The proportion of pigs remaining in pens upon shipping for slaughter (starting on d 82) was analyzed with a generalized linear model (GLIMMIX procedure) using the binomial distribution and the logit link function. The proportion of total feed eaten from the extra feeder was analyzed with GLIMMIX using a beta distribution and the logit link function. Growth performance data are reported until day 88. To test the hypotheses, $P < 0.05$ was considered significant, and $P < 0.10$ was a trend.

RESULTS

Dietary Nutrients

Comparing diets [5 phases × 2 barn turns = 10 diets of each; (Tables 1 and 2)], low NE diets had 2 %-points greater NDF ($P < 0.010$) and tended to have 0.6 %-points greater crude fibre content ($P = 0.075$). Starch, CP, ADF, ash, and crude fat content were not different between low and high NE diets.

Growth Performance

For the entire trial (Table 4), pigs fed low NE diets had 0.119 kg/d greater ($P < 0.001$) ADFD, but 0.556 MJ/d lower ($P < 0.050$) ADCD, and 0.017 kg/kg lower ($P < 0.001$) G:F than pigs fed high NE diets. There was an interaction between dietary NE level and sex for ADCD; barrows fed low NE diets had lower ADCD than barrows fed high NE diets, whereas dietary NE level had no effect on ADCD of gilts. ADWG was not different between pigs fed low or high NE diets. For the entire trial, pigs in pens with 3 feeder spaces had 0.051 kg/d greater ($P < 0.010$) ADFD, 0.511 MJ/d greater ($P = 0.050$) ADCD, and 0.004 kg/kg lower ($P < 0.050$) G:F than pigs in pens with 2 feeder spaces. ADWG was not different between pigs in pens with 2 or 3 feeder spaces. For the entire trial, pens with 18 pigs had 0.062 kg/d greater ($P < 0.001$) ADFD, 0.730 MJ/d greater ($P < 0.010$) ADCD, and 0.029 kg/d greater ($P < 0.001$) ADWG than pens with 22 pigs. Gain-to-feed was not affected by group size. For the entire trial, barrows had 0.314 kg greater ($P < 0.001$) ADFD, 4.219 MJ greater ADCD, 0.074 kg greater ADWG, but 0.015 kg/kg lower G:F than gilts.

There was a four-way interaction among dietary NE level, feeder space, group size, and sex for ADWG. Because ADWG was greater in barrows than gilts, the dataset was split by sex to interpret the interaction further. For both barrows and gilts, there was no effect of NE level on ADWG. In barrows, ADWG was greater for pens with 18 vs. 22 pigs, whereas feeder space had no effect on ADWG. In gilts, there was an interaction between feeder

Table 4. Effect of dietary net energy (NE) level (9.21 MJ/kg [low] vs. 9.84 MJ/kg [high]), feeder spaces (2 vs. 3), and group size (18 vs. 22 pigs/pen) on overall (d 0 to 88) average daily feed disappearance (ADFD), average daily caloric (NE) disappearance (ADCD), average daily weight gain (ADWG), and feed efficiency (ADWG/ADFD, G:F) of growing-finishing barrows and gilts

	Dietary NE level		Feeder space		Group size		Sex		SEM	*P*-value			
	Low	High	2	3	18	22	Barrows	Gilts		NE level	Feeder space	Group size	Sex
ADFD[1], kg/d	2.829	2.710	2.744	2.795	2.801	2.739	2.927	2.613	0.045	<0.001	<0.010	<0.001	<0.001
ADCD[1,2], MJ/d	28.865	29.421	28.888	29.399	29.508	28.778	31.253	27.034	0.496	<0.050	0.050	<0.010	<0.001
ADWG[3], kg	0.992	0.994	1.000	0.996	1.008	0.979	1.030	0.956	0.004	0.611	0.157	<0.001	<0.001
G:F[1]	0.351	0.368	0.361	0.357	0.361	0.358	0.352	0.367	0.002	<0.001	<0.050	0.126	<0.001

[1]Body weight on d 0 included as a covariate in the model.

[2]Interaction ($P < 0.050$) between dietary NE level and sex.

[3]Four-way interaction ($P < 0.050$) between NE level, group size, feeder space, and sex.

space and group size for ADWG; an extra feeder space only increased ADWG in pens with 18 pigs, not in pens with 22 pigs. Moreover, housing 18 vs. 22 pigs increased ADWG only in pens with 3 feeder spaces, not in pens with 2 feeder spaces.

Throughout the trial, there was no effect of dietary NE level or feeder space on BW (Table 5). On d 0, 20, and 41, BW was not different between pens with 18 vs. 22 pigs. BW tended to be greater ($P = 0.079$) on d 62 and was significantly greater ($P < 0.050$) on d 80 and 88 for pens with 18 vs. 22 pigs. As of d 41 and overall, barrows were heavier than gilts ($P < 0.001$). Throughout the trial, ADFD was greater ($P < 0.050$) for pigs fed low vs. high NE diets, although for d 0 to 20, d 42 to 62, and d 81 to 88 there was only a trend ($P < 0.100$). ADCD was lower for pigs fed low vs. high NE diets for d 0 to 20 and d 42 to 62, whereas dietary NE level did not affect ADCD for d 21 to 41, d 63 to 80 and d 81 to 88. Both ADFD and ADCD were consistently greater ($P < 0.050$) for pens with 3 vs. 2 feeding spaces, for pens with 18 vs. 22 pigs, and barrows vs. gilts. ADWG was not different for pigs fed low vs. high NE diets, except for d 42 to 62 when ADWG was lower ($P < 0.001$) for pigs fed low vs. high NE diets. Throughout the trial, feeder space did not affect ADWG, whereas pens with 18 pigs had consistently greater ($P < 0.001$) ADWG than pens with 22 pigs and so did barrows vs. gilts. Gain-to-feed was consistently lower ($P < 0.050$) for pigs fed low vs. high NE diets, for pens with 3 vs. 2 feeder spaces, and for barrows vs. gilts. Group size did not affect G:F for any growth phase.

