Kansas Agricultural Experiment Station Research Reports

Volume 4
Issue 9 *Swine Day*

Article 29

2018

The Effect of Phase-Feeding Strategies on Growth Performance and Carcass Characteristics of Growing-Finishing Pigs: I. Lysine Levels at the Estimated Requirement

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Recommended Citation

Menegat, M. B.; Dritz, S. S.; Tokach, M. D.; Woodworth, J. C.; DeRouchey, J. M.; and Goodband, R. D. (2018) "The Effect of Phase-Feeding Strategies on Growth Performance and Carcass Characteristics of Growing-Finishing Pigs: I. Lysine Levels at the Estimated Requirement," *Kansas Agricultural Experiment Station Research Reports*: Vol. 4: Iss. 9. https://doi.org/10.4148/2378-5977.7677

The Effect of Phase-Feeding Strategies on Growth Performance and Carcass Characteristics of Growing-Finishing Pigs: I. Lysine Levels at the Estimated Requirement

Abstract

The objective of this study was to evaluate phase-feeding strategies for grow-finish pigs under commercial research conditions and using lysine levels closely set to the pig's requirement estimates for maximum growth performance. A total of 1,188 pigs (PIC 359 × 1050; initially 60.4 lb body weight (BW)) were used in a randomized complete block design with 27 pigs per pen and 11 pens per treatment. Treatments consisted of four feeding programs: a 1-phase feeding program with 0.82% standardized ileal digestible (SID) lysine from 60 to 280 lb BW; a 2-phase feeding program with 0.96 and 0.77% SID lysine from 60 to 220 and 220 to 280 lb BW, respectively; a 3-phase feeding program with 1.13, 0.89, and 0.77% SID lysine from 60 to 110, 110 to 220, and 220 to 280 lb BW, respectively; and a 4-phase feeding program with 1.13, 0.96, 0.82, and 0.77% 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 100% 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 121, pigs fed the 1-phase program had decreased ($P = 0.007$) average daily gain (ADG) compared to 2- and 4-phase feeding programs, with the 3-phase feeding program intermediate. There was no evidence for difference on average daily feed intake (ADFI) and feed efficiency (F/G) across the feeding programs. Final BW was lower ($P = 0.050$) in pigs fed the 1-phase program compared to the 4-phase program, with pigs fed 2- and 3-phase programs intermediate. Similarly, hot carcass weight (HCW) was decreased ($P = 0.014$) in pigs fed the 1-phase program compared to 2- and 4-phase programs, with the 3-phase program intermediate. No evidence for differences was observed across the feeding programs for carcass yield, backfat thickness, loin depth, or percentage lean. For economics, the 1-phase feeding program resulted in the lowest ($P < 0.001$) feed cost per pig and feed cost per lb of gain, but also in the lowest ($P = 0.013$) revenue per pig. The 2-, 3-, and 4-phase feeding programs resulted in similar feed cost per pig, feed cost per lb of gain, and revenue per pig. The income over feed cost (IOFC) was similar across all phase-feeding programs. In conclusion, phase-feeding strategies provide advantages in growth performance over feeding a single diet throughout the grow-finish phase. However, simplification of feeding programs to two dietary phases with lysine levels closely set to requirement estimates to maximize growth performance does not compromise overall growth performance, carcass characteristics, and IOFC.

Keywords

compensatory growth, feeding regimen, finisher, nutrition, swine

Cover Page Footnote

Appreciation is expressed to New Horizon Farms (Pipestone, MN) for providing research facilities.

Authors

M. B. Menegat, S. S. Dritz, M. D. Tokach, J. C. Woodworth, J. M. DeRouchey, and R. D. Goodband

The Effect of Phase-Feeding Strategies on Growth Performance and Carcass Characteristics of Growing-Finishing Pigs: I. Lysine Levels at the Estimated Requirement[1]

M.B. Menegat,[2] S.S. Dritz,[2] M.D. Tokach, J.C. Woodworth, J.M. DeRouchey, and R.D. Goodband

