The Effect of Phase-Feeding Strategies on Growth Performance and Carcass Characteristics of Growing-Finishing Pigs: II. Field Approach on Lysine Levels

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The Effect of Phase-Feeding Strategies on Growth Performance and Carcass Characteristics of Growing-Finishing Pigs: II. Field Approach on Lysine Levels[1]

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Summary

The objective of this study was to evaluate phase-feeding strategies for grow-finish pigs under commercial research conditions and using a field approach with lysine levels slightly below the pig's requirement estimates for maximum growth performance. A total of 1,100 pigs (PIC 359 × 1050; initially 57 lb body weight (BW)) were used in a randomized complete block design with 25 pigs per pen and 11 pens per treatment. Treatments consisted of four feeding programs: a 1-phase feeding program with 0.79% standardized ileal digestible (SID) lysine from 60 to 280 lb BW; a 2-phase feeding program with 0.91 and 0.72% SID lysine from 60 to 220 and 220 to 280 lb BW, respectively; a 3-phase feeding program with 1.07, 0.85, and 0.72% SID lysine from 60 to 110, 110 to 220, and 220 to 280 lb BW, respectively; and a 4-phase feeding program with 1.07, 0.91, 0.79, and 0.72% SID lysine from 60 to 110, 110 to 160, 160 to 220, and 220 to 280 lb, respectively. The lysine levels were determined based on the estimated lysine requirements to achieve 98.5% of maximum growth rate for the weight range in each phase, using an equation developed by the genetic supplier. The experimental diets were based on corn, distillers dried grains with solubles (DDGS), and soybean meal. Overall, from d 0 to 119, pigs fed the 1-phase feeding program had decreased ($P = 0.009$) average daily gain (ADG) compared to those fed the 4-phase feeding program, with 2- and 3-phase feeding programs intermediate. The 1-, 2-, and 3-phase feeding programs resulted in poorer ($P < 0.001$) feed efficiency (F/G) compared to the 4-phase feeding program, with the poorest F/G observed in pigs fed the 1-phase feeding program. Final BW and hot carcass weight (HCW) were lower ($P < 0.05$) in pigs fed the 1-phase program compared to the 4-phase program, with 2- and 3-phase programs intermediate. No evidence for differences was observed across the feeding programs for average daily feed intake (ADFI), carcass yield, backfat thickness, loin depth, or percentage lean. For economics, income over feed costs (IOFC) per pig was increased ($P = 0.018$) in the 4-phase program compared to the 1-phase program, with the 2- and 3-phase feeding programs intermediate. In conclusion, phase-feeding strategies provide advantages in

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growth performance and economics over feeding a single diet throughout the grow-finish phase. Moreover, simplification of feeding programs to two or three dietary phases with lysine levels slightly below the requirement estimates (98.5% of maximum growth rate) have negative implications on overall feed efficiency compared to a feeding program with four dietary phases.

Introduction

Phase-feeding programs have been widely used to closely meet the nutrient requirements of grow-finish pigs and to reduce nutrient excretion in the environment.[3] Accurate estimates of nutritional requirements are essential to develop phase-feeding strategies and to minimize the supply of nutrients in excess or deficiency. Moreover, performance is typically optimized by meeting the nutritional requirements for growth. However, in practice, formulating diets to closely meet the requirements might not be the most prevailing or economically advantageous approach.

Previous studies suggest that simplification of feeding strategies to fewer phases can maximize growth performance, carcass characteristics, and economics.[4,5,6,7,8] This effect was particularly observed by using lysine levels at the requirement in either a 2- or 4-phase feeding program,[8] prompting further evaluation of phase-feeding strategies for grow-finish pigs. While a companion study evaluated phase-feeding strategies for grow-finish pigs using lysine levels at the requirement, the present study took a different approach by using lysine levels slightly below (approximately 98%) the requirement to maximize growth performance.

Therefore, the objective of this study was to evaluate phase-feeding strategies for grow-finish pigs by determining the effects on growth performance, carcass characteristics, and economics. This study is the second of a series of two companion phase-feeding studies developed under commercial research conditions and focused on using a field approach with lysine levels slightly below the estimated requirements for maximum growth rate.

[3] Han, I. K., Lee, J. H., Kim, J. H., Kim, Y. G., Kim, J. D., and Paik, I. K. 2000. Application of phase feeding in swine production. J Appl Anim Res. 17:27-56.

