[Kansas Agricultural Experiment Station Research Reports](https://newprairiepress.org/kaesrr)

Volume 4
Issue 9 *Swine Day*

Article 18

2018

Effects of Dietary Total Calcium to Total Phosphorus Ratio on Growth Performance, Carcass Characteristics, Bone Mineralization, and Economics in 58- to 281-lb Pigs

C. M. Vier
Kansas State University, Manhattan, carinevier@k-state.edu

S. S. Dritz
Kansas State University, Manhattan, dritz@k-state.edu

M. D. Tokach
Kansas State University, Manhattan, mtokach@k-state.edu

See next page for additional authors

Recommended Citation

Vier, C. M.; Dritz, S. S.; Tokach, M. D.; Gonçalves, M. A.; Orlando, U. A.; Bergstrom, J. R.; Woodworth, J. C.; Goodband, R. D.; and DeRouchey, J. M. (2018) "Effects of Dietary Total Calcium to Total Phosphorus Ratio on Growth Performance, Carcass Characteristics, Bone Mineralization, and Economics in 58- to 281-lb Pigs," *Kansas Agricultural Experiment Station Research Reports*: Vol. 4: Iss. 9. https://doi.org/10.4148/2378-5977.7666

Effects of Dietary Total Calcium to Total Phosphorus Ratio on Growth Performance, Carcass Characteristics, Bone Mineralization, and Economics in 58- to 281-lb Pigs

Abstract

A total of 1,134 barrows and gilts (PIC; 359 × Camborough) with an initial pen average body weight (BW) of 58.0 ± 1.57 lb were used in a 110-d growth trial to determine the effects of feeding different analyzed total calcium to phosphorus (Ca:P) ratios on performance of growing-finishing pigs from 58 to 281 lb. Pens of pigs were randomly assigned to 1 of 6 dietary treatments in a randomized complete block design with BW as a blocking factor. There were 7 replicate pens per treatment and 27 pigs per pen. The experimental diets were corn-soybean meal-based, and were fed in 4 phases. The 6 dietary treatments were formulated to contain 0:75:1, 1.00:1, 1.25:1, 1.50:1, 1.75:1, and 2.00:1 analyzed total Ca:P ratio. All diets were formulated to contain adequate standardized total tract digestible *P* across the dietary treatments in all phases. The treatments were achieved by increasing the amount of calcium carbonate at the expense of corn while maintaining monocalcium phosphate constant. Overall, increasing analyzed total Ca:P ratio increased (quadratic, $P < 0.05$) average daily gain (ADG), average daily feed intake (ADFI), and final BW. The greatest increase was observed as the ratio increased from 0.75:1 to 1.25:1, and decreased with higher ratios. Feed efficiency was relatively similar across analyzed total Ca:P ratios of 0.75:1 to 1.75:1, and worsened (quadratic, $P < 0.05$) at the highest ratio of 2.00:1. For carcass characteristics, hot carcass weight (HCW) and carcass ADG increased (quadratic, $P < 0.05$) as the analyzed total Ca:P ratio increased up to 1.25:1 and started to decrease thereafter. Carcass yield decreased (quadratic, $P < 0.05$) with increasing analyzed total Ca:P ratio. Bone mineralization increased quadratically ($P < 0.05$) with increasing analyzed total Ca:P ratio. The greatest improvement in bone ash was observed as the ratio increased from 0.75:1 to 1.25:1, with little increase thereafter. Feed cost per pig increased quadratically ($P < 0.05$) and feed cost per pound of gain increased linearly ($P < 0.05$) with increasing analyzed total Ca:P ratio, with the highest feed cost and cost per pound of gain observed at 2.00:1. Gain value and income over feed cost (IOFC) increased quadratically ($P < 0.05$), with the greatest revenue observed for pigs fed diets with 1.25:1 analyzed total Ca:P ratio, and IOFC for pigs fed 1.00:1 analyzed total Ca:P ratio. For ADG, ADFI, feed efficiency (modeled as gain-to-feed ratio, G:F), and bone ash the quadratic polynomial model demonstrated the best fit. The maximum responses in ADG, ADFI, G:F, HCW, IOFC, and bone ash were estimated at 1.38:1, 1.49:1, 1.29:1, 1.25:1, 1.10:1, and 1.93:1 analyzed total Ca:P ratio, respectively. In conclusion, for growing-finishing pigs from 53 to 287 lb, the total analyzed Ca:P ratio ranged from 1.10:1 to 1.49:1 to maximize growth performance, HCW, and IOFC criteria. A higher analyzed total Ca:P ratio, estimated at 1.93:1, was required to maximize bone mineralization.

Keywords

calcium, phosphorus, finishing pigs, growth performance, bone ash

Cover Page Footnote

Appreciation is expressed to Genus PIC and DSM Nutritional Products Inc. for partial funding, to New Horizon Farms for use of the feed mill and animal facilities, and to Marty Heintz, Whitney Adler and Heath Houselog for technical assistance.

Authors

C. M. Vier, S. S. Dritz, M. D. Tokach, M. A. Gonçalves, U. A. Orlando, J. R. Bergstrom, J. C. Woodworth, R. D. Goodband, and J. M. DeRouchey

Effects of Dietary Total Calcium to Total Phosphorus Ratio on Growth Performance, Carcass Characteristics, Bone Mineralization, and Economics in 58- to 281-lb Pigs[1]

C.M. Vier,[2] S.S. Dritz,[2] M.D. Tokach, M.A.D Gonçalves,[3] U.A.D. Orlando,[3] J.R. Bergstrom,[4] J.C. Woodworth, R.D. Goodband, and J.M. DeRouchey

Summary

A total of 1,134 barrows and gilts (PIC; 359 × Camborough) with an initial pen average body weight (BW) of 58.0 ± 1.57 lb were used in a 110-d growth trial to determine the effects of feeding different analyzed total calcium to phosphorus (Ca:P) ratios on performance of growing-finishing pigs from 58 to 281 lb. Pens of pigs were randomly assigned to 1 of 6 dietary treatments in a randomized complete block design with BW as a blocking factor. There were 7 replicate pens per treatment and 27 pigs per pen. The experimental diets were corn-soybean meal-based, and were fed in 4 phases. The 6 dietary treatments were formulated to contain 0:75:1, 1.00:1, 1.25:1, 1.50:1, 1.75:1, and 2.00:1 analyzed total Ca:P ratio. All diets were formulated to contain adequate standardized total tract digestible P across the dietary treatments in all phases. The treatments were achieved by increasing the amount of calcium carbonate at the expense of corn while maintaining monocalcium phosphate constant. Overall, increasing analyzed total Ca:P ratio increased (quadratic, $P < 0.05$) average daily gain (ADG), average daily feed intake (ADFI), and final BW. The greatest increase was observed as the ratio increased from 0.75:1 to 1.25:1, and decreased with higher ratios. Feed efficiency was relatively similar across analyzed total Ca:P ratios of 0.75:1 to 1.75:1, and worsened (quadratic, $P < 0.05$) at the highest ratio of 2.00:1. For carcass characteristics, hot carcass weight (HCW) and carcass ADG increased (quadratic, $P < 0.05$) as the analyzed total Ca:P ratio increased up to 1.25:1 and started to decrease thereafter. Carcass yield decreased (quadratic, $P < 0.05$) with increasing analyzed total Ca:P ratio. Bone mineralization increased quadratically ($P < 0.05$) with increasing analyzed total Ca:P ratio. The greatest improvement in bone ash was observed as the

[1]Appreciation is expressed to Genus PIC and DSM Nutritional Products Inc. for partial funding, to New Horizon Farms for use of the feed mill and animal facilities, and to Marty Heintz, Whitney Adler and Heath Houselog for technical assistance.

[2]Department of Diagnostic Medicine/Pathobiology, College of Veterinary Medicine, Kansas State University.

[3]Genus PIC, Hendersonville, TN 37075.

