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Summary
The objective of this study was to estimate the SID Lys requirement for growth and feed efficiency of 40- to 90-lb DNA pigs. A total of 300 pigs (600 × 241, DNA; initially 40.6 ± 1.11 lb) were used in a 24-d trial. Pens of pigs were blocked by BW and randomly allotted to 1 of 6 dietary treatments with 5 pigs per pen and 10 pens per treatment in a randomized complete block design. Dietary treatments were corn-soybean meal-based and formulated to contain 1.00, 1.10, 1.20, 1.30, 1.40, and 1.50% SID Lys. Increasing SID Lys increased (linear, $P = 0.003$) ADG, decreased (linear, $P = 0.012$) ADFI, and improved (linear, $P < 0.001$) feed efficiency. While these responses were linear, the greatest improvement in growth performance was observed as SID Lys increased from 1.00 to 1.10%. Although increasing SID Lys further slightly improved performance, the change was not great enough to economically justify feeding greater than 1.10% SID Lys. The quadratic polynomial model to maximize ADG predicted the maximum growth at 1.41% SID Lys. For F/G, the broken-line linear model predicted no further improvement past 1.35% SID Lys, while a similar fitting quadratic polynomial model predicted the optimum feed efficiency beyond the highest tested level of SID Lys. Additionally, the broken-line linear model for income over feed cost (IOFC) predicted maximum economic return at or below 1.12% SID Lys. In summary, the optimal SID Lys level for DNA pigs from 40 to 90 lb depends upon the response criteria, with growth performance maximized between 1.35 and > 1.50% SID Lys; however, economic responses were maximized at or below 1.12% SID Lys.

Introduction
Improvements in modern swine genetics have resulted in increased growth performance and protein accretion rates. Additionally, the recent shift of the US swine industry toward an emphasis on improved pork quality has led to the increased use of Duroc-sired pigs in the marketplace. As a result of changing genetic sources, it is important to continuously analyze, and potentially alter, the established dietary nutrient requirements.[2] Lysine is typically the first limiting amino acid in corn-soybean meal-based swine diets, and as such it is critically important to have an accurate estimation of Lys

[1] Department of Diagnostic Medicine/Pathobiology, College of Veterinary Medicine, Kansas State University.
[2] O'Connell, M., P. Lynch, J. O'Doherty, 2005. Determination of the optimum dietary lysine concentration for growing pigs housed in pairs and in groups. Animal Science, v. 81, p. 249-255.

requirements to maximize lean growth and economic returns. This study is a portion of an overarching project with the objective of predicting the SID Lys requirement of DNA 600 × 241 full program pigs from approximately 40 to 285 lb. The objective of this study was to determine the SID Lys requirement of DNA 600 × 241 pigs from 40- to 90-lb BW to optimize growth performance and economic returns.

Procedures

The Kansas State University Animal Care and Use Committee approved the protocol used in this experiment. The experiment was conducted at the Kansas State University Swine Teaching and Research Center. Each pen was equipped with a 4-hole, dry self-feeder, and a nipple waterer to provide *ad libitum* access to feed and water.

Animals and diets

A total of 300 pigs (600 × 241, DNA; initially 40.6 ± 1.11 lb) were used in a 24-d trial. There were 5 mixed-gender pigs per pen at a floor space of 3.2 ft^2 per pig. Pens of pigs were allotted by BW and randomly assigned to 1 of 6 dietary treatments with 10 replications per treatment in a complete randomized block design. Pigs were provided *ad libitum* access to water and to feed in meal form.

Dietary treatments were corn-soybean meal-based and formulated to 1.00, 1.10, 1.20, 1.30, 1.40, or 1.50% SID Lys containing 0.25, 0.30, 0.35, 0.40, 0.45, and 0.50% L-Lys HCl, respectively, with other feed-grade AAs added as necessary to maintain ratios relative to Lys (Table 1). Ratios of other AAs to Lys were maintained well above requirement estimates to ensure that Lys was the first-limiting AA. Pens of pigs were weighed, and feed disappearance was recorded on d 0, 7, 14, and 24 to determine ADG, ADFI, and F/G.