Summary

The objective of this study was to evaluate phase-feeding strategies for grow-finish pigs under commercial research conditions and using lysine levels closely set to the pig's requirement estimates for maximum growth performance. A total of 1,188 pigs (PIC 359 × 1050; initially 60.4 lb body weight (BW)) were used in a randomized complete block design with 27 pigs per pen and 11 pens per treatment. Treatments consisted of four feeding programs: a 1-phase feeding program with 0.82% standardized ileal digestible (SID) lysine from 60 to 280 lb BW; a 2-phase feeding program with 0.96 and 0.77% SID lysine from 60 to 220 and 220 to 280 lb BW, respectively; a 3-phase feeding program with 1.13, 0.89, and 0.77% SID lysine from 60 to 110, 110 to 220, and 220 to 280 lb BW, respectively; and a 4-phase feeding program with 1.13, 0.96, 0.82, and 0.77% 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 100% 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 121, pigs fed the 1-phase program had decreased ($P = 0.007$) average daily gain (ADG) compared to 2- and 4-phase feeding programs, with the 3-phase feeding program intermediate. There was no evidence for difference on average daily feed intake (ADFI) and feed efficiency (F/G) across the feeding programs. Final BW was lower ($P = 0.050$) in pigs fed the 1-phase program compared to the 4-phase program, with pigs fed 2- and 3-phase programs intermediate. Similarly, hot carcass weight (HCW) was decreased ($P = 0.014$) in pigs fed the 1-phase program compared to 2- and 4-phase programs, with the 3-phase program intermediate. No evidence for differences was observed across the feeding programs for carcass yield, backfat thickness, loin depth, or percentage lean. For economics, the 1-phase feeding program resulted in the lowest ($P < 0.001$) feed cost per

[1]Appreciation is expressed to New Horizon Farms (Pipestone, MN) for providing research facilities.
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pig and feed cost per lb of gain, but also in the lowest ($P = 0.013$) revenue per pig. The 2-, 3-, and 4-phase feeding programs resulted in similar feed cost per pig, feed cost per lb of gain, and revenue per pig. The income over feed cost (IOFC) was similar across all phase-feeding programs. In conclusion, phase-feeding strategies provide advantages in growth performance over feeding a single diet throughout the grow-finish phase. However, simplification of feeding programs to two dietary phases with lysine levels closely set to requirement estimates to maximize growth performance does not compromise overall growth performance, carcass characteristics, and IOFC.

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. However, in practice, it is challenging to accurately estimate and deliver the optimal concentration of nutrients required for growth. Thus, simplification of phase-feeding strategies has been a topic of growing interest.

Previous studies suggest that simplification of feeding strategies to fewer phases can maximize growth performance, carcass characteristics, and economics.[4,5,6,7,8] Setting the lysine concentration is the core component of developing a phase-feeding program. Generally, feeding programs with fewer dietary phases provide lysine levels below the requirements initially and rely on compensatory growth later on when lysine levels are adequate.[9] Pigs exhibiting compensatory growth utilize nutrients more efficiently and have reduced nitrogen excretion,[10] which may be beneficial to improve the overall efficiency of swine production.[4]

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,

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[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.
[9]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.
[10]Fabian, J., Chiba, L. I., Frobish, L. T., McElhenny, W. H., Kuhlers, D. L., Nadarajah, K. 2004. Compensatory growth and nitrogen balance in grower-finisher pigs. J Anim Sci. 82:2579–2587.

and economics. This study is the first of a series of two companion phase-feeding studies developed under commercial research conditions and focused on using lysine levels at the estimated requirement for maximum growth performance.

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 1,188 pigs (PIC 359 × 1050; initially 60.4 lb BW) were used in a 121-d growth trial with 27 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 0.82% SID lysine from 60 to 280 lb BW; a 2-phase feeding program with 0.96 and 0.77% SID lysine from 60 to 220 and 220 to 280 lb BW, respectively; a 3-phase feeding program with 1.13, 0.89, and 0.77% SID lysine from 60 to 110, 110 to 220, and 220 to 280 lb BW, respectively; and a 4-phase feeding program with 1.13, 0.96, 0.82, and 0.77% 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 × BW, lb + 6.6391, with estimated lysine levels set for 100% of maximum growth rate and 98.7% of maximum feed efficiency[11] for the weight range in each phase.

The diets were based on corn, DDGS, and soybean meal (Table 2). 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 acids (AOAC method 994.12 for all except Trp and 994.13 for Trp)[12] by Ajinomoto Heartland, Inc. (Chicago, IL).