[4]DSM Nutritional Products Inc., Parsippany, NJ 07054.

ratio increased from 0.75:1 to 1.25:1, with little increase thereafter. Feed cost per pig increased quadratically ($P < 0.05$) and feed cost per pound of gain increased linearly ($P < 0.05$) with increasing analyzed total Ca:P ratio, with the highest feed cost and cost per pound of gain observed at 2.00:1. Gain value and income over feed cost (IOFC) increased quadratically ($P < 0.05$), with the greatest revenue observed for pigs fed diets with 1.25:1 analyzed total Ca:P ratio, and IOFC for pigs fed 1.00:1 analyzed total Ca:P ratio. For ADG, ADFI, feed efficiency (modeled as gain-to-feed ratio, G:F), and bone ash the quadratic polynomial model demonstrated the best fit. The maximum responses in ADG, ADFI, G:F, HCW, IOFC, and bone ash were estimated at 1.38:1, 1.49:1, 1.29:1, 1.25:1, 1.10:1, and 1.93:1 analyzed total Ca:P ratio, respectively. In conclusion, for growing-finishing pigs from 53 to 287 lb, the total analyzed Ca:P ratio ranged from 1.10:1 to 1.49:1 to maximize growth performance, HCW, and IOFC criteria. A higher analyzed total Ca:P ratio, estimated at 1.93:1, was required to maximize bone mineralization.

Introduction

Calcium is the most abundant mineral in the body followed by phosphorus . These minerals are involved in many physiological functions such as protein synthesis, maintenance of osmotic and acid-base balances, components in membranes, and bone development and mineralization. Additional roles of Ca and P within the body include muscle contraction, transmission of nerve impulses, enzyme activation, and metabolic reactions. Moreover, an excess or deficiency of one mineral may affect the utilization of the other.[5]

To have an adequate absorption and utilization of both Ca and P, it is necessary to consider an appropriate Ca:P ratio when formulating diets for pigs. Research has shown that feeding excess Ca can result in reduced growth performance and bone mineralization,[6] especially when diets are marginally deficient in P.[7,8] A recent study has determined the requirement of standardized total tract digestible (STTD) P of growing-finishing pigs.[9] Therefore, the objective of the present study was to investigate the effects of feeding different Ca:P ratios in diets adequate in STTD P on growth performance, carcass characteristics, bone mineralization, and economics of growing-finishing pigs housed in a commercial environment.

---

[5]Crenshaw, T. D. 2001. Calcium, phosphorus, vitamin D, and vitamin K in swine nutrition. In: A. J. Lewis and L. L. Southern, editors, Swine nutrition. 2nd ed. CRC Press, Boca Raton, FL. p. 187–212.
[6]González-Vega, J. C., Y. Liu, J. C. McCann, C. L. Walk, J. J. Loor, and H. H. Stein. 2016. Requirement for digestible calcium by eleven- to twenty-five-kilogram pigs as determined by growth performance, bone ash concentration, calcium and phosphorus balances, and expression of genes involved in transport of calcium in intestinal and kidney cells. J. Anim. Sci. 94:33213334. doi:10.2527/jas.2016-0444.
[7]Wu, F., Tokach, M.D., Dritz, S. S., Woodworth, J. C., DeRouchey, J. M., Goodband, R. D., Gonçalves, M. A. D., and Bergstrom, J. R. 2018. Effects of dietary calcium to phosphorus ratio and addition of phytase on growth performance of nursery pigs. J. Anim. Sci. doi:10.1093/jas/sky101
[8]Merriman, L. A., Walk, C. L., Murphy, M. R., Parsons, C. M., & Stein, H. H. 2017. Inclusion of excess dietary calcium in diets for 100-to 130-kg growing pigs reduces feed intake and daily gain if dietary phosphorus is at or below the requirement. Journal of animal science, 95(12), 5439-5446.
[9]Vier C. M., Wu F., Menegat M. B., Cemin H., Dritz S. S., Tokach M. D., Gonçalves M. A. D., Orlando U. A. D., Woodworth J. C., Goodband R. D., DeRouchey J. M. 2017. Effects of standardized total tract digestible phosphorus on performance, carcass characteristics, and economics of 24 to 130 kg pigs. Animal Production Science 57, 2424-2424. https://doi.org/10.1071/ANv57n12Ab071

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. This experiment was conducted at a commercial research-finishing site in southwestern Minnesota. The barn was naturally ventilated and double-curtain-sided. Pens had completely slatted flooring and deep pits. Each pen was equipped with a 5-hole stainless steel feeder and cup 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 measuring and recording daily feed additions to individual pens.

A total of 1,134 barrows and gilts (PIC; 359 × Camborough, initial pen average BW of 58.0 ± 1.57 lb) were used in a 110-d growth trial. Upon arrival (38 lb), pigs were fed a common diet containing 0.66% total Ca and 0.42% STTD P until the initiation of the trial. On d 0, pigs were weighed in pens, and pens were ranked by average pig BW. Pens were then randomly allotted to 1 of 6 dietary treatments in a randomized complete block design, with BW as a blocking factor. There were 7 replicate pens per treatment and 27 pigs per pen.

A total of 3 samples of all the ingredients used in the diets that contained Ca and P were analyzed for Ca and P in duplicate (Ward Laboratories, Inc., Kearney, NE; Table 1). The average of the six lab results for each ingredient was used for diet formulation. The experimental diets were corn-soybean meal-based, and fed in 4 different phases (Tables 2, 3, 4, and 5). The diets were formulated to contain adequate STTD P across the dietary treatments in all phases based on the estimated requirement previously determined in this facility.[9] Thus, formulated STTD P levels were 0.38, 0.33, 0.29, and 0.25% for phases 1, 2, 3, and 4, respectively. Phase 1 diets were fed from d 0 to 28 (58.0 to 110.6 lb); phase 2 diets were fed from d 29 to 56 (110.6 to 172.4 lb); phase 3 diets were fed from d 57 to 85 (172.4 to 237.7 lb); and phase 4 diets were fed from d 86 to 110 (237.7 to 281.4 lb). The analyzed total Ca:P ratios were achieved by increasing the amount of calcium carbonate at the expense of corn while maintaining monocalcium phosphate constant. Experimental diets were manufactured at the New Horizon Farms Feed Mill (Pipestone, MN) and fed in meal form. 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 each phase and stored at -4°F. After blending, 6 subsamples were analyzed in duplicates for dry matter (DM), crude protein (CP), crude fiber, ash, ether extract, Ca, and P, and average values were reported (Tables 6 and 7; Ward Laboratories, Inc., Kearney, NE, and Midwest Laboratories, Omaha, NE).

Pens of pigs were weighed and feed disappearance was recorded on d 0, 28, 56, 85, and 110 to determine ADG, ADFI, and F/G. On d 86, the 2 heaviest pigs in each pen were selected, weighed, and sold according to standard farm procedures. On d 110, final pen weights were taken and one barrow and one gilt with intermediate weights were selected, tattooed with a pen ID and marketed for bone data collection. These pigs were transported to a commercial abattoir in northwest Iowa (Natural Foods, Sioux Center, IA) for processing and collection of metacarpal bone samples for analysis of their mineral content. The remaining pigs were individually tattooed with the specific pen identity on the shoulder to allow for carcass measurements to be recorded on a pen basis. These pigs were transported to a commercial packing plant in southwestern

Minnesota (JBS Swift and Company, Worthington, MN) for processing and carcass data collection. Carcass measurements included HCW, loin depth, backfat depth, and percentage lean. Percentage carcass yield was calculated by dividing the average pen HCW by the average final live weight at the farm. Carcass ADG was calculated by multiplying the overall ADG by percentage carcass yield. Carcass F/G was calculated by dividing the overall ADFI by carcass ADG.

