

Evaluation of standardized ileal digestible lysine requirement of nursery pigs from seven to fourteen kilograms^{1,2}

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ABSTRACT: Four experiments were conducted to determine the standardized ileal digestible (SID) Lys requirement of pigs (*Sus scrofa*) from 7 to 14 kg. In Exp. 1, 294 pigs (6.8 kg BW) were used in a 28-d growth trial with 7 pigs per pen and 7 pens per treatment. Treatment diets were fed from d 0 to 14, and a common diet was fed from d 14 to 28. The 6 SID Lys levels tested were 1.15, 1.23, 1.30, 1.38, 1.45, and 1.53%. The diets were corn- and soybean-meal [*Zea mays* L. and *Glycine max* (L.) Merr.] based, with 10% spray-dried whey, 4.5% fish meal, and contained 3.37 Mcal of ME/kg. From d 0 to 14, ADG increased (quadratic, $P < 0.001$) as SID Lys increased from 1.15 to 1.30% with no further increase at greater levels. Gain:feed increased (linear, $P < 0.001$) with increasing SID Lys. Experiments 2 to 4 were 14-d growth trials with diets containing 1.22, 1.32, 1.42, 1.52, or 1.62% SID Lys. Diets were corn- and soybean-meal based with 3.45 Mcal of ME/kg. Soybean meal and lactose were constant in all diets at 30 and 7% of the diet, respectively. In Exp. 2, 840 pigs (7.6 kg BW) were used, with 24 pigs per pen and 7 pens per treatment. Increasing SID Lys from 1.22 to 1.42% increased (quadratic, $P < 0.01$) ADG and G:F with no further improvement observed in pigs fed the 1.52 or 1.62%

SID Lys diets during d 0 to 14. In Exp. 3, 1,260 pigs (8.5 kg BW) were used with 42 pigs per feeder (2 pens per feeder) and 6 feeders per treatment. Increasing dietary Lys increased (quadratic, $P < 0.02$) ADG and G:F with the greatest response observed as SID Lys increased from 1.22 to 1.32% and, then, slight improvements with 1.42 and 1.52% during d 0 to 14. In Exp. 4, 770 pigs (7.4 kg BW) were used with 22 pigs per pen and 7 pens per treatment. Increasing SID Lys increased (quadratic, $P = 0.05$) ADG with pigs fed 1.32 and 1.42% SID Lys diets having the greatest BW gains during d 0 to 14. Increased SID Lys decreased (linear, $P < 0.001$) ADFI and increased (linear, $P < 0.001$; quadratic, $P = 0.02$) G:F. In conclusion, results of these experiments indicate that the 1998 NRC Lys recommendations (e.g., 1.19% SID Lys for 5 to 10 kg pigs) are less than required for optimal growth for 7 to 14 kg pigs. One-slope straight broken-line analysis indicated that the SID Lys requirement for optimal growth was at least 1.30% for ADG and 1.37% for G:F, or at least 3.86 and 4.18 g SID Lys/Mcal ME, respectively. Quadratic broken-line analysis indicated that the SID Lys requirement for optimal growth was at least 1.37% for ADG and 1.54% for G:F, or at least 4.19 and 4.92 g SID Lys/Mcal ME, respectively.

Key words: amino acids, growth, lysine, pig

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INTRODUCTION

Lysine is the first limiting AA in corn- and soybean-meal diets for pigs, and is used as a reference to estimate requirements of other indispensable AA. The NRC (1998) dietary estimates for 5 to 10 kg pigs is approximately 1.35% total Lys or 1.19% standardized ileal digestible (SID) Lys, with the range of research estimates reported

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in NRC (1998) varying widely from 1.10 to 1.40% total Lys. Results of other experiments have indicated that the requirement for total Lys for 5 to 10 kg pigs is between 1.45 and 1.49% (Gatel et al., 1992; Broekman et al., 1997). In a more recent report, Dean et al. (2007) suggested that 1.40% SID Lys is required for optimal growth of 6 to 12 kg pigs.

The requirement estimate by NRC (1998) for 10 to 20 kg pigs is 1.15% total Lys or 1.01% SID Lys; however, results of recent studies with pigs in this BW range have indicated the requirement is between 1.30 and 1.40% SID Lys (Lenehan et al., 2003; Hill et al., 2007; Kendall et al., 2008). Results of research with 25 to 120 kg pigs also has indicated that NRC (1998) estimates may be too low (De La Llata et al., 2007; Main et al., 2008) for modern genotypes.

Many factors can contribute to the variation in Lys requirement estimates, including formulating on a total, instead of SID, AA basis (Stein et al., 2007), methods of statistical analysis (Robbins et al., 2006), gender (Baker, 1986), or genotype (Schneider et al., 2010). In addition, all previous research on Lys requirements of early nursery pigs has been conducted in university research settings and not under commercial field conditions. Therefore, our objective was to evaluate the SID Lys requirement for nursery pigs from 7 to 14 kg in both university (Exp. 1) and commercial facilities (Exp. 2 to 4).

MATERIALS AND METHODS

All practices and procedures used in these experiments were approved by the Kansas State University Institutional Animal Care and Use Committee (Exp. 1 and 3) or the University of Missouri Institutional Animal Care and Use Committee (Exp. 2 and 4).

Experiment 1

A total of 294 weanling pigs (initial BW: 6.76 ± 0.08 kg) were used in a 28-d growth trial at the Kansas State University Swine Teaching and Research Center. Pigs were the offspring of TR4 males and L 1050 females (PIC, Henderson, TN). Pigs were weaned at approximately 21 d of age and fed a common starter diet (1.56% SID Lys) for 3 d. At weaning, pigs were allotted to pens by initial BW to achieve the same average weight for all pens. On d 3 after weaning, pens were allotted to 1 of 6 dietary treatments in a completely randomized design. Thus, d 3 after weaning was d 0 of the experiment. Each treatment had 7 pens with 7 pigs per pen. Each pen (1.22×1.52 m) contained a 4-hole, dry self-feeder and a nipple waterer to provide ad libitum access to feed and water.

A 2-phase diet sequence was used, with treatment diets fed from d 0 to 14, and a common diet fed from d 14 to 28 (Table 1). Six diets that were fed from d 0 to 14 were formulated to contain 1.15, 1.23, 1.30, 1.38, 1.45,

and 1.53% SID Lys. Treatment diets were corn- and soybean-meal based, contained 10% spray-dried whey and 4.5% Select Menhaden fish meal, and were formulated to contain 3.37 Mcal of ME/kg. Soybean meal and L-Lys-HCl were both increased to attain the greater SID Lys diets. Crystalline DL-Met, L-Thr, L-Trp, L-Ile, and L-Val were also increased with increasing SID Lys to maintain minimum AA ratios relative to Lys of 59% Ile, 116% Leu, 58% Met + Cys, 20% Trp, 64% Thr, and 70% Val (NRC, 1998). Large, 1,270 kg batches of the 1.15 and 1.53% Lys diets were manufactured and then blended at ratios of 80 to 20, 60 to 40, 40 to 60, and 20 to 80 to achieve the intermediate Lys diets. The common diet fed from d 14 to 28 was corn- and soybean-meal based and formulated to contain 1.26% SID Lys. Nutrients, ME, and SID AA digestibility values used for all diet formulations were obtained from NRC (1998).