[4] Lee, J. H., Kim, J. D., Kim, J. H., Jin, J., Han, In K. 2000. Effect of phase feeding on the growth performance, nutrient utilization and carcass characteristics in finishing pigs. Asian-Aust J Anim Sci. 13(8):1137-1146.

[5] O'Connell, M. K., Lynch P. B., O'Doherty, J. V. 2005. A comparison between feeding a single diet or phase feeding a series of diets, with either the same or reduced crude protein content, to growing finishing pigs. Anim Sci. 81:297-303.

[6] Garry, B. P., Pierce, K. M., O'Dogerty, J. V. 2007. The effect of phase-feeding on growth performance, carcass characteristics and nitrogen balance of growing and finishing pigs. Irish J Agr Food Res. 46:93-104.

[7] Moore, K. L., Mullan, B. P., Kim, J. C. 2012. Blend-feeding or feeding a single diet to pigs has no impact on growth performance or carcass quality. Anim Prod Sci 53(1):52-56.

[8] Menegat, M. B., Vier, C. M., Dritz, S. S., Tokach, M. D., Woodworth, J. C., DeRouchey, J. M., Goodband, R. D. 2017. Evaluation of phase feeding strategies and lysine specifications for grow-finish pigs on growth performance and carcass characteristics. Kansas Agricultural Experiment Station Research Reports. Vol. 3: Iss. 7.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The study was conducted at a commercial research facility in southwestern Minnesota. The barn was naturally ventilated and double-curtain-sided. Each pen was equipped with a 4-hole stainless steel dry self-feeder and a cup waterer for *ad libitum* access to feed and water. Feed additions to each individual pen were made and recorded by a robotic feeding system (FeedPro, Feedlogic Corp., Wilmar, MN).

A total of 1,100 pigs (PIC 359 × 1050; initially 57 lb BW) were used in a 119-d growth trial with 25 pigs per pen and 11 pens per treatment. Pigs were allotted to treatments based on initial BW in a randomized complete block design.

The treatments consisted of four phase-feeding programs and were arranged in a 1-way treatment structure, including: a 1-phase feeding program with 0.79% SID lysine from 60 to 280 lb BW; a 2-phase feeding program with 0.91 and 0.72% SID lysine from 60 to 220 and 220 to 280 lb BW, respectively; a 3-phase feeding program with 1.07, 0.85, and 0.72% SID lysine from 60 to 110, 110 to 220, and 220 to 280 lb BW, respectively; and a 4-phase feeding program with 1.07, 0.91, 0.79, and 0.72% SID lysine from 60 to 110, 110 to 160, 160 to 220, and 220 to 280 lb, respectively (Table 1 and Figure 1). The equation used for lysine requirement estimates for finishing gilts in g/Mcal NE was: $0.000056 \times BW^2$, lb - $0.02844 \times BW$, lb + 6.6391, with estimated lysine levels set for 98.5% of maximum growth rate and 97.5% of maximum feed efficiency[9] for the weight range in each phase.

The diets were based on corn, DDGS, and soybean meal (Table 2). A withdrawal strategy to remove DDGS from the diet was applied in the last phase of the 2-, 3-, and 4-phase feeding programs. Lysine levels in experimental diets were achieved by altering the ratio of corn to soybean meal while keeping the amount of L-Lys HCl constant within phases. Diet samples from each phase were taken from 6 feeders per dietary treatment 3 d after the beginning and 3 d before the end of each phase and stored at -4°F. Composite samples were homogenized, subsampled, and analyzed for dry matter (DM), crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), ether extract, Ca, and P (Ward Laboratories Inc., Kearney, NE). Composite samples were also analyzed for total amino acid (AOAS method 994.12 for all except Trp and 994.13 for Trp)[10] by Ajinomoto Heartland, Inc. (Chicago, IL).

Pens of pigs were weighed and feed disappearance measured on d 0, 13, 34, 50, 61, 71, 85, 98, and 119 to determine ADG, ADFI, and F/G. On d 119, final pen weights were taken and pigs were tattooed with a pen identification number and transported to a USDA-inspected packing plant (JBS Swift and Co., Worthington, MN) for processing and carcass data collection. Carcass measurements included HCW, backfat, loin depth, and percentage lean. Percentage lean was calculated from a plant proprietary equation.

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[9]PIC. 2016. Nutrient Specifications Manual. Available at: http://na.pic.com/tech_support/nutrition/nutrient_specifications_manual_download.aspx

[10]AOAC International. 2012. Official Methods of Analysis of AOAC International. 19th ed. Assoc. O . Anal. Chem., Gaithersburg, MD.

