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Standardized Total Tract Digestible Phosphorus Requirement of 25- to 50-lb Pigs

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Abstract

A total of 1,080 barrows and gilts (PIC; 337 × Camborough, initial pen average BW of 25.2 ± 0.64 lb) were used in a 21-d trial to determine the standardized total tract digestible (STTD) P requirement of nursery pigs from 25 to 50 lb. Two groups of pigs were weaned at approximately 21 d and allotted to pens according to BW and gender. There were 6 replicate pens per treatment and 23 to 27 pigs per pen. Pens of pigs were randomly allotted to experimental diets based on average BW at d 21 and 24 post-weaning, in a randomized complete block design. The 7 dietary treatments consisted of 0.26, 0.30, 0.33, 0.38, 0.43, 0.48, and 0.53% STTD P. These values represented 80, 90, 100, 115, 130, 145, and 160% of the NRC (2012) requirement estimate for STTD P for pigs weighing between 25 to 55 lb, respectively. Two corn-soybean meal-based diets were formulated to contain 0.26 and 0.53% STTD P by increasing the inclusion of limestone and monocalcium phosphate at the expense of corn, maintaining a similar 1.17:1 to 1.18:1 total Ca:P ratio, with no phytase added to the diets. Diets were blended using a robotic feeding system to achieve the intermediate STTD P levels.

Increasing STTD P improved ADG, ADFI, F/G, and final BW (linear, $P < 0.001$). There was also a marginally significant quadratic response for F/G ($P = 0.067$), with the greatest improvement as STTD P was increased from 0.26% to 0.33%. Income over feed cost also improved linearly through 0.53% STTD P ($P < 0.001$). 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 higher than the NRC requirement estimates. For ADG, the linear model demonstrated best fit, estimating the maximum response at greater than 0.53% STTD P. For feed efficiency, modeled as G:F, the best-fitting models were the quadratic polynomial (QP) and broken-line linear (BLL). The QP model estimated the maximum at 0.43%, with 99% of maximum G:F achieved at 0.36% STTD P. The BLL plateau was estimated at 0.34% STTD P.

In conclusion, the estimated STTD P requirement for nursery pigs from 25 to 50 lb ranged from 0.34 to at least 0.53% depending on the response criteria and statistical model used, which indicates that the NRC (2012) requirement estimate is lower than what is needed to optimize performance and economic return.

Keywords

growth, phosphorus, nursery pigs

Cover Page Footnote

Appreciation is expressed to Genus PIC for partial funding, to New Horizon Farms for use of the feed mill and animal facilities, and to Marty Heintz and Allan Morris for technical assistance.

Authors

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

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Summary

A total of 1,080 barrows and gilts (PIC; 337 × Camborough, initial pen average BW of 25.2 ± 0.64 lb) were used in a 21-d trial to determine the standardized total tract digestible (STTD) P requirement of nursery pigs from 25 to 50 lb. Two groups of pigs were weaned at approximately 21 d and allotted to pens according to BW and gender. There were 6 replicate pens per treatment and 23 to 27 pigs per pen. Pens of pigs were randomly allotted to experimental diets based on average BW at d 21 and 24 post-weaning, in a randomized complete block design. The 7 dietary treatments consisted of 0.26, 0.30, 0.33, 0.38, 0.43, 0.48, and 0.53% STTD P. These values represented 80, 90, 100, 115, 130, 145, and 160% of the NRC (2012) requirement estimate for STTD P for pigs weighing between 25 to 55 lb, respectively. Two corn-soybean meal-based diets were formulated to contain 0.26 and 0.53% STTD P by increasing the inclusion of limestone and monocalcium phosphate at the expense of corn, maintaining a similar 1.17:1 to 1.18:1 total Ca:P ratio, with no phytase added to the diets. Diets were blended using a robotic feeding system to achieve the intermediate STTD P levels.

Increasing STTD P improved ADG, ADFI, F/G, and final BW (linear, $P < 0.001$). There was also a marginally significant quadratic response for F/G ($P = 0.067$), with the greatest improvement as STTD P was increased from 0.26% to 0.33%. Income over feed cost also improved linearly through 0.53% STTD P ($P < 0.001$). 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 higher than the NRC[4] requirement estimates. For ADG, the linear model demonstrated best fit, estimating the maximum response at greater than 0.53% STTD P. For feed efficiency, modeled as G:F, the best-fitting models were the quadratic polynomial (QP) and broken-line linear (BLL). The QP model estimated the maximum at 0.43%,

[1] Appreciation is expressed to Genus PIC for partial funding, to New Horizon Farms for use of the feed mill and animal facilities, and to Marty Heintz and Allan Morris for technical assistance.