All experimental diets were in meal form and were prepared at the Kansas State University Animal Science Feed Mill. A subsample of all experimental diets was collected and analyzed for dietary AA (Ajinomoto Heartland LLC, Chicago, IL) using HPLC (Method 994.12; AOAC, 2000). Pigs and feeders were weighed on d 0, 7, 14, 21, and 28 to calculate ADG, ADFI, and G:F.

Experiments 2 to 4

In Exp. 2, a total of 840 weanling pigs (initial BW: 7.6 ± 0.1 kg) were used in a 14-d growth trial conducted at a commercial research nursery facility in Iowa. Pigs were the offspring of 280 males and L 1055 females (PIC, Henderson, TN). Each treatment had 7 replicate pens with 24 pigs per pen. Each pen (3.05×1.82 m) contained a stainless steel self-feeder and a single nipple waterer.

In Exp. 3, a total of 1,260 weanling pigs (initial BW: 8.5 ± 0.1 kg) were used in a 14-d growth trial at a commercial research nursery facility in southern Minnesota. Pigs were the offspring of 327 males and L C14 females (PIC, Henderson, TN). Each feeder was available to 2 adjacent pens, resulting in 42 pigs per feeder (21 pigs per pen) and 6 replicate feeders per treatment. Each pen (3.05×1.52 m) had access to a stainless steel self-feeder and 1-cup waterer.

In Exp. 4, a total of 770 weanling pigs (initial BW: 7.4 ± 0.1 kg) were used in a 14-d growth trial conducted at a commercial research nursery facility in Missouri. Pigs were the offspring of TR4 males and L C22 females (PIC, Henderson, TN). Each treatment had 7 replicate pens with 22 pigs per pen. Each pen (3.05×1.82 m) contained a stainless steel self-feeder and a 1-cup waterer.

Treatment diets were fed starting on d 10 (Exp. 3) or d 14 (Exp. 2 and 4) after weaning, which was considered d 0 of the experiments. In Exp. 2 and 4, pens were allotted to 1 of 5 dietary treatments in completely randomized designs. In Exp. 3, pairs of pens sharing a common feeder

Table 1. Ingredient composition and calculated concentration of nutrients in experimental diets, Exp. 1 (as-fed basis)¹

Item	Phase 1: SID Lys, %						Common phase ²
	1.15	1.23	1.30	1.38	1.45	1.53	
Ingredient, %							
Corn	61.12	58.85	56.58	54.31	52.04	49.77	65.05
Soybean meal (46.5% CP)	20.80	23.00	25.21	27.41	29.62	31.83	30.73
Spray-dried whey	10.00	10.00	10.00	10.00	10.00	10.00	–
Select menhaden fish meal	4.50	4.50	4.50	4.50	4.50	4.50	–
Soybean oil	1.00	1.00	1.00	1.00	1.00	1.00	–
Monocalcium phosphate (21% P)	0.55	0.53	0.51	0.49	0.47	0.45	1.08
Limestone	0.55	0.55	0.55	0.55	0.55	0.55	0.95
Salt	0.30	0.30	0.30	0.30	0.30	0.30	0.35
Zinc oxide	0.25	0.25	0.25	0.25	0.25	0.25	–
Trace mineral premix ³	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Vitamin premix ⁴	0.25	0.25	0.25	0.25	0.25	0.25	0.25
L-Lys·HCl	0.225	0.250	0.275	0.300	0.325	0.350	0.360
DL-Met	0.080	0.102	0.124	0.146	0.168	0.190	0.130
L-Thr	0.100	0.118	0.136	0.154	0.172	0.190	0.130
L-Trp	0.040	0.043	0.046	0.049	0.052	0.055	–
L-Val	0.005	0.021	0.037	0.053	0.069	0.085	–
Phytase ⁵	0.085	0.085	0.085	0.085	0.085	0.085	0.165
Total	100	100	100	100	100	100	100
Calculated analysis ⁶							
SID AA, %							
Lys	1.15	1.23	1.30	1.38	1.45	1.53	1.26
Ile:Lys	62	61	60	60	59	59	61
Leu:Lys	132	128	125	122	119	116	129
Met:Lys	34	34	35	35	36	36	33
Met + Cys:Lys	58	58	58	58	58	58	58
Thr:Lys	64	64	64	64	64	64	63
Trp:Lys	20	20	20	20	20	20	17.4
Val:Lys	70	70	70	70	70	70	68
Total Lys, %	1.27	1.35	1.43	1.51	1.59	1.67	1.39
ME, Mcal/kg	3.37	3.37	3.37	3.37	3.37	3.37	3.31
SID Lys:ME, g/Mcal	3.41	3.64	3.86	4.08	4.30	4.52	3.80
CP, %	19.3	20.2	21.1	22.0	22.9	23.8	20.8
Ca, %	0.71	0.71	0.72	0.72	0.72	0.72	0.69
P, %	0.64	0.64	0.65	0.65	0.66	0.66	0.62
Available P, %	0.47	0.47	0.47	0.47	0.47	0.47	0.42

¹SID = standard ileal digestible. Treatment diets were fed from d 0 to 14.

²Common diet was fed from d 14 to 28.

³Trace mineral premix provided per kilogram of complete feed: 16.5 mg of Cu from CuSO₄·5H₂O, 0.30 mg of I as C₂H₂(NH₂)₂·2HI, 165 mg of Fe as FeSO₄·H₂O, 39.7 mg of Mn as MnSO₄·H₂O, 0.30 mg of Se as Na₂SeO₃, and 165 mg of Zn as ZnSO₄.

⁴Vitamin premix provided per kilogram of complete feed: 11,023 IU of vitamin A, 1,377 IU of vitamin D, 44.1 IU of vitamin E, 4.4 mg of vitamin K, 0.04 mg of vitamin B₁₂, 50.0 mg of niacin, 27.6 mg of pantothenic acid, and 8.3 mg of riboflavin.

⁵Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 509 phytase units per kilogram of complete feed, which was assumed to release 0.10% P.

