PHOSPHORUS REQUIREMENTS OF GROW-FINISH PIGS RAISED IN A COMMERCIAL ENVIRONMENT[1]

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Summary

We conducted three experiments to identify available phosphorus (aP) requirements of pigs reared in commercial facilities. In a pilot study (Exp. 1), 600 gilts (PIC, initially 95.2 lb) were randomly allotted to a low or high dietary P regimen in a 98-d study. Pigs were phase-fed six diets from 95 to 106, 106 to 150, 150 to 183, 183 to 212, 212 to 245, and 245 to 267 lb. Corresponding aP concentrations were: 0.30, 0.28, 0.27, 0.27, 0.24, and 0.19% (low) and 0.37, 0.33, 0.30, 0.28, 0.27, and 0.26% (high).

No differences were observed (P > 0.10) in ADG and overall F/G was greater (P<0.07) for pigs fed the low aP regimen. In Exp. 2, 1,260 gilts (initially 74.5 lb) were randomly allotted to one of five dietary treatments in a 26-d study. Experimental diets contained 0.18, 0.22, 0.25, 0.29, or 0.32% aP, corresponding to 0.5, 0.6, 0.7, 0.8, or 0.9 g aP/Mcal ME. There were 28 pigs per pen and 9 pens per treatment. From d 0 to 14, increasing aP tended to increase (linear, P<0.03) ADG and F/G (quadratic, P<0.05) with the greatest response observed as aP increased from 0.18 to 0.22%. However, from d 0 to 26, no differences were observed for any growth traits (P>0.12). Pooled bending moment of the femur, 6th rib, and 3rd and 4th metatarsals increased with increasing aP (linear, P<0.01). Ash content of the rib and metatarsals numerically increased (P>0.10) with increasing aP. In Exp. 3, 1,236 gilts (initially 195.1 lb) were randomly allotted to one of five dietary treatments in a 28-d study. Experimental diets contained 0.05, 0.10, 0.14, 0.19, 0.23% aP, equivalent to 0.152, 0.277, 0.402, 0.527, or 0.652 g aP/Mcal ME. From d 0 to 14, increasing aP increased (linear, P<0.01) ADG and F/G. However, from d 0 to 28 increasing aP had no effect (P>0.17) on growth performance. Increasing aP increased (linear, P<0.05) bone ash and bending moment of the 3rd and 4th metacarpals. In commercial facilities, 74 to 121 lb pigs require approximately 0.22% aP to maximize ADG and F/G, whereas 195 to 240 lb pigs require approximately 0.19% aP. However, bone bending moment and ash continued to increase with increasing aP. These values correspond to 0.60 and 0.527 g aP/Mcal ME and 3.24 and 4.07 g/d of aP intake. Our results suggest percentage aP requirement estimates are similar to NRC (1998); however, because of the low feed intake of pigs in commercial facilities our study shows a lower requirement estimate on a g/d basis.

(Key Words: Grow-Finish Pigs, Phosphorus, Growth Performance.)

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Introduction

Most states in the U.S. regulate swine waste application based on N concentration but more are changing to P-based regulations. Because of the ratio between N and P in swine waste and their rate of uptake by most plants, P concentration can be first limiting for waste application if soil P accumulation is not permitted. Therefore, re-evaluation of P requirements of swine is an important step in minimizing its excretion.

Differences in feed intake have been observed between university and commercial environments. Therefore, expressing requirement estimates on a percentage basis could lead to nutrient deficiencies. The purpose of these experiments was to estimate the available P (aP) requirements of pigs reared in commercial facilities.

Procedures

General. All three trials were conducted at a commercial research facility in southwestern Minnesota. Each pen contained one 4-hole dry self-feeder and one cup-waterer to allow ad libitum access to feed and water. Pen weights and feed disappearance were measured approximately every 14 days to calculate ADG, ADFI, and F/G. Prior to starting experimental diets, pigs were fed a diet containing 0.40% aP in Exp. 1 and 2, and 0.27% aP in Exp. 3. All diets were formulated using NRC (1998) nutrient composition values for the respective ingredients.