Complete diets were manufactured at Hubbard Feeds, Beloit, KS. A sample of each diet was submitted for AA profile (Table 2). Representative diet samples were obtained from every third bag of feed. Diet samples were stored at -20°C (-4°F) until they were homogenized, subsampled, and submitted for analysis of crude protein (CP), dry matter (DM), and AA profile. All samples were submitted to Ajinomoto Animal Nutrition North America, Inc. (Eddyville, IA).

Economic analysis

For the economic analysis, feed cost/pig, feed cost/lb gain, revenue per pig, and IOFC were calculated for high- and low-priced diets. Diet costs were determined using the following ingredient costs for the high-priced diets: corn = $6.00/bushel ($214/ton); soybean meal = $400/ton; L-Lys HCl = $0.80/lb; DL-Met = $2.50/lb; L-Thr = $1.20/lb; L-Trp = $5.00/lb; and L-Val = $4.00/lb. Diet costs were determined using the following ingredient costs for the low-priced diets: corn = $3.00/bushel ($107/ton); soybean meal = $300/ton; L-Lys HCl = $0.65 /lb; DL-Met = $1.70/lb; L-Thr = $0.85/lb; L-Trp = $3.00/lb; and L-Val = $2.50/lb. Feed cost/pig was determined by total feed intake × diet cost ($/lb). Feed cost/lb of gain was calculated using feed cost/pig divided by total gain. Revenue per pig was determined for both a high price and a low price by total gain × $0.66/lb live gain, or total gain × $0.45/lb live gain, respectively. Income over feed cost was calculated using revenue/pig – feed cost/pig.

Chemical analysis
Diet samples were collected and sent to a commercial laboratory (Ajinomoto Heartland Inc., Eddyville, IA) for complete amino acid analysis (AOAC 994.12; AOAC, 2012).[3]

Statistical analysis
Data were analyzed as a randomized complete block design for one-way ANOVA using the lmer function from the lme4 package in R Studio (Version 3.5.2, R Core Team; Vienna, Austria) with pen serving as the experimental unit, pen average BW as blocking factor, and treatment as fixed effect. Dose response curves were evaluated using linear (LM), quadratic polynomial (QP), and broken-line linear (BLL) models. For each response variable, the best-fitting model was selected using the Bayesian Information Criterion (BIC). A decrease in BIC greater than 2.0 among models for a particular response criterion was considered an improved fit. Results were considered significant with $P \leq 0.05$ and were considered marginally significant with $P \leq 0.10$.

Results and Discussion
From d 0 to 7, increasing SID Lys improved (linear, $P < 0.001$) ADG and F/G. However, from d 7 to 14, increasing SID Lys did not affect ADG ($P > 0.05$), but ADFI decreased (linear, $P = 0.027$) with increasing SID Lys, resulting in pigs fed 1.50% SID Lys having the best F/G (linear, $P = 0.003$).

From d 14 to 24, increasing SID Lys tended to decrease (quadratic, $P = 0.100$) ADG, with pigs fed diets containing 1.10% SID Lys having the greatest numeric ADG. Additionally, increasing SID Lys decreased (linear, $P = 0.002$) ADFI and improved (linear, $P = 0.001$) F/G.

For overall growth performance (d 0 to 24), increasing SID Lys increased (linear, $P < 0.05$) ADG and final BW, decreased (linear, $P = 0.012$) ADFI, and improved (linear, $P < 0.001$) F/G. Despite the linear responses, the greatest change in performance occurred as SID Lys increased from 1.0 to 1.1%. Lysine intake/d and Lys intake/kg of gain increased (linear, $P < 0.001$) as SID Lys increased. Feed cost/pig and feed cost/lb of gain increased (linear, $P < 0.001$) with increasing SID Lys at both high and low ingredient and pig prices. Moreover, at both high and low ingredient and pig prices, increasing SID Lys tended to increase (linear, $P = 0.074$) total revenue/pig. At high ingredient and pig prices, there was no evidence of significant difference ($P > 0.05$) for IOFC. However, at low ingredient and pig prices, increasing SID Lys decreased (linear, $P = 0.049$) IOFC, with pigs fed diets containing 1.10% SID Lys having the greatest numeric IOFC.