Bones were collected following processing for mineralization analysis. The left front feet were separated at the junction of carpals and radius and ulna, and individually placed in a zip-lock plastic bag with a permanent identification tag within the bag, then stored at -20°C. Feet were thawed overnight, and then were autoclaved for 1 h at 121°C. The third metacarcapal of each foot were removed. These bones were cleaned of extraneous soft tissue, and refrozen. When it was time to process, bones were dried at ambient temperature for 24 h, cut in half, and weighed. They were wrapped in cheesecloth to keep their tag ID and defatted by petroleum ether using a Soxhlet apparatus for 7 d. De-fatted metacarpals were placed in a 105°C drying oven for another 7 d to determine the dry fat-free weight. Bones were then ashed in a muffle furnace at 600°C for 24 h to determine percentage ash. Ash is expressed as a percentage of dried fat-free bone weight.

For the economic analysis, total feed cost per pig, cost per lb of gain, gain value, and income over feed cost (IOFC) were calculated. The total feed cost per pig was calculated by multiplying ADFI by feed cost per pound and number of days the diet was fed in each respective period, then taking the sum of these values for each period. Cost per lb of gain was calculated by dividing total feed cost per pig by total gain per pig. Gain value per pig was calculated by multiplying carcass gain by an assumed carcass value of $58.35 per cwt. To calculate IOFC, total feed cost was subtracted from gain value. For all economic evaluations, prices of ingredients during spring of 2018 were used with corn 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, monocalcium phosphate at $0.29/lb, and calcium carbonate at $0.02/lb.

Growth performance data were analyzed as a randomized complete block design, with pen considered the experimental unit and BW the blocking factor. The study was structured as a split-plot design in a randomized complete block design for the bone data. The whole-plot treatments included the different analyzed Ca:P ratios. Within each of the dietary treatments, there was a one-way treatment structure with gender as the factor level. A random effect of block by treatment was used to identify the pair of pigs (one barrow and one gilt) within each pen as the experimental unit for gender. The two-way interaction between dietary treatments and gender was tested, and no significant interactions were observed. Response variables were analyzed using generalized linear and non-linear mixed models. Polynomial contrasts were implemented to evaluate the functional form of the dose response to increasing dietary total Ca:P on growth performance, carcass characteristics, and economic response variables. 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 analyzed total Ca:P dose response on ADG, feed efficiency (modeled as gain to feed, G:F), and percentage bone ash were fit using GLIMMIX and NLMIXED procedure of SAS according to Gonçalves et al.[10] 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.[11] 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, crude fiber, fat, and ash contents of experimental diets (Tables 6 and 7) showed that values were reasonably consistent with formulated estimates. Average values of analyzed Ca and P concentrations were slightly greater than the formulated values; however, they followed similar patterns as the designed treatment structure. The average Ca:P ratio across the four phases were 77, 102, 125, 155, 177, and 207% for the 75, 100, 125, 150, 175, and 200% treatments, respectively.

During the grower period, which corresponds to phases 1 and 2 (d 0 to 56), there was no evidence of differences ($P > 0.05$) in ADG as analyzed total Ca:P ratio increased (Table 8). On the other hand, increasing the analyzed total Ca:P ratio resulted in a marginal linear increase ($P < 0.10$) in ADFI, and in a quadratic change ($P < 0.05$) in F/G. The greatest improvement in feed efficiency occurred as the analyzed total Ca:P ratio increased from 0.75:1 to 1.00:1, and then it worsens at the highest ratio of 2.00:1 analyzed total Ca:P.

During the finisher period, which corresponds to phases 3 and 4 (d 56 to 110), increasing analyzed total Ca:P ratio resulted in an increase ($P < 0.05$) in ADG driven by an increase ($P < 0.05$) in ADFI, both in a quadratic manner. The greatest improvement occurred as the analyzed total Ca:P ratio increased from 0.75:1 to 1.25:1 for ADG and from 0.75:1 to 1.00:1 for ADFI, with no improvement thereafter. In contrast, F/G was not affected ($P > 0.05$) by the dietary treatment. Overall, increasing the analyzed total Ca:P ratio increased (quadratic, $P < 0.05$) ADG, ADFI, and final BW. The greatest increase was observed as the ratio increased from 0.75:1 to approximately 1.25:1, with no further improvement. Similarly, feed efficiency was relatively flat from an analyzed total Ca:P ratio of 0.75:1 to 1.75:1, starting to worsen (quadratic, $P < 0.05$) at the highest ratio of 2.00:1.

For carcass characteristics, HCW increased (quadratic, $P < 0.05$) as the analyzed total Ca:P ratio increased up to 1.25:1, and started to decrease thereafter. Similarly, carcass

---

[10]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.

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

ADG increased quadratically ($P < 0.05$), with the greatest response observed at 1.25:1 analyzed total Ca:P ratio. Percentage carcass yield decreased (quadratic, $P < 0.05$) from 0.75:1 analyzed total Ca:P ratio to 1.50:1, with no further changes. There was also a marginally significant response (quadratic, $P < 0.10$) in loin depth, with the greatest improvement occurring up to 1.50:1 analyzed total Ca:P ratio. No statistically significant differences ($P > 0.10$) were observed for carcass F/G, backfat, and fat-free lean measurements.

Feed cost per pig increased (quadratic, $P < 0.05$) with increasing analyzed total Ca:P ratio, with the highest feed cost observed at 2.00:1. Feed cost per pound of gain increased linearly ($P < 0.05$) up to the highest analyzed total Ca:P ratio. On the contrary, gain value per pig increased (quadratic, $P < 0.05$) with the greatest revenue observed for pigs fed diets with 1.25:1 analyzed total Ca:P ratio, which is a result of the quadratic improvement in ADG and final BW. The increased gain value was sufficient to overcome the increased cost, resulting in a quadratic improvement ($P < 0.05$) in IOFC, with the highest income observed at 1.00:1 analyzed total Ca:P ratio.

For bone mineralization, the two-way interaction between dietary treatment and gender was tested and no evidence ($P > 0.10$) for significant interaction was observed (Table 8). There was also no evidence ($P > 0.10$) for a significant gender effect on percentage bone ash (62.09 and 61.98% for barrows and gilts, respectively). Bone mineralization increased quadratically ($P < 0.05$) with increasing analyzed total Ca:P ratio. The greatest improvement in percentage bone ash was observed as analyzed total Ca:P ratio increased from 0.75:1 to 1.25:1, with little increase thereafter.

Homogeneous variance was used for ADG models and heterogeneous variance was used for ADFI, feed efficiency, HCW, IOFC, and bone ash models. The best fitting model for all these response criteria was the QP (Figures 1, 2, 3, 4, 5, and 6, respectively). The analyzed total Ca:P ratio for maximum ADG was estimated at 1.38:1 (95% CI: [1.00:1, 1.75:1]), with 99% of the maximum response being achieved at 1.04:1. Based on the best fitting model, the estimated regression equation was ADG, $g = 806.20 + 222.10 \times (Ca:P) - 80.5513 \times (Ca:P)^2$. The QP model estimated the maximum mean ADFI at 1.49 Ca:P ratio (95% CI: [0.90:1, >2.00:1]), with 99% of maximum ADFI achieved at 0.95:1 Ca:P. The estimated regression equation was ADFI, $g = 2219.21 + 245.73 \times (Ca:P) - 82.6743 \times (Ca:P)^2$. The analyzed total Ca:P ratio for maximum G:F was estimated at 1.29 Ca:P ratio (95% CI: [<0.75:1, >2.00:1]). The estimated regression equation was G:F, $g/kg = 376.77 + 33.5039 \times (Ca:P) - 13.0113 \times (Ca:P)^2$. The QP model estimated the maximum mean HCW at 1.25 Ca:P ratio (95% CI: [0.86:1, 1.72:1]). The estimated regression equation was HCW, $lb = 193.71 + 25.0413 \times (Ca:P) - 10.0143 \times (Ca:P)^2$. The analyzed total Ca:P ratio for maximum IOFC was estimated at 1.10:1 (95% CI: [1.00:1, 1.75:1]). Based on the best fitting model, the estimated regression equation was IOFC, $\$/pig = 29.32 + 9.9693 \times (Ca:P) - 4.53039 \times (Ca:P)^2$. The model estimated the maximum mean percentage bone ash at 1.93:1 Ca:P ratio (95% CI: [1.40:1, >2.00:1]). The estimated regression equation was bone ash, $\% = 58.91 + 3.67229 \times (Ca:P) - 0.95170 \times (Ca:P)^2$.

