Determining an optimum lysine:calorie ratio for barrows and gilts in a commercial finishing facility[1,2]

R. G. Main,*[3] S. S. Dritz,* M. D. Tokach,† R. D. Goodband,†[4] and J. L. Nelssen†

*Food Animal Health and Management Center; and †Department of Animal Sciences and Industry, Kansas State University, Manhattan 66506-0201

ABSTRACT: Our objective was to determine an optimum Lys:calorie ratio (g of total dietary Lys/Mcal of ME) for 35- to 120-kg barrows and gilts (Pig Improvement Company, L337 × C22) in a commercial finishing environment. Seven (3 barrow and 4 gilt) trials were conducted using randomized complete block designs (42 pens per trial, a total of 7,801 pigs). Six treatments with increasing Lys:calorie ratio were used in each study. Diets were corn-soybean meal-based with 6% choice white grease. Lysine:calorie ratios were attained by adjusting the amount of corn and soybean meal. No crystalline Lys was used. In barrow trial 1 (43 to 70 kg), increasing the Lys:calorie ratio (2.21, 2.55, 2.89, 3.23, 3.57, and 3.91) increased (quadratic, $P < 0.01$) ADG, G:F, income over feed costs (IOMFC), and feed cost per kilogram of gain, and decreased (linear, $P < 0.01$) backfat. In barrow trial 2 (69 to 93 kg), increasing the Lys:calorie ratio (1.53, 1.78, 2.03, 2.28, 2.53, and 2.78) improved (linear, $P < 0.01$) ADG, G:F, and IOMFC, and decreased (quadratic, $P < 0.01$) backfat. In barrow trial 3 (102 to 120 kg), increasing the Lys:calorie ratio (1.40, 1.60, 1.80, 2.00, 2.20, and 2.40) increased (linear, $P < 0.03$) ADG and G:F, and numerically improved (linear, $P = 0.12$) IOMFC. In gilt trials 1 (35 to 60 kg), 2 (60 to 85 kg), and 3 (78 to 103 kg), increasing the Lys:calorie ratio (2.55, 2.89, 3.23, 3.57, 3.91, and 4.25; 1.96, 2.24, 2.52, 2.80, 3.08, and 3.36; and 1.53, 1.78, 2.03, 2.28, 2.53, and 2.78, respectively) improved (quadratic, $P < 0.04$) ADG, G:F, IOMFC, and feed cost per kilogram of gain, and decreased (linear, $P < 0.01$) backfat. In gilt trial 4 (100 to 120 kg), increasing the Lys:calorie ratio (1.40, 1.60, 1.80, 2.00, 2.20, and 2.40) improved (linear, $P < 0.02$) ADG, G:F, LM depth, IOMFC, and (quadratic, $P < 0.06$) feed cost per kilogram of gain. These studies suggest that feed cost per kilogram of gain decreases, and reductions in biological performance and IOMFC are rather modest when feeding marginally Lys-deficient diets early (35 to 70 kg) in the grower-finishing period compared with the more severe penalties in growth and economic performance of feeding marginally deficient diets in the late finishing period (70 kg to slaughter). The equations (Lys:calorie ratio = $-0.0133 \times$ BW, kg, + 3.6944 and = $-0.0164 \times$ BW, kg, + 4.004, for barrows and gilts, respectively) best describe our interpretation of the Lys:calorie ratio that met biological requirements and optimized IOMFC on these pigs (PIC, L337 × C22; 35 to 120 kg) in this commercial finishing environment.

Key words: finishing, lysine, swine

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INTRODUCTION

Understanding the effects of increasing dietary Lys on grow-finish performance is a core component of developing cost-effective grower-finishing feeding strategies in commercial pig production. Lysine requirements are commonly expressed as a Lys:calorie ratio (g of Lys/Mcal of ME). Expressing Lys requirements relative to dietary energy content enables requirements to be applicable over a range of energy levels (Chiba et al., 1991; De La Llata et al., 2001) and is likely most appropriate for growing environments in which energy intake does not exceed the level required for maximum protein deposition (Campbell and Taverner, 1988; Mohn et al., 2000). Although grower-finishing Lys requirements have been well studied, modeled, and reported (NRC, 1998; Cline et al., 2000), it is generally understood that an optimum Lys:calorie regimen can be largely affected by genetic line, sex, environment, health status, method of interpreting response criteria, and economic indicator of success (Campbell and Tav-

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[3]Current address: 301 Alexander Ave., Suite B, Ames, IA.

[4]Corresponding author: Goodband@ksu.edu

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Table 1. Overview of trials evaluating effects of Lys:calorie ratio on finishing pig performance in a commercial environment[1]

Trial	Weight range, kg	Lys:calorie ratio[2]	Duration, d	Pigs per pen, n	Pigs on test, n
Barrows					
Trial 1	43 to 70	2.21 to 3.91	28	26 to 28	1,166
Trial 2	69 to 93	1.53 to 2.78	27	25 to 28	1,147
Trial 3	102 to 120	1.40 to 2.40	21	22 to 24	968
Gilts					
Trial 1	35 to 60	2.55 to 4.25	28	28	1,176
Trial 2	60 to 85	1.96 to 3.36	28	27 to 28	1,163
Trial 3	78 to 103	1.53 to 2.78	28	27 to 28	1,160
Trial 4	100 to 120	1.40 to 2.40	25	21 to 25	1,021

[1]Seven trials were conducted to evaluate effects of increasing Lys:calorie ratio (g of Lys/Mcal of ME) in grow-finish pigs (Pig Improvement Co., Hendersonville, TN; 337 × C22, n = 7,801) in a commercial finishing environment.

[2]Lys:calorie ratio is expressed as total g of Lys per Mcal of ME.

erner, 1988; Gahl et al., 1995; De La Llata et al., 2001). Thus, there is and will continue to be efforts needed to further characterize the effects of increasing dietary Lys in evolving genetic lines reared in commercial multi-site production system environments. When designing cost-effective feeding regimens for commercial application, it is also important to gain an appreciation for the biological and economic implications of feeding below, at, or above the biological requirements at the different phases of the grower-finishing period. The objective of these trials was to derive a Lys:calorie ratio that optimized biological performance and income over feed costs (**IOMFC**) for pigs [Pig Improvement Company (**PIC**), L337 × C22; PIC, Hendersonville, TN] grown in this commercial finishing environment.

MATERIALS AND METHODS

Pig welfare guidelines were in accordance with published guidelines (FASS, 1999) and the research protocol was approved by the Kansas State University Institutional Animal Care and Use Committee.

A series of 7 trials (3 barrow and 4 gilt) were conducted to determine the effects of increasing Lys:calorie ratio in barrows and gilts (L337 × C22, PIC) grown in commercial finishing facilities. Each trial independently evaluated 1 phase (weight range) of the grower-finishing period and had 6 dietary treatments with incrementally increasing Lys:calorie ratios. The trials ranged in length from 21 to 28 d. All diets were corn-soybean meal–based diets with 6% added choice white grease (as-fed basis). Increasing Lys:calorie ratio was attained by replacing corn with soybean meal. No crystalline Lys was used to ensure Lys was the first-limiting AA. All other nutrients were also formulated to be non-limiting (NRC, 1998). An overview describing phases of growth, range of Lys:calorie ratios used, trial duration, pigs per pen, and total pigs used in each trial are outlined in Table 1. Likewise, dietary treatments, calculated dietary analysis, diets costs, and diet composition are provided in Tables 2 and 3. The Lys:calorie ratios discussed in this paper are expressed as total grams of Lys/Mcal of ME. Additionally, the estimated true ileal digestible Lys (NRC, 1998) as a percentage of diet (as-fed) is shown in Table 2 and throughout response data summary tables (Tables 4 to 10). A subsample of each diet was analyzed for Lys content and all values were similar to calculated values (data not shown).