⁶All values were calculated from NRC (1998).

were allotted with gender as a blocking factor. The 5 diets were formulated to contain 1.22, 1.32, 1.42, 1.52, and 1.62% SID Lys. Diets were corn- and soybean-meal based and formulated to 3.45 Mcal of ME/kg. Soybean meal and lactose were kept constant between all treatments at 30 and 7% of the diet, respectively. Diets for Exp. 2 and 4 contained 5% select menhaden fish meal and 0.88% spray-dried blood cells (Table 2). In Exp. 3, select menhaden fish meal was added at 6.67% of the diet, and spray-dried blood cells were not included (Table 3). In all experiments, target

SID Lys levels were achieved by decreasing corn, and increasing crystalline L-Lys·HCl. Other crystalline AA were added as needed to maintain minimum SID ratios relative to Lys of 60% Met + Cys, 16.9% Trp, and 67.2% Val (as reported for Exp. 3). According to NRC (1998), the minimum ratio for SID Trp to Lys is 17%, and the SID Val to Lys minimum ratio is 68%. Nutrients, ME, and SID AA digestibility values used for all diet formulation were obtained from NRC (1998). A subsample of all experimental diets was collected and analyzed for dietary AA (Ajinomo-

Table 2. Ingredient composition and calculated concentration of nutrients in experimental diets, Exp. 2 and 4 (as-fed basis)¹

Item	SID Lys, %				
	1.22	1.32	1.42	1.52	1.62
Ingredient, %					
Corn	51.29	51.04	50.78	50.42	50.02
Soybean meal (48% CP)	30.00	30.00	30.00	30.00	30.00
Lactose ²	7.00	7.00	7.00	7.00	7.00
Select menhaden fish meal	5.00	5.00	5.00	5.00	5.00
Spray-dried blood cells	0.88	0.88	0.88	0.88	0.88
Choice white grease	3.00	3.00	3.00	3.00	3.00
Dicalcium phosphate (18.5% P)	1.15	1.15	1.15	1.15	1.15
Limestone	0.37	0.37	0.37	0.37	0.37
Salt	0.40	0.40	0.40	0.40	0.40
Tri-basic copper chloride	0.10	0.10	0.10	0.10	0.10
Trace mineral premix ³	0.15	0.15	0.15	0.15	0.15
Vitamin premix ⁴	0.25	0.25	0.25	0.25	0.25
L-Lys-HCl	0.00	0.13	0.26	0.38	0.51
DL-Met	0.09	0.15	0.21	0.27	0.34
L-Thr	0.07	0.14	0.21	0.27	0.34
L-Trp	–	–	–	0.02	0.04
L-Ile	–	–	–	0.01	0.07
L-Val	–	–	–	0.07	0.14
Medication ⁵	0.125	0.125	0.125	0.125	0.125
Total	100	100	100	100	100
Calculated analysis ⁶					
SID AA, %					
Lys	1.22	1.32	1.42	1.52	1.62
Ile:Lys	67.8	62.6	58.1	55.0	55.0
Met + Cys:Lys	60.0	60.0	60.0	60.0	60.0
Thr:Lys	65.0	65.0	65.0	65.0	65.0
Trp:Lys	19.8	18.3	17.0	17.0	17.0
Val:Lys	80.8	74.6	69.3	69.3	69.3
Total Lys, %	1.35	1.46	1.56	1.65	1.75
ME, Mcal/kg	3.45	3.45	3.45	3.45	3.45
SID Lys:ME, g/Mcal	3.54	3.83	4.12	4.41	4.70
CP, %	22.56	22.75	22.94	23.12	23.31
Ca, %	0.80	0.80	0.80	0.80	0.80
Available P, %	0.40	0.40	0.40	0.40	0.40

¹SID = standardized ileal digestible.

²Dairy Lac 80 (80% lactose equivalence) provided by International Ingredients, Inc., St. Louis, MO.

³Trace mineral premix provided per kilogram of diet: 16.5 mg of Cu from CuSO₄, 0.3 mg of I as Ca(IO₃)₂, 165.3 mg of Fe from FeSO₄, 33 mg of Mn from MnSO₄ and MnO, 0.29 mg of Se from Na₂SeO₃, and 165.3 mg of Zn from ZnSO₄.

⁴Vitamin premix provided per kilogram of diet: 11,000 IU of vitamin A, 1,100 IU of vitamin D, 22 IU of vitamin E, 3.99 mg of vitamin K as menadione, 0.03 mg of vitamin B₁₂, 3 mg of thiamin, 33 mg of niacin, 28.05 mg of pantothenic acid, 8.25 mg of riboflavin, 0.5 mg of biotin, and 1.5 mg of folic acid.

⁵Provided 27.5 mg/kg carbadox per kilogram of complete diet (Mecadox 10; Phibro Animal Health, Ridgefield Park, NJ).

⁶All values were calculated from NRC (1998).

to Heartland LLC) using HPLC (Method 994.12; AOAC, 2000). Pigs and feeders were weighed on d 0, 7, and 14 of the experiment to calculate ADG, ADFI, and G:F.

Table 3. Ingredient composition and calculated concentration of nutrients in experimental diets, Exp. 3 (as-fed basis)¹

Item	SID Lys, %				
	1.22	1.32	1.42	1.52	1.62
Ingredient, %					
Corn	50.39	50.13	49.87	49.53	49.13
Soybean meal (48% CP)	30.00	30.00	30.00	30.00	30.00
Lactose, edible grade	7.00	7.00	7.00	7.00	7.00
Select menhaden fish meal	6.67	6.67	6.67	6.67	6.67
Choice white grease	3.00	3.00	3.00	3.00	3.00
Dicalcium phosphate (18.5% P)	0.88	0.88	0.88	0.88	0.88
Limestone	0.33	0.33	0.33	0.33	0.33
Salt	0.40	0.40	0.40	0.40	0.40
Zinc oxide	0.25	0.25	0.25	0.25	0.25
Vitamin and trace mineral premix ²	0.30	0.30	0.30	0.30	0.30
L-Lys-HCl	0.00	0.13	0.26	0.38	0.51
DL-Met	0.05	0.12	0.18	0.24	0.30
L-Thr	0.04	0.10	0.17	0.24	0.30
L-Trp	–	–	–	0.02	0.04
L-Ile	–	–	–	–	0.06
L-Val	–	–	–	0.07	0.14
Medication ³	0.70	0.70	0.70	0.70	0.70
Total	100	100	100	100	100
Calculated analysis ⁴					
SID AA, %					
Lys	1.22	1.32	1.42	1.52	1.62
Ile:Lys	70.5	65.1	60.4	56.4	56.4
Met + Cys:Lys	60.0	60.0	60.0	60.0	60.0
Thr:Lys	65.0	65.0	65.0	65.0	65.0
Trp:Lys	19.7	18.2	16.9	16.9	16.9
Val:Lys	78.4	72.4	67.2	67.2	67.2
Total Lys, %	1.36	1.47	1.56	1.65	1.75
ME, kcal/kg	3.45	3.45	3.45	3.45	3.45
SID Lys:ME, g/Mcal	3.54	3.83	4.12	4.41	4.70
CP, %	22.63	22.81	23.00	23.25	23.53
Ca, %	0.80	0.80	0.80	0.80	0.80
Available P, %	0.40	0.40	0.40	0.40	0.40

¹SID = standardized ileal digestible.