The QP and LM models for ADG resulted in a similar fit (BIC = -88.0 vs. -90.1, QP vs. LM, respectively); with the QP predicting maximum growth response at 1.41% SID Lys, while the LM predicted maximum growth greater than 1.50% SID Lys (Figure 1). The QP model equation was: ADG = $-0.6220 \times (\text{SID Lys, \%})^2 + 1.7572 \times (\text{SID Lys, \%}) + 0.7471$; with 95% of the maximum ADG estimated at 1.01% SID Lys. For optimization of F/G, the resulting QP, BLL, and LM models had a similar fit (BIC = -155.9 vs. -156.6 vs. -157.8, QP vs. BLL vs. LM, respectively); with the QP predicting the lowest

[3] AOAC International. 2012. Official methods of analysis of AOAC Int. 19th ed. Gaithersburg (MD): Association of Official Analytical Chemists.

F/G response beyond the highest tested level of SID Lys, the BLL predicting no further improvement past 1.35% SID Lys, while the LM predicted optimum F/G beyond 1.50% SID Lys (Figure 2). The QP model equation was: F/G = 0.4303 (SID Lys, %)^2 – 1.3939 (SID Lys, %) + 2.6959; with 95% of the lowest F/G estimated at 1.39% SID Lys. For IOFC at low prices the LM and BLL models resulted in a similar fit (BIC = 178.4 vs. 179.8, LM vs. BLL, respectively). The BLL model predicted a reduction in profitability past 1.12% SID Lys, while the LM predicted maximum profitability at the lowest SID Lys concentrations (Figure 3).

In summary, for maximum growth and optimum feed efficiency, it is recommended that 40- to 90-lb DNA pigs should be fed diets containing no less than 1.35% SID Lys, with further improvements in selected response criteria at or above 1.50% SID Lys. Economic responses are a result of set ingredient and market pig prices, and as such expected returns should be compared with maximum growth potential to determine an optimal dietary SID Lys level. However, in the current study, IOFC was maximized at or below 1.12% SID Lys, contrary to maximum growth performance. As a result, in this experiment, increasing SID Lys beyond 1.10% SID Lys slightly improved performance, but the change was not great enough to economically justify feeding greater than 1.10% SID Lys.

Table 1. Diet composition (as-fed basis)[1,2]

	SID Lys, %					
Item	**1.00**	**1.10**	**1.20**	**1.30**	**1.40**	**1.50**
Ingredient, %						
Corn	69.40	66.55	63.67	60.81	57.93	55.13
Soybean meal	25.61	28.11	30.61	33.11	35.61	38.11
Corn oil	2.00	2.25	2.50	2.75	3.00	3.20
Limestone	1.00	1.00	0.98	0.98	0.95	0.95
Monocalcium P, 21% P	0.70	0.65	0.65	0.60	0.60	0.55
Sodium chloride	0.50	0.50	0.50	0.50	0.50	0.50
L-Lys-HCl	0.25	0.30	0.35	0.40	0.45	0.50
DL-Met	0.07	0.11	0.15	0.19	0.23	0.26
L-Thr	0.08	0.11	0.14	0.17	0.20	0.23
L-Trp	0.01	0.01	0.02	0.02	0.03	0.03
L-Val	0.00	0.02	0.05	0.08	0.11	0.15
Vitamin premix with phytase	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15
Total	100	100	100	100	100	100
Calculated analysis[1]						
SID AA, %						
Lys, %	1.00	1.10	1.20	1.30	1.40	1.50
Ile:Lys	65	63	61	59	58	57
Leu:Lys	140	132	126	120	116	112
Met:Lys	32	34	35	36	37	37
Met and Cys:Lys	58	58	58	58	58	58
Thr:Lys	63	63	63	63	63	63
Trp:Lys	19.2	19.1	19.1	19.1	19.0	19.0
Val:Lys	71	70	70	70	70	70
His:Lys	43	41	40	39	38	37
ME, kcal/lb	1,537	1,543	1,550	1,556	1,562	1,567
NE, kcal/lb	1,158	1,158	1,158	1,158	1,158	1,158
SID Lys:NE, g/Mcal	3.92	4.31	4.70	5.09	5.48	5.88
CP, %	18.3	19.3	20.4	21.5	22.6	23.7
Ca, %	0.68	0.68	0.68	0.68	0.68	0.68
STTD P, %	0.40	0.40	0.40	0.40	0.40	0.40