The additional feeder space was used more ($P < 0.001$) in the second vs. the first barn turn (Table 6). In both barn turns, pigs fed low NE diets ate proportionally more feed from the extra feeder than pigs fed high NE diets. In the first barn turn, there was no effect of group size on the use of the extra feeder space, whereas in the second barn turn pens with 22 pigs ate proportionally more from the extra feeder space than pens with 18 pigs. In the second barn turn, there was an interaction between NE level and sex; barrows fed high NE diets used the extra feeder spaceless ($P < 0.050$) than both gilts and barrows fed low NE diets. In the second barn turn, there was also an interaction between group size and sex; pens with 18 barrows used the extra feeder spaceless ($P < 0.050$) than pens with 22 barrows, whereas there was no effect of group size in pens with gilts.

Shipping for Slaughter and Carcass Characteristics

The proportion of pigs shipped on d 88 was not affected by dietary NE level, feeder space, or group size (Table 7). On d 98, a greater ($P < 0.010$) proportion of pigs had been shipped from pens with 18 vs. 22 pigs, whereas there was no effect of dietary NE level. On d 98, pens with 3 feeder spaces tended ($P = 0.066$) to have more pigs shipped than pens with 2 feeder spaces. Overall, the total proportion of pigs shipped to slaughter was not different among dietary NE levels, feeder spaces, and group sizes, but barrows shipped sooner ($P < 0.001$) than gilts.

As the number of days to shipping for slaughter (calculated from the start of the Finisher 2 phase [d 80 of the trial]) was confounded with the effects of dietary NE level and group size on ship weight (Table 8), the estimated number of days to reach 130 kg live BW was calculated. Pigs fed low NE diets tended ($P = 0.074$) to take 1.3 days longer to reach 130 kg BW than those fed high NE diets. Pens with 22 pigs took 2.8 days longer ($P < 0.001$) to reach 130 kg BW than pens with 18 pigs, whereas there was no difference between pens with 2 or 3 feeder spaces. There was a three-way interaction among dietary NE level, feeder space, and sex for the estimated number of days to reach 130 kg live BW; in gilts, there was no effect of NE level or feeder space, whereas barrows fed low NE diets in pens with 2 feeder spaces took longer ($P < 0.050$) to reach 130 kg BW than barrows fed high NE diets in pens with 3 feeder spaces. There was also an interaction between feeder space and group size for estimated number of days to reach 130 kg live BW; an extra feeder space only decreased days to 130 kg in pens with 18 pigs, not in pens with 22 pigs. Moreover, pens with 18 pigs only had decreased days to 130 kg in pens with 3 feeder spaces, not in pens with 2 feeder spaces.

Pigs fed low NE diets had 0.6 kg lower ($P < 0.050$) carcass weight and 0.9 mm lower ($P < 0.050$) loin depth than pigs fed high NE diets (Table 8). There was an interaction between dietary NE level and feeder space for carcass weight; carcass weight was lower ($P < 0.050$) for pigs fed low NE diets housed in pens with 3 feeder spaces compared with all other combinations (low NE, 2 feeders; high NE, 2 feeders; high NE, 3 feeders). Dietary NE level did not affect dressing percentage, backfat, lean yield, and index. Group size did not affect carcass traits, except for a 0.4 %-point decrease ($P < 0.050$) in dressing percentage for pens with 18 vs. 22 pigs. Number of feeder spaces did not affect any carcass traits. There was an interaction between dietary NE level and feeder space for carcass index; for pigs fed high NE diets, index was lower ($P < 0.050$) with 2 feeder spaces compared with 3 feeder

Table 5. Effect of dietary net energy (NE) level (9.21 MJ/kg [low] vs. 9.84 MJ/kg [high]), feeder spaces (2 vs. 3), and group size (18 vs. 22 pigs/pen) on body weight (BW), average daily feed disappearance (ADFD), average daily caloric (NE) disappearance (ADCD), average daily weight gain (ADWG), and feed efficiency (ADWG/ADFD, G:F) of growing-finishing barrows and gilts per growth phase