Carcass yield was calculated by dividing the pen average HCW by the pen average final live weight obtained at the farm.

For the economic analysis, feed cost per pig, feed cost per lb of gain, revenue per pig, and IOFC were calculated on a pen basis. Corn was valued at $3.53/bu ($126/ton), soybean meal at $350/ton, DDGS at $176/ton, L-lysine at $0.75/lb, DL-methionine at $1.40/lb, L-threonine at $1.05/lb, and L-tryptophan at $8/lb. Feed cost per pig was calculated by multiplying the feed cost per lb by ADFI and by the number of days in each phase, then adding up the values of each phase. Feed cost per lb of gain was calculated by dividing the feed cost per pig by the overall weight gain. Revenue was obtained by multiplying carcass gain by an assumed value of $70 per cwt of carcass. The IOFC was calculated by subtracting the feed cost per pig from revenue per pig.

Data were analyzed using a linear mixed model with treatment as fixed effect, block as random effect, and pen as the experimental unit. Hot carcass weight was used as a covariate for analyses of backfat, loin depth, and lean percentage. Statistical models were fitted using the GLIMMIX procedure of SAS version 9.4 (SAS Institute Inc., Cary, NC). Results were considered significant at $P \leq 0.05$.

Results and Discussion

The analyzed DM, CP, ADF, NDF, ether extract, Ca, P, and amino acid content of experimental diets (Table 3) were consistent with formulated estimates.

In Phase 1 (d 0 to 34), decreased ADG and poorer F/G were observed ($P < 0.001$) in pigs fed the 1- and 2-phase programs compared to those fed the 3- and 4-phase feeding programs, with the poorest performance observed in the 1-phase program. This response in growth performance was due to the lower lysine levels in 1- and 2-phase programs (0.79 and 0.91% SID Lys, respectively) compared to 3- and 4-phase programs (1.07% SID Lys). Consequently, pigs fed the 1- and 2-phase programs had lower ($P < 0.001$) BW than the other feeding programs at the end of Phase 1, with the lightest BW observed in pigs fed the 1-phase program.

In Phase 2 (d 34 to 61), decreased ADG and poorer F/G were observed ($P < 0.001$) in the 1-phase program compared to the other feeding programs. The impact on growth performance was again associated with the lower lysine levels in the 1-phase program (0.79% SID Lys) in comparison to the other feeding programs (0.85 and 0.91% SID Lys). Consequently, pigs fed the 1-phase program had the lowest ($P < 0.001$) BW at the end of Phase 2.

In Phase 3 (d 61 to 85), F/G was improved ($P = 0.004$) in pigs fed the 1-phase program compared to those fed the 3- and 4-phase programs, with the 2-phase program intermediate. The improvement in F/G in the 1-phase over the 4-phase program was observed even though the lysine level was the same (0.79% SID Lys). This suggests the occurrence of compensatory growth in pigs fed the 1-phase program following a period of low lysine intake in the previous phases. Although F/G was improved, pigs fed the 1-phase program had the lowest ($P < 0.001$) BW at the end of Phase 3.

In Phase 4 (d 85 to 119), ADG was increased ($P = 0.002$) in pigs fed the 1-phase program compared to those fed the 2- and 3-phase programs, with the 4-phase program intermediate. Also, F/G was improved ($P < 0.001$) in pigs fed the 1-phase program compared to the other feeding programs. This response in growth performance was due to the higher lysine level in the 1-phase program (0.79% SID Lys) in comparison to the other programs (0.72% SID Lys), but may also be attributed to a compensatory growth improvement.

Overall (d 0 to 119), the 1-phase feeding program resulted in lower ($P = 0.009$) ADG compared to the 4-phase program, with 2- and 3-phase programs intermediate. The 1-, 2-, and 3-phase programs resulted in poorer ($P < 0.001$) F/G compared to the 4-phase feeding program, with the poorest F/G observed in the 1-phase program. There was no evidence for difference ($P > 0.05$) in ADFI across the feeding programs. Final BW and HCW were lower ($P < 0.05$) in pigs fed the 1-phase program compared to those fed the 4-phase program, with 2- and 3-phase programs intermediate. No evidence for differences ($P > 0.05$) was observed across the feeding programs for the carcass traits: yield, backfat thickness, loin depth, or percentage lean.