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[4] NRC. 2012. Nutrient requirements of swine. 11th rev. ed. Natl. Acad. Press, Washington, D.C.

with 99% of maximum G:F achieved at 0.36% STTD P. The BLL plateau was estimated at 0.34% STTD P.

In conclusion, the estimated STTD P requirement for nursery pigs from 25 to 50 lb ranged from 0.34 to at least 0.53% depending on the response criteria and statistical model used, which indicates that the NRC (2012) requirement estimate is lower than what is needed to optimize performance and economic return.

Introduction

Phosphorus is the second most abundant mineral in the body after calcium. It is required for multiple biological functions such as energy metabolism, synthesis of nucleic acids, structure of cell membranes, and bone formation and mineralization. The requirement estimates of the NRC[4] for Standardized Total Tract Digestible (STTD) P are derived from a nutrient requirement model rather than empirical studies. Thus, determining the STTD P requirement of growing pigs remains an important issue in commercial pig production.

Phosphorus supplementation is typically associated with lower safety margins in swine diets compared to Ca.[5] This is likely driven by environmental and economic concerns. Phosphorus is considered the third most expensive component in swine diets after energy and protein. Current statistical modeling capabilities for dose-response studies have allowed for a more precise estimation of the minimum concentration of P needed to maximize growth performance and economics while minimizing P excretion. Therefore, the objective of this study was to determine the STTD P requirement for nursery pigs weighing approximately 25 to 55 lb housed under commercial conditions.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The study was conducted at a commercial research-nursery site in southwestern Minnesota. The facility was environmentally controlled and mechanically ventilated. One room was used containing 42 pens with completely slatted flooring and a deep pit for manure storage. 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. The facility was equipped with a computerized feeding system (FeedPro; Feedlogic Corp., Willmar, MN) capable of blending and distributing diets to each pen as specified. Furthermore, the system can measure and record daily feed additions to individual pens.

A total of 1,080 barrows and gilts (PIC; 337 × Camborough, initial pen average BW of 25.2 ± 0.64 lb) were used in a 21-d growth trial. Two groups of pigs were weaned at approximately 21 d of age and placed into the nursery in two different days with a 3-d difference between them. Both groups were allotted to pens according to BW and gender. After weaning, they were fed a common pelleted diet for 7 d, followed by a common diet in meal form for 14 or 17 d, both formulated to be at the pigs' STTD P requirement based on the NRC[4] estimates. Pigs were weighed in pens, and pens were

[5] Crenshaw, T. D. 2001. Calcium, phosphorus, vitamin D, and vitamin K in swine nutrition. In: Lewis, A. J., Southern, L. L., editors. Swine Nutrition. 2nd Ed. CRC Press; Boca Raton, Florida. pp. 187–212.

ranked by average BW. This occurred 21 d post-weaning for one group and 24 d for the other group, and was considered d 0 of the trial. Pens were then randomly assigned to 1 of 7 dietary treatments in a randomized complete block design, with BW as a blocking factor. There were 6 replicate pens per treatment and 23 to 27 pigs per pen.

Two experimental corn-soybean meal–based diets were formulated (Table 1) to contain 0.26 and 0.53% STTD P and then were blended using the robotic feeding system to create the intermediate STTD P levels. The STTD P levels were achieved by increasing the inclusion of limestone and monocalcium phosphate at the expense of corn. A similar 1.17:1 to 1.18:1 total Ca:P ratio was maintained across dietary treatments, with no phytase added to the diets. The percentage of low and high STTD P blended to create the treatment diets were 100:0, 88:12, 75:25, 56:44, 37:63, 19:81, and 0:100 to achieve 0.26, 0.30, 0.33, 0.38, 0.43, 0.48, and 0.53% STTD P, respectively. The NRC[4] 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 80, 90, 100, 115, 130, 145, and 160% of the NRC[4] requirement. 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, grams of STTD P intake per day, and grams of STTD P intake per kilogram of gain. The STTD P, based on formulated values, were 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 DM, CP, ash, ether extract, Ca, and P (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. The 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 $47 per cwt. To calculate IOFC, total feed cost was subtracted from pig revenue. For all economic evaluations, price of ingredients during fall of 2016 was used; therefore, corn was valued at $3.30/bu ($152.50/ton), soybean meal at $300/ton, L-lysine HCL at $0.70/lb, DL-methionine at $1.66/lb, L-threonine at $0.98/lb, L-tryptophan at $4.09/lb, L-valine at $5.00/lb, monocalcium phosphate at $0.32/lb, and calcium carbonate 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 fitted 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.[6] 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.[7] A decrease in BIC greater than 2 was considered a significant improvement in 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 DM, CP, Ca, P, fat, and ash contents of experimental diets (Table 2) showed that all the values were reasonably consistent with formulated estimates.