²Vitamin and trace mineral premix provided per kilogram of diet: 12,000 IU of vitamin A, 1,801 IU of vitamin D, 60.1 IU of vitamin E, 4.4 mg of vitamin K, 0.03 mg of vitamin B₁₂, 50.0 mg of niacin, 28.6 mg of pantothenic acid, 8.3 mg of riboflavin, 0.33 mg of biotin, 3.6 mg of folic acid, 5.0 mg of pyridoxine, 11.2 mg of Cu from CuSO₄, 0.66 mg of I as Ca(IO₃)₂, 151 mg of Fe from FeSO₄, 55.6 mg of Mn from MnSO₄ and MnO, 0.30 mg of Se from Na₂SeO₃, 198 mg of Zn from ZnSO₄, and 300 phytase units, which was assumed to release 0.10% P.

³Provided 154 mg/kg Neomycin sulfate and 154 mg/kg oxytetracycline per kilogram of complete diet (Neo/Oxy 10/10; Penfield Animal Health, Omaha, NE).

⁴All values were calculated from NRC (1998).

Statistical Analysis

Experimental data were analyzed for linear and quadratic effects of increasing SID Lys using the PROC MIXED procedure (SAS Inst. Inc., Cary, NC). The pen was the experimental unit for data analysis in Exp. 1, 2, and 4. Feeder was the experimental unit for data analysis in Exp. 3. Significant effects for all experiments were

Table 4. Analyzed total AA composition of diets, Exp. 1 (%; as-fed basis)^{1,2}

Item	SID Lys, %					
	1.15	1.23	1.30	1.38	1.45	1.53
Lys	1.20 (1.27)	1.24 (1.35)	1.34 (1.43)	1.39 (1.51)	1.46 (1.59)	1.50 (1.67)
Ile	0.78 (0.80)	0.79 (0.84)	0.84 (0.88)	0.89 (0.93)	0.92 (0.96)	0.95 (1.01)
Met	0.41 (0.42)	0.42 (0.45)	0.46 (0.48)	0.48 (0.52)	0.47 (0.55)	0.51 (0.58)
Met + Cys	0.68 (0.74)	0.70 (0.79)	0.75 (0.83)	0.77 (0.88)	0.79 (0.92)	0.82 (0.97)
Thr	0.83 (0.85)	0.85 (0.91)	0.90 (0.96)	0.95 (1.01)	0.97 (1.06)	1.01 (1.12)
Trp	0.26 (0.26)	0.26 (0.28)	0.28 (0.29)	0.30 (0.31)	0.32 (0.32)	0.32 (0.34)
Val	0.86 (0.91)	0.90 (0.97)	0.96 (1.03)	1.00 (1.09)	1.07 (1.14)	1.09 (1.20)

¹SID = standardized ileal digestible. A representative sample of each diet was collected and analyzed for AA composition.

²Values in parentheses indicate formulated values (NRC, 1998).

declared at $P < 0.05$ and trends were declared at $P < 0.10$. For combined data, 1-slope straight broken-line and quadratic broken-line analyses described by Robbins et al. (2006) were used to determine estimates of requirements. The breakpoint analysis was initially conducted separately for the experiment conducted in the university facility (Exp. 1) and compared with analysis from the commercial facilities (Exp. 2, 3, and 4). Because similar requirement estimates were observed using university and commercial environments, all data were combined for final analysis as described by Kendall et al. (2008). When combining results from all experiments, data were expressed as a percentage of maximum ADG or G:F within each experiment.

RESULTS

Diet Analysis

Diet samples collected for Exp. 4 were lost between the time of collection and chemical analysis. Analyzed AA levels for Exp. 1 to 3 are shown in Tables 4 to 6, respectively. Analyzed AA concentrations are within acceptable limits for analytical variation according to AAF-CO (2005). The AA analyses are in agreement with the design of the experiments, confirming that dietary total

Table 5. Analyzed total AA composition of diets, Exp. 2 (%; as-fed basis)^{1,2}

Item	SID Lys, %				
	1.22	1.32	1.42	1.52	1.62
Lys	1.40 (1.35)	1.52 (1.45)	1.60 (1.55)	1.72 (1.65)	1.84 (1.75)
Ile	0.95 (0.92)	0.96 (0.92)	0.98 (0.92)	1.01 (0.93)	1.04 (0.99)
Met	0.40 (0.46)	0.39 (0.52)	0.42 (0.58)	0.40 (0.64)	0.40 (0.70)
Met + Cys	0.89 (0.81)	0.94 (0.87)	1.03 (0.93)	1.03 (0.99)	1.15 (1.05)
Thr	0.83 (0.91)	0.85 (0.97)	0.90 (1.04)	0.95 (1.10)	0.97 (1.17)
Trp	0.28 (0.26)	0.29 (0.26)	0.26 (0.27)	0.26 (0.29)	0.31 (0.30)
Val	1.14 (1.04)	1.17 (1.03)	1.17 (1.10)	1.26 (1.17)	1.33 (1.24)

¹SID = standardized ileal digestible. A representative sample of each diet was collected and analyzed for AA composition.

²Values in parentheses indicate formulated values (NRC, 1998).

Lys increased with the expected increases in SID Lys.

Experiment 1

From d 0 to 14, ADG and ADFI increased (quadratic, $P < 0.002$) as SID Lys increased from 1.15 to 1.30%, but no further increase occurred at greater levels of SID Lys (Table 7). Gain:feed increased (linear, $P < 0.001$) with increasing SID Lys. The SID Lys intake per kilogram of gain increased (linear, $P < 0.001$) as SID Lys increased and was 16.6 and 16.7 g/kg at 1.30 and 1.38% SID Lys, respectively. From d 14 to 28, when the common diet was fed, no difference was observed in ADG, ADFI, or G:F.

Average daily gain and ADFI increased (quadratic, $P < 0.05$) from d 0 to 28 as SID Lys increased. As SID Lys increased, a trend ($P = 0.10$) toward increased G:F was observed. Body weight increased (quadratic, $P = 0.05$) and pigs fed 1.30% SID Lys from d 0 to 14 had the greatest BW on d 28.