Experiment 1. A total of 600 gilts with an initial weight of 95.2 lb were blocked by weight and randomly allotted to one of two dietary treatments in a 98-d pilot study. Within each treatment, pigs were phase-fed six diets from 95 to 106, 106 to 150, 150 to 183, 183 to 212, 212 to 245, and 245 to 267 lb. Corresponding aP concentrations were 0.30, 0.28, 0.27, 0.27, 0.24, and 0.19% for pigs fed the low aP regimen (low) or 0.37, 0.33, 0.30, 0.28, 0.27, and 0.26% aP in the high aP regimen (high; Table 1). There were 25 pigs per pen and 12 pens per treatment. A constant Ca:P ratio of 1.1:1 was maintained in all diets. The range of values used represented recommendations similar to those proposed by swine breeding stock companies and nutritionists for commercial production in the United States. Our objective with this pilot study was to obtain an aP estimate from which we could more efficiently conduct titration studies.

Experiment 2. A total of 1,260 gilts with an initial weight of 74.5 lb were blocked by weight and randomly allotted to one of five dietary treatments in a 26-d experiment. The corn-soybean meal-based diets contained 6% added fat and were formulated to 1.25% total lysine. Treatments consisted of five levels of aP; 0.18, 0.22, 0.25, 0.29, or 0.32%, which correspond to 0.5, 0.6, 0.7, 0.8, or 0.9 g of aP/Mcal ME, (Table 2). There were 28 pigs per pen and 9 pens per treatment. A constant Ca:P ratio of 1.1:1 was maintained in all diets by varying the amounts of monocalcium phosphate and limestone to attain the desired levels of Ca and P.

At the conclusion of Exp. 2, one pig from each pen was randomly selected and humanely euthanized. The right 5th, 6th, and 7th ribs and the right rear leg were collected, labeled, placed in plastic bags, and stored in a cooler filled with ice for transport to Kansas State University for bone analysis.

Experiment 3. A total of 1,260 gilts with an initial weight of 195.1 lb were blocked by weight and randomly allotted to one of five dietary treatments in a 28-d experiment. Pigs were fed diets with either 0.05, 0.10, 0.14, 0.19, or 0.23% aP, which correspond to 0.152, 0.277, 0.402, 0.527, or 0.652 g aP/Mcal (Table 3). There were 28 pigs per pen and 9 pens per treatment. A constant Ca:P ratio of 1.1:1 was maintained for all diets, while varying the amounts of monocalcium phosphate and limestone to attain the desired levels of Ca and P in the diets.

At the conclusion of Exp. 3, two pigs from each pen where randomly selected, tattooed, and shipped to a commercial meat packing facility for slaughter (Sioux-Preme, Sioux Center, IA). After pigs were processed, the lower third of the front right leg was removed, labeled, and placed in a plastic bag and stored in a cooler on ice for transport to Kansas State University for bone analysis.

Bone Analysis. Bones were cleaned of adhering tissue then tested for mechanical properties with force applied by an Instron Universal Testing Machine. Following mechanical tests bones were cut in half, measured for dimensions, then placed in petroleum ether for 7 d, and dried for 12 h at 105°C three times to determine the absolute dry, fat free weight. Bones were then ashed at 600°C for 24 h to determine percentage ash. Ash is expressed as a percentage of dried, fat free bone weight.

Treatments for all three trials were arranged in a randomized complete block design. Analysis of variance was conducted on all data using the PROC MIXED procedure of SAS, while repeated measure methods were used for bone data analysis.

Results and Discussion

In Exp. 1, over the entire 98-d experiment, no differences were observed ($P>0.10$) for ADG or ADFI, but pigs fed the low aP regimen tended ($P<0.07$) to have better F/G than those fed the high aP regimen. These results suggest that the aP levels in the high regimen were above those necessary for maximum growth.