Pigs were allotted to 1 of the 6 dietary treatments in a randomized completed block design with 7 pens per treatment. Different groups of pigs were used in each individual experiment so that previous dietary treatment would not bias results. Before each study, pigs were fed a corn-soybean meal–based diet formulated to 20% above the Lys requirement estimate previously determined for this production system (De La Llata et al., 2007). Each pen was 3.05 × 5.49 m with a 4-hole dry self-feeder and 1-cup waterer. Finishing facilities had total slat flooring, a deep pit, and were operated with mechanical ventilation in the winter and natural ventilation (double curtain-sided) in the summer. Pig weights by pen and feed disappearance were measured throughout all trials. In trials not ending at slaughter (barrow trials 1 and 2; gilt trials 1, 2, and 3), 5 pigs per pen were individually identified, weighed, and scanned with real-time ultrasound to measure fat depth and LM area (**LMA**) at the 10th rib. These 5 selected pigs were identified, weighed, and scanned at the beginning of the trial, and again at the end. The scanning data served to study the effects of dietary Lys on body compositional changes during the feeding period. Changes in fat depth and LMA were the primary measures of interest. In the trials terminating at slaughter (barrow trial 3; gilt trial 4), pen identity was maintained through slaughter at a commercial slaughter facility (Swift Inc., Worthington, MN). Maintaining pen identification enabled carcass data (carcass yield, fat and LM depth at the 10th rib, calculated lean percentage, fat-free lean index, and grade premium) to be collected for each pen. Lean percentage was provided from the packing plant using a proprietary equation and fat-free lean index calculated according to NPPC (2000) procedures.

Gain, feed intake, feed efficiency, feed cost per kilogram of gain, and IOMFC were measured in each study. Income over marginal feed costs is defined as

Table 2. Description of dietary treatments (as fed) and diets costs used to determine the effects of Lys:calorie ratio on barrow and gilt performance in a commercial finishing environment[1,2,3,4]

Item	Lys:calorie ratio					
Barrow trials						
Trial 1 (43 to 70 kg)	2.21	2.55	2.89	3.23	3.57	3.91
Total Lys, %	0.79	0.91	1.04	1.16	1.28	1.40
True ileal digestible Lys, %	0.69	0.80	0.91	1.02	1.13	1.24
ME, kcal/kg	3,581	3,580	3,580	3,580	3,579	3,579
Diet cost/1,000 kg, $	130.18	134.16	138.19	142.22	147.03	151.06
Trial 2 (69 to 93 kg)	1.53	1.78	2.03	2.28	2.53	2.78
Total Lys, %	0.55	0.64	0.73	0.82	0.91	1.00
True ileal digestible Lys, %	0.47	0.55	0.63	0.72	0.80	0.88
ME, kcal/kg	3,596	3,596	3,596	3,596	3,596	3,596
Diet cost/1,000 kg, $	120.78	123.74	126.70	129.69	132.64	135.63
Trial 3 (102 to 120 kg)	1.40	1.60	1.80	2.00	2.20	2.40
Total Lys, %	0.51	0.58	0.65	0.72	0.80	0.87
True ileal digestible Lys, %	0.43	0.50	0.56	0.63	0.69	0.76
ME, kcal/kg	3,616	3,615	3,615	3,614	3,614	3,614
Diet cost/1000 kg, $	118.27	120.69	122.97	125.38	127.77	130.15
Gilt trials						
Trial 1 (35 to 60 kg)	2.55	2.89	3.23	3.57	3.91	4.25
Total Lys, %	0.91	1.04	1.16	1.28	1.40	1.52
True ileal digestible Lys, %	0.80	0.91	1.02	1.13	1.24	1.35
ME, kcal/kg	3,580	3,580	3,580	3,579	3,579	3,578
Diet cost/1,000 kg, $	134.17	138.21	142.24	147.05	151.08	155.47
Trial 2 (60 to 85 kg)	1.96	2.24	2.52	2.80	3.08	3.36
Total Lys, %	0.71	0.81	0.91	1.01	1.11	1.21
True ileal digestible Lys, %	0.61	0.70	0.79	0.88	0.98	1.07
ME, kcal/kg	3,589	3,589	3,589	3,589	3,589	3,588
Diet cost/1,000 kg, $	126.69	129.98	133.31	136.60	140.30	144.03
Trial 3 (78 to 103 kg)	1.53	1.78	2.03	2.28	2.53	2.78
Total Lys, %	0.55	0.64	0.73	0.82	0.91	1.00
True ileal digestible Lys, %	0.47	0.55	0.63	0.72	0.80	0.88
ME, kcal/kg	3,596	3,596	3,596	3,596	3,596	3,596
Diet cost/1,000 kg, $	120.80	123.75	126.71	129.70	132.66	135.64
Trial 4 (100 to 120 kg)	1.40	1.60	1.80	2.00	2.20	2.40
Total Lys, %	0.51	0.58	0.65	0.72	0.80	0.87
True ileal digestible Lys, %	0.43	0.50	0.56	0.63	0.69	0.76
ME, kcal/kg	3,616	3,615	3,615	3,614	3,614	3,613
Diet cost/1,000 kg, $	118.28	120.70	122.98	125.40	127.78	130.16

[1]All diets were corn-soybean meal diets with 6% added choice white grease. No crystalline Lys was used to ensure Lys was the first limiting AA with all other nutrients being non-limiting (NRC, 1998).

[2]Diets were formulated using NRC (1998) nutrient and digestibility values for all ingredients.

[3]Diets were analyzed for Lys content and were consistent with formulated composition.

[4]Diets costs were calculated with $72.83/1,000 kg of corn and $165.36/1,000 kg, 46.5% CP soybean meal, along with a $13.23/1,000 kg manufacturing and delivery charge.

the value of the pigs weighed at the end of the trial less the feed costs incurred during the trial period. In the trials not terminating at slaughter, an average pig value was calculated by assessing value to the weight gain during the trial period at $88.18/100 kg, and subsequently subtracting feed costs incurred during the trial period. In trials terminating at slaughter, an average pig value was calculated by using the calculated carcass weight and carcass grade premium data from each pen. Because there were no treatment differences in carcass yield, the trial mean carcass yield was applied to all pens' off-test weights to attain a calculated carcass weight for each pen. The average feed cost per pig was subtracted from the derived pig value to attain

Table 3. Diet composition (as-fed basis)[1]

	Barrows			Gilts			
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 4
Item	43 to 70 kg	69 to 93 kg	102 to 120 kg	35 to 60 kg	60 to 85 kg	78 to 103 kg	100 to 120 kg
Ingredient, %							
Corn	49.04 to 70.83	63.90 to 76.78	68.18 to 82.14	44.70 to 66.49	56.3 to 66.49	63.90 to 80.0	69.17 to 82.14
Soybean meal, 46.5% CP	20.14 to 42.14	14.58 to 27.61	9.75 to 23.79	24.51 to 46.51	16.95 to 35.05	11.3 to 27.60	9.75 to 22.79
Choice white grease	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Monocalcium phosphate, 21% P	1.24 to 1.38	1.10 to 1.18	0.70 to 0.78	1.23 to 1.35	1.16 to 1.26	1.10 to 1.20	0.70 to 0.78
Limestone	0.95 to 1.05	0.88 to 0.95	0.825	0.93 to 1.05	0.88 to 0.975	0.88 to 0.97	0.825
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[2]	0.08	0.06	0.06	0.08	0.08	0.06	0.06
Trace mineral premix[3]	0.15	0.10	0.10	0.15	0.15	0.10	0.10
DL-Methionine	0 to 0.025	—	—	0 to 0.0375	0 to 0.0125	—	—
Calculated analysis[4]							
CP, %	15.4 to 23.8	12.1 to 18.3	11.5 to 16.5	17.1 to 25.4	14.2 to 21.1	12.1 to 18.3	11.5 to 16.5
Lys:calorie ratio, g of Lys/Mcal of ME	2.21 to 3.91	1.53 to 2.78	1.40 to 2.40	2.55 to 4.25	1.96 to 3.36	1.53 to 2.78	1.40 to 2.40
Ca, %	0.75	0.65	0.51 to 0.54	0.75	0.68	0.65	0.51 to 0.54
Available P, %	0.35	0.30	0.21	0.35	0.32	0.30	0.21

[1]Increasing Lys:calorie ratios were achieved by replacing corn with soybean meal.

[2]Provided the following per kilogram of complete diet: vitamin A, 8,818 IU; vitamin D, 1,323 IU; vitamin E, 35.3 IU; menadione (menadione sodium bisulfate complex), 3.5 mg; vitamin B_{12}, 0.04 mg; riboflavin, 7.9 mg; pantothenic acid, 26.5 mg; and niacin, 44.1 mg.

[3]Provided the following per kilogram of complete diet: Mn, 40 mg; Fe, 165 mg; Zn, 165 mg; Cu, 17 mg; I, 0.3 mg; and Se, 0.3 mg.

[4]Calculated values from NRC (1998) were used in diet formulation.