	Dietary NE level		Feeder space		Group size		Sex		SEM	*P*-value			
	Low	High	2	3	18	22	Barrows	Gilts		NE level	Feeder space	Group size	Sex
BW, kg													
Overall										0.956	0.988	<0.050	<0.001
d 0	30.9	31.0	31.0	30.8	30.9	31.0	31.1	30.7	0.6	n/a[1]	n/a	0.773	0.144
d 20	47.9	47.7	47.8	47.7	48.0	47.6	48.3	47.2	0.6	n/a	n/a	0.536	0.105
d 41	69.2	69.0	69.1	69.0	69.5	68.6	70.6	67.5	0.6	n/a	n/a	0.272	<0.001
d 62	90.3	90.7	90.5	90.5	91.2	89.8	93.1	88.0	0.6	n/a	n/a	0.079	<0.001
d 80	109.4	109.5	109.2	109.7	110.6	108.4	112.9	106.5	0.6	n/a	n/a	<0.001	<0.001
d 88	115.5	115.4	115.5	115.4	116.3	114.6	117.9	113.0	0.6	n/a	n/a	<0.050	<0.001
ADFD[2], kg/d													
d 0 to 20	2.103	2.069	2.068	2.104	2.104	2.068	2.115	2.058	0.029	0.055	n/a	n/a	<0.010
d 21 to 41	2.673	2.564	2.606	2.631	2.651	2.585	2.762	2.474	0.031	<0.001	n/a	n/a	<0.001
d 42 to 62	2.962	2.901	2.897	2.966	2.976	2.886	3.154	2.709	0.035	0.060	n/a	n/a	<0.001
d 63 to 80	3.278	3.028	3.097	3.209	3.220	3.086	3.614	2.692	0.073	<0.050	n/a	n/a	<0.001
d 81 to 88	3.420	3.296	3.309	3.407	3.382	3.334	3.560	3.156	0.054	0.063	n/a	n/a	<0.001
ADCD[2], MJ/d													
d 0 to 20	19.635	20.578	19.922	20.292	20.274	19.939	20.390	19.823	0.166	<0.001	n/a	n/a	<0.010
d 21 to 41	25.212	25.527	25.247	25.492	25.688	25.051	26.765	23.974	0.195	0.175	n/a	n/a	<0.001
d 42 to 62	28.219	29.201	28.366	29.054	29.144	28.277	30.900	26.520	0.239	<0.010	n/a	n/a	<0.001
d 63 to 80	30.726	30.048	29.864	30.910	30.993	29.781	34.734	26.039	0.608	0.425	n/a	n/a	<0.001
d 81 to 88	31.888	32.788	31.919	32.757	32.504	32.173	34.222	30.454	0.431	0.131	n/a	n/a	<0.001
ADWG[2,3], kg/d													
d 0 to 20	0.966	0.962	0.966	0.962	0.976	0.952	0.986	0.942	0.008	0.694	n/a	n/a	<0.001
d 21 to 41	1.041	1.035	1.031	1.044	1.048	1.027	1.087	0.989	0.008	0.504	n/a	n/a	<0.001
d 42 to 62	1.005	1.041	1.015	1.031	1.041	1.005	1.072	0.974	0.008	<0.001	n/a	n/a	<0.001
d 63 to 80	0.932	0.927	0.918	0.941	0.960	0.899	1.037	0.822	0.020	0.864	n/a	n/a	<0.001
d 81 to 88	0.990	1.011	0.995	1.006	1.007	0.993	1.016	0.985	0.016	0.349	n/a	n/a	0.159
G:F[2], kg/kg													
d 0 to 20	0.459	0.466	0.467	0.457	0.464	0.461	0.466	0.459	0.005	<0.050	n/a	n/a	<0.050
d 21 to 41	0.391	0.404	0.397	0.398	0.396	0.398	0.394	0.401	0.005	<0.001	n/a	n/a	<0.050
d 42 to 62	0.341	0.360	0.352	0.349	0.351	0.350	0.341	0.360	0.005	<0.001	n/a	n/a	<0.001
d 63 to 80	0.287	0.308	0.300	0.296	0.302	0.294	0.290	0.306	0.006	<0.001	n/a	n/a	<0.001
d 81 to 88	0.293	0.307	0.302	0.298	0.301	0.299	0.288	0.312	0.006	<0.010	n/a	n/a	<0.001

[1]*P*-value is only given if there was an interaction with time. Otherwise, not available (n/a) means that the effect for each phase was the same as the overall effect (Table 4).

[2]Body weight on d 0 included as a covariate in the model.

[3]Interaction ($P < 0.050$) between group size and feeder space.

Table 6. Effect of dietary net energy (NE) level (9.21 MJ/kg [low] vs. 9.84 MJ/kg [high]), group size (18 vs. 22 pigs/pen), and sex (barrows vs. gilts) on the use of the extra feeder space (as % of total pen feed disappearance) in the first and second barn turn

	Dietary NE level		Group size		Sex		SEM	*P*-value		
	Low	High	18	22	Barrows	Gilts		NE level	Group size	Sex
First barn turn	9.3	5.8	7.1	7.7	7.2	7.6	0.9	<0.001	0.408	0.550
Second barn turn[1,2]	22.5	15.9	16.4	21.9	14.8	24.1	1.2	<0.001	<0.010	<0.001

[1]Interaction ($P < 0.001$) between dietary NE level and sex.

[2]Interaction ($P < 0.050$) between group size and sex.

Table 7. Effect of dietary net energy (NE) level (9.21 MJ/kg [low] vs. 9.84 MJ/kg [high]), feeder spaces (2 vs. 3), and group size (18 vs. 22 pigs/pen) on the proportion (%) of barrows and gilts shipped per period (d 82 to 129)

	Dietary NE level		Feeder space		Group size		Sex		SEM	*P*-value			
	Low	High	2	3	18	22	Barrows	Gilts		NE level	Feeder space	Group size	Sex
Shipped by day 88, %	8.1	8.7	7.9	8.9	9.5	7.4	20.5	3.2	1.2	0.709	0.554	0.189	<0.001
Shipped by day 98, %	41.9	45.6	41.5	45.9	47.3	40.2	56.6	31.6	1.6	0.126	0.066	<0.010	<0.001
Shipped total, %	96.1	95.8	96.0	95.9	96.5	95.3	94.8	96.9	0.7	0.759	0.932	0.200	<0.050

spaces, whereas in pens fed low NE diets there was no effect of feeder space. There was also an interaction between group size and sex for index; for gilts, index was lower ($P < 0.050$) for pens with 22 pigs vs. 18 pigs, whereas for barrows, there was no difference in index between 18 and 22 pigs/pen.