Using this data, we then established a range of aP concentrations to evaluate in the subsequent experiments, which used 74 to 121 and 195 to 240 lb pigs. We expanded our response criteria to include bone mechanical properties because typically aP requirements to maximize bone strength are greater than those required to maximize growth.

In Exp. 2, from d 0 to 14, increasing aP tended to increase (linear, $P<0.03$) ADG and F/G (quadratic, $P<0.05$). The greatest improvement in both ADG and F/G was observed as aP increased from 0.18 to 0.22%. This corresponded with aP intakes of 2.70 and 3.21 g/d. However, from d 14 to 26 and for the overall study, no differences were observed ($P>0.10$) in ADG, ADFI, or F/G. Although not different ($P>0.10$) numerical trends similar to those observed from d 0 to 14 were observed for overall ADG and F/G as aP increased from 0.18 to 0.22% or 2.75 to 3.24 g/d.

The aP requirement based on the growth data observed in our study (0.22%) is very similar to that suggested by NRC for 44 to 110 lb pigs (0.23%). However, because of differences in ADFI between our study and that projected by NRC, our results suggest a lower aP requirement estimate on a g/d basis compared to NRC (1998, 3.24 vs 4.27 g/d). Our findings correspond to a requirement of 0.60 g aP/Mcal ME, compared to 0.71 g aP/Mcal ME calculated from NRC.

There were no bone × treatment interactions. Rib and femur bending moment increased (quadratic $P<0.03$, and linear $P<0.01$, respectively) with increasing aP. However, increasing aP had no effect ($P>0.10$) on metatarsal bending moment (Table 6). Percentage ash increased (linear, $P<0.01$) with increasing aP in the 4th metatarsal, but not in the 3rd metatarsal or rib. Femurs were only evaluated for bending moment. Based on the repeated measures analysis, the main effect of dietary aP was significant, with increasing aP increasing (linear, P<0.007) bending moment, but bone ash was not affected.

These results suggest that 0.22% aP or 0.60 g aP/Mcal ME is adequate to maintain growth and bone strength in pigs from 74 to 121 lb. The 3.21 g/d aP intake observed in our study is similar to other studies, but the percentage of the diet necessary to achieve this intake in our study was higher.

In Exp. 3, from d 0 to 14 increasing aP increased (linear, P<0.01) ADG and F/G (Table 7). Although the response in ADG to increasing aP was linear, the greatest ADG was observed in pigs fed 0.19% aP. Average daily feed intake tended to increase (quadratic, P<0.09), with the greatest increase observed as aP increased from 0.05 to 0.10% aP. This corresponds to an increase from 0.96 to 2.00 g/d aP intake. From d 14 to 28 and 0 to 28, no differences (P > 0.17) were observed for ADG, ADFI, or F/G. For bone properties, no bone × treatment interactions were observed, bending moment increased (linear, P < 0.003) with increasing aP in the 3rd but not the 4th metacarpal (Table 8). Repeated measures analysis of both bones indicated a linear increase (P<0.04) with increasing aP. Bone ash increased (linear, P<0.01) in both metacarpals; this relationship was also evident with repeated measures analysis.

Some nutritionists suggest, and universities trials have shown, that no inorganic P is needed during the last phase of production; however, this has caused known problems such as vertebral breakage during stunning in some production systems and higher incidence of broken limbs in finishing barns. The results of Exp. 3 suggest that some added inorganic P (in diets without added phytase) is necessary in corn-soybean meal-based finishing diets for pigs from 195 to 240 lb raised in commercial facilities. Therefore, it appears that at least 0.19% aP or 0.527 g aP/Mcal ME is adequate for maintaining growth and bone strength in pigs from 195 to 240 lb.

