Standardized Total Tract Digestible Phosphorus Requirement of 25- to 50-lb Pigs Fed Diets Containing Phytase[1]

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Summary

A total of 2,140 barrows and gilts (PIC 337 × Camborough) with an initial pen average body weight (BW) of 24.5 ± 0.53 lb were used in a 21 d growth trial to determine the standardized total tract digestible phosphorus (STTD P) requirement of nursery pigs from 25 to 50 lb fed diets containing 1,000 phytase units (FYT). Pigs were weaned at approximately 19 d of age and allotted to pens according to gender and sow farm of origin. There were 12 replicate pens per treatment and 24 to 27 pigs per pen. Pens of pigs were randomly allotted to experimental diets based on average BW 25 d post-weaning, in a randomized complete block design. The 7 dietary treatments consisted of 0.30, 0.33, 0.38, 0.43, 0.48, 0.53, and 0.58% STTD P, which included the expected release of phytase. These values represented 90, 100, 115, 130, 145, 160 and 175% of the National Research Council (NRC)[3] requirement estimate for STTD P for pigs weighing between 25 to 55 lb, respectively. The diets contained 1,000 FYT of Rono-zyme Hiphos 2500 (DSM Nutritional Products, Inc., Parsippany, NJ) with assumed releasing values of 0.15% available P and 0.132% STTD P. Two corn-soybean meal-based diets were formulated to contain 0.30 and 0.58% STTD P by increasing the inclusion of limestone and monocalcium phosphate at the expense of corn, maintaining a similar 1.17:1 total Ca:P ratio across treatments. These two diets were blended using a robotic feeding system to achieve the intermediate STTD P levels.

Increasing STTD P quadratically improved ($P < 0.05$) average daily gain (ADG) and feed efficiency (F/G). The greatest improvement was observed as the STTD P was increased from 0.30 to 0.43% for ADG, and from 0.30 to 0.38% for F/G, with no further improvements thereafter. Final BW and average daily feed intake (ADFI) increased linearly ($P < 0.05$) up to the highest STTD P level. The grams of STTD P intake per day and grams of STTD P intake per kilogram of gain where growth rate reached a point of diminishing returns in response to increased STTD P were greater

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than the NRC[3] requirement estimates. Income over feed cost improved quadratically ($P < 0.05$), with the highest income being observed at 0.43% STTD P. For both ADG and feed efficiency (modeled as G:F), the broken-line linear (BLL) model demonstrated best fit. The BLL plateau was estimated at 0.40% STTD P for ADG and at 0.37% STTD P for G:F.

In conclusion, the estimated STTD P requirement for nursery pigs from 25 to 50 lb fed diets containing 1,000 units of phytase ranged from 0.37 to 0.43% depending on the response criteria. These results indicate that STTD P required to optimize performance and economic return of 25- to 50-lb pigs is greater than the NRC[3] requirement estimate.

Introduction

Adequate dietary phosphorus (P) concentration is essential for growth performance; however, due to costs and environmental concerns, its supplementation is typically associated with low safety margins in swine diets. The standardized total tract digestible (STTD) P requirement estimated by the NRC[3] for 25- to 50-lb pigs is 0.33%. In a previous study,[4] we demonstrated that the STTD P requirement for this pig weight range is actually higher than the NRC[3] recommendations for growth and economic return.

Cereal grains represent a great portion of swine diets, but feed ingredients of plant origin contain a substantial amount of P in the form of phytic acid. Phytate P (PP) is only partially utilized by pigs because they lack the necessary enzyme to cleave the phosphates from PP to make them available for absorption. Consequently, swine diets are typically formulated with the inclusion of phytase in order to increase the P availability to the pig.