For economics, feed cost per pig was lower ($P = 0.033$) in the 1-phase feeding program compared to the 3-phase program, with 2- and 4-phase feeding programs intermediate. However, feed cost per lb of gain was lower ($P = 0.006$) in the 4-phase program compared to 2- and 3-phase programs, with the 1-phase feeding program intermediate. Revenue and IOFC per pig were increased ($P < 0.05$) in the 4-phase program compared to the 1-phase program, with 2- and 3-phase feeding programs resulting in intermediate values.

This study suggests that feeding a single diet throughout the grow-finish period compromises overall growth rate and both live and carcass weight as compared to phase-feeding. As a consequence, there is an impact on IOFC associated with the 1-phase feeding strategy. In contrast, previous studies have shown no effect on growth performance by feeding a single phase during the grow-finish period.[11,12,13,14] This could be due to differences in lysine levels or weight range used in those studies, as well as genetic and experimental conditions.

This study also indicates that simplification of feeding programs to 2 or 3 dietary phases might have negative implications on overall feed efficiency and IOFC compared to a feeding program with 4 dietary phases. Previous research conducted by our group demonstrated that implementing a feeding program with either 2 or 4 dietary phases

[11]Lee, J. H., Kim, J. D., Kim, J. H., Jin, J., Han, In K. 2000. Effect of phase feeding on the growth performance, nutrient utilization and carcass characteristics in finishing pigs. Asian-Aust J Anim Sci. 13(8):1137-1146.

[12]O'Connell, M. K., Lynch P. B., O'Doherty, J. V. 2005. A comparison between feeding a single diet or phase feeding a series of diets, with either the same or reduced crude protein content, to growing finishing pigs. Anim Sci. 81:297-303.

[13]Garry, B. P., Pierce, K. M., O'Dogerty, J. V. 2007. The effect of phase-feeding on growth performance, carcass characteristics and nitrogen balance of growing and finishing pigs. Irish J Agr Food Res. 46:93-104.

[14]Moore, K. L., Mullan, B. P., Kim, J. C. 2012. Blend-feeding or feeding a single diet to pigs has no impact on growth performance or carcass quality. Anim Prod Sci 53(1):52-56.

in grow-finish led to similar growth performance, carcass characteristics, and IOFC.[15] However, in the previous study lysine levels were closely set to the requirements for 100% of maximum growth rate and 98.7% of maximum feed efficiency. In the present study, lysine levels were slightly below the requirements, with levels set for 98.5% of maximum growth rate and 97.5% of maximum feed efficiency. Apparently, feeding lysine levels slightly below the requirements seems to be sufficient to impact growth performance in phase-feeding programs with fewer dietary phases.

Feeding strategies with fewer dietary phases generally provide lysine levels below the requirements initially and rely on compensatory growth later on when lysine levels are adequate. In this case, pigs exhibiting compensatory growth have improved feed efficiency and increased amino acid requirements.[16] Although this study was not purposefully designed to evaluate compensatory growth, the growth performance of pigs fed the 1-phase program during Phase 3 and 4 seems to indicate compensatory growth. It may be speculated that the lysine levels used in the present study were not sufficient to allow for an appropriate compensatory growth in late finishing that would overcome the poor performance in early grower stage. Alternatively, the reduction in lysine levels in early grower may have been too severe and/or too long.

In conclusion, phase-feeding strategies provide advantages in growth performance and economics over feeding a single diet throughout the grow-finish phase. Moreover, simplification of feeding programs to two or three dietary phases with lysine levels slightly below the requirement estimates (98.5% of maximum growth rate) have negative implications on overall feed efficiency compared to a feeding program with four dietary phases.

[15]Menegat, M. B., Vier, C. M., Dritz, S. S., Tokach, M. D., Woodworth, J. C., DeRouchey, J. M., Goodband, R. D. 2017. Evaluation of phase feeding strategies and lysine specifications for grow-finish pigs on growth performance and carcass characteristics. Kansas Agricultural Experiment Station Research Reports. Vol. 3: Iss. 7.

[16]Whang, K. Y., Kim, S. W., Donovan, S. M., McKeith, F. K., Easter, R. A. 2003. Effects of protein deprivation on subsequent growth performance, gain of body components, and protein requirements in growing pigs. J Anim Sci. 81:705–716.