[1] National Research Council. 2012. Nutrient Requirements of Swine: Eleventh Revised Edition. Washington, DC: The National Academies Press. *https://doi.org/10.17226/13298*.
[2] Diets were fed from 40- to 90-lb BW.

Table 2. Amino acid analysis of diets (as-fed basis)[1]

	SID Lys, %					
Item	**1.00**	**1.10**	**1.20**	**1.30**	**1.40**	**1.50**
Amino acid analysis, %[2]						
Lys	1.160	1.300	1.341	1.484	1.516	1.639
Ile	0.741	0.813	0.757	0.869	0.897	0.947
Met	0.345	0.403	0.382	0.454	0.496	0.534
Met + Cys	0.640	0.713	0.698	0.801	0.828	0.890
Thr	0.793	0.883	0.897	1.022	1.047	1.112
Trp	0.237	0.249	0.277	0.308	0.310	0.332
Val	0.831	0.910	0.876	0.999	1.066	1.135
His	0.475	0.512	0.498	0.553	0.554	0.585
Phe	0.976	1.041	1.020	1.124	1.126	1.170

[1]Diet samples were taken from every third bag of feed 7 d after the beginning of the trial and stored at -20°C (-4°F).
[2]Composite sample was submitted to Ajinomoto Heartland Inc. (Eddyville, IA) for amino acid analysis.

Table 3. Effects of increasing SID Lys on growth performance of DNA pigs weighing 40–90 lb[1]

	SID Lys, %							*P* =	
Item	1.00	1.10	1.20	1.30	1.40	1.50	SEM	Linear	Quadratic
BW, lb									
d 0	40.6	40.7	40.6	40.5	40.6	40.6	1.11	0.918	0.863
d 7	51.2	51.5	52.6	52.6	53.3	53.4	1.45	< 0.001	0.523
d 14	64.9	65.4	66.3	65.6	67.0	67.3	1.66	0.004	0.889
d 24	85.9	88.0	88.0	87.3	88.5	88.7	1.89	0.040	0.537
d 0 to 7									
ADG, lb	1.51	1.55	1.71	1.73	1.72	1.82	0.057	< 0.001	0.344
ADFI, lb	2.55	2.59	2.61	2.52	2.56	2.52	0.079	0.455	0.547
F/G	1.69	1.68	1.52	1.46	1.49	1.38	0.030	< 0.001	0.333
d 7 to 14									
ADG, lb	1.88	1.98	1.95	1.88	1.96	1.97	0.053	0.417	0.944
ADFI, lb	3.18	3.17	3.15	3.04	3.14	3.04	0.074	0.027	0.989
F/G	1.70	1.61	1.62	1.62	1.61	1.55	0.029	0.003	0.804
d 14 to 24									
ADG, lb	2.10	2.23	2.17	2.17	2.15	2.14	0.037	0.891	0.100
ADFI, lb	3.82	3.74	3.76	3.68	3.66	3.58	0.071	0.002	0.761
F/G	1.82	1.68	1.73	1.69	1.70	1.67	0.025	0.001	0.121
Overall (d 0 to 24)									
ADG, lb	1.86	1.96	1.97	1.96	1.97	2.00	0.038	0.003	0.166
ADFI, lb	3.26	3.24	3.25	3.15	3.19	3.11	0.069	0.012	0.676
F/G	1.75	1.65	1.64	1.61	1.62	1.56	0.017	< 0.001	0.132
SID Lys, g/d	14.74	16.12	17.63	18.53	20.19	21.12	0.386	< 0.001	0.470
SID Lys, g/kg gain	17.46	18.15	19.69	20.87	22.59	23.28	0.218	< 0.001	0.719
Economic, $									
High ingredient and pig prices[2]									
Feed cost/pig	11.91	12.49	12.73	12.92	13.47	13.64	0.314	< 0.001	0.702
Feed cost/lb gain[3]	0.265	0.260	0.269	0.273	0.285	0.284	0.0029	< 0.001	0.272
Total revenue/pig[4]	29.72	31.74	31.26	31.22	31.21	31.73	0.687	0.074	0.265
IOFC[5]	17.81	19.25	18.54	18.30	17.74	18.09	0.427	0.298	0.169
Low ingredient and pig prices[6]									
Feed cost/pig	7.54	7.99	8.22	8.42	8.85	9.03	0.203	< 0.001	0.673
Feed cost/lb gain	0.167	0.166	0.174	0.178	0.187	0.188	0.0019	< 0.001	0.339
Total revenue/pig[4]	20.26	21.64	21.32	21.29	21.28	21.63	0.468	0.074	0.265
IOFC	12.72	13.65	13.09	12.87	12.43	12.60	0.300	0.049	0.182