Increasing the analyzed total Ca:P ratio quadratically improved ADG, ADFI, final BW, HCW, as well as carcass ADG, yield, loin depth, and bone ash. Although feed cost increased with increasing analyzed total Ca:P ratios, the improved value in gain was sufficient to overcome the increase in diet cost. Thus, the return over the feed cost increased quadratically with increasing analyzed total Ca:P ratio. In conclusion, the estimated total Ca:P ratio requirement for finishing pigs from 58 to 281 lb when fed diets adequate in STTD P ranged from 1.10:1 to 1.49:1 to maximize growth performance, HCW, and IOFC criteria. To maximize bone mineralization, a higher analyzed total Ca:P ratio was required, which was estimated at 1.93:1.

Table 1. Analyzed Ca and P concentrations in feed ingredients (as-fed basis)[1]

Item	Ca, %	P, %
Corn	0.03	0.22
Soybean meal, 46.5% crude protein	0.51	0.65
Monocalcium P (21% P)	15.23	18.78
Limestone	34.64	0.07
Vitamin and trace mineral premix	6.21	0.02

[1]A total of six samples of each ingredient were submitted to Ward Laboratories, Inc. (Kearney, NE) and were analyzed in duplicate for Ca and P concentration. Average values were reported and were used in diet formulation.

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

	Phase 1					
	Analyzed Ca:P ratio					
Item	0.75:1	1.00:1	1.25:1	1.50:1	1.75:1	2.00:1
Ingredient, %						
Corn	67.09	66.28	65.47	64.72	63.92	63.12
Soybean meal, 46.5% crude protein	29.97	30.03	30.08	30.13	30.19	30.25
Beef tallow	0.50	0.80	1.10	1.35	1.65	1.95
Monocalcium phosphate, 21% P	1.25	1.25	1.25	1.25	1.25	1.25
Limestone	0.20	0.65	1.10	1.55	1.99	2.44
Sodium chloride	0.35	0.35	0.35	0.35	0.35	0.35
L-Lysine HCl	0.30	0.30	0.30	0.30	0.30	0.30
DL-Methionine	0.09	0.09	0.09	0.09	0.09	0.10
L-Threonine	0.10	0.10	0.10	0.10	0.10	0.10
L-Tryptophan	0.01	0.01	0.01	0.01	0.01	0.01
Vitamin and trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis						
Standardized ileal digestible (SID) amino acids, %						
Lysine	1.15	1.15	1.15	1.15	1.15	1.15
Isoleucine:lysine	63	63	63	63	63	63
Leucine:lysine	132	131	131	130	130	130
Methionine:lysine	32	32	32	32	32	32
Methionine and cysteine:lysine	56	56	56	56	56	56
Threonine:lysine	62	62	62	62	62	62
Tryptophan:lysine	18.9	18.9	18.9	18.9	18.9	18.9
Valine:lysine	69	69	68	68	68	68
Total lysine, %	1.29	1.29	1.29	1.29	1.29	1.29
ME, kcal/lb[2]	1,510	1,509	1,509	1,508	1,507	1,507
NE, kcal/lb[2]	1,120	1,120	1,120	1,120	1,120	1,120
SID Lysine:ME, g/Mcal	3.46	3.46	3.46	3.46	3.46	3.46
Crude protein, %	19.4	19.4	19.3	19.3	19.3	19.3
Calcium, %	0.48	0.64	0.80	0.96	1.11	1.27
STTD Ca,[3] %	0.36	0.49	0.61	0.73	0.85	0.97
Phosphorus, %	0.64	0.64	0.64	0.64	0.63	0.63
STTD P,[4] %	0.38	0.38	0.38	0.38	0.38	0.38
Available phosphorus, %	0.32	0.32	0.32	0.32	0.32	0.32
Calcium:phosphorus	0.75	1.00	1.25	1.50	1.75	2.00
STTD Ca:STTD P	0.95	1.27	1.59	1.92	2.24	2.56

[1]Phase 1 diets were fed from d 0 to 28 (58.0 to 110.6 lb).
[2]ME = metabolizable energy. NE = net energy.
[3]Standardized total tract digestible calcium.
[4]Standardized total tract digestible phosphorus.

Table 3. Diet formulation, Phase 2 (as-fed basis)[1]

	Phase 2					
	Analyzed Ca:P ratio					
Item	0.75:1	1.00:1	1.25:1	1.50:1	1.75:1	2.00:1
Ingredient, %						
Corn	75.42	74.74	74.04	73.34	72.63	71.94
Soybean meal, 46.5% crude protein	21.79	21.84	21.89	21.94	21.99	22.04
Beef tallow	0.50	0.75	1.00	1.25	1.50	1.75
Monocalcium phosphate, 21% P	1.08	1.08	1.08	1.08	1.08	1.08
Limestone	0.25	0.64	1.04	1.44	1.84	2.23
Sodium chloride	0.35	0.35	0.35	0.35	0.35	0.35
L-Lysine HCl	0.30	0.30	0.30	0.30	0.30	0.30
DL-Methionine	0.06	0.06	0.06	0.06	0.07	0.07
L-Threonine	0.09	0.09	0.09	0.10	0.10	0.10
L-Tryptophan	0.01	0.01	0.01	0.01	0.01	0.01
Vitamin and trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis						
Standardized ileal digestible (SID) amino acids, %						
Lysine	0.95	0.95	0.95	0.95	0.95	0.95
Isoleucine:lysine	62	62	62	62	62	62
Leucine:lysine	139	139	138	138	138	137
Methionine:lysine	32	32	32	32	32	32
Methionine and cysteine:lysine	57	57	57	57	57	57
Threonine:lysine	63	63	63	63	63	63
Tryptophan:lysine	18.6	18.6	18.6	18.6	18.6	18.6
Valine:lysine	69	69	69	69	69	69
Total lysine, %	1.07	1.07	1.07	1.07	1.07	1.07
ME, kcal/lb[2]	1,515	1,515	1,514	1,513	1,513	1,512
NE, kcal/lb[2]	1,143	1,143	1,143	1,143	1,143	1,143
SID Lysine:ME, g/Mcal	2.84	2.85	2.85	2.85	2.85	2.85
Crude protein, %	16.0	16.0	16.0	16.0	16.0	15.9
Calcium, %	0.43	0.56	0.70	0.84	0.98	1.12
STTD Ca,[3] %	0.32	0.42	0.53	0.64	0.75	0.85
Phosphorus, %	0.57	0.57	0.56	0.56	0.56	0.56
STTD P,[4] %	0.33	0.33	0.33	0.33	0.33	0.33
Available phosphorus, %	0.28	0.28	0.28	0.28	0.28	0.28
Calcium:phosphorus	0.75	1.00	1.25	1.50	1.75	2.00
STTD Ca:STTD P	0.95	1.28	1.61	1.94	2.27	2.60

[1]Phase 2 diets were fed from d 29 to 56 (110.6 to 172.4 lb).
[2]ME = metabolizable energy. NE = net energy.
[3]Standardized total tract digestible calcium.
[4]Standardized total tract digestible phosphorus.