Table 1. Description of feeding phases and lysine levels of experimental diets[1]

Phase:	1	2	3	4
Duration, d:	0 to 34	34 to 61	61 to 85	85 to 119
Weight range, lb:	60 to 110	110 to 160	160 to 220	220 to 280
	SID Lysine, %			
Phase-feeding strategy				
1-Phase	0.79	0.79	0.79	0.79
2-Phase	0.91	0.91	0.91	0.72
3-Phase	1.07	0.85	0.85	0.72
4-Phase	1.07	0.91	0.79	0.72
	SID Lysine:ME, g/Mcal			
1-Phase	2.38	2.38	2.38	2.38
2-Phase	2.74	2.74	2.74	2.14
3-Phase	3.23	2.55	2.55	2.14
4-Phase	3.23	2.73	2.36	2.14
	SID Lysine:NE, g/Mcal			
1-Phase	3.10	3.10	3.10	3.10
2-Phase	3.61	3.61	3.61	2.81
3-Phase	4.31	3.34	3.34	2.81
4-Phase	4.31	3.60	3.08	2.81

[1]The equation used for lysine requirements for finishing gilts in g/Mcal NE was: $0.000056 \times BW^2$, lb - $0.02844 \times BW$, lb + 6.6391 (PIC, 2016), with estimated lysine levels for 98.5% of maximum growth rate and 97.5% of maximum feed efficiency.

SID = standardized ileal digestible. ME = metabolizable energy. NE = net energy.

Table 2. Composition of experimental diets (as-fed basis)[1,2]

| | 1-Phase | 2-Phase | | 3-Phase | | | 4-Phase | | | |
| Feeding program: | 60 to 280 lb BW | 60 to 220 lb BW | 220 to 280 lb BW | 60 to 110 lb BW | 110 to 220 lb BW | 220 to 280 lb BW | 60 to 110 lb BW | 110 to 160 lb BW | 160 to 220 lb BW | 220 to 280 lb BW |
Item										
Ingredient, %										
Corn	69.81	64.99	80.21	58.50	67.75	80.21	58.50	65.34	70.38	80.21
DDGS	20.00	20.00	---	20.00	20.00	---	20.00	20.00	20.00	---
Soybean meal, 47% crude protein	6.46	11.35	17.21	17.88	8.88	17.21	17.88	11.33	6.42	17.21
Tallow	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Monocalcium phosphate, 21.5% aP	0.60	0.50	0.20	0.45	0.30	0.20	0.45	0.25	0.10	0.20
Limestone	1.23	1.23	0.95	1.20	1.15	0.95	1.20	1.15	1.18	0.95
Sodium chloride	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
L-Lysine HCl	0.50	0.50	0.15	0.50	0.50	0.15	0.50	0.50	0.50	0.15
DL-Methionine	---	0.03	---	0.06	0.02	---	0.06	0.03	---	---
L-Threonine	0.10	0.11	0.02	0.12	0.11	0.02	0.12	0.11	0.11	0.02
L-Tryptophan	0.05	0.04	0.00	0.04	0.05	0.00	0.04	0.04	0.06	0.00
VTM premix[3]	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Phytase[4]	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 2. Composition of experimental diets (as-fed basis)[1,2]

Feeding program:	1-Phase	2-Phase		3-Phase			4-Phase			
Item	60 to 280 lb BW	60 to 220 lb BW	220 to 280 lb BW	60 to 110 lb BW	110 to 220 lb BW	220 to 280 lb BW	60 to 110 lb BW	110 to 160 lb BW	160 to 220 lb BW	220 to 280 lb BW
Calculated analysis										
SID amino acids, %										
Lysine	0.79	0.91	0.72	1.07	0.85	0.72	1.07	0.91	0.79	0.72
Isoleucine:lysine	56	58	71	59	57	71	59	58	56	71
Leucine: lysine	168	159	169	150	164	169	150	159	169	169
Methionine:lysine	30	31	31	32	31	31	32	31	30	31
Methionine and cysteine:lysine	58	58	62	58	58	62	58	58	58	62
Threonine:lysine	63	63	64	63	63	64	63	63	64	64
Tryptophan:lysine	18.7	18.6	19.7	18.8	19.0	19.7	18.8	18.6	19.9	19.7
Valine:lysine	70	69	81	69	70	81	69	69	70	81
Total lysine, %	0.92	1.05	0.83	1.23	0.98	0.83	1.23	1.05	0.92	0.83
ME, kcal/lb	1,507	1,506	1,524	1,505	1,512	1,524	1,505	1,511	1,515	1,524
NE, kcal/lb	1,155	1,143	1,161	1,127	1,153	1,161	1,127	1,147	1,162	1,161
SID Lysine:ME, g/Mcal	2.38	2.74	2.14	3.23	2.55	2.14	3.23	2.73	2.36	2.14
SID Lysine:NE, g/Mcal	3.10	3.61	2.81	4.31	3.34	2.81	4.31	3.60	3.08	2.81
Crude protein, %	14.2	16.2	14.0	18.9	15.2	14.0	18.9	16.2	14.2	14.0
Calcium, %	0.60	0.60	0.45	0.60	0.53	0.45	0.60	0.53	0.50	0.45
STTD phosphorus, %	0.38	0.38	0.26	0.38	0.33	0.26	0.38	0.33	0.29	0.26