Table 4. Effect of Lys:calorie ratio on 43- to 70-kg BW barrows (barrow trial 1)[1]

	Lys:calorie (g of Lys/Mcal of ME)								
	2.21	2.55	2.89	3.23	3.57	3.91			
	Total Lys, %								
	0.79	0.91	1.04	1.16	1.28	1.40			
	True ileal digestible Lys (TID), %							Probability ($P <$)	
Item	0.69	0.80	0.91	1.02	1.13	1.24	SE	Linear	Quadratic
Initial BW, kg	43.4	43.7	43.5	43.7	43.6	43.4	0.98	0.99	0.30
ADG, g	913	970	992	966	963	943	23	0.50	0.007
ADFI, g	2,069	2,087	2,111	2,043	2,063	2,005	41	0.06	0.14
G:F, g/g	0.441	0.464	0.470	0.474	0.467	0.472	0.006	0.002	0.01
Off-test weight,[2] kg	69.2	70.7	71.4	70.6	70.5	70.0	0.54	0.50	0.01
10th rib fat depth change,[3] mm	4.8	3.9	4.1	3.3	3.4	2.5	0.24	0.001	0.86
Change in LM area,[3] cm^2	7.7	8.7	8.5	9.0	8.8	8.5	0.29	0.03	0.008
Feed cost/kg of gain, US $	0.295	0.289	0.293	0.300	0.315	0.322	0.004	0.001	0.01
IOMFC,[4] US $/head	15.00	16.11	16.33	15.73	15.28	14.83	0.43	0.22	0.005
TID Lys,[5] g/d	14.3	16.7	19.2	20.8	23.3	24.9	0.41	0.001	0.09
TID Lys,[5] g/kg of gain, g	15.7	17.2	19.4	21.6	24.3	26.4	0.31	0.001	0.07

[1]A total of 1,166 barrows (Pig Improvement Co., Hendersonville, TN; L337 × C22) housed at the rate of 26 to 28 pigs per pen and 7 replications per treatment in a 28-d trial. The diets contained 3,580 kcal/kg.

[2]Off-test weight = start BW + (ADG × number of d of trial); and adjusting to a common initial BW.

[3]Change in fat depth and LM area = difference in fat depth and LM area on the 5 animals/pen ultrasonically scanned at the beginning and at the end of the feeding period. These differences in fat depth and LM area were adjusted to a common change in liveweight.

[4]IOMFC = income over marginal feed costs = value of gain on a $88.18/100 kg liveweight basis – feed costs during trial period.

[5]Grams of true ileal digestible (TID) Lys consumed per day and per kilogram of gain, respectively.

Table 5. Effect of Lys:calorie ratio on 69- to 93-kg BW barrows (barrow trial 2)[1]

	Lys:calorie (g of Lys/Mcal of ME)								
	1.53	1.78	2.03	2.28	2.53	2.78			
	Total Lys, %								
	0.55	0.64	0.73	0.82	0.91	1.00			
	True ileal digestible Lys (TID), %							Probability ($P <$)	
Item	0.47	0.55	0.63	0.72	0.80	0.88	SE	Linear	Quadratic
Initial BW, kg	68.6	69.6	69.7	69.1	68.9	69.2	1.77	0.92	0.27
ADG, g	818	828	893	902	916	946	17	0.001	0.51
ADFI, g	2,278	2,302	2,312	2,352	2,287	2,350	32	0.15	0.66
G:F, g/g	0.358	0.360	0.386	0.382	0.400	0.402	0.005	0.001	0.52
Off-test weight, kg[2]	91.5	91.7	93.5	93.7	94.1	94.9	0.50	0.001	0.52
10th-rib fat depth change,[3] mm	5.0	4.7	3.7	3.9	3.5	4.2	0.29	0.003	0.008
Change in LM area,[3] cm^2	7.6	8.0	8.5	9.3	9.7	8.6	0.45	0.006	0.06
Feed cost/kg of gain, $	0.337	0.344	0.328	0.339	0.331	0.337	0.004	0.46	0.47
IOMFC,[4] $/head	12.06	12.03	13.35	13.21	13.63	13.92	0.35	0.001	0.50
TID Lys,[5] g/d	10.7	12.7	14.6	17.0	18.3	20.7	0.21	0.001	0.93
TID Lys,[5] g/kg of gain, g	13.1	15.3	16.3	18.9	20.0	21.9	0.23	0.001	0.60

[1]A total of 1,147 barrows (Pig Improvement Co., Hendersonville, TN; L337 × C22) housed at the rate of 25 to 28 pigs per pen and 7 replications per treatment in a 27-d trial. The diets contained 3,596 kcal/kg.

[2]Off-test weight = start BW + (ADG × number of d of trial); and adjusting to a common initial BW.

[3]Change in fat depth and LM area = difference in fat depth and LM area on the 5 animals/pen ultrasonically scanned at the beginning and at the end of the feeding period. These differences in fat depth and LM area were adjusted to a common change in liveweight.

[4]IOMFC = income over marginal feed costs = value of gain on a $88.18/100 kg liveweight basis – feed costs during trial period.

[5]Grams of true ileal digestible (TID) Lys consumed per day and per kilogram of gain, respectively.

Table 6. Effect of Lys:calorie ratio on 102- to 120-kg BW barrows (barrow trial 3)[1]

	Lys:calorie (g of Lys/Mcal of ME)								
	1.40	1.60	1.80	2.00	2.20	2.40			
	Total Lys, %								
	0.51	0.58	0.65	0.72	0.80	0.87			
	True ileal digestible (TID) Lys, %							Probability ($P <$)	
Item	0.43	0.50	0.56	0.63	0.69	0.76	SE	Linear	Quadratic
Initial BW, kg	102.7	102.9	102.9	103.0	102.9	102.9	1.45	0.77	0.67
ADG, g	818	818	857	865	868	877	24	0.03	0.66
ADFI, g	2,616	2,623	2,644	2,661	2,598	2,605	41	0.75	0.39
G:F, g/g	0.312	0.312	0.324	0.325	0.334	0.337	0.005	0.001	0.93
Off-test weight,[2] kg	120.1	120.1	120.9	121.0	121.1	121.3	0.48	0.02	0.64
Carcass yield, %	76.2	76.1	76.2	76.3	75.4	76.1	0.24	0.27	0.96
10th-rib fat depth change,[3] mm	19.6	19.7	20.2	20.0	19.3	19.4	0.24	0.27	0.96
LM depth,[3] mm	58.6	59.0	59.1	58.2	58.8	59.8	0.53	0.33	0.28
Fat free lean index, %	49.2	49.1	48.9	49.0	49.3	49.3	0.19	0.41	0.20
Lean,[3,4] %	53.9	53.9	53.6	53.6	54.2	54.2	0.26	0.31	0.14
Grade premium,[5] $/100 kg	6.53	6.55	6.19	6.34	6.83	7.03	0.37	0.26	0.21
Feed cost/kg of gain, $	0.379	0.388	0.381	0.386	0.384	0.388	0.007	0.57	0.87
IOMFC,[6,7] $/head	106.64	106.66	106.98	107.09	107.60	107.81	1.40	0.12	0.78
TID Lys,[8] g/d	11.2	13.1	14.8	16.8	17.9	19.8	0.25	0.001	0.38
TID Lys,[8] g/kg of gain	13.8	16.1	17.3	19.4	20.1	22.6	0.29	0.001	0.55

[1]A total of 968 barrows (Pig Improvement Co., Hendersonville, TN; L337 × C22) housed at the rate of 22 to 24 pigs per pen and 7 replications per treatment in a 21-d trial. The diets contained 3,615 kcal/kg.

[2]Off-test weight = start BW + (ADG × number of d of trial); and adjusting to a common initial BW.

[3]10th-rib backfat, LM depth, and lean percent were adjusted to a common carcass weight for statistical analysis.

[4]Lean percent is a calculated estimate using the measured 10th-rib backfat and LM depth measurements as inputs into a proprietary prediction equation (Swift Inc., Worthington, MN).

[5]Grade premium was the actual lean premium observed at slaughter (Swift Inc., Worthington, MN).

[6]IOMFC = income over marginal feed costs = carcass value – feed costs during trial period.

[7]Base meat price of $117.57/100 kg, actual feed costs and lean premium, and carcass weights attained by applying the trial mean carcass yield (76.03%) to off-test weights in the IOMFC analysis.

[8]Grams of true ileal digestible (TID) Lys consumed per day and per kilogram of gain, respectively.

the IOMFC for each pen. A standard set of ingredient prices and feed manufacturing costs were used for all trials (Table 2). All monetary values used in this paper are expressed in US dollars. Additionally, Lys intake expressed as grams of true ileal digestible Lys (**TID**) intake per day and per kilogram of gain was also calculated for reader reference and to enable retrospective associations between Lys intake and growth.