We hypothesized that the STTD P requirements would be similar for pigs fed diets with and without the inclusion of phytase given the P release values from the phytase are correct. However, to our knowledge, there are few empirical studies examining the STTD P requirement of nursery pigs with diets containing phytase. Thus, the objective of this study was to determine the STTD P requirement of nursery pigs from 25 to 50 lb fed diets containing 1,000 phytase units.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The experiment was conducted at a commercial research nursery site in southwestern Minnesota. The facilities were environmentally controlled and mechanically ventilated. Two rooms, each containing 42 pens with completely slatted flooring and a deep pit for manure storage, were used. Each pen was equipped with a 5-hole stainless steel dry self-feeder (SDI Industries, Alexandria, SD) and a pan waterer to allow *ad libitum* access to feed and water. Both rooms were equipped with a computerized feeding system (FeedPro; Feedlogic Corp., Willmar,

[4]Vier, C. M., F. Wu, S. S. Dritz, M. D. Tokach, M. A. D. Gonçalves, U. A. D. Orlando, J. C. Woodworth, R. D. Goodband, and J. M. DeRouchey. 2017. Standardized total tract digestible phosphorus requirement of 11- to 25-kg pigs. J. Anim. Sci. 95(Suppl. 2):56. (Abstr.). doi:10.2527/asasmw.2017.119

MN) capable of blending and distributing diets to each pen as specified. Moreover, the system is capable of measuring and recording daily feed additions to individual pens.

A total of 2,140 barrows and gilts (PIC 337 × Camborough, initial pen average BW of 24.5 ± 0.53 lb) were used in a 21-d growth trial. Pigs were weaned at approximately 19 d of age and placed into the nursery with 13 barrows and 14 gilts per pen. After weaning, they were fed a common pelleted diet for approximately 7 d, followed by a common diet in meal form for 18 d, both formulated to be approximately at the pigs' STTD P requirement based on the NRC[3] estimates (0.44 and 0.41%, respectively). On d 0 of the trial, pigs were weighed in pens, and pens were ranked by average BW and within sow farm of origin. Pens were then randomly assigned to 1 of 7 dietary treatments within each room in a randomized complete block design, with BW within sow farm being included as a blocking factor. There were a total of 12 replicate pens per treatment and 24 to 27 pigs per pen.

Two experimental corn-soybean meal–based diets were formulated (Table 1) to contain 0.30 and 0.58% STTD P and then were blended using the robotic feeding system to create the intermediate STTD P levels. The diets contained 1,000 phytase units (FYT) of Ronozyme Hiphos 2500 (DSM Nutritional Products, Inc., Parsippany, NJ) with assumed release values of 0.15% available P and 0.132% STTD P. The STTD P levels were achieved by increasing the amount of limestone and monocalcium phosphate at the expense of corn. A similar 1.17:1 total Ca:P ratio was maintained across dietary treatments. The percentage of low and high STTD P diet blended to create the treatment diets were 100:0, 89:11, 71:29, 53:47, 36:64, 18:82, and 0:100 to achieve 0.30, 0.33, 0.38, 0.43, 0.48, 0.53, and 0.58% STTD P, respectively. These STTD P concentrations included the expected phytase release of 0.132% STTD P. The NRC[3] requirement estimate for nursery pigs from 25 to 55 lb, expressed as a percentage of the diet, is 0.33% STTD P. Therefore, treatment concentrations represented 90, 100, 115, 130, 145, 160 and 175% of the NRC[3] requirement. The lowest STTD P diet did not contain any monocalcium phosphate. Thus, the STTD P was entirely from corn, soybean meal, and the P liberated by phytase. Experimental diets were fed in meal form and were manufactured at the New Horizon Farms Feed Mill (Pipestone, MN).

Pens of pigs were weighed and feed disappearance was recorded on d 0, 7, 14, and 21 to determine ADG, ADFI, F/G, STTD P intake per day, and grams of STTD P intake per kilogram of gain. The STTD P, based on formulated values, was multiplied by ADFI to calculate grams of STTD P intake per day. The total grams of STTD P intake, based on formulated values, were divided by total BW gain to calculate the grams of STTD P intake per kilogram of gain.