Cost vs. Benefit

Feeding low vs. high NE diets reduced ($P < 0.001$) overall feed cost by Can$21.87/tonne, $3.34/pig, $0.03/kg gain, and increased ($P < 0.05$) gross income subtracting feed cost (ISFC) by $1.82/pig (Table 9). Other than the extra cost of the feeder, installing it, and hooking up the water line, providing pigs 3 vs. 2 feeder spaces had no effect on cost vs. benefit. Housing 18 vs. 22 pigs per pen increased ($P < 0.010$) ISFC by $1.98 per pig. Barrows had greater feed cost per pig ($3.60), and per kg gain ($0.03) but lower ISFC ($2.35) than gilts ($P < 0.010$; Table 9).

DISCUSSION

Dietary Energy Level

In our trial, calculated dietary NE levels based on chemical analyses of the diets were generally greater than formulated NE levels. Nonetheless, low NE diets had consistently lower NE values than high NE diets, meaning that effects of NE levels could be interpreted. The low NE diets had a greater inclusion of barley and lower inclusions of wheat grain, field pea or faba bean, and canola oil than the high NE diets. Similar to our previous trials (Smit et al., 2017, 2018), changes in feedstuffs led to greater NDF and crude fiber content in low vs. high NE diets. Crude fat content was not different between low and high NE diets, which contrasts with many other studies that increased dietary NE level by adding fat to the diet (Smith et al., 1999; Schinckel et al., 2012; Lee et al., 2015).

Pigs in our facility have consistently responded to lower NE diets by increasing feed intake, but not enough to keep caloric intake up. Lower caloric intake when fed a lower NE diet happened in the Grower phases more so than the Finisher phases, which is consistent with gut capacity being limiting in growing but not finishing pigs (Whittmore et al., 2001). Nonetheless, weight gain was not affected by dietary NE level, thus leading to a lower gain-to-feed ratio but greater caloric efficiency feeding low vs. high NE diets (Smit et al., 2017, 2018, and this study). Similar caloric intake in the Finisher phases resulted in no difference in backfat depth for pigs fed low or high NE diets. The decrease in loin depth for pigs fed low NE diets compared with those fed high NE diets was not expected. We formulated low and high NE diets to equal SID Lys/MJ ratio, suggesting that pigs on the low NE diet should have had the same potential for lean growth. Indeed, lean yield was not affected by dietary NE level. Feed cost per tonne, per pig, and per kg BW gain was lower for pigs fed low vs. high NE diets, resulting in Can$1.82 greater ISFC. Reducing NE level had a greater impact on cost vs. benefit than

Table 8. Effect of dietary net energy (NE) level (9.21 MJ/kg [low] vs. 9.84 MJ/kg [high]), feeder spaces (2 vs. 3), and group size (18 vs. 22 pigs/pen) on days to shipping, days to 130 kg live body weight (BW), and carcass characteristics of growing-finishing barrows and gilts

	Dietary NE level		Feeder space		Group size		Sex		SEM	*P*-value			
	Low	High	2	3	18	22	Barrows	Gilts		NE level	Feeder space	Group size	Sex
Days to shipping	24.0	23.4	24.2	23.2	22.7	24.7	20.1	27.3	1.5	0.436	0.177	<0.010	<0.001
Days to 130[1,2] kg BW	24.5	23.2	24.3	23.5	22.5	25.3	20.0	27.8	0.9	0.074	0.232	<0.001	<0.001
Ship weight[3,4], kg	129.3	130.1	129.8	129.7	130.3	129.1	130.1	129.3	0.7	<0.050	0.745	0.001	<0.050
Carcass weight[5], kg	102.0	102.6	102.4	102.2	102.5	102.1	102.5	102.1	0.4	<0.050	0.398	0.184	0.364
Dressing, %	78.7	78.8	78.9	78.6	78.5	78.9	78.6	78.8	0.1	0.591	0.120	<0.050	0.255
Back fat, mm	18.6	18.7	18.6	18.7	18.8	18.5	19.9	17.4	0.6	0.532	0.447	0.101	<0.001
Loin depth, mm	61.4	62.3	61.9	61.8	62.2	61.5	60.9	62.8	0.6	<0.050	0.700	0.126	<0.001
Lean yield, %	60.7	60.7	60.7	60.6	60.6	60.7	60.1	61.3	0.2	0.991	0.346	0.321	<0.001
Index[5,6]	110.5	110.5	110.3	110.7	110.6	110.3	110.4	110.6	0.3	0.933	0.388	0.486	0.618

[1]Three-way interaction ($P < 0.050$) among dietary NE level, feeder space, and sex.

[2]Interaction ($P < 0.050$) between group size and feeder space.

[3]Interaction ($P < 0.050$) between feeder space and sex.

[4]Three-way interaction ($P < 0.050$) among group size, feeder space, and sex.

[5]Interaction ($P < 0.050$) between dietary NE level and feeder space.

[6]Interaction ($P < 0.010$) between group size and sex.

group size. These findings agree with our previous observations (Beltranena and Smit, 2015).