Analysis of variance was used to analyze growth and economic performance data as a randomized complete block design using the MIXED procedures (SAS Inst. Inc., Cary, NC). The statistical model included the fixed effect of dietary treatment (Lys:calorie ratio) with block as the random component. Linear and quadratic contrasts were used to determine the effects of increasing Lys:calorie ratio (g of Lys/Mcal of ME). Pen was used as the experimental unit. Probability values ≤0.10 and ≥0.06 were considered trends, whereas $P \leq 0.05$ was considered significant. Additionally, the dietary Lys levels interpreted as meeting biological needs and optimizing IOMFC for each finishing phase evaluated were plotted on the mid-point BW to derive a prediction equation estimating the Lys:calorie ratio needed for maximum performance throughout the finishing period.

RESULTS AND DISCUSSION

Barrow Trial 1

In trial 1 (43- to 70-kg barrows), ADG and G:F improved (quadratic, $P < 0$ 0.01; Table 4) with increasing Lys:calorie ratio. Average daily gain was maximized at 2.89 g of Lys/Mcal of ME, whereas feed efficiency was maximized at 3.23 g of Lys/Mcal of ME. Feed intake tended to be reduced (linear, $P = 0.06$) as the Lys:calorie ratio increased and appeared to be due to the reduced intake observed at the highest level of Lys fed (3.91 g of Lys/Mcal of ME). This reduction in intake may be due to the level of soybean meal (42% of total diet) that was needed to meet this Lys:calorie ratio without the use of crystalline Lys. A reduction in NE as Lys (CP) levels increased may also be a factor affecting the responses in this and the subsequent trials as well. Fat deposition, as measured by a change in 10th-rib backfat during the feeding period, was decreased (linear, $P < 0.001$) with increasing Lys:calorie ratio. The change in LMA increased (quadratic, $P < 0.008$) with increasing dietary Lys. However, only the lowest Lys:calorie ratio fed (2.21 g of Lys/Mcal of ME) had a different ($P < 0.05$) change in LMA than all other treatments. Feed cost per kilogram of gain increased (quadratic, $P < 0.01$) when increasing the Lys:calorie ratio with numeric increases continuing to occur through the greatest Lys level fed. Income over feed costs improved (quadratic, $P < 0.005$) with increasing dietary Lys. Income over feed cost was maximized at 2.89 g of Lys/Mcal of ME. These data indicate that feeding 43- to 70-kg barrows a diet containing 2.89 g of Lys/Mcal of ME adequately meets biological Lys requirements for growth and optimized return over feed costs. However, feed cost per kilogram of gain was minimized while feeding below these biological requirements at 2.55 g of Lys/Mcal of ME.

In the trials not ending in slaughter (barrow trials 1 and 2; gilt trials 1, 2, and 3), we used the weight gain and body compositional change data obtained from the sample of pigs scanned with ultrasound to retrospectively compare our measured estimate of the optimum Lys:calorie ratio to a predicted Lys requirement. The predicted Lys requirement used as a source of comparison was derived using previously described methods for estimating Lys requirements based on estimated changes in body composition and weight gain (Schinckel and de Lange, 1996; Smith et al., 1999). We only used the data from pigs fed at or above the estimated optimum Lys:calorie ratio described in these experiments to attain a predicted Lys requirement. The predicted Lys requirement in barrow trial 1 was 3.14 g of Lys/Mcal of ME. Thus, the predicted requirement from the ultrasound data and the observed biological responses were in general agreement. Chiba et al. (1991) and Yen et al. (1986a) estimated approximately 3.13 g of Lys/Mcal of ME to maximize performance in 20- to 55-kg barrows. The Chiba et al. (1991) and Yen et al. (1986a) studies also observed an intake of 19 to 20 g of TID Lys/kg of gain at the dietary Lys level required to maximize performance, which is similar to the 19.2 g of TID Lys/kg of gain observed in the current study.

Barrow Trial 2

In trial 2 (69- to 93-kg barrows), ADG and G:F improved (linear, $P < 0$ 0.001; Table 5) with increasing Lys:calorie ratio. Although gain improved at a steady rate through the greatest Lys level fed (2.78 g of Lys/Mcal of ME), feed efficiency was minimally improved beyond 2.53 g of Lys/Mcal of ME. Feed intake was not affected by increasing Lys:calorie ratio. Fat deposition as measured by a change in backfat depth during the feeding period was decreased (quadratic, $P < 0.008$) with increasing Lys:calorie ratio. Reduction in fat deposition was not observed beyond 2.53 g of Lys/Mcal of ME. Longissimus muscle area tended to be increased (quadratic, $P < 0.06$) with increasing dietary Lys. The greatest change in LMA was observed at 2.53 g of Lys/Mcal of ME. Increasing the Lys:calorie ratio did not affect feed cost per kilogram of gain because of the magnitude of the linear improvements in G:F. However, IOMFC improved (linear, $P < 0.001$) with increasing dietary Lys. Although growth responses and IOMFC were improved linearly, improvements in G:F and carcass composition were not significantly improved beyond 2.53 g of Lys/Mcal of ME. Thus, the Lys:calorie ratio for maximum growth, feed efficiency, and carcass performance in these pigs is likely between 2.53 and 2.78 g of Lys/Mcal of ME. These data suggest that feeding these barrows (69 to 93 kg) between 2.53 and 2.78 g of Lys/Mcal of ME provides an adequate blend of meet-

Table 7. Effect of Lys:calorie ratio on 35- to 60-kg BW gilts (gilt trial 1)[1]

	Lys:calorie (g of Lys/Mcal of ME)								
	2.55	2.89	3.23	3.57	3.91	4.25			
	Total Lys, %								
	0.91	1.04	1.16	1.28	1.40	1.52			
	True ileal digestible (TID) Lys, %							Probability ($P <$)	
Item	0.80	0.91	1.02	1.13	1.24	1.35	SE	Linear	Quadratic
Initial BW, kg	35.0	35.1	35.0	35.1	35.1	35.2	0.80	0.46	0.60
ADG, g	895	910	930	907	905	890	15	0.50	0.03
ADFI, g	1,948	1,924	1,944	1,907	1,899	1,897	27	0.05	0.99
G:F, g/g	0.460	0.473	0.479	0.475	0.476	0.469	0.007	0.32	0.04
Off-test weight,[2] kg	60.2	60.6	61.1	60.5	60.4	60.0	0.40	0.41	0.02
10th-rib fat depth change,[3] mm	2.5	2.5	2.3	2.1	1.9	1.5	0.21	0.0002	0.30
Change in LM area,[3] cm^2	9.3	9.8	9.6	9.4	10.1	9.7	0.56	0.60	0.86
Feed cost/kg of gain, $	0.292	0.292	0.297	0.310	0.318	0.332	0.004	0.001	0.03
IOMFC,[4] $/head	14.78	15.02	15.21	14.53	14.29	13.70	0.32	0.001	0.02
TID Lys,[5] g/d	15.6	17.5	19.8	21.5	23.5	25.6	0.3	0.001	0.80
TID Lys,[5] g/kg of gain	17.4	19.2	21.3	23.8	26.1	28.8	0.35	0.001	0.07

[1]A total of 1,176 barrows (Pig Improvement Co., Hendersonville, TN; L337 × C22) housed at the rate of 28 pigs per pen and 7 replications per treatment in a 28-d trial. The diets contained 3,580 kcal/kg.

[2]Off-test weight = start BW + (ADG × number of days of trial); and adjusting to a common initial BW.

[3]Change in fat depth and LM area = difference in fat depth and LM area on the 5 animals/pen ultrasonically scanned at the beginning and at the end of the feeding period. These differences in fat depth and LM area were adjusted to a common change in liveweight.

[4]IOMFC, income over marginal feed costs = value of gain on a $88.18/100 kg liveweight basis – feed costs during trial period.

[5]Grams of true ileal digestible (TID) Lys consumed per day and per kilogram of gain, respectively.