Representative samples of treatment diets were taken from 6 feeders per dietary treatment 3 d after the beginning and 3 d before the end of the trial and stored at -4°F. After blending, subsamples were analyzed for dry matter, crude protein, ash, ether extract, calcium, and phosphorus (Ward Laboratories, Inc., Kearney, NE, Table 2).

For the economic analysis, total feed cost per pig, cost per lb of gain, revenue, and income over feed cost (IOFC) were calculated. Total feed cost per pig was calculated by multiplying the ADFI by diet cost and the number of days it was fed. Cost per lb of

gain was calculated by dividing the total feed cost per pig by the total lb gained overall. Revenue per pig was calculated by multiplying the ADG by the total days in the trial times the assumed live price of $58.35 per cwt. To calculate IOFC, total feed cost was subtracted from pig revenue. For all economic evaluations, price of ingredients during spring of 2018 were used; therefore, corn was valued at $3.55/bu ($127/ton), soybean meal at $373/ton, L-lysine HCL at $0.74/lb, DL-methionine at $1.40/lb, L-threonine at $1.05/lb, L-tryptophan at $9.00/lb, L-valine at $5.00/lb, Ronozyme Hiphos 2500 at $0.77/lb, monocalcium phosphate at $0.29/lb, and limestone at $0.02/lb.

The study consisted of a randomized complete block design, with pen as the experimental unit. Response variables were analyzed using general linear and non-linear models. Polynomial contrasts were implemented to evaluate the functional form of the dose response to increasing dietary STTD P on ADG, ADFI, BW, F/G, feed cost/pig, feed cost/lb of gain, total revenue/pig, IOFC, grams of STTD P intake per day, and grams of STTD P intake per kilogram of gain. The coefficients for the unequally spaced linear and quadratic contrasts were derived using the IML procedure in SAS. Statistical models were fit using GLIMMIX procedure of SAS (Version 9.3, SAS Institute Inc., Cary, NC). Results were considered significant at $P \leq 0.05$ and marginally significant at $0.05 \leq P \leq 0.10$.

In addition, the effects of the STTD P levels on ADG and feed efficiency (modeled as gain to feed, G:F) were fit using GLIMMIX and NLMIXED procedure of SAS according to Gonçalves et al. (2016).[5] Models were expanded to account for heterogeneous residual variances when needed. Competing statistical models included a linear (LM), quadratic polynomial (QP), broken-line linear (BLL), and broken-line quadratic (BLQ). Dose response models were compared based on the Bayesian information criterion (BIC), where the smaller the value, the better.[6] A decrease in BIC greater than 2 was considered a significant improvement in model fit. The 95% confidence interval of the estimated requirement to reach maximum performance or to reach plateau performance was computed. Results reported correspond to inferences yielded by the best fitting models.

Results and Discussion

Analysis of dry matter, crude protein, fat, and ash contents of experimental diets (Table 2) showed that all the values were reasonably consistent with formulated estimates. Although some variation in analyzed P existed, analyzed P content still increased with increasing STTD P treatments. Average values of analyzed Ca was approximately 15% higher than formulated values. Chemical analysis of dietary Ca is typically more variable, with a higher coefficient of variation than P. However, they followed a stepwise increase consistent with the designed treatment structure.

[5]Gonçalves, M., N. Bello, S. Dritz, M. Tokach, J. DeRouchey, J. Woodworth, and R. Goodband. 2016. An update on modeling dose–response relationships: Accounting for correlated data structure and heterogeneous error variance in linear and nonlinear mixed models. Journal of Animal Science. 94(5): 1940-1950.
[6]G. A. Milliken, and D. E. Johnson. 2009. Analysis of messy data: designed experiments. Vol. 1, 2nd ed., CRC Press, Boca Raton, FL.