Table 4. Diet formulation, Phase 3 (as-fed basis)[1]

	Phase 3					
	Analyzed Ca:P ratio					
Item	0.75:1	1.00:1	1.25:1	1.50:1	1.75:1	2.00:1
Ingredient, %						
Corn	80.49	79.86	79.23	78.61	77.93	77.33
Soybean meal, 46.5% crude protein	16.88	16.92	16.97	17.01	17.06	17.10
Beef tallow	0.50	0.73	0.95	1.18	1.45	1.65
Monocalcium phosphate, 21% P	0.90	0.90	0.90	0.90	0.90	0.90
Limestone	0.28	0.64	1.00	1.35	1.70	2.06
Sodium chloride	0.35	0.35	0.35	0.35	0.35	0.35
L-Lysine HCl	0.30	0.30	0.30	0.30	0.30	0.30
DL-Methionine	0.04	0.04	0.04	0.04	0.05	0.05
L-Threonine	0.10	0.10	0.10	0.10	0.10	0.10
L-Tryptophan	0.02	0.02	0.02	0.02	0.02	0.02
Vitamin and trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis						
Standardized ileal digestible (SID) amino acids, %						
Lysine	0.83	0.83	0.83	0.83	0.83	0.83
Isoleucine:lysine	61	61	61	61	61	61
Leucine:lysine	146	145	145	144	144	143
Methionine:lysine	31	31	31	31	32	32
Methionine and cysteine:lysine	58	58	58	58	58	58
Threonine:lysine	65	65	65	65	65	65
Tryptophan:lysine	18.7	18.7	18.6	18.6	18.6	18.6
Valine:lysine	70	70	69	69	69	69
Total lysine, %	0.94	0.94	0.94	0.94	0.94	0.94
ME, kcal/lb[2]	1,520	1,519	1,518	1,518	1,519	1,517
NE, kcal/lb[2]	1,158	1,158	1,158	1,158	1,158	1,158
SID Lysine:ME, g/Mcal	2.48	2.48	2.48	2.48	2.48	2.48
Crude protein, %	14.1	14.0	14.0	14.0	14.0	13.9
Calcium, %	0.38	0.51	0.64	0.76	0.88	1.01
STTD Ca,[3] %	0.28	0.37	0.47	0.57	0.66	0.76
Phosphorus, %	0.51	0.51	0.51	0.51	0.50	0.50
STTD P,[4] %	0.29	0.29	0.29	0.29	0.29	0.29
Available phosphorus, %	0.24	0.24	0.24	0.24	0.24	0.24
Calcium:phosphorus	0.75	1.00	1.25	1.50	1.75	2.00
STTD Ca:STTD P	0.96	1.30	1.65	1.99	2.33	2.68

[1]Phase 3 diets were fed from d 57 to 85 (172.4 to 237.7 lb).
[2]ME = metabolizable energy. NE = net energy.
[3]Standardized total tract digestible calcium.
[4]Standardized total tract digestible phosphorus.

Table 5. Diet formulation, Phase 4 (as-fed basis)[1]

	Phase 4					
	Analyzed Ca:P ratio					
Item	0.75:1	1.00:1	1.25:1	1.50:1	1.75:1	2.00:1
Ingredient, %						
Corn	80.91	80.34	79.77	79.14	78.58	78.02
Soybean meal, 46.5% crude protein	16.82	16.86	16.90	16.94	16.98	17.02
Beef tallow	0.50	0.70	0.90	1.15	1.35	1.55
Monocalcium phosphate, 21% P	0.68	0.68	0.68	0.68	0.68	0.68
Limestone	0.29	0.61	0.94	1.27	1.59	1.92
Sodium chloride	0.35	0.35	0.35	0.35	0.35	0.35
L-Lysine HCl	0.23	0.23	0.23	0.23	0.23	0.23
DL-Methionine	0.01	0.01	0.02	0.02	0.02	0.02
L-Threonine	0.08	0.08	0.08	0.08	0.08	0.08
L-Tryptophan	0.01	0.01	0.01	0.01	0.01	0.01
Vitamin and trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis						
Standardized ileal digestible (SID) amino acids, %						
Lysine	0.77	0.77	0.77	0.77	0.77	0.77
Isoleucine:lysine	66	66	66	66	65	65
Leucine:lysine	157	157	156	156	155	155
Methionine:lysine	30	30	30	30	30	30
Methionine and cysteine:lysine	59	59	59	59	59	59
Threonine:lysine	67	67	67	67	67	67
Tryptophan:lysine	18.8	18.8	18.8	18.8	18.8	18.8
Valine:lysine	75	75	75	75	75	74
Total lysine, %	0.88	0.88	0.88	0.88	0.88	0.88
ME, kcal/lb[2]	1,522	1,521	1,521	1,521	1,521	1,520
NE, kcal/lb[2]	1,160	1,160	1,160	1,160	1,160	1,160
SID Lysine:ME, g/Mcal	2.29	2.30	2.30	2.30	2.30	2.30
Crude protein, %	13.9	13.9	13.9	13.9	13.9	13.8
Calcium, %	0.35	0.46	0.58	0.69	0.81	0.92
STTD Ca,[3] %	0.25	0.34	0.43	0.52	0.60	0.69
Phosphorus, %	0.46	0.46	0.46	0.46	0.46	0.46
STTD P,[4] %	0.25	0.25	0.25	0.25	0.25	0.25
Available phosphorus, %	0.19	0.19	0.19	0.19	0.19	0.19
Calcium:phosphorus	0.75	1.00	1.25	1.50	1.75	2.00
STTD Ca:STTD P	1.00	1.36	1.72	2.09	2.45	2.81

[1]Phase 4 diets were fed from d 86 to 110 (237.7 to 281.4 lb).
[2]ME = metabolizable energy. NE = net energy.
[3]Standardized total tract digestible calcium.
[4]Standardized total tract digestible phosphorus.

Table 6. Analyzed composition of experimental diets (as-fed-basis)[1]

	Phase 1					
	Analyzed Ca:P ratio					
Item, %	0.75:1	1.00:1	1.25:1	1.50:1	1.75:1	2.00:1
Dry matter	86.50	86.75	86.95	86.90	87.20	87.15
Crude protein	20.75	21.60	21.80	21.40	21.55	21.25
Crude fiber	3.80	4.05	4.15	3.65	3.50	3.75
Ether extract	3.49	4.50	4.42	4.47	4.76	4.62
Ash	5.00	5.36	5.51	5.76	6.92	6.79
Calcium	0.49	0.74	1.08	1.24	1.37	1.74
Phosphorus	0.70	0.80	0.83	0.76	0.80	0.78
Ca:P ratio	0.70	0.93	1.30	1.63	1.71	2.23
	Phase 2					
Dry matter	86.05	86.20	86.20	86.65	86.20	86.40
Crude protein	17.40	18.10	17.70	17.00	17.80	17.60
Crude fiber	3.30	3.35	3.35	3.20	3.70	4.15
Ether extract	3.49	4.11	3.97	4.07	4.27	4.73
Ash	4.41	5.55	5.94	5.22	6.72	6.12
Calcium	0.62	0.97	0.85	1.12	1.31	1.33
Phosphorus	0.70	0.73	0.71	0.70	0.72	0.67
Ca:P ratio	0.89	1.33	1.20	1.60	1.82	1.99

[1]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 phase and stored at -4°F. After blending, subsamples were submitted to Ward Laboratories, Inc. (Kearney, NE) and Midwest Laboratories (Omaha, NE) and were analyzed for dry matter, crude protein, crude fiber, ash, ether extract, calcium, and phosphorus. Values represent the average across laboratory results.