Overall, increasing STTD P increased ADG, ADFI, F/G, and final BW (linear, $P < 0.001$; Table 3). There also was a marginal quadratic response for F/G ($P < 0.067$) with the greatest improvement in F/G as STTD P increased from 0.26 to 0.33%. Similarly, grams of STTD P intake per day and grams of STTD P intake per kilogram of gain increased linearly ($P < 0.001$). 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 3.52 g/d and 6.31 g/kg of gain at 0.43%. These values are greater than NRC[4] requirement estimates of 2.99 g/d and 5.11 g/kg of gain.

Feed cost per pig increased (linear, $P < 0.001$) as STTD P increased. On the contrary, feed cost per pound of gain was reduced in a quadratic manner with an estimated lowest at 0.33% STTD P ($P < 0.049$). Total revenue per pig increased through the highest STTD P (linear, $P < 0.001$), which is a result of the linear improvement in ADG and final BW. Similarly, IOFC increased through 0.53% STTD P (linear, $P < 0.001$).

Homogeneous variance was used for ADG models and heterogeneous variance was used for feed efficiency models. For ADG (Figure 1), the best fitting model was the LM. The STTD P level for maximum ADG was estimated to be at least 0.53%. Based on the best fitting model, the estimated regression equation was ADG, lb = 0.98 + 0.55 × (STTD P). Feed efficiency (Figure 2), modeled as G:F, had similar fitting models for the QP

[6] 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.

[7] G. A. Milliken, and D. E. Johnson. 2009. Analysis of messy data: designed experiments. Vol. 1, 2nd ed., CRC Press, Boca Raton, FL.

and BLL. The BLL plateau for G:F was estimated at 0.34% STTD P (95% CI: [0.30, 0.37%]). For the QP [G:F, g/kg = 456.59 + 1107.49 × (STTD P) – 1307.16 × (STTD P)^2], the maximum G:F was estimated at 0.42% (95% CI: [0.36, >0.53%]), with 99% of maximum performance being achieved with 0.36% STTD P.

Overall, growth rate and economic variables improved in a linear fashion with increasing STTD P, while feed efficiency improved in a quadratic manner. Although feed cost increased with the increasing STTD P levels, the greater 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 ranged from 0.34% to at least 0.53% depending on the response criteria and statistical model used, which indicates that the NRC[4] requirement estimate is lower than what is needed to optimize performance and economic return.

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

	Formulated STTD P, %	
Item	0.26	0.56
Ingredient, %		
Corn	64.95	63.10
Soybean meal (46.5% CP)	31.72	31.85
Monocalcium P (21% P)	0.52	1.92
Limestone	1.00	1.30
Salt	0.60	0.60
L-Lys HCl	0.48	0.48
DL-Met	0.21	0.21
L-Thr	0.16	0.16
L-Trp	0.03	0.03
L-Val	0.08	0.08
Trace mineral premix	0.10	0.10
Vitamin premix	0.13	0.13
Added Cu[2]	0.04	0.04
Total	100	100
Calculated analysis		
Standardized ileal digestible (SID) amino acids, %		
Lys	1.33	1.33
Ile:Lys	57	56
Leu:Lys	117	116
Met:Lys	37	37
Met and Cys:Lys	58	58
Thr:Lys	60	60
Trp:Lys	19	19
Val:Lys	67	67
Total Lys, %	1.48	1.47
ME, kcal/lb	1,493	1,467
NE, kcal/lb	1,102	1,082
SID Lys:ME, g/Mcal	4.04	4.11
CP, %	21.30	21.20
Ca, %	0.59	0.94
P, %	0.51	0.80
Standardized total tract digestible P, %	0.26	0.53
Available P, %	0.19	0.49
Ca:P	1.17	1.18

[1] Treatments 0.26% and 0.53% STTD P were manufactured and blended using the robotic feeding system to create the intermediate levels of 0.30, 0.33, 0.38, 0.43, and 0.48% STTD P.