Overall, increasing STTD P quadratically improved ($P < 0.05$) ADG and F/G (Table 3). The greatest improvement was observed as the STTD P was increased from 0.30 to 0.43% for ADG, and from 0.30 to 0.38% for F/G, with no further improvements thereafter. Average daily feed intake increased linearly ($P = 0.05$) up to the highest STTD P level. There was a marginal quadratic response ($P < 0.10$) for final BW. The highest final weight was observed at 0.43% STTD P, with no benefits thereafter. Grams of STTD P intake per day and grams of STTD P intake per kilogram of gain increased linearly ($P < 0.05$). However, at 0.43% STTD P, which corresponded to the highest ADG and final weight observed, grams of STTD P intake per day and grams of STTD P intake per kilogram of gain were 3.30 g/d and 6.01 g/kg of gain. These values are greater than NRC[3] requirement estimates of 2.99 g/d and 5.11 g/kg of gain.

Feed cost per pig increased linearly ($P < 0.001$) as STTD P concentration in the diet increased. In contrast, feed cost per pound of gain was reduced (quadratic, $P < 0.05$) with the lowest value observed at 0.38% STTD P. Total revenue per pig increased (quadratic, $P < 0.05$) up to 0.43% STTD P, which is a result of the quadratic improvement in ADG and final BW. Similarly, IOFC increased quadratically ($P < 0.05$), with the highest income being observed at 0.43% STTD P.

Homogeneous variance was used for ADG models and heterogeneous variance was used for feed efficiency models. The best fitting model was the BLL for both ADG and G:F (Figures 1 and 2). The BLL plateau for ADG was estimated at 0.40% (95% CI: [0.33, 0.47]%). Based on the best fitting model, the estimated regression equation was ADG, g = 543.97 − 289.79 × (0.3993 − STTD P) if STTD P < 0.40%, and ADG, g = 543.97 if STTD P ≥ 0.40%. In a previous study that evaluated the effects of increasing STTD P through inorganic P sources to 25- to 55-lb pigs, growth increased linearly.[7] However, there were diminishing returns in ADG above 0.43% STTD P, which is similar to results from this study that estimated the requirement at 0.40% STTD P. In the present trial, the BLL plateau for G:F was estimated at 0.37% (95% CI: [0.29, 0.45]%). Based on the best fitting model, the estimated regression equation was G:F, g/kg = 711.76 − 301.08 × (0.37 − STTD P) if STTD P < 0.37%, and G:F, g/kg = 711.76 if STTD P ≥0.37%. These results are in agreement with a recent study in 25- to 50-lb nursery pigs, in which the BLL model estimated the plateau for G:F at 0.34% STTD P, and 99% of maximum performance based on the QP model was achieved with 0.36% STTD P.[7]

Overall, growth rate, feed efficiency, and economic variables improved quadratically with increasing STTD P, while feed intake improved linearly. Although feed cost increased with increasing STTD P, the incremental value of the increased growth rate negated the increased diet cost. In conclusion, the estimated STTD P requirement for nursery pigs from 25 to 50 lb fed diets containing 1,000 FYT of phytase ranged from 0.37% to 0.43%, depending on the response criteria being considered. These results indicate that the 0.33% STTD P estimated requirement of the NRC[3] is below the level needed to optimize performance and economic return.

[7]Vier, C. M.; Wu, F.; Dritz, S. S.; Tokach, M. D.; Gonçalves, M. A.; Orlando, U. A.; Woodworth, J. C.; Goodband, R. D.; and DeRouchey, J. M. (2017) "Standardized Total Tract Digestible Phosphorus Requirement of 25- to 50-lb Pigs," Kansas Agricultural Experiment Station Research Reports: Vol. 3: Iss. 7. https://doi.org/10.4148/2378-5977.7471