In conclusion P requirements of commercially reared pigs are similar to the NRC suggestion when expressed on a dietary percentage basis, but because of decreased feed intake, the grams per day requirements in our studies were less. These estimates are slightly lower than current estimates and may help decrease phosphorus excretion in commercial swine operations.

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

	Low regimen, aP %[b]						High regimen, aP %[b]					
Phase:	1	2	3	4	5	6	1	2	3	4	5	6
Ingredient, %	0.30	0.28	0.27	0.27	0.24	0.19	0.37	0.33	0.30	0.28	0.27	0.26
Corn	62.26	67.14	71.10	73.53	75.44	76.85	61.86	66.88	70.95	73.45	75.33	76.48
Soybean meal (46.5 %)	29.08	24.26	20.40	17.99	16.21	15.05	29.12	24.29	20.41	17.99	16.22	15.08
Choice white grease	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Monocalcium P, 21% P	1.08	1.03	1.01	1.01	0.90	0.64	1.43	1.26	1.13	1.07	1.00	0.98
Limestone	0.84	0.88	0.83	0.81	0.85	0.86	0.86	0.88	0.85	0.83	0.85	0.86
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.09	0.08	0.06	0.06	0.05	0.05	0.09	0.08	0.06	0.06	0.05	0.05
Trace mineral premix	0.15	0.13	0.10	0.10	0.05	0.05	0.15	0.13	0.10	0.10	0.05	0.05
L-lysine HCl	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Calculated composition												
Lysine, %	1.18	1.04	0.93	0.86	0.81	0.78	1.18	1.04	0.93	0.86	0.81	0.78
ME, kcal/kg	3,590	3,594	3,599	3,601	3,606	3,615	3,578	3,586	3,594	3,598	3,602	3,603
Ca, %	0.64	0.62	0.59	0.58	0.57	0.52	0.71	0.67	0.62	0.59	0.59	0.58
Total P, %	0.60	0.57	0.55	0.54	0.51	0.45	0.67	0.62	0.58	0.55	0.53	0.52
g aP/ Mcal ME	0.83	0.78	0.76	0.75	0.68	0.52	1.03	0.92	0.83	0.78	0.74	0.72
Analyzed values,%												
Ca	0.68	0.59	0.54	0.52	0.57	0.56	0.68	0.64	0.70	0.60	0.49	0.60
P	0.60	0.52	0.51	0.48	0.46	0.42	0.60	0.58	0.55	0.53	0.43	0.51

[a]Diet composition was calculated using NRC (1998) values for ingredient composition.

[b]Diets were phase-fed: 1 = 95 to 106, 2 = 106 to 150, 3 = 150 to 183, 4 = 183 to 212, 5 = 212 to 245, and 6 = 245 to 267 lb.

Table 2. Diet Composition[a] (Exp. 2, as-fed basis)

	Available P, %				
Ingredient, %	0.18	0.22	0.25	0.29	0.32
Corn	59.93	59.56	59.18	58.81	58.43
Soybean meal, 46.5 CP%	31.98	32.01	32.05	32.08	32.11
Choice white grease	6.00	6.15	6.30	6.45	6.60
Monocalcium P, 21% P	0.51	0.68	0.85	1.02	1.20
Limestone	0.85	0.87	0.89	0.91	0.93
Salt	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.08	0.08	0.08	0.08	0.08
Trace mineral premix	0.15	0.15	0.15	0.15	0.15
L-lysine HCl	0.15	0.15	0.15	0.15	0.15
Calculated composition					
Lysine, %	1.25	1.25	1.25	1.25	1.25
ME, kcal/kg	3601	3601	3601	3601	3601
CP, %	20.13	20.11	20.09	20.08	20.06
Ca, %	0.54	0.58	0.62	0.66	0.70
P, %	0.49	0.53	0.57	0.60	0.64
g aP / Mcal ME	0.50	0.60	0.70	0.80	0.90
Analyzed values, %					
Ca	0.53	0.53	0.56	0.59	0.67
P	0.45	0.46	0.50	0.55	0.57

[a]Diet composition was calculated using NRC (1998) composition values for ingredients.