[1]Diets were fed *ad libitum* in meal form from 57.0 to 289.8 lb body weight (BW).

[2]Lysine levels in experimental diets were achieved by manipulating the ratio of corn to soybean meal.

[3]Vitamin and trace mineral premix provided per lb of diet: 111 ppm Zn, 111 ppm Fe, 33 ppm Mn, 17 ppm Cu, 0.33 ppm I, 0.30 ppm Se, 2,400 IU vitamin A, 600 IU vitamin D, 12 IU vitamin E, 1.2 mg vitamin K, 22.5 mg niacin, 7.5 mg pantothenic acid, 2.25 mg riboflavin, and 10.5 µg vitamin B12.

[4]Optiphos 2000 (Huvepharma Inc, Peachtree City, GA) provided 91 FTU per lb of diet.

DDGS = distillers dried grains with solubles. SID = standardized ileal digestible. ME = metabolizable energy. NE = net energy. STTD = standardized total tract digestible.

Table 3. Chemical analysis of experimental diets (as-fed basis)[1,2]

Item	Phase 1				Phase 2				Phase 3				Phase 4			
	1-Phase	2-Phase	3-Phase	4-Phase	1-Phase	2-Phase	3-Phase	4-Phase	1-Phase	2-Phase	3-Phase	4-Phase	1-Phase	2-Phase	3-Phase	4-Phase
Proximate analysis, %[3]																
DM	87.9	87.9	88.6	88.2	88.1	87.9	88.1	88.8	86.9	87.5	86.5	87.0	88.3	87.0	87.7	87.3
CP	14.5	16.3	19.2	19.0	14.2	16.3	15.7	16.2	14.4	14.1	14.1	13.6	14.5	13.8	14.5	13.6
ADF	3.1	3.6	3.9	3.9	3.4	3.7	3.4	3.7	3.7	2.3	2.4	2.6	3.3	2.5	2.5	2.5
NDF	9.5	10.0	10.6	10.0	9.9	10.5	9.4	9.9	9.6	6.7	6.1	6.9	8.9	6.6	6.4	6.7
Ether extract	3.9	3.7	3.6	3.7	4.5	4.3	4.0	3.9	4.0	3.1	2.8	3.3	4.2	3.3	3.3	3.4
Ca	0.81	0.71	0.77	0.77	0.65	0.65	0.53	0.73	0.79	0.55	0.57	0.59	0.91	0.56	0.42	0.56
P	0.51	0.49	0.52	0.50	0.53	0.51	0.45	0.46	0.51	0.35	0.35	0.34	0.49	0.33	0.35	0.34
Amino acid analysis, %																
Lysine	0.86	1.05	1.21	1.19	0.97	1.03	0.68	1.02	0.90	0.73	0.82	0.79	1.01	0.80	0.80	0.88
Isoleucine	0.50	0.59	0.73	0.70	0.52	0.63	0.40	0.57	0.49	0.54	0.54	0.51	0.52	0.52	0.60	0.55
Leucine	1.45	1.59	1.82	1.76	1.45	1.66	1.14	1.59	1.39	1.20	1.31	1.27	1.46	1.28	1.34	1.33
Methionine	0.22	0.27	0.33	0.32	0.23	0.28	0.20	0.29	0.23	0.20	0.22	0.21	0.24	0.22	0.22	0.23
Methionine and cysteine	0.47	0.55	0.66	0.63	0.50	0.57	0.40	0.57	0.49	0.42	0.46	0.45	0.51	0.45	0.45	0.48
Threonine	0.58	0.68	0.79	0.78	0.60	0.69	0.47	0.67	0.58	0.49	0.56	0.54	0.63	0.53	0.54	0.57
Tryptophan	0.16	0.19	0.23	0.23	0.16	0.19	0.18	0.19	0.16	0.15	0.17	0.16	0.19	0.16	0.18	0.16
Valine	0.65	0.73	0.88	0.85	0.66	0.77	0.51	0.71	0.62	0.62	0.63	0.64	0.67	0.64	0.68	0.67
Histidine	0.35	0.40	0.48	0.46	0.36	0.43	0.29	0.41	0.36	0.33	0.37	0.35	0.38	0.36	0.36	0.38

[1]Diet samples from each phase were taken from 6 feeders per dietary treatment throughout the study. Composite samples were homogenized and subsampled for analysis.