Pens of pigs were weighed and feed disappearance measured on d 0, 17, 36, 49, 63, 80, 88, 100, and 121 to determine ADG, ADFI, and F/G. On d 100, the 3 heaviest pigs in each pen were weighed and marketed according to the farm marketing strategy. On d 121, final pen weights were taken and pigs were tattooed with a pen identifica-

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

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

tion 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 lean percentage. Percentage lean was calculated from a plant proprietary equation. 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 36), decreased ADG and poorer F/G were observed ($P < 0.001$) in pigs fed the 1-phase program compared to the other feeding programs. This response in growth performance was due to the lower lysine levels in the 1-phase program (0.82% SID Lys) compared to 2-, 3-, and 4-phase programs (0.96, 1.13, and 1.13% SID Lys, respectively). Consequently, pigs fed the 1-phase program had the lowest ($P < 0.001$) BW at the end of Phase 1.

In Phase 2 (d 36 to 63), there was no evidence for difference ($P > 0.05$) in ADG, ADFI, and F/G across the feeding programs. However, pigs fed the 1-phase program still had the lowest ($P < 0.001$) BW at the end of Phase 2.

In Phase 3 (d 63 to 88), F/G was improved ($P = 0.002$) in pigs fed either the 1- and 2-phase programs compared to the 4-phase program, with the 3-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 (0.82% 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. The improvements in F/G in the 2-phase over the 4-phase program was associated to the higher lysine level fed in the former over the latter (0.96 and 0.82% SID Lys, respectively). 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 88 to 121), greater ADG and improved F/G were observed ($P < 0.01$) in pigs fed the 1-phase program compared to those fed the 2- and 3-phase programs, with pigs fed the 4-phase program intermediate. This response in growth performance could be due to the higher lysine level in the 1-phase program (0.82% SID Lys) compared to the other programs (0.77% SID Lys), but may also be attributed to a compensatory growth improvement.

Overall (d 0 to 121), pigs fed the 1-phase program had decreased ($P = 0.007$) ADG compared to those fed the 2- and 4-phase programs, with the 3-phase program intermediate. The feeding programs with either 2 or 4 dietary phases resulted in similar ($P > 0.05$) ADG in the overall grow-finish period. There was no evidence for difference ($P > 0.05$) in ADFI and F/G across the feeding programs. Final BW was lower ($P = 0.050$) in pigs fed the 1-phase program compared to the 4-phase program, with 2- and 3-phase programs intermediate. Similarly, HCW was lower ($P = 0.014$) in pigs fed the 1-phase program compared to 2- and 4-phase programs, with the 3-phase program 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, the 1-phase feeding program resulted in the lowest ($P < 0.001$) feed cost per pig and feed cost per lb of gain, but also the lowest revenue per pig ($P = 0.013$). The 2-, 3-, and 4-phase feeding programs resulted in similar ($P > 0.05$) feed cost per pig, feed cost per lb of gain, and revenue per pig. The IOFC was similar across all phase-feeding programs ($P > 0.05$).

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 a phase-feeding program. In contrast, previous studies have shown no impact on growth performance by feeding a single phase during the grow-finish period.[13,14,15,16] This could be due to differences in lysine levels or weight range used in the studies, as well as genetic and experimental conditions. However, in accordance with those studies, feeding a single diet reduced feed cost and led to a similar IOFC compared to the other phase-feeding strategies.

This study also demonstrates that implementing a feeding program with either 2 or 4 dietary phases in grow-finish leads to similar growth performance, carcass characteristics, and IOFC. This validates previous research conducted by our group in the same commercial research facility and using the same lysine levels estimated for 100% of

[13]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.

[14]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.

[15]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.

[16]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.

maximum growth rate.[17] The 3-phase feeding program resulted in intermediate growth performance between a single phase or 2- or 4-phase programs, although there is no clear reason for this response. A simplified feeding program with fewer phases might provide benefits in logistics in the swine production system, such as in feed delivery and storage. Also, it provides an opportunity to improve efficiency in the feed milling process.

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. Compensatory growth results from improved feed efficiency following a period of nutrient intake restriction.[18,19] In this case, pigs showed ability to compensate from previous periods of lysine deficiency with improved feed efficiency when fed adequate levels of lysine. Similarly, compensatory growth seems to occur in pigs fed the 2-phase program during Phase 3.

In conclusion, phase-feeding strategies provide advantages in growth performance over feeding a single diet throughout the grow-finish phase. However, simplification of feeding programs to two dietary phases with lysine levels closely set to requirement estimates to maximize growth performance does not compromise overall growth performance, carcass characteristics, and income over feed cost.

[17]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.

[18]Bikker, P., Verstege, M. W. A., Kemp, B., Bosch, M. W. 1996. Performance and body composition of finishing gilts (45 to 85 kilograms) as affected by energy intake and nutrition in earlier life: I. Growth of the body and body components. J Anim Sci. 74:806–816.