Considering that a high stocking density (pigs growing larger in the same amount of floor area) and a low number of feeder spaces might interfere with the pig's ability to increase feed intake when fed low NE diets, we expected to see interactions between these parameters. Surprisingly, no interactions were found for feed disappearance at all, suggesting that the increase in feed intake when feeding low NE diets was similar for pens with both 18 and 22 pigs, and pens with 2 or 3 feeding spaces. This finding agrees with results from Brumm and Miller (1996) and Rozeboom (2014), who also did not report an interaction for feed intake between dietary energy level and space allocation. In our previous trials (Smit et al., 2017, 2018), when 21 pigs were kept in pens with 2 feeder spaces, pigs were able to increase feed intake to maintain growth performance. The one extra pig per pen in the current study was not enough of an increase in group size to make a difference in that regard. Moreover, the increase in feed intake when feeding low NE diets was not greater when an extra feeder space was added, likely because even with 2 feeding spaces, pigs were able to maintain the growth rate. This finding indicates that older pigs eat to meet their requirements for growth, rather than pigs growing because of their drive to eat as suggested by Whittemore et al. (2001).

Group Size

Adjustments to floor space allocation for pigs can be achieved in two ways: either by changing the size of the pen (floor area) or by changing the number of pigs per pen. These different strategies could potentially lead to different outcomes assuming that it is harder to establish a social hierarchy, leading to increased aggression in larger groups (Ewbank, 1976). However, several trials have shown that group size had no effect on aggression, welfare, injuries, or growth performance when adequate pen floor area was provided (Randolph et al., 1981; Wolter et al., 2001; Schmolke et al., 2003, 2004). Changing the number of pigs per pen is easier to implement on commercial farms where pen size is often fixed. Therefore, we chose to keep the pen floor area constant and to change group size instead. The regular group size on this commercial farm was 21 pigs/pen. We chose 22 pigs/pen for the high group size, and we decreased this to 18 pigs/pen to provide more pen floor area per pig. The floor area available to pigs (pen area minus

Table 9. Effect of net energy (NE) level (9.21 MJ/kg [low] vs. 9.84 MJ/kg [high]), group size (18 vs. 22 pigs/pen), and feeder spaces (2 vs. 3) on feed cost[1] (Can$) and income subtracting feed cost (Can$; ISFC)

	Dietary NE level		Feeder space		Group size		Sex		SEM	*P*-value			
	Low	High	2	3	18	22	Barrows	Gilts		NE level	Feeder space	Group size	Sex
Feed cost/tonne	211.14	233.01	222.09	222.06	222.15	222.00	222.38	221.77	6.06	<0.001	0.951	0.754	0.203
Feed cost/pig	64.74	68.08	66.11	66.71	66.34	66.48	68.21	64.61	5.35	<0.001	0.148	0.742	<0.001
Feed cost/kg gain	0.63	0.66	0.64	0.65	0.64	0.65	0.66	0.63	0.01	<0.001	0.202	0.052	<0.001
ISFC	71.88	70.06	71.44	70.51	71.96	69.98	69.80	72.15	24.31	<0.050	0.206	<0.010	<0.010

[1]Cost (Can$/1,000 kg) wheat 171.5, barley 145, wheat distillers dried grain and solubles 172.5, field pea 230, zero-tannin faba bean 212, limestone 108, mono-/di-calcium phosphate 857, salt 84, L-lysine HCl 2,100, DL-methionine 4,500, L-threonine 2,700, L-tryptophan 12,000, $CuSO_4 \cdot 5\,H_2O$ 2,920, Ronozyme P-(M) 200 2,910, vitamin/trace mineral premix 6,100.

feeder area) was 14.43 m^2/pen. Following floor area allowance recommendations ($k \geq 0.0335$ for slatted floors; NFACC, 2014), pens with 18 pigs were not restricted in the floor area as by day 82 (>110 kg) the first pig(s) were sent for slaughter, whereas pens with 22 pigs were restricted in floor area from the end of the Grower 3 phase (~d 57 or ~85 kg) and throughout the Finisher 1 phase but improved weight gain upon shipping the heaviest pig(s) in each pen. This finding matches previous trials we have conducted in this barn where we have seen an effect of floor area allowance after but not before day 60 with pigs starting at similar BW (Seneviratne et al., 2010; Smit et al., 2017, 2018). Pigs often react to lower floor area allowance by decreasing their feed intake and consequently weight gain (Gonyou and Stricklin, 1998; Gonyou et al., 2006). Indeed, for pens with 22 pigs, weight gain was lower in Finisher 1 vs. either Grower 3 or Finisher 2 phases. However, this reduction also occurred in pens with 18 pigs that had more pen floor area, suggesting that group size was not the only factor decreasing weight gain in Finisher 1 phase. Nonetheless, BW tended to be lower for 22 vs. 18 pigs/pen at the end of the Grower 3 phase and was significantly lower from the Finisher 1 phase onward, indicating that pen floor area allowance did affect weight gain in these phases.

Although some studies have not found an effect of pen floor area allowance on feed intake (Hyun et al., 1998; Street and Gonyou, 2008; Kim et al., 2017), in most other studies a decrease in floor area allowance resulted in reduced feed intake, and a subsequent reduction in growth rate (Brumm and Miller, 1996; Edmonds and Baker, 2003; Brumm et al., 2004; Johnston et al., 2017; Thomas et al., 2017). Our results also showed both lower feed disappearance and weight gain in pens with 22 vs. 18 pigs. The effect of floor area allowance on feed efficiency has been variable, with some studies showing an increase in gain-to-feed with decreasing floor area (Edmonds et al., 1998; Street and Gonyou, 2008; Kim et al., 2017) and others including ours, showing no effect of floor area allowance on gain-to-feed (Brumm et al., 2001; Edmonds and Baker, 2003; Johnston et al., 2017). Because of lower weight gain, pigs from pens with 22 vs. 18 pigs took almost three more days to reach slaughter weight. Filling pens to near capacity (e.g., 15% under k) followed by scheduled (end of each growth phase) removal of underperforming pigs (e.g., 15% over k) may not only maximize weight gain but would also increase barn throughput. A constraint to this strategy is what to do with underperforming pigs removed (Beltranena and Smit, 2015). Why group size affected carcass dressing percentage may relate to the greater feed disappearance of pigs in pens of 18 vs. 22 pigs, thus slightly more feed was retained in the gut at slaughter despite similar transit and lairage times for both stocking densities.