[1]A total of 300 pigs (DNA 600 × 241; initially 40.6 ± 1.11 lb BW) were used with 5 pigs per pen and 10 replications per treatment.
[2] For high priced diets, corn was valued at $6.00/bushel ($214/ton), soybean meal at $400/ton, L-Lys at $0.80/lb, DL-Met at $2.50/lb, L-Thr at $1.20/lb, L-Trp at $5.00/lb, and L-Val at $4.00/lb.
[3] Feed cost/lb gain = (feed cost/pig) / total gain.
[4] Total revenue/pig = total gain/pig × gain value ($0.66/lb at high prices; $0.45/lb at low prices)
[5] Income over feed cost = total revenue/pig – feed cost/pig.
[6] For low priced diets, corn was valued at $3.00/bushel ($107/ton), soybean meal at $300/ton, L-Lys at $0.65/lb, DL-Met at $1.70/lb, L-Thr at $0.85/lb, L-Trp at $3.00/lb, and L-Val at $2.50/lb.

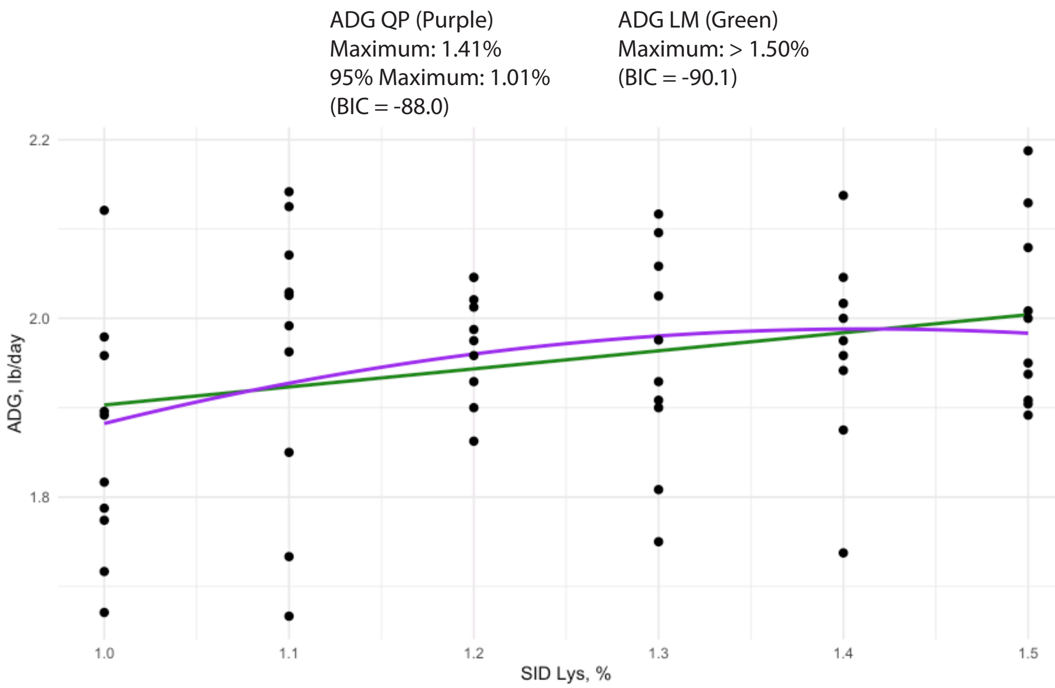

Figure 1. Estimation of SID Lys requirement to maximize ADG for 40- to 90-lb DNA pigs.

A total of 300 pigs (600 × 241, DNA; initially 40.6 ± 1.11 lb) were used in a 24-d trial. Linear (LM), quadratic polynomial (QP), and broken-line linear (BLL) models were fit to estimate SID Lys level to maximize ADG. The LM and QP models resulted in the best fit, based on Bayesian Information Criterion (BIC), with a lower number being indicative of an improved fit. The QP model predicted 95 and 100% of maximum ADG at 1.01 and 1.41% SID Lys, respectively. The QP model equation was: ADG = -0.6220 × (SID Lys, %)^2 + 1.7572 × (SID Lys, %) + 0.7471.