[19]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 36	36 to 63	63 to 88	88 to 121
Weight range, lb:	60 to 110	110 to 160	160 to 220	220 to 280
	SID Lysine, %			
Phase-feeding strategy				
1-Phase	0.82	0.82	0.82	0.82
2-Phase	0.96	0.96	0.96	0.77
3-Phase	1.13	0.89	0.89	0.77
4-Phase	1.13	0.96	0.82	0.77
	SID Lysine:ME, g/Mcal			
1-Phase	2.47	2.47	2.47	2.47
2-Phase	2.89	2.89	2.89	2.30
3-Phase	3.41	2.67	2.67	2.30
4-Phase	3.41	2.88	2.46	2.30
	SID Lysine:NE, g/Mcal			
1-Phase	3.23	3.23	3.23	3.23
2-Phase	3.83	3.83	3.83	3.01
3-Phase	4.57	3.51	3.51	3.01
4-Phase	4.57	3.81	3.21	3.01

[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 100% of maximum growth rate and 98.7% 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]

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
Ingredient, %										
Corn	68.64	62.98	69.87	56.09	66.17	69.87	56.09	63.32	69.16	69.87
DDGS	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
Soybean meal, 47% crude protein	7.68	13.39	7.19	20.33	10.51	7.19	20.33	13.37	7.64	7.19
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	0.55	0.50	---	0.40	0.25	---	0.40	0.25	0.10	---
Limestone	1.23	1.20	1.10	1.20	1.15	1.10	1.20	1.13	1.18	1.10
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	0.45	0.50	0.50	0.45	0.50	0.50	0.50	0.45
DL-Methionine	---	0.03	---	0.07	0.01	---	0.07	0.03	0.00	---
L-Threonine	0.10	0.11	0.09	0.13	0.11	0.09	0.13	0.11	0.11	0.09
L-Tryptophan	0.05	0.04	0.05	0.04	0.04	0.05	0.04	0.04	0.05	0.05
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

continued

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	0.82	0.96	0.77	1.13	0.89	0.77	1.13	0.96	0.82	0.77
Isoleucine:lysine	57	58	59	60	58	59	60	58	57	59
Leucine: lysine	166	156	176	147	161	176	147	156	166	176
Methionine:lysine	29	30	31	32	30	31	32	30	29	31
Methionine and cysteine:lysine	57	57	60	57	57	60	57	57	57	60
Threonine:lysine	63	63	64	63	63	64	63	63	64	64
Tryptophan:lysine	18.8	18.9	19.7	19.0	18.6	19.7	19.0	18.9	19.4	19.7
Valine:lysine	70	69	73	69	70	73	69	69	70	73
Total lysine, %	0.95	1.11	0.90	1.29	1.03	0.90	1.29	1.11	0.95	0.90
ME, kcal/lb	1,507	1,506	1,162	1,504	1,512	1,162	1,504	1,511	1,159	1,162
NE, kcal/lb	1,152	1,138	1,162	1,121	1,150	1,162	1,121	1,142	1,159	1,162
SID Lysine:ME, g/Mcal	2.47	2.89	2.30	3.41	2.67	2.30	3.41	2.88	2.46	2.30
SID Lysine:NE, g/Mcal	3.23	3.83	3.01	4.57	3.51	3.01	4.57	3.81	3.21	3.01
Crude protein, %	14.7	17.0	14.5	19.9	15.8	14.5	19.9	17.0	14.7	14.5
Calcium, %	0.60	0.60	0.46	0.60	0.53	0.46	0.60	0.53	0.50	0.46
STTD phosphorus, %	0.38	0.38	0.27	0.38	0.33	0.27	0.38	0.33	0.29	0.27

[1]Diets were fed *ad libitum* in meal form from 60.4 to 276.8 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]