Table 3. Diet Composition[a] (Exp. 3, as-fed basis)

	Available P, %				
Ingredient, %	0.05	0.10	0.14	0.19	0.23
Corn	75.68	75.68	75.68	75.68	75.68
Soybean meal, 46.5 CP%	15.90	15.90	15.90	15.90	15.90
Choice white grease	6.00	6.00	6.00	6.00	6.00
Monocalcium P, 21% P	0.00	0.21	0.43	0.64	0.86
Limestone	0.73	0.76	0.78	0.81	0.83
Salt	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.08	0.08	0.08	0.08	0.08
Trace mineral premix	0.15	0.15	0.15	0.15	0.15
Sand	0.96	0.72	0.48	0.24	0.00
L-lysine HCl	0.15	0.15	0.15	0.15	0.15
Calculated composition					
Lysine, %	0.80	0.80	0.80	0.80	0.80
ME, Mcal/kg	3,596	3,596	3,596	3,596	3,596
Ca, %	0.35	0.40	0.45	0.50	0.55
P, %	0.32	0.37	0.41	0.46	0.50
g aP / Mcal ME	0.152	0.277	0.402	0.527	0.652
Analyzed values %					
Ca	0.36	0.42	0.43	0.55	0.49
P	0.30	0.35	0.37	0.40	0.45

[a]Diet composition was calculated using NRC (1998) composition values for ingredients.

Table 4. Effects of Dietary P Regimen on Pig Growth Performance, Exp. 1[a]

Item	Low aP[b]	High aP[b]	SEM	P-value
Overall, d 0 to 98				
ADG, lb	1.76	1.76	0.01	0.81
ADFI, lb	4.66	4.73	0.05	0.20
Feed/gain	2.65	2.69	0.02	0.07

[a]A total of 600 gilts, initially, 95.2 lb were used. Values represent the means of 25 pigs per pen and 12 pens per treatment.

[b]Diets were fed according to feed budget, with weights of 95 to 106, 106 to 150, 150 to 183,183 to 212, 212 to 245, and 245 to 267 lb for each regimen. Available P was 0.30, 0.28, 0.27, 0.27, 0.24, and 0.19% for pigs fed the low aP regimen or 0.37, 0.33, 0.30, 0.28, 0.27, and 0.26% aP in the high aP regimen.

Table 5. Effects of Increasing Available P on Pig Growth Performance, Exp. 2[a]

	Available P,%					P-value		
Item	0.18	0.22	0.25	0.29	0.32	Linear	Quadratic	SEM
Day 0 to 14								
ADG, lb	1.75	1.85	1.82	1.88	1.85	0.03	0.13	0.03
ADFI, lb	3.31	3.22	3.25	3.19	3.28	0.67	0.24	0.06
Feed/gain	1.90	1.74	1.79	1.70	1.78	0.06	0.05	0.05
aP intake, g/d[b]	2.70	3.21	3.69	4.20	4.76	< 0.01	0.62	0.07
Day 14 to 26								
ADG, lb	1.94	1.95	1.96	1.96	1.95	0.89	0.70	0.04
ADFI, lb	3.41	3.41	3.45	3.51	3.46	0.46	0.79	0.08
Feed/gain	1.77	1.75	1.76	1.79	1.78	0.71	0.88	0.05
aP intake, g/d[b]	2.79	3.41	3.91	4.62	5.02	< 0.01	0.51	0.09
Day 0 to 26								
ADG, lb	1.84	1.90	1.88	1.92	1.89	0.12	0.19	0.03
ADFI, lb	3.36	3.31	3.34	3.34	3.36	0.81	0.63	0.06
Feed/gain	1.83	1.74	1.77	1.74	1.78	0.38	0.19	0.04
aP intake, g/d[b]	2.75	3.24	3.81	4.35	4.91	< 0.01	0.89	0.07

[a]A total of 1,260 gilts, initially 74.5 lb were used. Values represent the means of 25 pigs per pen and 9 pens per treatment.