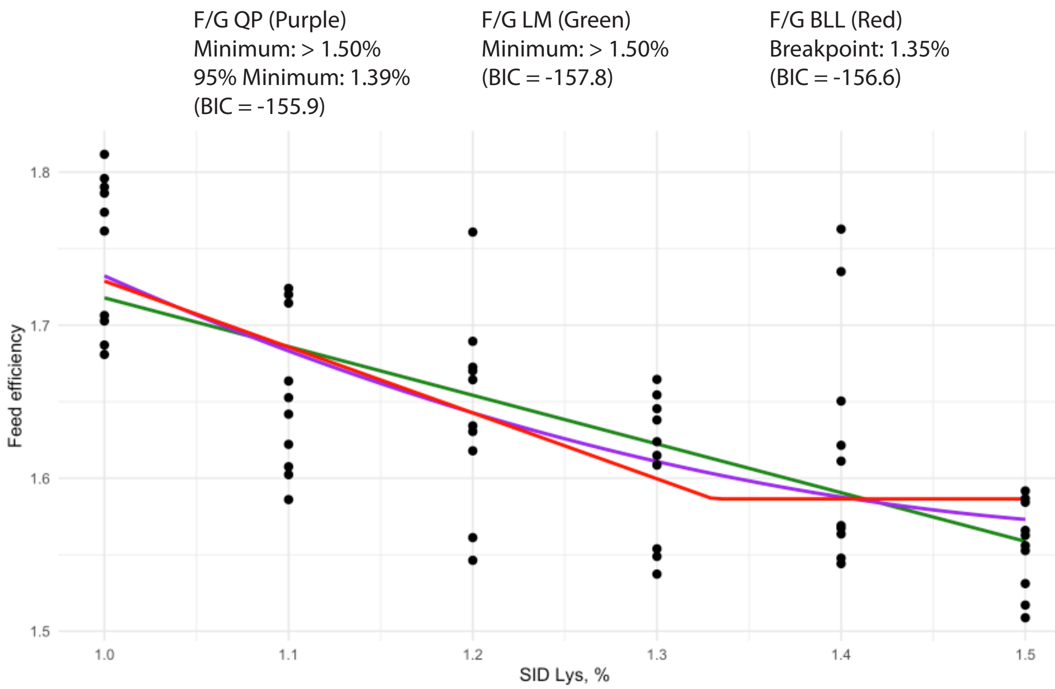

Figure 2. Estimation of SID Lys requirement to optimize F/G for 40- to 90-lb DNA pigs. A total of 300 pigs (600 × 241, DNA; initially 40.6 ± 1.11 lb) were used in a 24-d trial. Linear (LM), quadratic polynomial (QP), and broken-line linear (BLL) models were fit to estimate SID Lys level to maximize F/G. The LM, QP, and BLL models resulted in a similar best fit, based on Bayesian Information Criterion (BIC), with a lower number being indicative of an improved fit. The QP model predicted the lowest F/G response beyond the highest tested level of SID Lys. The QP model equation was: F/G = 0.4303 (SID Lys, %)^2 – 1.3939 (SID Lys, %) + 2.6959. The BLL model predicted no further improvement past 1.35% SID Lys.