[2]Composite samples were submitted to Ward Laboratories Inc. (Kearney, NE) for proximate analysis and to Ajinomoto Heartland, Inc. (Chicago, IL) for total amino acid analysis.

[3]DM = dry matter. CP = crude protein. ADF = acid detergent fiber. NDF = neutral detergent fiber.

Table 4. Effect of phase-feeding strategy on growth performance, carcass characteristics, and economics of grow-finish pigs[1,2,3]

Item[4]	1-Phase	2-Phase	3-Phase	4-Phase	SEM	Probability, $P =$
BW, lb						
d 0	57.0	57.0	57.0	57.0	0.69	0.997
d 34	106.0[c]	111.4[b]	115.6[a]	115.0[a]	1.28	<0.001
d 61	160.5[b]	171.5[a]	172.4[a]	175.4[a]	1.81	<0.001
d 85	212.8[b]	221.9[a]	223.2[a]	225.1[a]	2.19	<0.001
d 119	284.5[b]	290.1[ab]	290.6[ab]	294.0[a]	2.42	0.022
Phase 1 (d 0 to 34)						
ADG, lb	1.43[c]	1.58[b]	1.71[a]	1.69[a]	0.03	<0.001
ADFI, lb	3.34	3.37	3.30	3.23	0.06	0.328
F/G	2.33[a]	2.13[b]	1.93[c]	1.90[c]	0.02	<0.001
Phase 2 (d 34 to 61)						
ADG, lb	2.01[b]	2.19[a]	2.10[ab]	2.20[a]	0.03	<0.001
ADFI, lb	4.99	4.98	5.03	4.97	0.08	0.940
F/G	2.48[a]	2.28[c]	2.39[b]	2.26[c]	0.02	<0.001
Phase 3 (d 61 to 85)						
ADG, lb	2.17	2.12	2.10	2.09	0.03	0.402
ADFI, lb	5.81	5.75	5.87	5.87	0.08	0.668
F/G	2.68[b]	2.71[ab]	2.79[a]	2.81[a]	0.03	0.004
Phase 4 (d 85 to 119)						
ADG, lb	2.11[a]	1.99[b]	1.98[b]	2.03[ab]	0.02	0.002
ADFI, lb	6.35	6.37	6.40	6.43	0.07	0.853
F/G	3.01[b]	3.20[a]	3.24[a]	3.18[a]	0.03	<0.001
Overall (d 0 to 119)						
ADG, lb	1.90[b]	1.94[ab]	1.96[ab]	1.98[a]	0.02	0.009
ADFI, lb	5.05	5.05	5.09	5.05	0.05	0.953
F/G	2.66[a]	2.60[b]	2.60[b]	2.55[c]	0.01	<0.001

continued

Table 4. Effect of phase-feeding strategy on growth performance, carcass characteristics, and economics of grow-finish pigs[1,2,3]

Item[4]	1-Phase	2-Phase	3-Phase	4-Phase	SEM	Probability, P =
Carcass characteristics						
HCW, lb	210.4[b]	213.8[ab]	215.3[ab]	217.4[a]	1.61	0.005
Yield, %	74.0	73.7	74.1	74.0	0.37	0.932
Backfat, in.[5]	0.67	0.66	0.66	0.64	0.011	0.432
Loin depth, in.[5]	2.66	2.71	2.66	2.68	0.024	0.401
Lean, %	56.6	56.9	56.7	57.0	0.21	0.411
Economics, $ per pig[6]						
Feed cost	52.78[b]	54.69[ab]	54.96[a]	54.60[ab]	0.57	0.033
Feed cost per lb gain[7]	0.233[ab]	0.237[a]	0.236[a]	0.232[b]	0.001	0.006
Revenue[8]	117.33[b]	119.73[ab]	120.78[ab]	122.25[a]	1.00	0.005
IOFC[9]	64.56[b]	65.04[ab]	65.82[ab]	67.65[a]	0.69	0.018

[1] A total of 1,100 pigs (PIC 337 × 1050) with initial body weight (BW) of 57 lb were used with 25 pigs per pen and 11 pens per treatment.