Experiment 2

Increasing SID Lys during the first week (d 0 to 7) increased ADG (linear, $P = 0.004$; quadratic, $P = 0.10$), ADFI (linear, $P = 0.04$), and G:F (linear, $P = 0.003$; quadratic, $P = 0.01$; Table 8). Pigs fed 1.42%

Table 6. Analyzed total AA composition of diets, Exp. 3 (%; as-fed basis)^{1,2}

Item	SID Lys, %				
	1.22	1.32	1.42	1.52	1.62
Lys	1.25 (1.36)	1.36 (1.47)	1.47 (1.56)	1.54 (1.65)	1.65 (1.75)
Ile	0.92 (0.96)	0.93 (0.96)	0.93 (0.96)	0.93 (0.95)	0.95 (1.01)
Met	0.45 (0.46)	0.51 (0.52)	0.56 (0.58)	0.60 (0.64)	0.72 (0.70)
Met + Cys	0.79 (0.81)	0.85 (0.87)	0.90 (0.93)	0.94 (0.99)	1.04 (1.05)
Thr	0.93 (0.91)	0.98 (0.97)	1.05 (1.04)	1.08 (1.10)	1.16 (1.17)
Trp	0.26 (0.26)	0.26 (0.26)	0.26 (0.27)	0.27 (0.29)	0.28 (0.30)
Val	1.04 (1.01)	1.05 (1.00)	1.04 (1.00)	1.11 (1.09)	1.16 (1.16)

¹SID = standardized ileal digestible. A representative sample of each diet was collected and analyzed for AA composition.

²Values in parentheses indicate formulated values (NRC, 1998).

Table 7. Effects of standardized ileal digestible (SID) lysine on growth performance of nursery pigs, Exp. 1¹

Item	SID Lys, % ²						SEM	P-value	
	1.15	1.23	1.30	1.38	1.45	1.53		Linear	Quadratic
d 0 to 14									
ADG, g	290	306	342	328	330	284	13	0.80	0.001
ADFI, g	388	394	435	396	398	336	16	0.04	0.002
G:F	0.743	0.775	0.787	0.830	0.830	0.846	0.015	0.001	0.36
SID Lys: BW gain, g/kg	15.5	15.9	16.6	16.7	17.5	18.1	0.3	0.001	0.57
d 14 to 28									
ADG, g	474	482	473	477	455	472	16	0.54	0.96
ADFI, g	799	812	827	798	805	793	19	0.61	0.36
G:F	0.593	0.594	0.570	0.598	0.567	0.595	0.015	0.75	0.44
d 0 to 28									
ADG, g	382	393	407	403	392	378	12	0.81	0.05
ADFI, g	594	602	630	597	602	564	15	0.17	0.03
G:F	0.643	0.653	0.645	0.675	0.653	0.669	0.011	0.10	0.81
BW, kg									
d 0	6.76	6.76	6.75	6.76	6.77	6.74	0.08	0.96	0.90
d 14	10.81	11.04	11.53	11.36	11.38	10.75	0.22	0.76	0.004
d 28	17.44	17.73	18.22	18.03	17.76	17.36	0.34	0.86	0.05

¹Pigs with an initial BW of 6.76 ± 0.08 kg were used in a 28-d growth experiment to determine effects of SID Lys level on growth performance. There were 7 pigs per pen and 7 pens per treatment.

²Treatment diets were fed from d 0 to 14 and a common diet was fed from d 14 to 28.

SID Lys had the greatest performance. From d 7 to 14, ADG increased (linear, $P = 0.05$; quadratic, $P = 0.01$) as SID Lys increased. Increasing SID Lys increased (linear, $P = 0.01$) G:F, with pigs fed 1.42% SID Lys having the greatest G:F. As Lys increased from d 7 to 14, no differences among treatments were observed for ADFI.

For the overall trial (d 0 to 14), increasing SID Lys increased (linear, $P < 0.003$; quadratic, $P < 0.01$) ADG and

G:F with the greatest growth performance occurring in pigs fed 1.42% SID Lys. As SID Lys increased, no difference was measured in ADFI for the overall trial. The SID Lys intake per kilogram of BW gain increased (linear, $P < 0.001$; quadratic, $P = 0.005$) as SID Lys increased and was 17.1 g/kg at 1.42% SID Lys.

Table 8. Effects of standardized ileal digestible (SID) lysine on growth performance of nursery pigs, Exp. 2¹

Item	SID Lys, %					SEM	P-value	
	1.22	1.32	1.42	1.52	1.62		Linear	Quadratic
d 0 to 7								
ADG, g	329	334	393	358	373	11	0.004	0.10
ADFI, g	407	385	429	426	419	9	0.04	0.64
G:F	0.807	0.865	0.915	0.838	0.890	0.013	0.003	0.01
d 7 to 14								
ADG, g	490	509	529	536	509	10	0.05	0.01
ADFI, g	677	665	680	702	653	16	0.84	0.28
G:F	0.725	0.767	0.780	0.766	0.780	0.013	0.01	0.11
d 0 to 14								
ADG, g	410	421	461	447	441	9	0.003	0.01
ADFI, g	542	524	554	564	536	11	0.44	0.34
G:F	0.756	0.803	0.832	0.793	0.823	0.008	0.001	0.001
SID Lys:BW gain, g/kg	16.2	16.4	17.1	19.2	19.7	0.2	0.001	0.005
BW, kg								
d 0	7.56	7.56	7.57	7.57	7.57	0.14	0.94	0.98
d 7	9.86	9.89	10.32	10.07	10.18	0.18	0.17	0.45
d 14	13.29	13.55	14.02	13.83	13.80	0.21	0.06	0.12

¹Pigs with an initial BW of 7.57 ± 0.14 kg were used in a 14-d growth experiment to determine effects of SID Lys level on growth performance in a commercial nursery research facility in Iowa. Data represent means of 7 replicate pens per treatment with 24 pigs per pen.

Experiment 3

From d 0 to 7, increasing SID Lys from 1.22 to 1.52% increased (linear, $P < 0.001$; quadratic, $P < 0.03$) ADG and G:F with no further improvement in growth performance for pigs fed 1.62% SID Lys (Table 9). A trend (linear, $P = 0.06$) also occurred toward increased ADFI for pigs fed increased SID Lys. From d 7 to 14, increasing SID Lys from 1.22 to 1.32% increased (linear, $P < 0.001$) ADG and G:F with smaller improvements at greater levels. No difference was observed in ADFI.

For the overall trial (d 0 to 14), increasing dietary Lys increased (linear, $P < 0.001$; quadratic, $P < 0.02$) ADG and G:F with the greatest response observed for pigs fed 1.32% SID Lys and smaller improvements for pigs fed the diets containing greater levels of SID Lys. No difference occurred in ADFI with increasing SID Lys. Lysine intake per kilogram of BW gain increased and was 18.0 g if the diet contained 1.32% SID Lys and increased (linear, $P < 0.001$; quadratic, $P = 0.01$) to more than 19 g Lys per kilogram of BW gain for pigs fed diets containing 1.52 or 1.62% SID Lys.