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

Item	Formulated STTD P,[2] %	
	0.30	0.58
Ingredient, %		
Corn	65.79	63.73
Soybean meal, 46.5% crude protein	31.66	31.80
Monocalcium phosphate, 21% P	0.00	1.60
Limestone	0.74	1.05
Sodium chloride	0.65	0.65
L-Lysine HCl	0.48	0.48
DL-Methionine	0.21	0.21
L-Threonine	0.16	0.16
L-Tryptophan	0.03	0.03
L-Valine	0.08	0.08
Phytase[3]	0.04	0.04
Vitamin and trace mineral premix	0.15	0.15
Copper chloride[4]	0.04	0.04
Total	100	100
Calculated analysis		
Standardized ileal digestible (SID) amino acids, %		
Lysine	1.33	1.33
Isoleucine:lysine	57	57
Leucine:lysine	117	116
Methionine:lysine	37	37
Methionine and cysteine:lysine	58	58
Threonine:lysine	60	60
Tryptophan:lysine	19.1	19.1
Valine:lysine	67	67
Total lysine, %	1.48	1.47
Metabolizable energy, kcal/lb	1,506	1,477
Net energy, kcal/lb	1,112	1,089
SID Lysine:ME, g/Mcal	4.01	4.09
Crude protein, %	20.5	20.4
Calcium, %	0.47	0.84
Phosphorus, %	0.40	0.71
Standardized total tract digestible phosphorus, %	0.30	0.58
Available phosphorus,%	0.23	0.54
Calcium:phosphorus	1.17	1.17

[1]Treatments 0.30% and 0.58% STTD P were manufactured and blended using the robotic feeding system to create the intermediate levels of 0.33, 0.38, 0.43, 0.48, and 0.53% STTD P.

[2] Standardized total tract digestible phosphorus.

[3]Phytase (Ronozyme HiPhos, DSM Nutritional Products, Parsippany, NJ) included at 1000 FYT/kg releasing an assumed 0.15% available phosphorus and 0.132% STTD P.

[4]Supplemental copper provided in the form of tri-basic copper chloride (TBCC; Intellibond C; Micronutrients, Indianapolis, IN) at 150 ppm.

Table 2. Analyzed composition of experimental diets (as-fed-basis)[1]

Item, %	STTD P, %						
	0.30	0.33	0.38	0.43	0.48	0.53	0.58
Dry matter	88.42	88.53	89.20	88.83	88.90	88.51	88.60
Crude protein	18.23	19.68	20.40	19.60	20.60	19.20	19.23
Ether extract	2.30	2.03	2.05	2.23	2.33	2.15	2.13
Ash	3.62	3.96	4.52	4.57	4.55	4.76	5.11
Calcium	0.54	0.61	0.65	0.79	0.77	0.83	0.95
Phosphorus	0.33	0.42	0.46	0.52	0.58	0.60	0.66

[1]A representative sample of each diet was collected from 6 feeders, homogenized, then analyses were conducted on composite samples (Ward Laboratories, Inc., Kearney, NE).

Table 3. Effects of increasing standardized total tract digestible (STTD) P with the inclusion of phytase on nursery pig growth performance[1]

Item[5]	% of NRC[6]:	STTD P, %[2,3,4]							SEM	Probability, P =	
		0.30	0.33	0.38	0.43	0.48	0.53	0.58		Linear	Quadratic
		90	100	115	130	145	160	175			
d 0 to 21											
ADG, lb		1.14	1.15	1.19	1.21	1.21	1.20	1.20	0.019	0.001	0.008
ADFI, lb		1.65	1.65	1.66	1.69	1.71	1.70	1.68	0.034	0.054	0.187
F/G		1.45	1.43	1.40	1.40	1.41	1.42	1.40	0.011	0.002	0.033
STTD P, g/d		2.24	2.47	2.86	3.30	3.71	4.07	4.42	0.072	<0.001	0.321
STTD P, g/kg gain		4.34	4.72	5.31	6.01	6.79	7.51	8.10	0.049	<0.001	0.223
BW, lb											
d 0		24.5	24.5	24.5	24.5	24.5	24.5	24.5	0.53	0.978	0.990
d 21		48.6	48.9	49.6	50.0	49.8	49.8	49.8	0.85	0.024	0.082
Economics, $											
Feed cost/pig		4.23	4.23	4.30	4.41	4.46	4.46	4.45	0.089	<0.001	0.200
Feed cost/lb gain[7]		0.177	0.176	0.173	0.174	0.176	0.178	0.176	0.0014	0.418	0.030
Total revenue/pig[8]		13.92	14.13	14.55	14.83	14.77	14.65	14.73	0.233	<0.001	0.009
IOFC[9]		9.70	9.87	10.25	10.42	10.31	10.19	10.29	0.154	<0.001	0.003