	Phase 1				Phase 2				Phase 3				Phase 4			
Item	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	88.3	88.8	89.0	88.9	88.6	87.4	88.6	88.0	88.3	88.0	87.8	88.6	87.5	87.9	87.5	87.1
CP	14.3	16.6	20.3	16.6	14.1	16.5	16.0	16.3	14.1	17.1	16.7	15.0	14.6	15.1	15.0	15.2
ADF	3.7	4.0	4.0	4.1	3.6	4.3	4.1	3.8	3.7	4.1	4.1	3.7	3.9	3.8	3.7	3.5
NDF	10.8	11.0	10.4	10.8	9.3	10.1	10.1	9.8	9.3	10.0	9.8	10.0	10.6	10.2	10.3	9.6
Ether extract	4.2	4.3	4.1	4.3	4.2	4.2	4.3	4.3	4.1	4.3	4.7	4.5	4.4	4.6	4.5	4.1
Ca	0.77	0.70	0.81	0.68	0.85	0.77	0.76	0.71	0.86	0.79	0.60	0.57	0.75	0.63	0.47	0.74
P	0.51	0.51	0.51	0.46	0.48	0.52	0.43	0.44	0.51	0.52	0.46	0.40	0.48	0.38	0.37	0.36
Amino acid analysis, %																
Lysine	0.85	0.97	1.25	1.09	0.91	1.06	0.99	1.04	0.89	1.07	1.00	0.88	0.93	0.90	0.92	0.99
Isoleucine	0.50	0.57	0.76	0.62	0.48	0.60	0.62	0.61	0.49	0.63	0.63	0.53	0.53	0.51	0.52	0.59
Leucine	1.40	1.50	1.90	1.64	1.41	1.63	1.69	1.62	1.41	1.65	1.70	1.53	1.49	1.45	1.52	1.54
Methionine	0.22	0.25	0.34	0.27	0.21	0.27	0.27	0.27	0.22	0.29	0.27	0.24	0.23	0.23	0.23	0.25
Methionine and cysteine	0.47	0.52	0.66	0.55	0.47	0.56	0.57	0.55	0.47	0.59	0.58	0.50	0.51	0.48	0.49	0.53
Threonine	0.57	0.64	0.83	0.72	0.60	0.68	0.69	0.68	0.61	0.71	0.71	0.62	0.60	0.58	0.59	0.63
Tryptophan	0.17	0.20	0.24	0.20	0.16	0.19	0.19	0.19	0.17	0.21	0.19	0.18	0.17	0.17	0.17	0.19
Valine	0.63	0.69	0.90	0.76	0.62	0.74	0.76	0.74	0.63	0.77	0.77	0.68	0.67	0.66	0.67	0.72
Histidine	0.35	0.39	0.51	0.42	0.35	0.42	0.43	0.42	0.35	0.43	0.44	0.38	0.37	0.35	0.37	0.40

[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	60.4	60.4	60.5	60.5	1.46	0.962
d 36	107.0[b]	112.8[a]	113.8[a]	115.4[a]	2.54	<0.001
d 63	158.8[b]	167.3[a]	168.6[a]	169.4[a]	3.03	<0.001
d 88	212.1[b]	220.5[a]	220.8[a]	220.9[a]	3.12	<0.001
d 121	273.2[b]	278.3[ab]	276.6[ab]	279.2[a]	2.56	0.050
Phase 1 (d 0 to 36)						
ADG, lb	1.25[b]	1.43[a]	1.47[a]	1.49[a]	0.04	<0.001
ADFI, lb	3.23	3.28	3.21	3.32	0.08	0.140
F/G	2.60[a]	2.30[b]	2.19[b]	2.23[b]	0.04	<0.001
Phase 2 (d 36 to 63)						
ADG, lb	1.92	2.00	2.01	1.99	0.03	0.098
ADFI, lb	4.86	4.96	5.01	5.03	0.10	0.165
F/G	2.54	2.48	2.49	2.53	0.03	0.440
Phase 3 (d 63 to 88)						
ADG, lb	2.13	2.13	2.07	2.05	0.03	0.095
ADFI, lb	6.03	6.16	6.06	6.15	0.09	0.549
F/G	2.83[b]	2.89[b]	2.93[ab]	3.00[a]	0.03	0.002
Phase 4 (d 88 to 121)						
ADG, lb	1.95[a]	1.81[b]	1.78[b]	1.84[ab]	0.05	0.008
ADFI, lb	6.23	6.41	6.30	6.38	0.06	0.230
F/G	3.22[b]	3.58[a]	3.56[a]	3.47[ab]	0.10	0.002
Overall (d 0 to 121)						
ADG, lb	1.76[b]	1.80[a]	1.79[ab]	1.81[a]	0.01	0.007
ADFI, lb	4.94	5.04	4.99	5.07	0.07	0.126
F/G	2.81	2.80	2.78	2.80	0.03	0.412