Experiment 4

From d 0 to 7, ADG was not different among dietary treatments (Table 10); however, ADFI decreased (linear, $P = 0.02$) and G:F increased (linear, $P < 0.001$) as SID Lys increased. From d 7 to 14, ADG increased (quadratic, $P = 0.01$) as dietary Lys increased, with the pigs fed 1.42% SID Lys demonstrating the numerically greatest ADG. Similar to the previous period, ADFI decreased

(linear, $P < 0.001$) and G:F increased (linear, $P < 0.001$; quadratic, $P = 0.02$) as SID Lys increased.

Overall from d 0 to 14, increasing SID Lys increased (quadratic, $P = 0.05$) ADG, with pigs fed the intermediate SID Lys diets (1.32 and 1.42%) having the greatest BW gains. Also, ADFI decreased (linear; $P < 0.001$) and G:F increased (linear, $P < 0.001$; quadratic, $P = 0.02$) with increasing SID Lys. Lysine intake per kilogram of BW gain increased (linear, $P < 0.001$; quadratic, $P = 0.05$) as SID Lys increased; it was 16.8, 17.7, and 18.3 g/kg for pigs fed diets containing 1.32, 1.42, and 1.52% SID Lys, respectively.

Combined Results (Experiments 1 to 4)

One-slope straight broken-line analysis of combined data of all experiments indicated that the breakpoint for ADG occurred at 1.30% SID Lys, whereas the estimate using quadratic broken-line analysis was slightly greater at 1.37% SID Lys (Figure 1A). When a separate analysis was conducted with only the data from the experiments conducted in commercial facilities (Exp. 2, 3, and 4), the estimate was 1.31 and 1.42% for the 1-slope straight broken-line and quadratic broken-line analysis, respectively, and these values were not different from the results obtained when all 4 experiments were included in the analysis. Based on G:F for all experiments, the estimated requirement for SID Lys was 1.39% using 1-slope straight broken-line analysis and 1.54% using quadratic broken-line analysis (Figure 1B).

When expressing the SID Lys requirement in relationship to dietary energy, the requirement estimate for

Table 9. Effects of standardized ileal digestible (SID) lysine on growth performance of nursery pigs, Exp. 3¹

Item	SID Lys, %					SEM	P-value	
	1.22	1.32	1.42	1.52	1.62		Linear	Quadratic
d 0 to 7								
ADG, g	244	282	291	313	308	8.7	0.001	0.03
ADFI, g	391	404	399	417	409	8.0	0.06	0.57
G:F	0.622	0.697	0.731	0.750	0.751	0.015	0.001	0.01
d 7 to 14								
ADG, g	454	491	504	505	514	12	0.001	0.13
ADFI, g	643	645	656	653	650	9	0.47	0.52
G:F	0.705	0.761	0.768	0.774	0.790	0.012	0.001	0.09
d 0 to 14								
ADG, g	349	386	397	409	410	8	0.001	0.02
ADFI, g	517	524	527	535	529	8	0.16	0.50
G:F	0.674	0.737	0.754	0.765	0.775	0.010	0.001	0.01
SID Lys:BW gain, g/kg	18.1	18.0	18.9	19.9	20.9	0.2	0.001	0.01
BW, kg								
d 0	8.47	8.44	8.45	8.46	8.45	0.11	0.99	0.94
d 7	10.17	10.41	10.48	10.66	10.60	0.14	0.02	0.35
d 14	13.35	13.86	14.03	14.20	14.22	0.17	0.001	0.13

¹Pigs with an initial BW of 8.45 ± 0.11 kg were used in a 14-d growth experiment to determine effects of SID Lys level on growth performance in a commercial nursery research facility in Minnesota. Data represent means of 6 replicate feeders per treatment with 42 pigs per feeder.

Table 10. Effects of standardized ileal digestible (SID) lysine on growth performance of nursery pigs, Exp. 4¹

Item	SID Lys, %					SEM	P-value	
	1.22	1.32	1.42	1.52	1.62		Linear	Quadratic
d 0 to 7								
ADG, g	355	363	355	354	350	16	0.71	0.77
ADFI, g	468	454	436	422	422	16	0.02	0.13
G:F	0.761	0.795	0.810	0.837	0.827	0.015	0.001	0.29
d 7 to 14								
ADG, g	463	491	500	488	468	16	0.88	0.01
ADFI, g	625	621	622	581	567	17	0.001	0.13
G:F	0.743	0.792	0.805	0.838	0.826	0.010	0.001	0.02
d 0 to 14								
ADG, g	409	427	427	422	409	16	0.74	0.05
ADFI, g	545	541	526	503	494	17	0.001	0.61
G:F	0.752	0.790	0.809	0.837	0.826	0.009	0.001	0.02
SID Lys:BW gain, g/kg	16.3	16.8	17.7	18.3	19.8	0.2	0.001	0.05
BW, kg								
d 0	7.35	7.32	7.40	7.44	7.39	0.14	0.50	0.79
d 7	9.84	9.89	9.86	9.93	9.85	0.20	0.95	0.86
d 14	13.10	13.30	13.37	13.30	13.12	0.25	0.98	0.17

¹Pigs with an initial BW of 7.38 ± 0.14 kg were used in a 14-d growth experiment to determine effects of SID Lys level on growth performance in a commercial nursery research facility in Missouri. Data represent means of 7 replicate pens per treatment with 22 pigs per pen.

ADG was 3.86 g SID Lys/Mcal ME using the 1-slope straight broken-line model and 4.19 g SID Lys/Mcal ME using the quadratic broken-line model (Figure 2A). The requirement for G:F was greater than ADG and was estimated as 4.18 g SID Lys/Mcal ME using a 1-slope straight broken-line model or 4.92 g SID Lys/Mcal ME using a quadratic broken-line model (Figure 2B).

The Lys requirement was also expressed as grams of SID Lys required per kilogram of daily BW gain (Figure 3). Broken-line analysis for the combined data was inconclusive due to 2 outliers in the data set for ADG and 1 outlier for G:F. The requirements for each trial were 16.6, 17.1, 18.0 to 19.9, and 16.8 to 17.7 g SID Lys/kg gain for Exp. 1, 2, 3, and 4, respectively. If the outliers were removed, the requirement estimates as grams of SID Lys/kg BW gain using 1-slope straight broken-line analysis were 16.7 and 17.1 g SID Lys/kg BW gain for ADG and G:F, respectively. Quadratic broken-line analysis with outliers removed was 17.2 and 18.2 g of SID Lys/kg gain for ADG and G:F, respectively.