Table 8. Effect of Lys:calorie ratio on 60- to 85-kg BW gilts (gilt trial 2)[1]

	Lys:calorie (g of Lys/Mcal of ME)								
	1.96	2.24	2.52	2.80	3.08	3.36			
	Total Lys, %								
	0.71	0.81	0.91	1.01	1.11	1.21			
	True ileal digestible (TID) Lys, %							Probability ($P <$)	
Item	0.61	0.70	0.79	0.88	0.98	1.07	SE	Linear	Quadratic
Initial BW, kg	59.9	59.6	59.8	59.6	59.8	59.8	0.83	0.89	0.17
ADG, g	916	937	960	974	951	936	12	0.09	0.001
ADFI, g	2,309	2,309	2,364	2,322	2,379	2,312	23	0.32	0.11
G:F, g/g	0.397	0.405	0.407	0.419	0.400	0.405	0.005	0.29	0.03
Off-test weight,[2] kg	85.3	85.9	86.6	86.9	86.33	85.9	0.35	0.09	0.002
10th-rib fat depth change,[3] mm	4.0	3.3	3.3	3.3	2.9	2.9	0.23	0.001	0.34
Change in LM area,[3] cm^2	9.3	9.6	9.9	9.5	9.6	9.5	0.38	0.78	0.43
Feed cost/kg of gain, $	0.320	0.321	0.328	0.326	0.351	0.356	0.004	0.001	0.02
IOMFC,[4] $/head	14.42	14.68	14.90	15.14	14.13	13.80	0.25	0.04	0.002
TID Lys,[5] g/d	14.1	16.2	18.7	20.4	23.3	24.7	0.21	0.001	0.31
TID Lys,[5] g/kg of gain	15.4	17.3	19.5	21.0	24.5	26.5	0.20	0.001	0.01

[1]A total of 1,163 gilts (Pig Improvement Co., Hendersonville, TN; L337 × C22) housed at the rate of 27 to 28 pigs per pen and 7 replications per treatment in a 28-d trial. The diets contained 3,589 kcal/kg.

[2]Off-test weight = start BW + (ADG × number of d of trial); and adjusting to a common initial BW.

[3]Change in fat depth and LM area = difference in fat depth and LM area on the 5 animals/pen ultrasonically scanned at the beginning and at the end of the feeding period. These differences in fat depth and LM area were adjusted to a common change in liveweight.

[4]IOMFC = income over marginal feed costs = value of gain on a $88.18/100 kg liveweight basis – feed costs during trial period.

[5]Grams of true ileal digestible (TID) Lys consumed per day and per kilogram of gain, respectively.

Table 9. Effect of Lys:calorie ratio on 78- to 103-kg BW gilts (gilt trial 3)[1]

	Lys:calorie (g of Lys/Mcal of ME)								
	15.3	1.78	2.03	2.28	2.53	2.78			
	Total Lys, %								
	0.55	0.64	0.73	0.82	0.91	1.00			
	True ileal digestible (TID) Lys, %							Probability ($P <$)	
Item	0.47	0.55	0.63	0.72	0.80	0.88	SE	Linear	Quadratic
Initial BW, kg	78.2	78.4	78.4	78.5	78.4	78.2	1.15	0.93	0.65
ADG, g	806	812	899	916	911	896	16	0.001	0.003
ADFI, g	2,540	2,550	2,550	2,545	2,513	2,520	41	0.43	0.73
G:F, g/g	0.317	0.319	0.352	0.361	0.363	0.356	0.005	0.001	0.001
Off-test weight,[2] kg	101.0	101.1	103.6	104.0	103.9	103.5	0.29	0.001	0.01
10th-rib fat depth change,[3] mm	4.7	4.1	3.1	3.4	3.6	2.6	0.28	0.001	0.27
Change in LM area,[3] cm^2	5.4	6.5	7.7	7.2	9.3	8.4	0.47	0.001	0.10
Lean,[4] %	53.0	53.5	54.7	53.6	54.5	55.3	0.37	0.001	0.93
Feed cost/kg of gain, $	0.381	0.388	0.359	0.361	0.365	0.382	0.006	0.16	0.001
IOMFC,[5] $/head	11.32	11.24	13.18	13.41	13.20	12.56	0.36	0.001	0.001
TID Lys,[6] g/d	11.9	14.0	16.1	18.3	20.1	22.2	0.3	0.001	0.68
TID Lys,[6] g/kg of gain	14.8	17.3	17.9	20.0	22.1	24.8	0.3	0.001	0.01

[1]A total of 1,160 gilts (Pig Improvement Co., Hendersonville, TN; L337 × C22) housed at the rate of 27 to 28 pigs per pen and 7 replications per treatment in a 28-d trial. The diets contained 3,596 kcal/kg.

[2]Off-test weight = start BW + (ADG × number of days of trial); and adjusting to a common initial BW.

[3]Change in fat depth and LM area = difference in fat depth and LM area on the 5 animals/pen ultrasonically scanned at the beginning and at the end of the feeding period. These differences in fat depth and LM area were adjusted to a common change in liveweight.

[4]Calculated lean percentage from established equations (National Pork Board) from ultrasound fat depth and LM area data.

[5]IOMFC = income over marginal feed costs = value of gain on a $88.18/100 kg of liveweight basis – feed costs during trial period.

[6]Grams of true ileal digestible (TID) Lys consumed per day and per kilogram of gain, respectively.

ing biological requirements and optimizing return over marginal feed costs. The predicted Lys requirement using the estimated protein and fat accretion from the sample of pigs ultrasonically scanned (see barrow trial 1) was 2.10 g of Lys/Mcal of ME. This predicted Lys requirement is substantially below our estimate of between 2.53 and 2.78 g of Lys/Mcal of ME. Yen et al. (1986b) demonstrated the optimum Lys:calorie ratio to be 2.34 g of Lys/Mcal ME in 50- to 90-kg barrows. However, at this level of dietary Lys, Yen et al. (1986b) observed a Lys intake of 20.1 g of TID Lys/kg of gain, which is similar to the 20.0 to 21.9 g of TID Lys/kg of gain observed in the present study at the estimated optimum between 2.53 and 2.78 g of Lys/Mcal of ME. Cromwell et al. (1993) demonstrated that growth and feed efficiency was maximized when feeding 51- to 105-kg barrows 2.26 g of Lys/Mcal of ME. Cromwell et al. (1993) observed a Lys intake of 21 g of TID Lys/kg of gain at this level of dietary Lys. Hahn et al. (1995) estimated an optimum Lys level of 0.58% TID Lys (or 1.94 g of Lys/Mcal ME) while observing 18.5 g of TID Lys/kg of gain in 50- to 95-kg barrows.

Barrow Trial 3

In trial 3 (102- to 120-kg barrows), ADG and G:F improved (linear, $P < 0.03$; Table 6) with increasing Lys:calorie ratio. Although the response in ADG to increasing Lys was linear through the greatest level of Lys fed (2.40 g of Lys/Mcal of ME), improvement in G:F was minimal beyond 2.20 g of Lys/Mcal of ME. Increasing Lys:calorie ratio did not affect feed intake. Carcass yield was not affected by dietary treatment. Fat depth, LM depth, and lean percentage were not improved by increasing Lys:calorie ratio. However, pigs fed 2.20 or 2.40 g of Lys/Mcal of ME had numerically improved percentage lean, fat-free lean index, and grade premium (>1 SE) compared with the other treatments. Dietary Lys concentration did not affect feed cost per kilogram of gain due to the linear improvements in feed efficiency. Although IOMFC was not improved (linear, $P = 0.12$) with increasing Lys:calorie ratio, stepwise numeric improvements in IOMFC were observed as dietary Lys increased. This improvement in IOMFC was driven by the improvements in gain, feed efficiency, and numerically improved grade (lean) premium. These data indicate that feeding barrows (from 102 to 120 kg) a diet containing 2.20 g of Lys/Mcal of ME adequately meets biological requirements and optimizes IOMFC. In trials terminating at slaughter (barrow trial 3 and gilt trial 4), we used the estimated fat-free lean gain, average pig weight, and feed intake information during this final phase of growth to attain a predicted estimate of the Lys:calorie required (NRC, 1998). These predicted estimates were made only from the pigs that were fed at or above the estimated Lys requirement determined in the current experiments. The predicted Lys requirement in barrow trial 3 was 1.89 g of Lys/Mcal of ME, which is below our measured estimate of 2.20 g of Lys/Mcal of ME. Hahn et al. (1995) determined that 0.49% TID Lys (1.65 g of Lys/Mcal of ME) was needed to maximize performance in 90- to 110-kg barrows. At the observed optimum Lys level in the Hahn et al. (1995) experiment, Lys intake was 17.5 g of TID Lys/kg of gain compared with the 20 g of TID Lys/kg of gain observed at the dietary Lys level (2.20 g of Lys/Mcal of ME) that maximized performance in the current experiment.