Feeder Space

Assuming pigs have no preference for one feeder over another, the proportion of total feed disappearance for any one of the three feeders would be roughly 33%. However, feed disappearance from the additional feeder was much lower than that. In the first barn turn, when the additional feeder was a dry feeder, on average only 7.7% of total feed disappearance could be attributed to the additional feeder. In the second barn turn, when the water line was installed effectively turning the feeder into a wet-dry feeder, the proportion of feed disappearance attributed to the additional feeder increased to 20.1%. These results confirm that growing-finishing pigs prefer wet-dry over dry feeders, which has been previously reported (Brumm and Dahlquist, 1997; Magowan et al., 2008; Myers et al., 2013). Because the water nipple is in the feeder trough more feed is consumed in the same or less time (Gonyou and

Lou, 2000). Even when the additional feeder was turned into a wet-dry feeder like the existing pen feeder, usage still did not approach 33% of total pen feed disappearance. One of the reasons was likely the location of the extra feeder. The existing two-place feeder had two feeding spaces on opposing sides of the feeder. The feeder was located parallel to the side wall, and pigs eating from this feeder were sheltered by the pen wall on one side, resulting in less disturbance while eating from other pigs. The additional feeder, on the other hand, was located on the opposing side wall but with the feeder space facing the middle of the pen. A pig eating from this feeder would not only block the pathway for other pigs transiting through but could also be more easily disturbed while eating by other nearby pigs on both sides. This feeder positioning likely resulted in the additional feeder being less popular than the existing feeder despite increased access with the trough facing to the middle of the pen.

It was interesting to see that the extra feeder was used more in pens that were fed low vs. high NE diets and in pens with 22 vs. 18 pigs. In both cases, pigs would have to wait longer for feeder space to become available, either because of the increased time to eat in the case of low NE diets or because of the increased number of pigs queuing for the feeders. Walker (1991) showed that pigs have a diurnal pattern of feeding with two peaks of activity before and after midday. When the number of pigs per feeder was increased from 10 to 30, resulting in more pigs queuing for the feeders, the time when the feeder was occupied increased mostly due to increased feeding activity during the night and in the middle of the day (Walker, 1991). The extra feeder in our study likely allowed pigs to follow their preferred diurnal feeding pattern rather than having to eat at other times of the day as was needed for pigs in pens without an extra feeder.

Pigs in pens with only 2 feeder spaces were able to eat enough to satisfy their requirements as evidenced by weighing gain and BW that were not different from pigs from pens with 3 feeder spaces and by a lack of an effect of feeder space on carcass characteristics. There was a maximum of 11 pigs per feeder in our trial for the 22-pig pens with two feeder spaces, equivalent to a minimum of 3.4 cm linear trough width per pig vs. 2.9 to 3.1 cm recommended for wet-dry feeders (PIC, 2019). This finding agrees with existing literature suggesting that between 12 (Gonyou and Lou, 2000) and 20 (Spoolder et al., 1999) pigs can feed on a feeder space without affecting productivity. The fact that an extra feeder space increased feed disappearance without affecting weight gain resulting in a lower feed efficiency throughout the trial, suggests that some of the feed disappearance may have been due to feed waste rather than feed intake. The extra feeder allowed pigs to spend more time at the feeder and potentially to root more or play with and waste feed. Morrow and Walker (1994) found that the total time feeders were occupied and the number of visits to feeders were both increased when an extra feeder was provided. They, too, noted increased feed disappearance that did not result in changes in growth rate (Morrow and Walker, 1994). The lower feed efficiency for pens with 3 vs. 2 feeder spaces resulted in a higher feed cost per kg gain and Can$1.98 lower ISFC.

In conclusion, dietary energy level, feeder space, and group size independently affected pig growth performance and had no interactive effect on carcass traits either. Reducing group size from 22 to 18 resulted in pigs growing faster. Decreasing dietary energy level increased feed disappearance without affecting weight gain. Even pigs in pens that had more reduced floor area allowance as they grew during part of the Finishing phase (0.66 m^2/pig) and that had only 2 instead of 3 feeder spaces (11 pigs/feeder space), were able to increase feed consumption enough to sustain weight gain. As such, while decreasing group size from 22 to 18 pigs per pen and increasing feeder space from 2 to 3 per pen increased feed disappearance, these effects were independent of dietary energy level. A lack of interactions between NE level, feeder space, and group size for feed disappearance indicates that a lower energy dietary regimen can be fed to pigs even when faced with temporary floor area reduction during part of the Finishing phase.