Table 7. Analyzed composition of experimental diets (as-fed-basis)[1]

	Phase 3					
	Analyzed Ca:P ratio					
Item, %	0.75:1	1.00:1	1.25:1	1.50:1	1.75:1	2.00:1
Dry matter	86.60	86.75	86.80	86.80	86.95	87.40
Crude protein	15.85	16.15	15.70	15.45	16.15	16.00
Crude fiber	3.35	3.75	3.50	3.30	2.75	2.95
Ether extract	3.83	3.90	4.47	4.43	4.38	4.58
Ash	4.11	4.45	5.27	5.29	5.21	6.22
Calcium	0.47	0.68	0.74	0.95	1.03	1.33
Phosphorus	0.64	0.69	0.67	0.68	0.68	0.64
Ca:P ratio	0.73	0.99	1.10	1.40	1.51	2.08
	Phase 4					
Dry matter	86.65	86.25	86.75	86.65	86.85	86.75
Crude protein	15.90	16.35	15.60	15.80	15.20	16.25
Crude fiber	3.65	3.10	3.15	2.85	2.95	2.85
Ether extract	3.75	4.09	4.35	4.63	4.85	5.20
Ash	3.63	4.22	5.09	5.88	5.42	5.78
Calcium	0.41	0.48	0.73	0.88	1.12	1.13
Phosphorus	0.55	0.58	0.52	0.56	0.55	0.57
Ca:P ratio	0.75	0.83	1.40	1.57	2.04	1.98

[1]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 phase and stored at -4°F. After blending, subsamples were submitted to Ward Laboratories, Inc. (Kearney, NE) and Midwest Laboratories (Omaha, NE) and were analyzed for dry matter, crude protein, crude fiber, ash, ether extract, calcium, and phosphorus. Values represent the average across laboratory results.

Table 8. Effects of analyzed total Ca:P ratio on growth performance, carcass characteristics, and economics of growing-finishing pigs[1]

	Analyzed Ca:P ratio[2]							Probability, *P* =	
Item[3]	0.75:1	1.00:1	1.25:1	1.50:1	1.75:1	2.00:1	SEM	Linear	Quadratic
Grower period (d 0 to 56)									
ADG, lb	1.99	2.05	2.04	2.01	2.08	2.03	0.024	0.129	0.279
ADFI, lb	4.22	4.21	4.26	4.20	4.30	4.32	0.070	0.073	0.439
F/G	2.10	2.04	2.07	2.08	2.05	2.11	0.023	0.677	0.045
Finisher period (d 57 to 110)									
ADG, lb	2.08	2.15	2.19	2.17	2.10	2.05	0.007	0.001	0.001
ADFI, lb	6.20	6.57	6.55	6.48	6.30	6.32	0.082	0.708	0.002
F/G	3.01	3.08	3.01	3.01	3.04	3.12	0.062	0.367	0.360
Overall period (d 0 to 110)									
ADG, lb	2.04	2.11	2.12	2.09	2.10	2.06	0.023	0.952	0.005
ADFI, lb	5.15	5.31	5.33	5.28	5.25	5.25	0.063	0.483	0.028
F/G	2.53	2.52	2.52	2.52	2.51	2.57	0.025	0.435	0.045
BW, lb									
d 0	58.0	58.0	58.0	58.0	58.0	58.0	1.57	0.966	0.853
d 28	108.8	111.4	111.3	110.2	111.0	110.7	2.23	0.359	0.176
d 56	170.0	173.4	173.3	171.1	174.5	172.1	2.52	0.277	0.217
d 85	233.0	239.9	240.5	238.1	239.6	235.0	2.91	0.656	0.003
d 110	275.3	284.4	286.7	282.6	282.1	276.9	2.47	0.904	0.005
Carcass characteristics[4]									
Pig count	113	123	127	129	132	128			
HCW, lb	205.0	211.4	212.1	208.6	208.1	204.3	2.59	0.298	0.003
Yield, %	74.5	74.4	74.0	73.8	73.8	73.8	0.06	<0.001	<0.001
Carcass ADG, lb[5]	1.52	1.56	1.57	1.54	1.55	1.51	0.002	0.001	0.001
Carcass F/G[6]	3.40	3.39	3.40	3.42	3.40	3.48	0.031	0.050	0.189
Backfat, mm[8]	16.8	16.3	16.8	16.9	16.3	16.5	-[7]	0.584	0.823
Fat-free lean, %[8]	56.8	56.7	56.9	57.1	57.3	57.0	-[7]	0.236	0.832
Loin depth, mm[8]	68.4	69.0	68.8	70.9	69.7	68.3	-[7]	0.597	0.067

continued

Table 8. Effects of analyzed total Ca:P ratio on growth performance, carcass characteristics, and economics of growing-finishing pigs[1]

	Analyzed Ca:P ratio[2]							Probability, P =	
Item[3]	0.75:1	1.00:1	1.25:1	1.50:1	1.75:1	2.00:1	SEM	Linear	Quadratic
Economics, $/pig									
Feed cost	60.16	62.38	63.11	62.96	63.08	63.53	0.751	0.001	0.031
Feed cost/lb gain[9]	0.269	0.270	0.271	0.274	0.274	0.282	0.0027	<0.001	0.105
Gain value[10]	94.22	97.94	98.36	96.32	96.07	93.79	1.097	0.277	0.002
IOFC[11]	34.06	35.56	35.25	33.37	32.98	31.25	0.806	<0.001	0.007
Bone characteristics[12,13]									
Ash, %[14,15]	61.23	61.49	62.39	62.25	62.38	62.46	0.188	<0.001	0.017

[1]A total of 1,134 pigs (PIC 359 × Camborough, initial pen average BW of 58.0 lb) were used in a 110-d growth trial with 27 pigs per pen and 7 pens per treatment.
[2]Treatments were formulated to be adequate in standardized total tract digestible (STTD) P within phases, which corresponded to 0.38, 0.32, 0.29, and 0.26 % STTD P for phases 1, 2, 3, and 4, respectively.
[3]ADG = average daily gain. ADFI = average daily feed intake. F/G = feed-to-gain ratio. BW= body weight. HCW = hot carcass weight. IOFC = income over feed cost.
[4]907 pigs were transported to a commercial packing plant for processing and data collection (Swift and Company, Worthington, MN).
[5]Carcass average daily gain = overall average daily gain × carcass yield.
[6]Carcass F/G = overall average daily feed intake/carcass average daily gain.
[7]SEM for backfat were 0.31, 030, 0.29, 0.29, and 0.29. SEM for fat free lean were 0.30, 0.29, 0.28, 0.28, 0.28, and 0.28. SEM for loin depth were 0.84, 0.82, 0.81, 0.81, 0.80, and 0.81 for 0.75:1, 1.00:1, 1.25:1, 1.50:1, 1.75:1, and 2.00:1 analyzed total Ca:P, respectively.
[8]Adjusted for HCW.
[9]Feed cost/lb gain = total feed cost divided by total gain per pig.
[10]Gain value = (HCW × $0.5835) – (d 0 BW × 0.75 × $0.5835).
[11]Income over feed cost = gain value – feed cost.
[12]84 pigs (2 pigs/pen, 1 barrow/1 gilt) visually assumed to represent the mean live weight of the pen were subsampled and shipped to a separate processing facility for bone collection (Natural Foods Holdings, Inc., Sioux Center, IA).
[13]A total of 84 third metacarpals were autoclaved for 1 h. After cleaning, bones were placed in Soxhlets containing petroleum ether for 7 d as a means of removing water and fat. They were then dried at 105°C for 7 d, and then ashed at 600°C for 24 h.
[14]Adjusted for HCW.
[15]The two-way interaction and the effect of gender were tested and no evidence for significant effects was observed.