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	209.7[b]	215.3[a]	212.6[ab]	215.7[a]	2.31	0.014
Yield, %	76.7	77.5	77.0	77.3	0.26	0.139
Backfat, in[5]	0.66	0.64	0.65	0.64	0.01	0.365
Loin depth, in[5]	2.68	2.69	2.63	2.64	0.02	0.111
Lean, %	56.8	57.1	56.8	57.0	0.19	0.519
Economics, $ per pig[6]						
Feed cost	55.28[b]	58.61[a]	57.73[a]	58.63[a]	0.76	<0.001
Feed cost per lb gain[7]	0.260[b]	0.269[a]	0.266[a]	0.268[a]	0.003	<0.001
Revenue[8]	115.07[b]	118.97[a]	117.08[ab]	119.21[a]	1.12	0.013
IOFC[9]	59.79	60.36	59.34	60.58	0.83	0.601

[1]A total of 1,188 pigs (PIC 359 × 1050) with initial body weight (BW) of 60.4 lb were used with 27 pigs per pen and 11 pens per treatment.

[2]Dietary treatments were: 1-phase, a 1-phase feeding program with 0.82% SID lysine from 60 to 280 lb BW; 2-phase, a 2-phase feeding program with 0.96 and 0.77% SID lysine from 60 to 220 and 220 to 280 lb BW, respectively; 3-phase, a 3-phase feeding program with 1.13, 0.89, and 0.77% 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 1.13, 0.96, 0.82, and 0.77% 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.

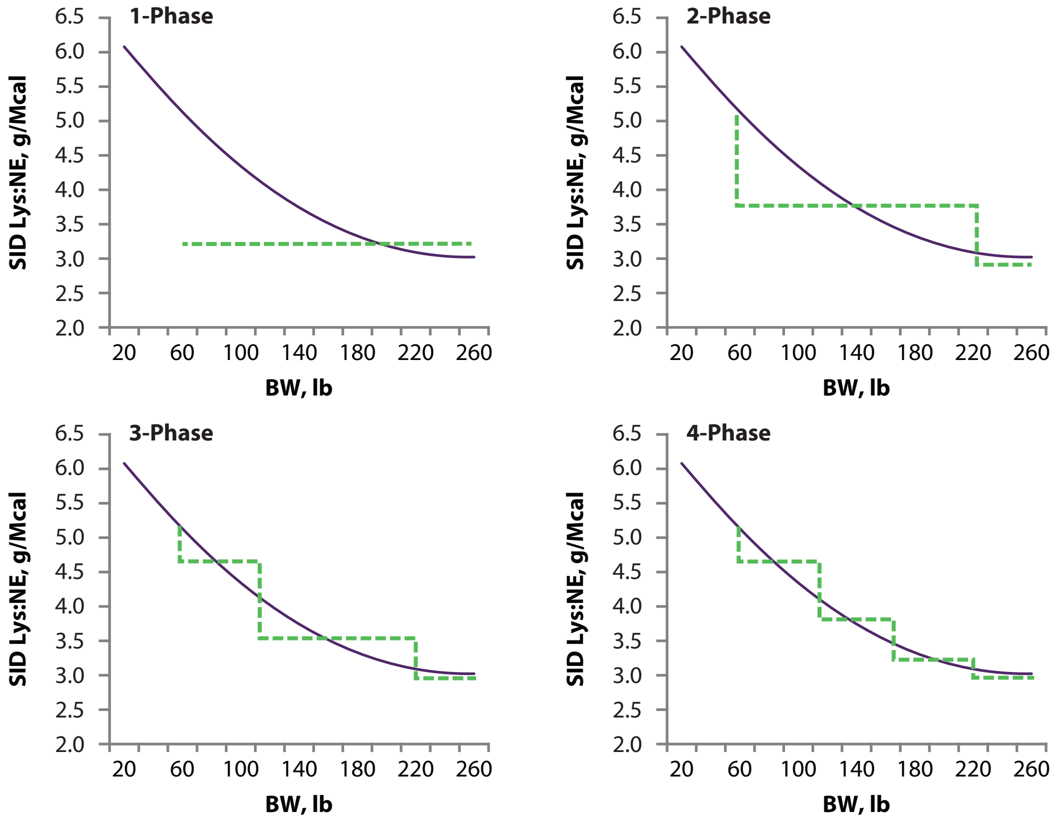

Figure 1. Representation of phase-feeding strategies (dash line) during the grow-finish phase in relation to the estimated lysine requirement (solid line) expressed as a ratio of standardized ileal digestible lysine to net energy (SID Lys:NE).