As the success of feeding low energy diets depends on the ability of pigs to increase feed intake, it is not recommended to feed low NE diets during the warm summer months when feed intake may be reduced due to heat stress or when pigs are challenged by disease. Moreover, in situations where more than 11 pigs share a feeder, there is a potential that pigs may not have enough access to feeder space to eat to meet their growth requirements. More research is warranted to study interactions between dietary energy level and feeder space availability when more pigs share a feeder space or pen floor area is reduced for longer periods. These variables not only affect growth performance, animal welfare, and feed cost but also impact barn throughput and thus return on asset.

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LITERATURE CITED

AAFC; CVC; and CCP. 1994. Enquête nationale sur le rendement boucher du porc (1992): une initiative de recherche commune d'Agriculture et Agro-alimentaire Canada, le Conseil des viandes du Canada et le Conseil canadien du porc. Canada: Agriculture and Agri-Food, p. 107.

AOAC. 2006. Official methods of analysis. 18th ed. Arlington (VA): AOAC Int.

Beltranena, E., and M. Smit. 2015. Impact of low energy diets on the bottom line. Adv. Pork Prod. 26:185–192.

Brumm, M., and J. Dahlquist. 1997. Impact of feeder and drinker designs of pig performance, water use and manure production. Nebraska Swine Reports 193. [accessed July 14, 2021]. Available from http://digitalcommons.unl.edu/coopext_swine/193.

Brumm, M. C., M. Ellis, L. J. Johnston, D. W. Rozeboom, and D. R. Zimmerman; NCR-89 Committee on Swine Management. 2001. Interaction of swine nursery and grow-finish space allocations on performance. J. Anim. Sci. 79:1967–1972. doi:10.2527/2001.7981967x.

Brumm, M. C., and P. S. Miller. 1996. Response of pigs to space allocation and diets varying in nutrient density. J. Anim. Sci. 74:2730–2737. doi:10.2527/1996.74112730x.

Brumm, M. C., P. S. Miller, and R. C. Thaler. 2004. Response of barrows to space allocation and ractopamine. J. Anim. Sci. 82:3373–3379. doi:10.2527/2004.82113373x.

Canadian Council on Animal Care in Science (CCAC). 2009. The care and use of farm animals in research, teaching and testing. Ottawa (ON, Canada): Canadian Council on Animal Care in Science.

Edmonds, M. S., B. E. Arentson, and G. A. Mente. 1998. Effect of protein levels and space allocations on performance of growing-finishing pigs. J. Anim. Sci. 76:814–821. doi:10.2527/1998.763814x.

Edmonds, M. S., and D. H. Baker. 2003. Effect of dietary protein fluctuations and space allocation on performance and carcass quality of growing-finishing pigs. J. Anim. Sci. 81:2783–2791. doi:10.2527/2003.81112783x.

Ewbank, R. 1976. Social hierarchy in suckling and fattening pigs: a review. Livest. Prod. Sci. 3:363–372. doi:10.1016/0301-6226(76)90070-1

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. Spoolder, et al. 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. doi:10.2527/2006.841229x.

Gonyou, H. W., and Z. Lou. 2000. Effects of eating space and availability of water in feeders on productivity and eating behavior of grower/finisher pigs. J. Anim. Sci. 78:865–870. doi:10.2527/2000.784865x.

Gonyou, H. W., and W. R. Stricklin. 1998. Effects of floor area allowance and group size on the productivity of growing/finishing pigs. J. Anim. Sci. 76:1326–1330. doi:10.2527/1998.7651326x.

Holst, D. O. 1973. Holst filtration apparatus for Van Soest detergent fiber analysis. J. Assoc. Off. Anal. Chem. 56:1352–1356.

Hyun, Y., M. Ellis, and R. W. Johnson. 1998. Effects of feeder type, space allowance, and mixing on the growth performance and feed intake pattern of growing pigs. J. Anim. Sci. 76:2771–2778. doi:10.2527/1998.76112771x.

Johnston, L. J., D. W. Rozeboom, R. D. Goodband, S. J. Moeller, M. C. Shannon, and S. J. Schieck. 2017. Effect of floor space allowances on growth performance of finishing pigs marketed at 138 kilograms. J. Anim. Sci. 95:4917–4925. doi:10.2527/jas2017.1870.

Kim, K. H., K. S. Kim, J. E. Kim, D. W. Kim, K. H. Seol, S. H. Lee, B. J. Chae, and Y. H. Kim. 2017. The effect of optimal space allowance on growth performance and physiological responses of pigs at different stages of growth. Animal 11:478–485. doi:10.1017/S1751731116001841.

Lee, G. I., K. S. Kim, J. H. Kim, and D. Y. Kil. 2015. Growth performance of early finishing gilts as affected by different net energy concentrations in diets. Asian-Australas. J. Anim. Sci. 28:1614–1623. doi:10.5713/ajas.15.0216.

Magowan, E., M. E. E. McCann, and N. E. O'Connell. 2008. The effect of feeder type and change of feeder type on growing and finishing pig performance and behaviour. Anim. Feed Sci. Technol. 142:133–143. doi:10.1016/j.anifeedsci.2007.06.035

Morrow, A. T. S., and N. Walker. 1994. Effects of number and siting of single-space feeders on performance and feeding behaviour of growing pigs. J. Agr. Sci. 122: 465–470. doi: 10.1017/S002185960006740X

Myers, A. J., R. D. Goodband, M. D. Tokach, S. S. Dritz, J. M. DeRouchey, and J. L. Nelssen. 2013. The effects of diet form and feeder design on the growth performance of finishing pigs. J. Anim. Sci. 91:3420–3428. doi:10.2527/jas.2012-5612.

NFACC. 2014. National Farm Animal Care Council's code of practice for the care and handling of pigs. Ottawa (ON, Canada): Canadian Pork Council.