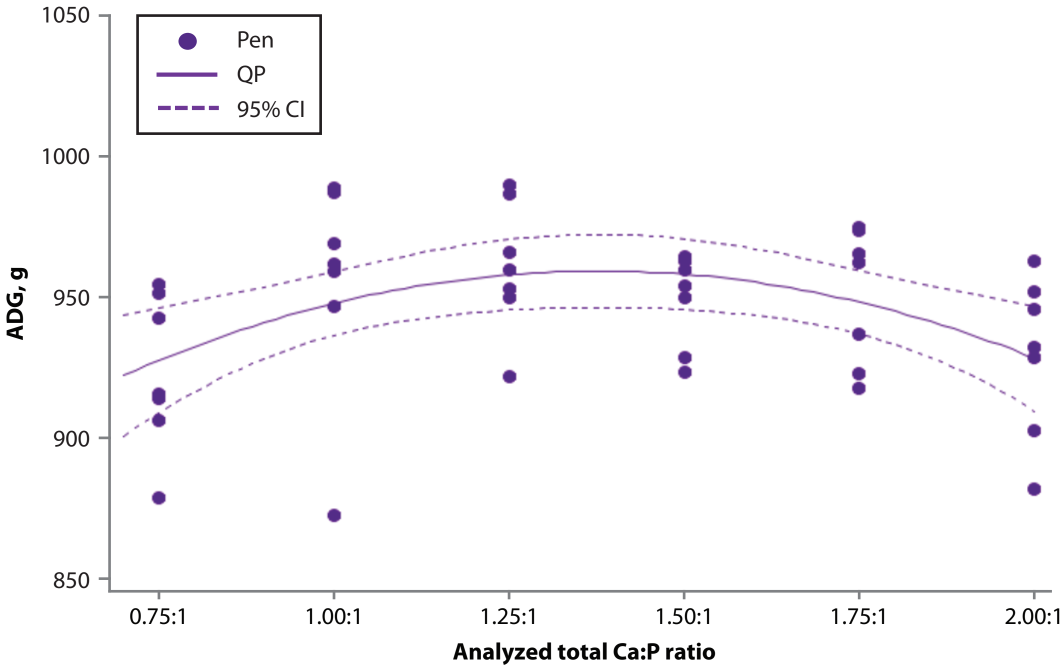

Figure 1. Fitted quadratic polynomial (QP) regression model on average daily gain (ADG) as a function of increasing analyzed total calcium to total phosphorus (Ca:P) ratio in growing-finishing pigs. The QP model estimated the maximum mean ADG at 1.38 Ca:P ratio (95% CI: [1.00:1, 1.75:1]), with 99% of maximum ADG achieved at 1.04 Ca:P. The estimated regression equation was ADG, g = 806.20 + 222.10 × (Ca:P) – 80.5513 × $(Ca:P)^2$.

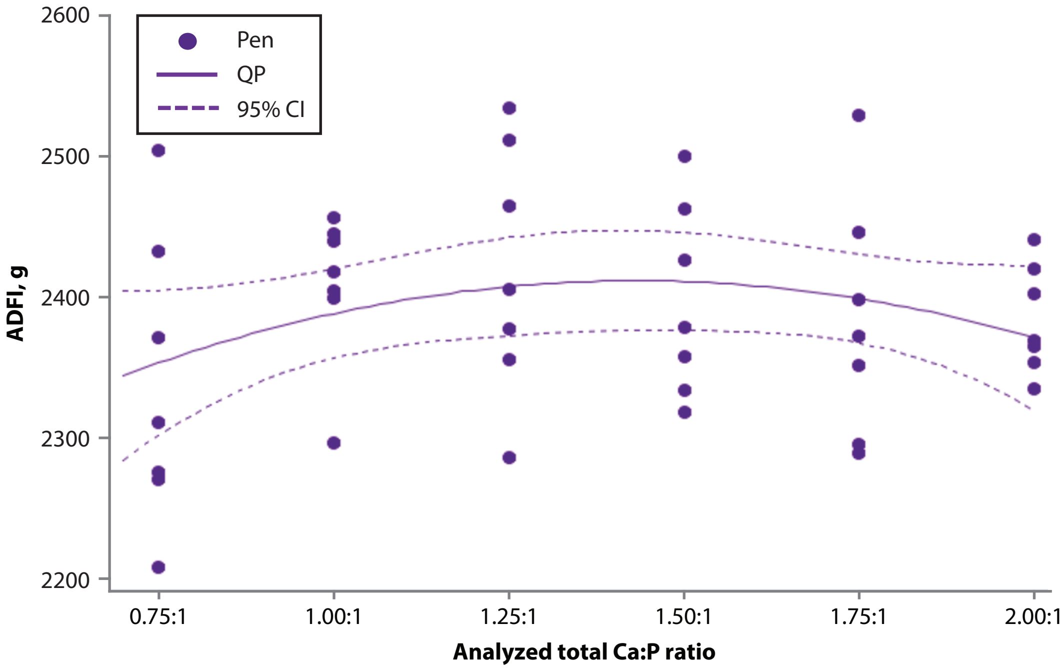

Figure 2. Fitted quadratic polynomial (QP) regression model on average daily feed intake (ADFI) as a function of increasing analyzed total calcium to total phosphorus (Ca:P) ratio in growing-finishing pigs. The QP model estimated the maximum mean ADFI at 1.49 Ca:P ratio (95% CI: [0.90:1, >2.00:1]), with 99% of maximum ADFI achieved at 0.95:1 Ca:P. The estimated regression equation was ADFI, g = 2219.21 + 245.73 × (Ca:P) – 82.6743 × $(Ca:P)^2$.

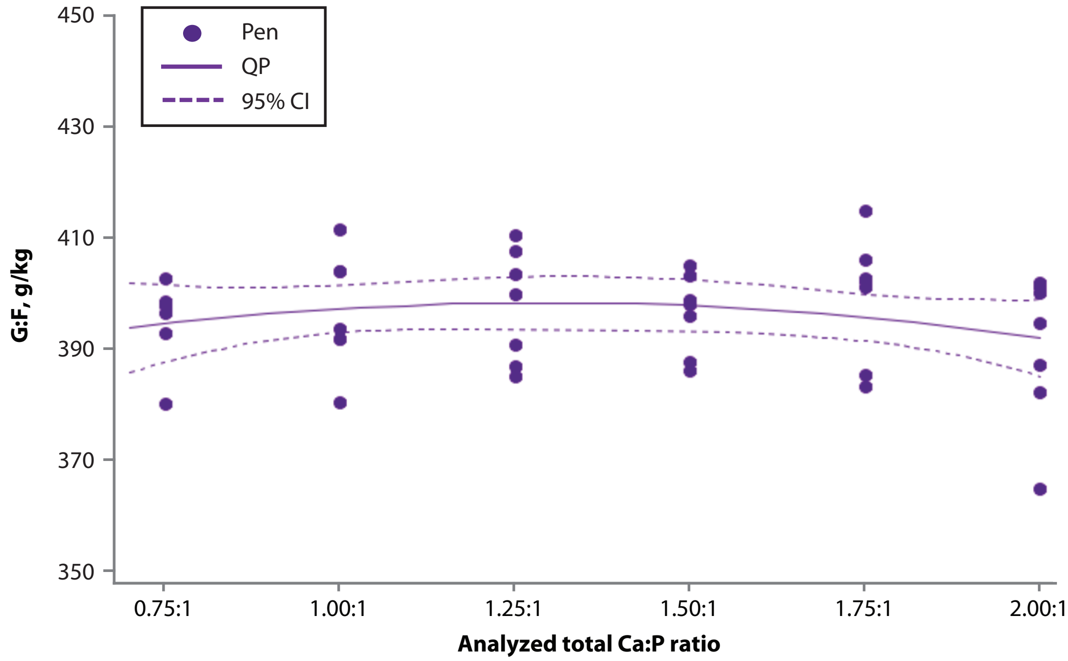

Figure 3. Fitted quadratic polynomial (QP) regression model on feed efficiency (G:F) as a function of increasing analyzed total calcium to total phosphorus (Ca:P) ratio in growing-finishing pigs. The QP model estimated the maximum mean G:F at 1.29 Ca:P ratio (95% CI: [<0.75:1, >2.00:1]). The estimated regression equation was G:F, g/kg = 376.77 + 33.5039 × (Ca:P) – 13.0113 × (Ca:P)^2.