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

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

	STTD P, %						
Item	0.26	0.30	0.33	0.38	0.43	0.48	0.53
DM, %	87.78	87.75	88.18	87.84	87.87	88.02	88.14
CP, %	19.6	20.2	21.4	21.5	21.4	20.3	20.7
Ether extract, %	2.4	2.4	2.3	2.3	2.3	2.4	2.3
Ash, %	3.81	4.25	4.56	4.98	4.88	4.93	5.14
Ca, %	0.65	0.74	0.73	0.85	0.90	0.82	0.88
P, %	0.44	0.49	0.54	0.64	0.66	0.71	0.75

[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 standardized total tract digestible (STTD) P on nursery pig growth performance[1]

	STTD P, %[2]								Probability, $P <$	
Item	0.26	0.30	0.33	0.38	0.43	0.48	0.53			
% of NRC[3]	80	90	100	115	130	145	160	SEM	Linear	Quadratic
d 0 to 21										
ADG, lb	1.13	1.12	1.17	1.17	1.25	1.24	1.26	0.026	0.001	0.718
ADFI, lb	1.72	1.68	1.71	1.72	1.80	1.82	1.82	0.043	0.001	0.603
F/G	1.52	1.50	1.46	1.47	1.45	1.46	1.45	0.015	0.001	0.067
BW, lb										
d 0	25.2	25.2	25.2	25.2	25.2	25.2	25.2	0.63	0.935	0.932
d 21	49.1	49.0	49.9	50.0	51.4	51.3	51.7	0.92	0.001	0.759
STTD P, g/d	2.03	2.29	2.56	2.97	3.52	3.95	4.39	0.082	0.001	0.418
STTD P, g/kg gain	3.85	4.41	4.89	5.53	6.31	7.19	7.68	0.067	0.001	0.579
Economics, $										
Feed cost/pig	3.88	3.81	3.88	3.93	4.15	4.20	4.25	0.098	0.001	0.589
Feed cost/lb gain[4]	0.163	0.161	0.158	0.160	0.158	0.161	0.160	0.0017	0.451	0.049
Total revenue/pig[5]	11.14	11.07	11.58	11.56	12.29	12.23	12.44	0.251	0.001	0.718
IOFC[6]	7.26	7.26	7.69	7.62	8.14	8.03	8.19	0.168	0.001	0.408

[1] A total of 1,080 barrows and gilts (PIC; 337 × Camborough, initial pen average BW of 25.2 ± 0.64 lb) were used in a 21-d growth trial with 23 to 27 pigs per pen and 6 pens per treatment. Two groups of pigs were weaned at approximately 21 d of age, fed a common phase 1 and phase 2 diet for 21 or 24 d post-weaning, then fed experimental diets.

[2] Low (0.26% STTD P) and high (0.53% STTD P) diets were blended at the farm by a robotic feeding system to create the 0.30, 0.33, 0.38, 0.43, and 0.48% STTD P dietary treatments.

[3] 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 80, 90, 100, 115, 130, 145, and 160% of the NRC (2012) requirement.

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

[5] Total revenue per pig = total gain multiplied by an assumed live price of $47 per cwt.

[6] IOFC = income over feed cost.