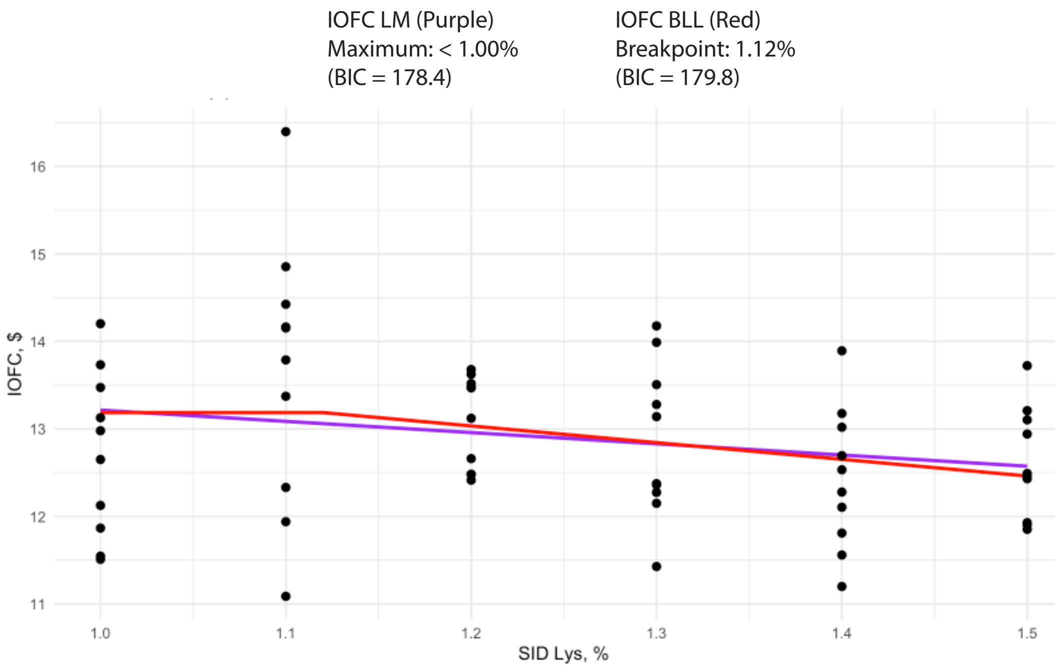

Figure 3. Estimation of SID Lys requirement to maximize IOFC at low ingredient and pig prices for 40- to 90-lb DNA pigs.
A total of 300 pigs (600 × 241, DNA; initially 40.6 ± 1.11 lb) were used in a 24-d trial. Linear (LM), quadratic polynomial (QP), and broken-line linear (BLL) models were fit to estimate SID Lys level to maximize income over feed cost (IOFC) using low ingredient and pig prices. The BLL and LM models resulted in the best fit, based on Bayesian Information Criterion (BIC), with a lower number being indicative of an improved fit. The BLL model predicted a reduction in IOFC when SID Lys increased past 1.12% SID Lys.