DISCUSSION

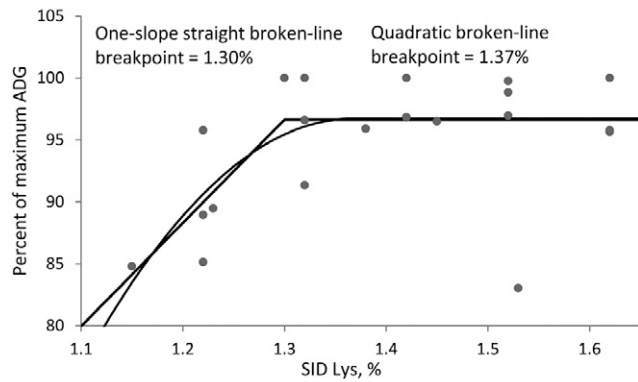
After NRC (1998) publication of dietary guidelines, results of many experiments conducted with late nursery pigs have indicated that Lys requirements may be greater than previously estimated. The NRC (1998) requirement estimate for 10 to 25 kg pigs is 1.15% total Lys, or 1.01% SID Lys; however, Kendall et al. (2008) conducted 5 experiments with pigs from 11 to 27 kg and reported that 1.30% SID Lys was required for optimal growth. Similarly, other recent studies with nursery pigs

ranging from 7 to 22 kg BW have estimated that the SID Lys requirement may be as great as 1.40%, also indicating that NRC (1998) estimates may be too low (Lenehan et al., 2003; Hill et al., 2007) for the modern lean genotype pig of today. Reevaluation of the Lys requirement for nursery pigs in a lighter BW range is, therefore, necessary.

To evaluate the SID Lys requirement of pigs from 7 to 14 kg, the present experiments were conducted using similar methods and design as those used by Kendall et al. (2008). In the present studies, as well as the experiments conducted by Kendall et al. (2008), a single-slope, broken-line analysis estimated a similar SID Lys requirement for BW gain of 1.30%; however, when comparing the results from Kendall et al. (2008) and our data, our r^2 is smaller, indicating that less of the variation in growth performance is explained by SID Lys in our model than in the model generated by Kendall et al. (2008). Although the primary difference was the BW range of the pigs, a number of other differences also existed that may help explain the variation. These include varying locations, genetics, and minor changes in diet formulation in the current experiments, which were more consistent among trials by Kendall et al. (2008). Our experiments purposely involved 4 different nursery facilities and pig sources to encompass a broader range of environments in our SID Lys estimates. Despite the differences among experiments, similar requirements for ADG and G:F were observed, allowing for the combination of data from all 4 experiments.

Statistical models are also an important consideration when evaluating nutritional requirements that

A



B

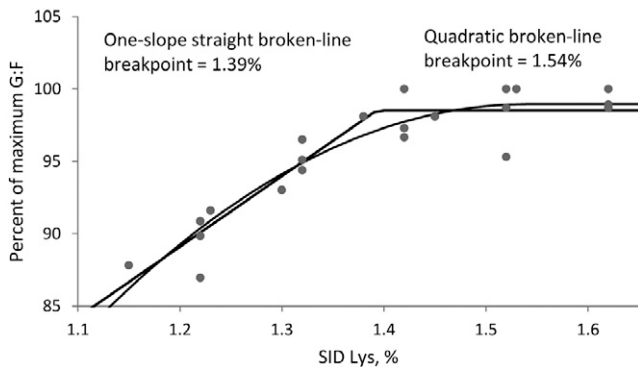
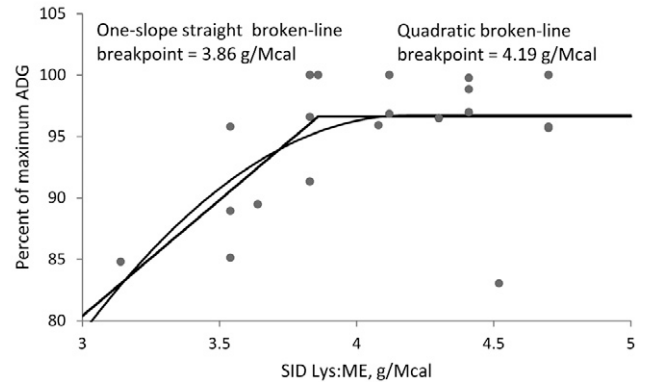


Figure 1. Data points represent treatment means from 4 experiments totaling 3,164 pigs. Fitted 1-slope straight broken-line and quadratic broken-line plot of percentage of maximum ADG and G:F expressed as a function of standardized ileal diestible (SID) Lys in 7 to 14 kg pigs. (A) The 1-slope straight broken-line model yielded a SID Lys requirement of 1.30% (Y plateau = 96.7%; slope below breakpoint = -83.5 ; and $r^2 = 0.42$) and the quadratic broken-line model yielded a SID Lys requirement of 1.37% [$Y = 96.7 - 280.3(1.37 - \text{SID Lys})^2$; $r^2 = 0.40$]. (B) The 1-slope straight broken-line model yielded a SID Lys requirement of 1.39% (Y plateau = 98.5%, slope below breakpoint = -48.8 ; $r^2 = 0.88$), and the quadratic broken-line model yielded a SID Lys requirement of 1.54% [$Y = 99.0 - 83.6(1.54 - \text{SID Lys})^2$; $r^2 = 0.87$].

may change depending on the method of analysis (Robbins et al., 1979; Kendall et al., 2008). When analyzing the combined results, 2 different models were used. A 1-slope straight broken-line model is 1 of the most common models for determining nutritional requirements because it is a simple method that yields a breakpoint estimate, SE, and a description of the response (Robbins et al., 2006). The potential downside to this method is that it assumes the response leading up to the breakpoint remains linear. If the response becomes curvilinear before reaching the requirement, a quadratic broken-line model may provide a more appropriate estimate (Robbins et al., 2006). For the combined data set, using a quadratic broken-line model resulted in greater requirements and a greater difference of estimates between ADG and G:F than a 1-slope straight broken-line.

Much of the earlier research reported the Lys re-

A



B

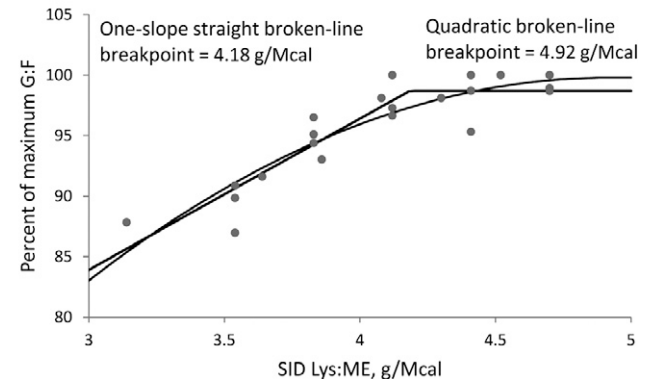


Figure 2. Data points represent treatment means from 4 experiments totaling 3,164 pigs. Fitted 1-slope straight broken-line and quadratic broken-line plot of percentage of maximum ADG and G:F expressed as a function of standardized ileal digestible (SID) Lys:ME in 7 to 14 kg pigs. (A) The 1-slope straight broken-line model yielded a SID Lys:ME requirement of 3.86 g/Mcal (Y plateau = 96.7%; slope below breakpoint = -12.6 ; $r^2 = 0.31$) and the quadratic broken-line model yielded a SID Lys:ME requirement of 4.19 g/Mcal [$Y = 96.7 - 12.6(4.19 - \text{g of SID Lys/Mcal})^2$; $r^2 = 0.47$]. (B) The 1-slope straight broken-line model yielded a SID Lys:ME requirement of 4.18 g/Mcal (Y plateau = 98.7%; slope below breakpoint = -12.5 ; $r^2 = 0.85$), and the quadratic broken-line model yielded a SID Lys:ME requirement of 4.92 g/Mcal [$Y = 99.8 - 4.6(4.92 - \text{g of SID Lys/Mcal})^2$; $r^2 = 0.82$].