[1]A total of 2,140 pigs (PIC 337 × Camborough, initial pen average BW of 24.5 lb) were used in a 21-d growth trial with 24 to 27 pigs per pen and 12 pens per treatment. Pigs were weaned at approximately 19 d of age, fed a common phase 1 and phase 2 diets for 25 d post-weaning, then fed experimental diets.

[2]Standardized total tract digestible phosphorus.

[3]Low (0.30% STTD P) and high (0.58% STTD P) diets were blended at the farm by a robotic feeding system to create the 0.33, 0.38, 0.43, 0.48, and 0.53% STTD P dietary treatments.

[4]Phytase (Ronozyme HiPhos, DSM Nutritional Products, Parsippany, NJ) was included at 1000 FYT/kg releasing an assumed 0.15% available phosphorus and 0.132% STTD P.

[5]ADG = average daily gain. ADFI = average daily feed intake. F/G = feed-to-gain ratio. BW = body weight. IOFC = income over feed cost.

[6]The NRC requirement estimate for nursery pigs from 25 to 55 lb, expressed as a percentage of the diet, is 0.33% STTD P. Therefore, treatment concentrations represented 90, 100, 115, 130, 145, 160, and 175% of the NRC (2012) requirement.

[7]Feed cost/lb gain = total feed cost divided by total gain per pig.

[8]Total revenue per pig = total gain multiplied by an assumed live price of $58.35 per cwt.

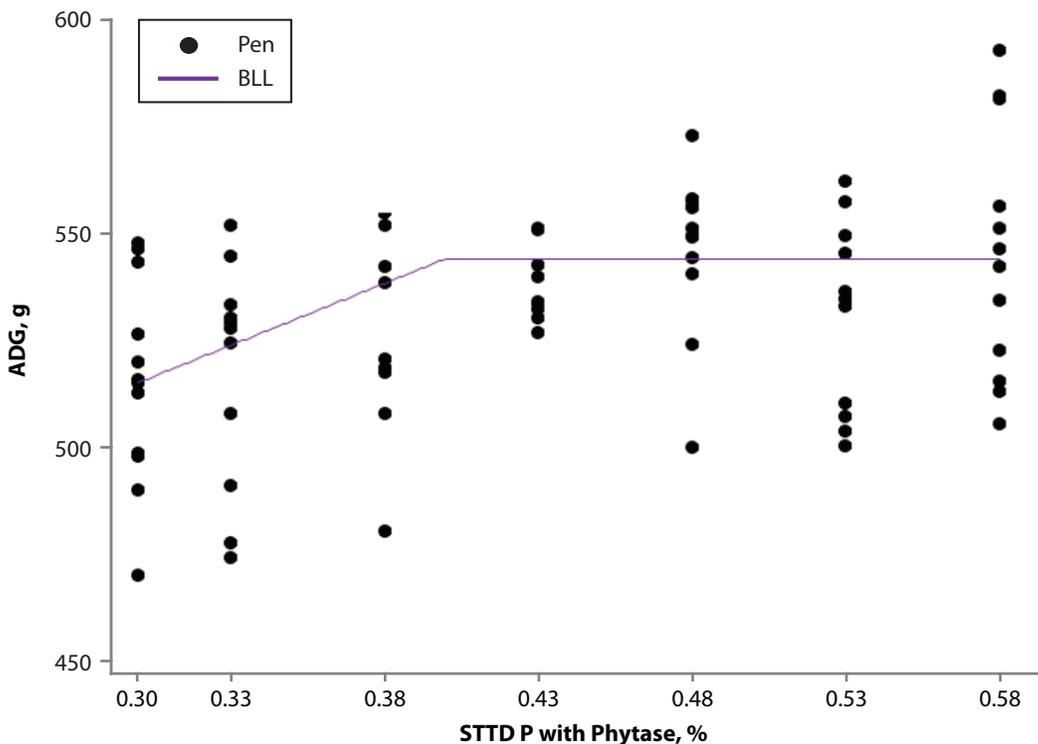[9]Income over feed cost = total revenue − feed cost.