Gilt Trial 1

In trial 1 (35- to 60-kg gilts), ADG and G:F improved (quadratic, $P < 0.04$; Table 7) with increasing Lys:calorie ratio. Gain and feed efficiency were maximized at 3.23 g of Lys/Mcal of ME. Increasing the Lys:calorie ratio from 2.55 to 4.25 g of Lys/Mcal of ME decreased (linear, $P < 0.05$) feed intake from 1,948 to 1,897 g/d. As was mentioned in the discussion of barrow trial 1, this reduction in feed intake may be associated with the high levels of soybean meal needed to achieve the predetermined Lys:calorie ratio. Fat deposition (as measured by a change in backfat depth) during the feeding period was reduced (linear, $P < 0.001$) with increasing Lys:calorie ratio. Increasing Lys:calorie ratio did not affect a change in LMA. Feed cost per kilogram of gain increased (quadratic, $P < 0.03$) when increasing the Lys:calorie ratio with stepwise numeric increases observed through the 4.25 g of Lys/Mcal of ME treatment. Income over marginal feed costs improved (quadratic, $P < 0.02$) with increasing dietary Lys and was maximized at 3.23 g of Lys/Mcal of ME. These data indicate that feeding gilts 3.23 g of Lys/Mcal of ME from 35 to 60 kg adequately meets biological requirements and optimizes IOMFC. However, because of the relatively modest magnitude of the biological responses, feed cost per kilogram of gain numerically increased with Lys:calorie ratio. The predicted Lys requirement from the sample of pigs scanned ultrasonically was 3.55 g of Lys/Mcal of ME, which was slightly greater than the observed requirement of 3.23 g of Lys/Mcal of ME. Yen et al. (1986a) estimated a Lys requirement of 3.34 g of Lys/Mcal of ME in 25- to 55-kg gilts and observed an intake of 19.2 g of TID Lys/kg of gain at this optimum Lys:calorie ratio, which is similar to the 19.8 g of TID Lys/kg of gain observed in the current study. Friesen et al. (1994) demonstrated maximal growth performance at 3.10 g of Lys/Mcal of ME in gilts from 34 to 55 kg and an intake of 19.1 g of TID Lys/kg of gain at this optimal level of dietary Lys.

Gilt Trial 2

In trial 2 (60- to 85-kg gilts), ADG and G:F improved (quadratic, $P < 0.03$; Table 8) with increasing Lys:calorie ratio. Gain and feed conversion were maximized at 2.80 g of Lys/Mcal of ME. Feed intake was not affected by increasing Lys:calorie ratio. Fat deposition as measured by a change in backfat depth during the

Table 10. Effect of Lys:calorie ratio on 100- to 120-kg BW gilts (gilt trial 4)[1]

	Lys:calorie (g of Lys/Mcal of ME)								
	1.40	1.60	1.80	2.00	2.20	2.40			
	Total Lys, %								
	0.51	0.58	0.65	0.72	0.80	0.87			
	True ileal digestible (TID) Lys, %							Probability ($P <$)	
Item	0.43	0.50	0.56	0.63	0.69	0.76	SE	Linear	Quadratic
Initial BW, kg	100.5	100.5	100.9	100.8	100.8	100.6	1.49	0.73	0.60
ADG, g	721	726	767	839	880	880	19	0.001	0.90
ADFI, g	2,431	2,386	2,331	2,400	2,472	2,463	41	0.15	0.05
G:F, g/g	0.297	0.301	0.328	0.348	0.356	0.356	0.006	0.001	0.04
Off-test weight,[2] kg	118.9	118.9	120.0	121.8	122.8	122.8	0.42	0.001	0.96
Carcass yield, %	75.4	76.0	76.3	76.2	75.7	76.2	0.30	0.28	0.25
10th rib fat depth change,[3] mm	17.7	17.3	18.0	17.7	17.4	17.1	0.39	0.37	0.34
LM depth,[3] mm	56.2	57.1	57.2	58.0	58.3	58.5	0.38	0.02	0.67
Lean,[3] %	54.8	55.2	54.7	55.1	55.2	55.4	0.28	0.15	0.48
Fat-free lean index, %	50.1	50.3	49.9	50.1	50.2	50.4	0.19	0.41	0.32
Grade premium, $/100 kg	7.76	8.28	7.68	8.37	8.45	8.84	0.35	0.02	0.51
Feed cost/kg of gain, $	0.399	0.401	0.375	0.359	0.359	0.365	0.007	0.001	0.06
IOMFC,[4,5] $/head	105.66	106.19	107.46	108.87	109.64	109.64	1.57	0.001	0.47
TID Lys,[6] g/d	10.5	12.0	13.1	15.1	17.0	18.7	0.23	0.001	0.05
TID Lys,[6] g/kg of gain	14.5	16.6	17.1	18.1	19.4	21.3	0.37	0.001	0.39

[1]A total of 1,021 gilts (Pig Improvement Co., Hendersonville, TN; L337 × C22) housed at the rate of 21 to 25 pigs per pen and 7 replications per treatment in a 25-d trial. The diets contained 3,615 kcal/kg.

[2]Off-test weight = start BW + (ADG × number of days of trial); and adjusting to a common initial BW.

[3]10th-rib backfat, LM depth, and lean percentage were all adjusted to a common carcass weight for statistical analysis.

[4]IOMFC = income over marginal feed costs = carcass value – feed costs during trial period.

[5]Base meat price of $117.57/100 kg, actual feed costs and lean premium, and carcass weights attained by applying the trial mean carcass yield (75.94%) to off-test weights in the IOMFC analysis.

[6]Grams of true ileal digestible (TID) Lys consumed per day and per kilogram of gain, respectively.

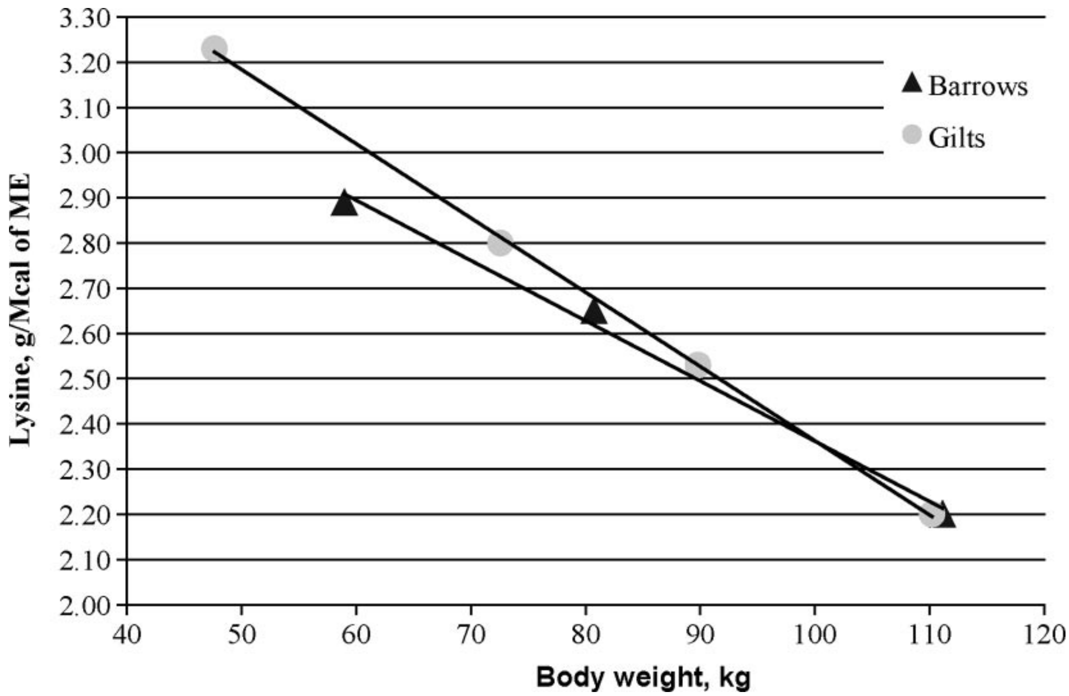

Figure 1. Optimal Lys:calorie ratio (g of Lys/Mcal of ME) prediction equations were developed for barrows and gilts using our interpretation of the 7 trials conducted to determine an optimum Lys:calorie ratio for pigs (Pig Improvement Co., Hendersonville, TN; L337 × C22; 35 to 120 kg) fed in this commercial finishing environment. In the barrow trials (▲; 43 to 120 kg), the linear equation Lys:calorie ratio, g of total Lys/Mcal of ME = −0.0133 × BW, kg, + 3.6944 describes the optimum Lys:calorie ratio observed. In the gilt studies (●; 35 to 120 kg), the linear equation Lys:calorie ratio, g of total Lys/Mcal of ME = −0.0164 × BW, kg, + 4.004 describes the optimum Lys:calorie ratio observed.