quirement based on total dietary Lys, whereas investigating Lys requirements based on SID Lys can allow for more accurate estimates and may explain much of the variation among trials (Stein et al., 2005, 2007). We observed that the calculated total Lys required was at least 1.43% for ADG and 1.52% for G:F. Although some experiments (Gatel et al., 1992; Broekman et al., 1997) agree with the total dietary Lys required in the present trials, NRC (1998) reported experiments with estimates from 1.10 to 1.40% total Lys. Results of the present experiments indicate that at least 1.30% SID Lys is required for optimal ADG, and 1.39% is required for optimal G:F in pigs from 7 to 14 kg based on a 1-slope straight broken-line. These estimates are slightly less than those reported by Dean et al. (2007), who used broken-line analysis and reported that the SID Lys requirement for optimal ADG is between 1.40 and 1.43%

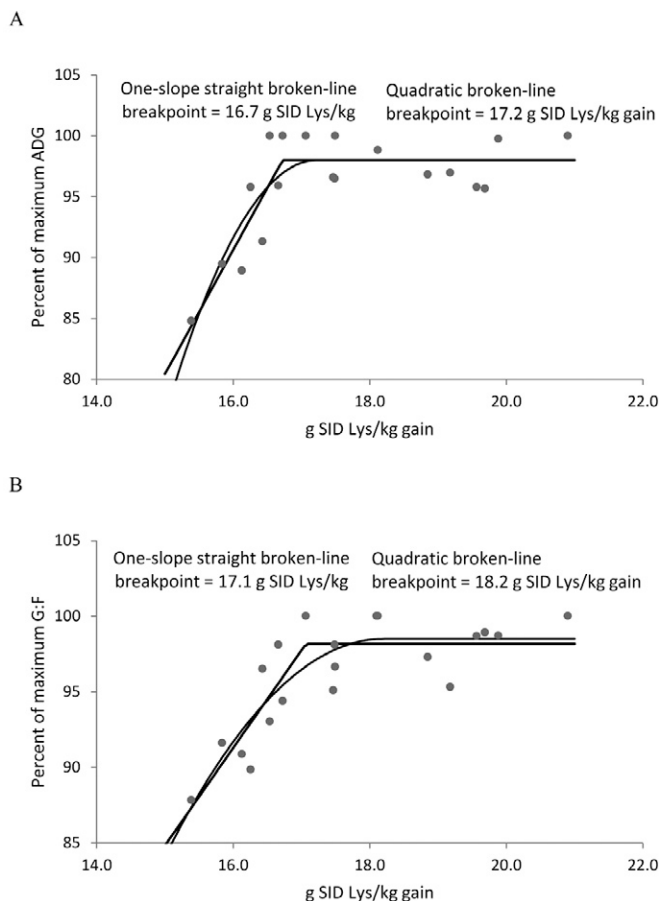


Figure 3. Data points represent treatment means from 4 experiments totaling 2,863 and 2,912 pigs for Panels A and B, respectively. Two outliers for ADG and 1 outlier for G:F were removed. Fitted 1-slope straight broken-line and quadratic broken-line plot of percentage of maximum ADG and G:F expressed as a function of standard ileal digestible (SID) Lys required per kilogram of daily BW gain in 7 to 14 kg pigs. (A) The 1-slope straight broken-line model yielded a SID Lys per kilogram BW gain requirement of 16.7 g/kg (Y plateau = 98.0%; slope below breakpoint = -10.2 ; $r^2 = 0.76$) and the quadratic broken-line model yielded a SID Lys requirement of 17.2 g/kg [$Y = 98.0 - 4.2(17.2 - \text{g of SID Lys/kg of ADG})^2$; $r^2 = 0.72$]. (B) The 1-slope straight broken-line model yielded a SID Lys per kilogram BW gain requirement of 17.1 g/kg (Y plateau = 98.2%; slope below breakpoint = -6.5 ; $r^2 = 0.75$) and the quadratic broken-line model yielded a SID Lys requirement of 18.2 g/kg [$Y = 98.5 - 1.4(18.2 - \text{g of SID Lys/kg of ADG})^2$; $r^2 = 0.73$].

in pigs from 6 to 12 kg; however, when calculated as a Lys:calorie ratio, this can be expressed as 4.1 g SID Lys/Mcal ME, which is similar to estimates in the current experiments of 3.9 to 4.2 g SID Lys/Mcal ME. Also in agreement, Schneider et al. (2010) reported that the Lys:calorie ratio requirement may differ between genotypes in weanling pigs, but reported the requirement of a similar genetic source as used in our trials to be 3.9 to 4.2 g SID Lys/Mcal ME. When expressed as a function of SID Lys required per kilogram of daily BW gain, our estimated requirements ranged from 16.6 to 19.9 g SID Lys/kg BW gain, with 3 of the experiments estimating requirements of 16.5 to 17.7 g/kg. If we express the requirement reported by Dean et al. (2007) in terms of daily BW gain, the requirement is 18.9 g SID Lys/kg BW gain for 6 to 12 kg pigs. Similarly, Kendall et al. (2008)

observed that the requirement for heavier nursery pigs is 19.0 g SID Lys/kg BW gain. Based on those results, the SID Lys estimates (expressed as g/kg BW gain) seem to range from 17 to 19 g SID Lys/kg of BW gain.

In summary, results of our experiments agree with nursery pig research, indicating that the NRC (1998) Lys estimates seem to be too low. For pigs from 7 to 14 kg, the present data indicate that the SID Lys requirement for optimal growth is at least 1.30% for ADG and 1.39% for G:F if a 1-slope straight broken-line analysis is used to estimate the requirement. Using quadratic broken-line models provided greater estimates, which were more variable, ranging from 1.37 to 1.54% SID Lys. Thus, the SID Lys requirement for optimal growth of 7 to 14 kg pigs based on the average value of these 2 regression estimates was 1.34% for ADG and 1.46% for G:F. When calculated as SID Lys:ME, the requirement was at least 3.86 g/Mcal ME.

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