Figure 1. Fitted linear (BLL) regression model on average daily gain (ADG) as a function of increasing standardized total tract digestible (STTD) P with the inclusion of phytase in 25-to 50-lb pigs. The BLL plateau was estimated at 0.40% (95% CI: [0.33, 0.47]%). Based on the best fitting model, the estimated regression equation was ADG, g = 543.97 – 289.79 × (0.3993 – STTD P) if STTD P < 0.40%, and ADG, g = 543.97 if STTD P ≥ 0.40%.
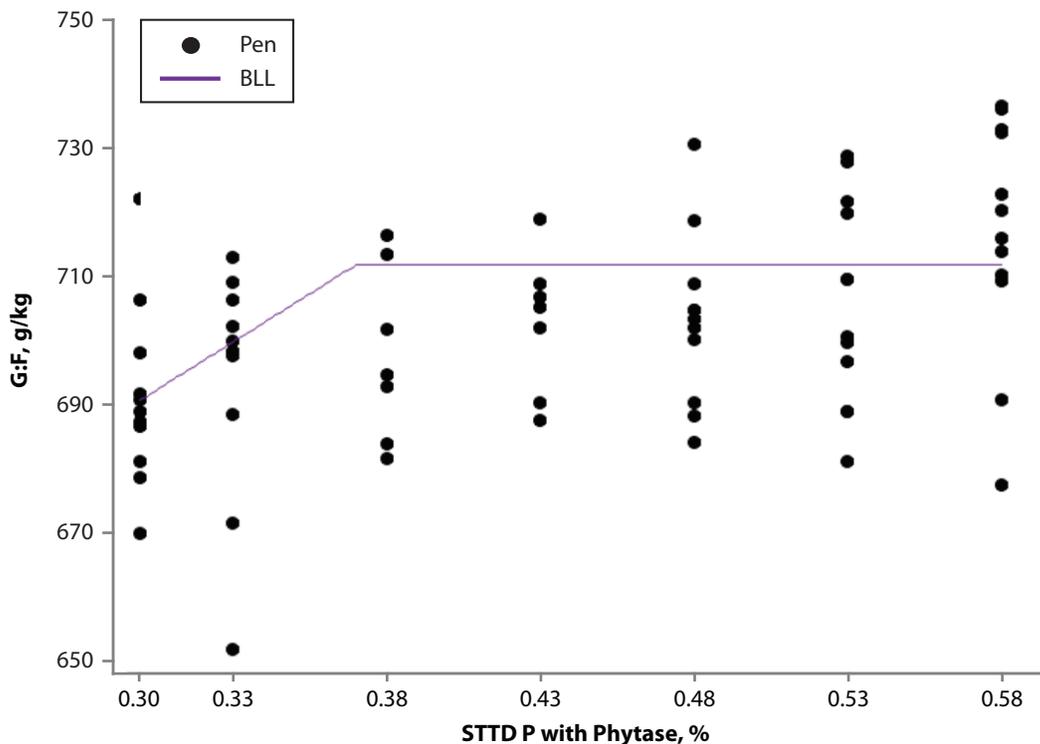
Figure 2. Fitted linear (BLL) regression model on feed efficiency (G:F) as a function of increasing standardized total tract digestible (STTD) P with the inclusion of phytase in 25-to 50-lb pigs. The BLL plateau was estimated at 0.37% (95% CI: [0.29, 0.45]%). Based on the best fitting model, the estimated regression equation was G:F, g/kg = 711.76 – 301.08 × (0.37 – STTD P) if STTD P < 0.37%, and G:F, g/kg = 711.76 if STTD P ≥ 0.37%.