feeding period was decreased (linear, $P < 0.001$) with increasing Lys:calorie ratio. Increasing dietary Lys did not affect the change in LMA. Feed cost per kilogram of gain increased (quadratic, $P < 0.02$) with increasing Lys:calorie ratio, with the greatest increase occurring as the Lys:calorie ratio was increased from 2.80 to 3.08 g of Lys/Mcal of ME. However, numeric increases in feed cost per kilogram of gain were observed through the greatest dietary Lys diet fed. Income over feed costs improved (quadratic, $P < 0.002$) with increasing dietary Lys and was maximized at the apparent biological requirement of 2.80 g of Lys/Mcal of ME. These data indicate that feeding 60- to 85-kg gilts a diet with 2.80 g of Lys/Mcal of ME will meet biological requirements for maximum growth, feed efficiency, and optimized IOMFC. However, feed cost per kilogram of gain was numerically reduced through the lowest dietary Lys level fed (1.96 g of Lys/Mcal of ME) in this study. The predicted Lys requirement from the ultrasound scanning data was 2.68 g of Lys/Mcal of ME, which is similar to our measured estimate of 2.80 g of Lys/Mcal of ME. Yen et al. (1986b) demonstrated an optimal Lys:calorie ratio of 2.73 g of Lys/Mcal of ME in 50- to 90-kg gilts and observed 21.3 g of TID Lys/kg of gain at this level of dietary Lys. Friesen et al. (1994) demonstrated maximum performance when feeding 2.78 g of Lys/Mcal of ME in 55- to 72.5-kg gilts while observing a 20.3 g of TID Lys/kg of gain at this level of dietary Lys. Similar to the Yen et al. (1986b) and Friesen et al. (1994) experimental data, the current trial had an intake of 20.4 g of TID Lys/kg of gain at our estimated Lys requirement of 2.80 g of Lys/Mcal of ME. Hahn et al. (1995) demonstrated maximum performance with diets containing 0.64% TID Lys (or 2.11 g of Lys/Mcal of ME) in 50- to 95-kg gilts while observing 18.5 g of TID Lys/kg of gain.

Gilt Trial 3

In trial 3 (78- to 103-kg gilts), ADG and G:F improved (quadratic, $P < 0.003$; Table 9) with increasing Lys:calorie ratio. Gain and feed efficiency were maximized at 2.28 and 2.53 g of Lys/Mcal of ME, respectively. Increasing the Lys:calorie ratio did not affect feed intake. Change in fat depth at the 10th rib was reduced (linear, $P < 0.001$), and LMA tended to increase (linear, $P < 0.01$; quadratic, $P < 0.10$) with increasing dietary Lys. The improvements in LMA were maximized at 2.53 g of Lys/Mcal of ME. Feed cost per kilogram of gain and IOMFC were improved (quadratic, $P < 0.001$) as Lys:calorie ratio increased. Feed cost per kilogram of gain was maximized at 2.03 g of Lys/Mcal of ME, which again is below the biological Lys requirement for maximum performance. Income over feed cost improved (quadratic, $P < 0.001$) with increasing dietary Lys, and was optimized at 2.28 g of Lys/Mcal of ME.

Table 11. Summary of the determined optimum Lys:calorie ratio as well as the associated dietary Lys percentage and Lys intake that met the biological requirements for growth performance and optimized return over feed costs[1]

Trial	BW range, kg	Midpoint BW, kg	Lys:calorie ratio, g of Lys/Mcal of ME	Dietary Lys,[2] %	True ileal digestible Lys, g/d	True ileal digestible Lys, g/kg of gain
Barrows						
Trial 1	43 to 70	59	2.89	1.04	19	19
Trial 2	69 to 93	81	2.65	0.96	20	21
Trial 3	102 to 120	111	2.20	0.80	18	20
Gilts						
Trial 1	35 to 60	48	3.23	1.16	20	21
Trial 2	60 to 85	73	2.80	1.01	20	21
Trial 3	78 to 103	90	2.53	0.91	20	22
Trial 4	100 to 120	110	2.20	0.80	17	19

[1]Seven trials were conducted to determine optimum Lys:calorie ratio (g of Lys/Mcal of ME) in grow-finish pigs (PIC 337 × C22, n = 7,801) in a commercial finishing environment.

[2]All diets were corn-soybean meal-based with 6% added fat and no added synthetic Lys.

The predicted Lys requirement using the protein and fat accretion data obtained from the sample of pigs scanned ultrasonically was 1.84 g of Lys/Mcal of ME, which is well below our measured estimate of 2.28 g of Lys/Mcal of ME. Cromwell et al. (1993) estimated biological performance to be maximized at 2.73 g of Lys/Mcal of ME in 51- to 105-kg gilts while observing an intake of 24 g of TID Lys/kg of gain, which is greater than the 20 g of TID Lys/kg of gain observed at the Lys level (2.28 g of Lys/Mcal of ME) demonstrating maximum performance in the current study.

Gilt Trial 4

In trial 4 (100- to 120-kg gilts), ADG improved (linear, $P < 0.001$) and G:F improved (quadratic, $P < 0.04$) with increasing Lys:calorie ratio (Table 10). Although the response in gain increased linearly through the greatest Lys level fed (2.40 g of Lys/Mcal of ME), numeric improvement in gain was not observed above 2.20 g of Lys/Mcal of ME. Likewise, feed conversion was maximized at 2.20 g of Lys/Mcal of ME. Carcass yield, fat depth, and calculated lean percentage were not affected by increasing Lys:calorie ratio. However, LM depth and grade premium increased (linear, $P < 0.02$) as dietary Lys increased to 2.40 g of Lys/Mcal of ME. Feed cost per kilogram of gain tended to be reduced (quadratic, $P = 0.06$) as dietary Lys increased. Feed cost per kilogram of gain was minimized and equal in pigs fed 2.00 or 2.20 g of Lys/Mcal of ME. However, IOMFC increased (linear, $P < 0.001$) with increasing dietary Lys. These linear responses in IOMFC were due to improvements in growth performance and lean premium associated with increasing Lys:calorie ratio. However, numeric improvements in IOMFC were not observed above 2.20 g of Lys/Mcal of ME. These data suggest that feeding gilts from 100 to 120 kg a diet with 2.20 g of Lys/Mcal of ME adequately meets biological requirements and optimizes IOMFC. The predicted Lys requirement attained using fat-free lean gain estimates from 100 to 120 kg and actual feed intake was 2.19 g of Lys/Mcal of ME, which is similar to the measured estimate of 2.20 g of Lys/Mcal of ME. Hahn et al. (1995) determined 0.52% TID Lys (1.77 g of Lys/Mcal of ME) to

Table 12. Comparing the estimated optimum Lys:calorie ratio from the current gilt studies to the NRC (1998) growth model predicted Lys requirement using fat-free lean gain and feed intake data from gilts from the same farm, genetic line, and grow-finish facility fed at or above the estimated Lys requirement throughout the finishing period[1]

		Optimum Lys:calorie ratio, g of Lys/Mcal of ME		
Weight range, kg	Midpoint BW, kg	Estimates from current gilt studies	Predicted optimum in using NRC growth model	Difference, %
35 to 60	48	3.23	2.80	13
60 to 85	73	2.80	2.51	10
78 to 103	90	2.53	2.31	9
100 to 120	110	2.20	2.08	6

[1]The estimated optimum Lys:calorie ratio determined in the gilt trials reviewed in this paper compared with the predicted Lys:calorie ratio obtained by using the NRC (1998) growth model. Fat-free lean gain and feed intake data from gilts in a companion experiment that were fed at or above their estimated Lys requirement from 35 to 120 kg were used to obtain a Lys requirement estimate using the NRC growth model (Main et al., 2005).

be required for maximum performance in 90- to 110-kg gilts. At the observed optimum Lys level in the Hahn et al. (1995) experiment, Lys intake was 17.3 g of TID Lys/kg of gain compared with the 19 g of TID Lys/kg of gain observed at the dietary Lys level (2.20 g of Lys/Mcal of ME) that maximized performance in the current experiment.