NRC. 2012. Nutrient requirements of swine. 11th rev. ed. Washington (DC): National Academy Press.

Patience, J. F. 2013. Managing energy intake and costs of grow-finish pigs. Adv. Pork Prod. 24:29–36.

PIC. 2019. Wean to finish guidelines. Available from https://www.pic.com/resources/wean-to-finish-materials/Wean-To-Finish-Manual-2019-FINAL%20.pdf [accessed July 14, 2021].

Pomar, C., and M. Marcoux. 2003. Comparing the Canadian pork lean yields and grading indexes predicted from grading methods based on Destron and Hennessy probe measurements. Can. J. Anim. Sci. 83:451–458. doi:10.4141/A02-107

Potter, M. L., S. S. Dritz., M. D. Tokach, J. M. DeRouchey, R. D. Goodband, and J. L. Nelssen. 2010. Effects of increasing stocking density on finishing pig performance. Report of progress 1038. Kansas State University, Agricultural Experiment Station and Cooperative Extension Service. Available from https://krex.k-state.edu/dspace/bitstream/handle/2097/13499/Swine11pg262-265.pdf?sequence=1 [accessed July 29, 2021].

Randolph, J. H., G. L. Cromwell, T. S. Stahly, and D. D. Kratzer. 1981. Effects of group size and space allowance on performance and behavior of swine. J. Anim. Sci. 53:922–927. doi: 10.2527/jas1981.534922x

Rozeboom, G. N. 2014. Maximizing net income for pork producers by determining the interaction between dietary energy concentration and stocking density on finishing pig performance, welfare, and carcass composition [M.Sc. thesis]. Saskatoon (SK): University of Saskatchewan. Available from https://harvest.usask.ca/handle/10388/ETD-2014-11-1846.

Schinckel, A. P., M. E. Einstein, S. Jungst, J. O. Matthews, C. Booher, T. Dreadin, C. Fralick, E. Wilson, and R. D. Boyd. 2012. Daily feed intake, energy intake, growth rate and measures of dietary energy efficiency of pigs from four sire lines fed diets with high or low metabolizable and net energy concentrations. Asian-Australas. J. Anim. Sci. 25:410–420. doi:10.5713/ajas.2011.11212.

Schmolke, S. A., Y. Z. Li, and H. W. Gonyou. 2003. Effect of group size on performance of growing-finishing pigs. J. Anim. Sci. 81:874–878. doi:10.2527/2003.814874x.

Schmolke, S. A., Y. Z. Li, and H. W. Gonyou. 2004. Effects of group size on social behavior following regrouping of growing-finishing pigs. Appl. Anim. Behav. Sci. 88:27–38. doi: 10.1016/j.applanim.2004.02.017

Seneviratne, R. W., M. G. Young, E. Beltranena, L. A. Goonewardene, R. W. Newkirk, R. T. Zijlstra. 2010. The nutritional value of expeller pressed canola meal for grower-finisher pigs. J. Anim. Sci. 88:2073–2083. doi:10.2527/jas.2009-2437.

Smit, M. N., J. L. Landero, M. G. Young, and E. Beltranena. 2017. Feeding diets with reduced net energy level to growing-finishing barrows and gilts. Can. J. Anim. Sci. 97:30–41. doi: 10.1139/cjas-2016-0045

Smit, M. N., J. L. Landero, M. G. Young, and E. Beltranena. 2018. Effects of feeding canola meal or soy expeller at two dietary net energy levels on growth performance, dressing and carcass characteristics of barrows and gilts. Anim. Feed Sci. Technol. 235:166–176. doi:10.1016/j.anifeedsci.2017.11.013

Smith, J. W., M. D. Tokach, P. R. O'Quinn, J. L. Nelssen, and R. D. Goodband. 1999. Effects of dietary density and lysine:calorie ratio on growth performance and carcass characteristics of growing-finishing pigs. J. Anim. Sci. 77:3007–3015. doi:10.2527/1999.77113007x

Spoolder, H. A. M., S. A. Edwards, and S. Corning. 1999. Effects of group size and feeder space allowance on welfare in finishing pigs. Anim. Sci. 69:481–489. doi:10.1017/S135772980005133X

Street, B. R., and H. W. Gonyou. 2008. Effects of housing finishing pigs in two group sizes and at two floor space allocations on production, health, behavior, and physiological variables. J. Anim. Sci. 86:982–991. doi:10.2527/jas.2007-0449.

Thomas, L. L., R. D. Goodband, J. C. Woodworth, M. D. Tokach, J. M. DeRouchey, and S. S. Dritz. 2017. Effects of space allocation on finishing pig growth performance and carcass characteristics. Transl. Anim. Sci. 1:351–357. doi:10.2527/tas2017.0042.

Walker, N. 1991. The effects of performance and behaviour of number of growing pigs per mono-place feeder. Anim. Feed Sci. Technol. 35:3–13. doi:10.1016/0377-8401(91)90094-9

Whittemore, C. T., D. M. Green, and P. W. Knap. 2001. Technical review of the energy and protein requirements of growing pigs: food intake. Anim. Sci. 73:3–17. doi:10.1017/S1357729800058008

Wolter, B. F., M. Ellis, S. E. Curtis, N. R. Augspurger, D. N. Hamilton, E. N. Parr, and D. M. Webel. 2001. Effect of group size on pig performance in a wean-to-finish production system. J. Anim. Sci. 79:1067–1073. doi:10.2527/2001.7951067x.