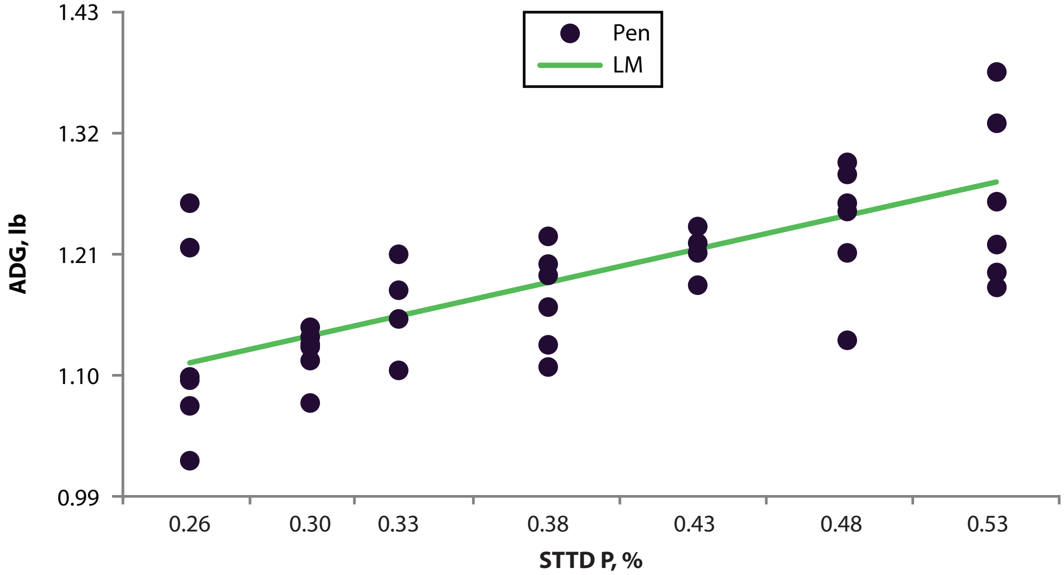

Figure 1. Fitted linear (LM) regression model on ADG as a function of increasing standardized total tract digestible (STTD) P in 25- to 50-lb pigs. The maximum mean ADG was estimated at greater than 0.53% STTD P. Based on the best fitting model, the estimated regression equation was ADG, lb = 0.98 + 0.55 × (STTD P).

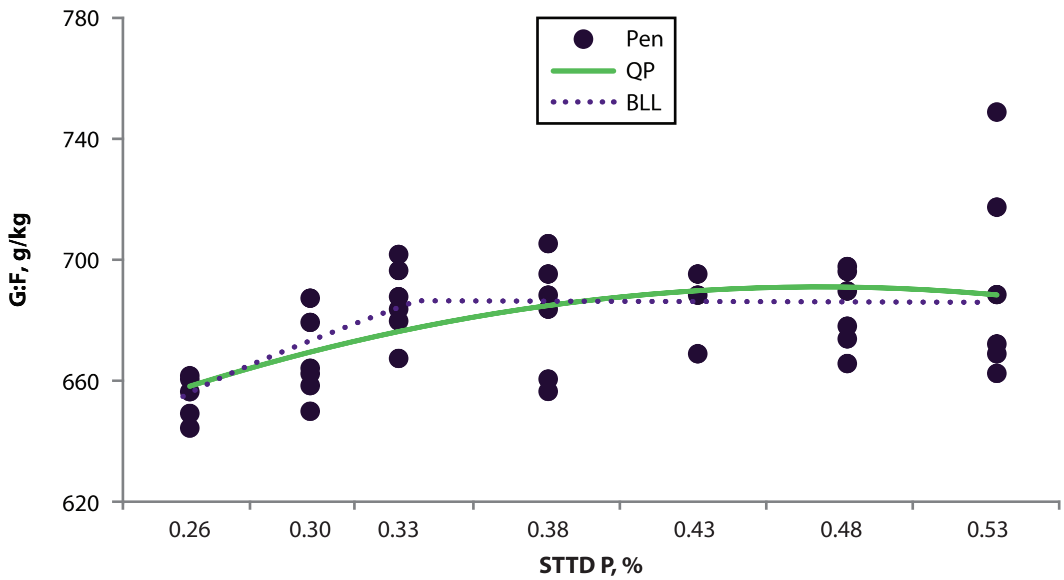

Figure 2. Fitted quadratic polynomial (QP) and broken-line linear (BLL) regression models on G:F as a function of increasing standardized total tract digestible (STTD) P in 25- to 50-lb pigs. The QP model estimated the maximum mean G:F at 0.42% (95% CI: [0.36, >0.53]%), with 99% of maximum G:F achieved at 0.36%. The estimated regression equation was G:F, g/kg = 456.59 + 1107.49 × (STTD P) – 1307.16 × (STTD P)^2. The BLL plateau was estimated at 0.34% (95% CI: [0.30, 0.37]%).