Prediction Equations

The estimated optimum Lys:calorie ratio from both the barrow and gilt trials were plotted at the midpoint weight from each study. These data were used to develop regression equations to predict the optimum Lys:calorie feeding regimen based on BW for barrows and gilts, respectively. These curves describe the Lys:calorie ratio that best met biological requirements for growth performance and optimized IOMFC for barrows and gilts fed in this series of trials (Figure 1). In the barrow trials (43 to 120 kg), the linear equation Lys:calorie ratio, g of total Lys/Mcal of ME = −0.0133 × BW, in kg, + 3.6944, describes the optimum Lys:calorie ratio observed. The linear equation Lys:calorie ratio, g of total Lys/Mcal of ME = −0.0164 × BW, in kg, + 4.004, describes the optimum Lys:calorie ratio observed in the gilt studies (35 to 120 kg). Table 11 summarizes our interpretation of the optimum Lys:calorie ratio observed in each trial. Additionally, we included the associated TID Lys intake per day and per kilogram of gain. To further compare these measured estimates to other published methods of predicting Lys requirements, we used the NRC growth model (NRC, 1998) to generate a predicted Lys requirement using fat-free lean gain and feed intake data from gilts in a companion study. The gilts used to capture input data for use in the NRC growth model (NRC, 1998) prediction were from the same farm, same genetic line, housed in the same grow-finishing facilities, had similar levels of overall performance, and were fed at or above these estimated Lys requirements from 32 to 115 kg (Main et al., 2005). The comparison of the optimum Lys:calorie ratio determined in the gilt trials to the NRC (1998) growth model predicted requirement of gilts similar to the gilts used in the current experiments is illustrated in Table 12. The predicted requirements are directionally similar but 6 to 13% lower than the estimated optimum Lys:calorie ratio measured in the current studies.

These experiments suggest the Lys:calorie ratio that maximized biological performance and optimized IOMFC was similar between barrows and gilts at a common weight. This similarity between barrows and gilts would resemble findings by Hahn et al. (1995) that showed barrows and gilts had similar digestible Lys requirements (0.49 vs. 0.52% of diet) from 90 to 110 kg, as well as Smith et al. (1999) who estimated Lys requirements to be similar between barrows and gilts using farm-specific lean accretion curves. Campbell et al. (1988) showed Lys requirements to be similar between boars and gilts at BW less than 60 kg, and that the requirement began to diverge as BW increased, with boars having a greater Lys requirement than gilts. Others have shown gilts to have a greater Lys requirement than barrows in the finishing period (Yen et al., 1986b; Cromwell et al., 1993; Castell et al., 1994; Hahn et al., 1995).

Overall

Among all trials, improvements in growth and feed efficiency were observed as Lys:calorie ratio increased. Similarly, in all trials not ending in slaughter (barrow trials 1 and 2; gilt trials 1, 2, and 3), backfat deposition was reduced as dietary Lys increased. These observations indicate that all trials included dietary treatments below the biological requirements for maximum performance, and that growth performance improved as the biological requirement for Lys was met by increasing dietary Lys concentration. Similarly, all trials included dietary treatments that appeared to be above the Lys required for maximum performance when using the combination of all primary response criteria (ADG, G:F, carcass lean, and IOMFC) measured. Thus, it appears that the range of Lys:calorie ratios used in each trial was adequate to allow an estimate of an optimum Lys:calorie ratio.

In general, our interpretation of the Lys:calorie ratio that maximized biological performance and optimized IOMFC with these pigs in this commercial production system environment is directionally similar to the Lys requirements described in the NRC (1998) and estimated using the NRC (1998) growth model (Figure 1 and Table 12). It is understood that alternative methods of analysis may derive alternative interpretations of the data observed in the current experiments (Gahl et al., 1995). However, this manuscript is intended to add to the relatively small body of published literature available measuring the biologic and economic responses to graded levels of dietary Lys at multiple phases of growth in a commercial finishing environment, while accomplishing the primary objective of determining an optimum Lys:calorie ratio for the commercial pig producer cooperating in this study. One shortcoming of the current study is that the economic sensitivity of these findings to alternative feed ingredient and live hog price scenarios was not reviewed. Although the magnitude of the differences in IOMFC among treatments may change, the order of treatments (worst to best) is largely insensitive to changes in feed grain or live hog market prices (De La Llata et al., 2001; Main et al., 2005). However, the ordering of feed cost per unit of gain can be more sensitive to changing feed ingredient conditions (De La Llata et al., 2001). It should also be noted that the estimated optimum Lys:calorie ratio regimen was derived by linking the optimum Lys:calorie ratio determined for each phase of finishing growth. This method of estimation would not account for any potential carry-over or compensatory growth effects that may affect the Lys:calorie regimen that optimizes IOMFC for the entire finishing period.

It has been well described that inputs that alter feed intake (Mohn et al., 2000), genetic potential for lean growth (Campbell and Taverner, 1988), composition of growth (Friesen et al., 1996; Schinckel and de Lange, 1996; NRC, 1998; Smith et al., 1999), method of interpreting responses (Gahl et al., 1995), and economic indicator of success (De La Llata et al., 2001) will influence the Lys:calorie ratio required to maximize performance. Therefore, responses to Lys:calorie ratio should be expected to vary among genetic lines and production environments. The level of feed intake (and associated growth rate or protein deposition) may be a significant source of discrepancy in estimated Lys requirements among studies. If pigs with high genetic potential for protein deposition are marginally restricted in feed intake due to their health status or growing environment, the ideal Lys:calorie ratio will be less than pigs of the same genetic line and sex consuming greater levels of feed with increased rates of protein deposition. Williams et al. (1997) concluded that the reason pigs with low immune stimulation had an increased dietary Lys requirement was due to increased protein deposition, which is largely driven by increased feed intake (Campbell and Taverner, 1988). These examples further highlight the need to determine production system-specific Lys:calorie ratio requirements. One unique observation of interest with the pigs used in these trials was that the TID Lys intake per kilogram of gain seemed to be fairly consistent (±20 g of TID Lys/kg of gain) at the Lys:calorie ratio that maximized growth performance and IOMFC. De La Llata (2000) conducted 2 experiments evaluating 4 Lys:calorie regimens in barrows and gilts from 30 to 120 kg with the same genetic lines and in the same facilities as used in the current series of trials. In those experiments, pigs fed the greatest Lys:calorie regimen had optimized IOMFC. Although the Lys:calorie regimen that maximized performance was lower in late finishing than the estimated optimum Lys:calorie ratio in the present studies, the overall Lys intake per unit of gain (20 g of TID Lys/kg of gain) was similar to those observed throughout the present series of studies. The notable difference between these previous experiments (De La Llata, 2000) was that the Lys:calorie regimens tested were not as high in late finishing as in our study. Furthermore, overall growth performance was decreased (approximately 15% lower ADG) compared with the current studies. Therefore, these data may suggest that within a given genetic line, an appropriate Lys:calorie ratio could be determined with the knowledge of the production system-specific growth rate and feed intake of pigs fed nonlimiting diets.

The comparisons made to previously reported prediction models provide reference to how these predicted values compared with the growth and efficiency responses measured in this study (Schinckel and de Lange, 1996; NRC, 1998; Smith et al., 1999). One key observation from the predicted Lys requirements from lean growth data captured from the sample of pigs ultrasonically scanned (barrow trials 1 and 2, and gilt trials 1, 2, and 3) seemed to generate reasonable predictions in early finishing, but largely underestimate the Lys required for maximum growth and IOMFC in late (>70 kg) finishing. These rather large discrepancies are not well understood and will require further study.

These studies illustrate the biologic and economic effects of increasing Lys:calorie ratio, and how the magnitude of the effects change during the grower-finishing period. In the trials with initial pig BW of less than 70 kg, the biologic and resulting economic effects were relatively modest in magnitude compared with responses later in the finishing period. In these early finishing (<70 kg initial BW) trials, feed cost per kilogram of gain incrementally increased with Lys:calorie ratio. However, IOMFC was optimized when the biological requirements for growth were achieved. In late finishing (>70 kg initial BW), the biologic and economic responses to increasing Lys were more significant. Feed cost per kilogram of gain was not affected or was reduced quadratically as the Lys:calorie ratio increased. However, finishing feed cost per kilogram of gain was numerically minimized below the Lys:calorie ratio required for maximum biological performance and optimized IOMFC. These studies indicate that barrows and gilts (PIC, L337 × C22) fed high-fat diets in commercial facilities have a modest response to increasing dietary Lys in early finishing (<70 kg initial BW). However, the consequences for feeding below the Lys requirement in late finishing (>70 kg initial BW) are severe due to the more quantitatively significant effects on gain, feed efficiency, and lean deposition. These studies suggest that the consequences for being above the perceived requirement for maximum growth are minimal in late finishing, contrary to being below the requirement. In the late finishing trials (>70 kg initial BW), IOMFC tended to plateau or incrementally improve as the Lys:calorie ratio increased beyond the requirement for maximum growth performance. These studies indicate that feed cost per kilogram of gain is consistently minimized below the biological requirement for maximum growth performance and optimizing IOMFC. In summary, these studies illustrate the need to understand the dynamic biology and economic implications involved when making strategic nutritional decisions.

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