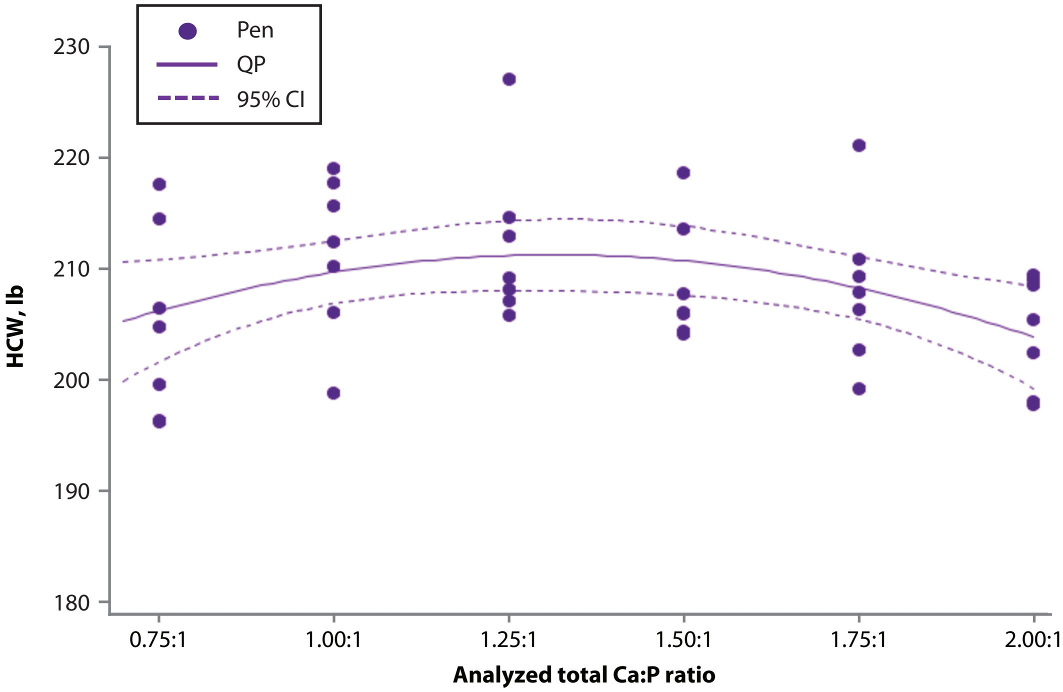

Figure 4. Fitted quadratic polynomial (QP) regression model on hot carcass weight (HCW) as a function of increasing analyzed total calcium to total phosphorus (Ca:P) ratio in growing-finishing pigs. The QP model estimated the maximum mean HCW at 1.25 Ca:P ratio (95% CI: [0.86:1, 1.72:1]). The estimated regression equation was HCW, lb = 193.71 + 25.0413 × (Ca:P) – 10.0143 × $(Ca:P)^2$.

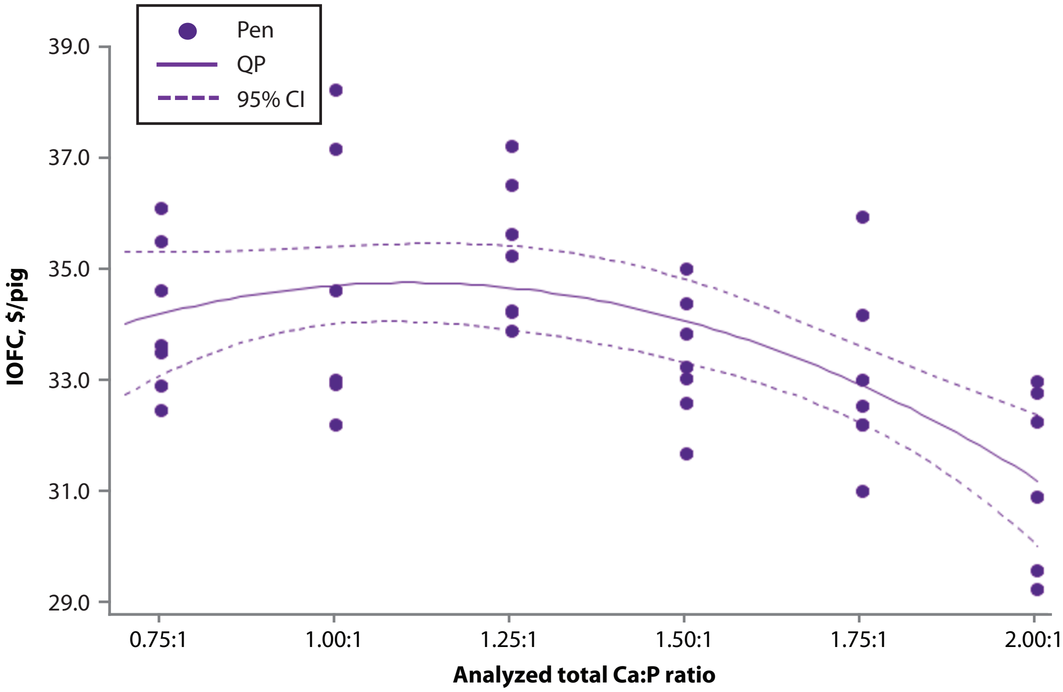

Figure 5. Fitted quadratic polynomial (QP) regression model on income over feed cost (IOFC) as a function of increasing analyzed total calcium to total phosphorus (Ca:P) ratio in growing-finishing pigs. The QP model estimated the maximum mean IOFC at 1.10 Ca:P ratio (95% CI: [<0.75:1, 1.50:1]). The estimated regression equation was IOFC, $\$ = 29.32 + 9.9693 \times (Ca:P) - 4.53039 \times (Ca:P)^2$.

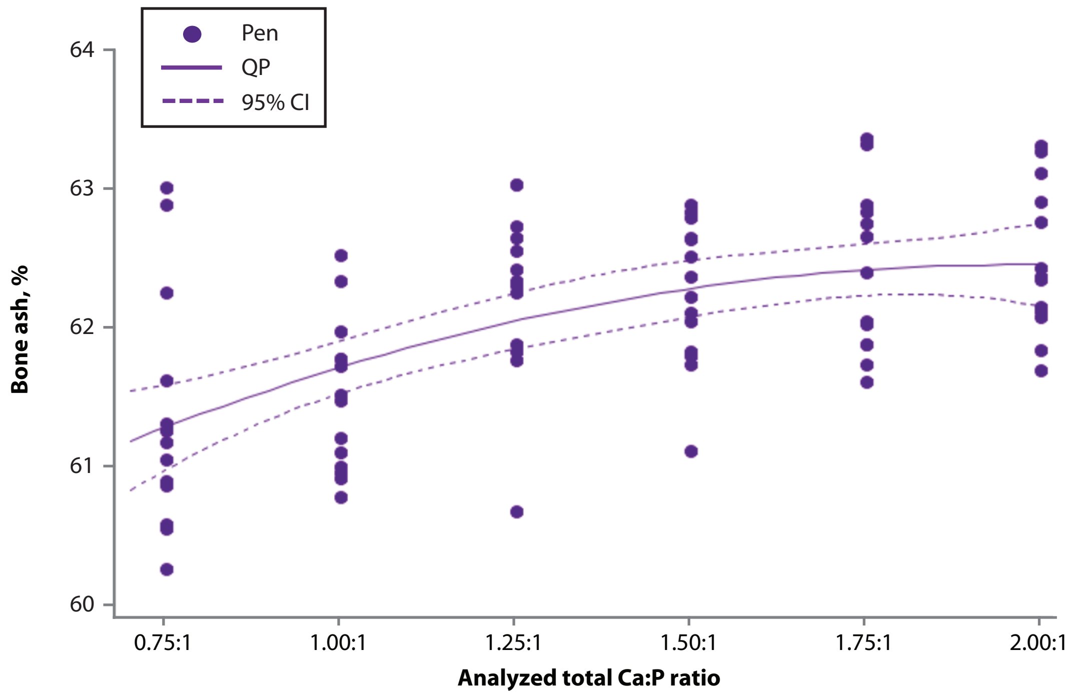

Figure 6. Fitted quadratic polynomial (QP) regression model on percentage bone ash as a function of increasing analyzed total calcium to total phosphorus (Ca:P) ratio in growing-finishing pigs. The QP model estimated the maximum mean percentage bone ash at 1.93 Ca:P ratio (95% CI: [1.40:1, >2.00:1]). The estimated regression equation was bone ash, % = 58.91 + 3.67229 × (Ca:P) – 0.95170 × (Ca:P)².