[2] Dietary treatments were: 1-phase, a 1-phase feeding program with 0.79% SID lysine from 60 to 280 lb BW; 2-phase, a 2-phase feeding program with 0.91 and 0.72% SID lysine from 60 to 220 and 220 to 280 lb BW, respectively; 3-phase, a 3-phase feeding program with 1.07, 0.85, and 0.72% SID lysine from 60 to 110, 110 to 220, and 220 to 280 lb BW, respectively; and 4-phase, a 4-phase feeding program with 1.07, 0.91, 0.79, and 0.72% SID lysine from 60 to 110, 110 to 160, 160 to 220, and 220 to 280 lb, respectively

[3] Means with different superscripts are significantly different ($P < 0.05$) in the row.

[4] ADG = average daily gain. ADFI = average daily feed intake. F/G = feed efficiency.

[5] Adjusted for hot carcass weight (HCW).

[6] Corn was valued at $3.53/bu ($126/ton), soybean meal at $350/ton, DDGS at $176/ton, and L-lysine at $0.75/lb.

[7] Feed cost per lb gain = feed cost per pig / overall gain per pig.

[8] Revenue = (HCW × $0.70) – (d 0 BW × 0.75 × $0.70).

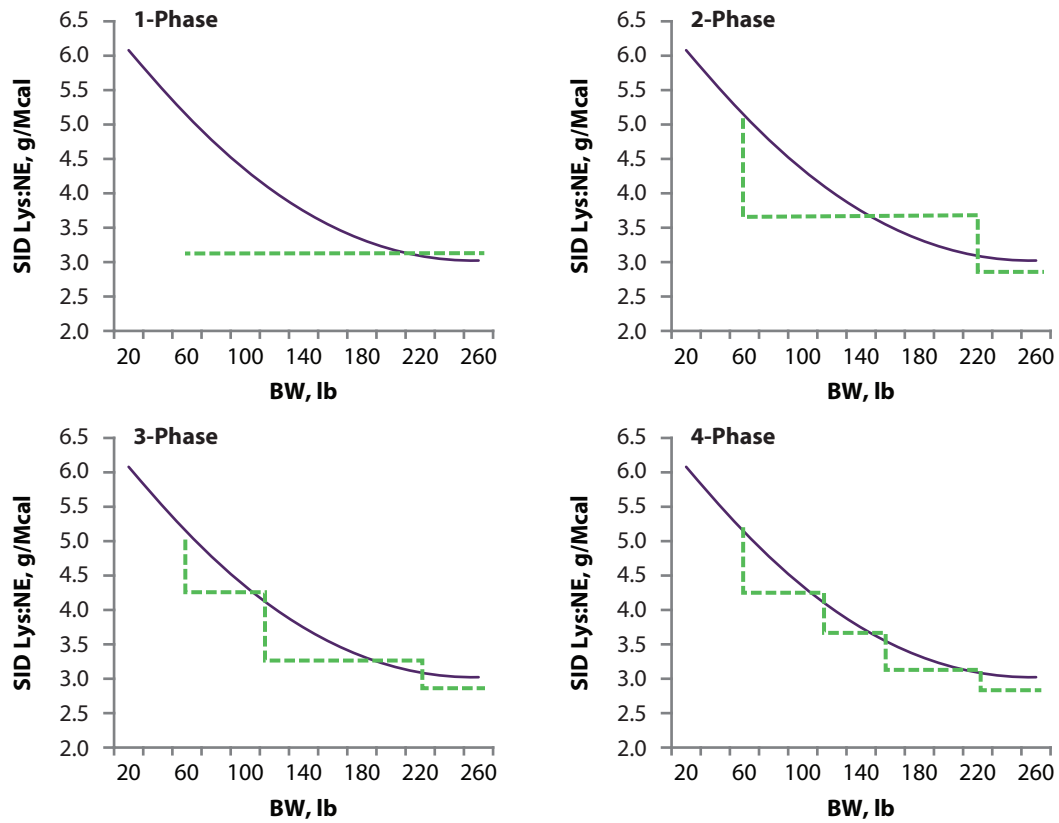[9] Income over feed cost = revenue – feed cost.

Figure 1. Representation of phase-feeding strategies (dash line) during the grow-finish phase in relation to the estimated lysine requirement (solid line) expressed as a ratio of standardized ileal digestible lysine to net energy (SID Lys:NE).