[b]Values represent the calculated dietary aP values multiplied by the ADFI.

Table 6. Effects of Increasing Available P on Bone Properties, Exp. 2[a]

	Available P,%					P-value		
Item	0.18	0.22	0.25	0.29	0.32	Linear	Quadratic	SEM
Metatarsal 3								
Bending moment, kg-cm	36.1	27.8	24.0	28.2	32.8	0.77	0.18	6.60
Ash, %	49.1	52.1	50.1	50.3	49.8	0.97	0.51	1.90
Metatarsal 4								
Bending moment, kg-cm	36.7	31.8	37.2	37.1	32.2	0.82	0.76	4.69
Ash, %	46.3	49.5	48.1	48.4	49.8	0.01	0.40	0 .64
Rib								
Bending moment, kg-cm	18.7	25.5	24. 8	27.7	27.6	0.001	0.03	1.24
Ash, %	47.1	48.1	48.3	48.8	48.3	0.16	0.64	0 .92
Femur								
Bending moment, kg-cm	289.1	338.2	319.1	339.4	338.1	0.01	0.17	11.78
Main effects of bone[b]								
Bending moment, kg-cm	96.1	105.8	101.3	108.1	107.7	0.007	0.35	3.07
Ash, %[c]	47.5	49.9	48.8	49.2	49.5	0.24	0.40	0.90

[a]One pig from each pen was randomly selected for harvest of bones. Values represent the mean of 9 observations per treatment.

[b]Values represent means of bones combined by treatment using repeated measures analysis of SAS.

[c]Percent ash was not conduct on femurs. Values represent the main effects of metatarsals and rib.

Table 7. Effects of Increasing Available P on Finishing Pig Growth Performance, Exp. 3[a]

	Available P, %					P-value		
Item	0.05	0.10	0.14	0.19	0.23	Linear	Quadratic	SEM
Day 0 to 14								
ADG, lb	1.37	1.51	1.52	1.62	1.56	0.008	0.14	0.06
ADFI, lb	4.23	4.42	4.42	4.48	4.33	0.44	0. 09	0.10
Feed/gain	3.13	2.96	2.94	2.79	2.78	0.01	0.59	0.10
aP intake g/d[b]	0.96	2.00	2.81	3.86	4.51	< 0.01	0.01	0.05
Day 14 to 28								
ADG, lb	1.68	1.63	1.68	1.67	1.68	0.89	0.82	0.09
ADFI, lb	4.96	4.82	5.03	4.94	5.03	0.49	0.73	0.12
Feed/gain	3.08	3.01	3.01	2.99	3.08	0.97	0.59	0.14
aP intake g/d[b]	1.12	2.19	3.19	4.26	5.25	< 0.01	0.78	0.08
Day 0 to 28								
ADG, lb	1.54	1.57	1.60	1.64	1.63	0.17	0.63	0.06
ADFI, lb	4.62	4.64	4.75	4.72	4.70	0.34	0.52	0.08
Feed/gain	3.06	2.96	2.96	2.88	2.92	0.18	0.53	0.08
aP intake g/d[b]	1.05	2.10	3.01	4.07	4.91	< 0.01	0.11	0.05

[a]A total of 1,236 gilts, initially 195.1 lb were used. Values represent the means of 28 pigs per pen and nine pens per treatment.

[b]Values represent the calculated dietary aP values multiplied by the ADFI.

Table 8. Effects of Increasing Available P on Finishing Pig Bone Properties, Exp. 3[a]

	Available P,%					P-value		
Item	0.05	0.10	0.14	0.19	0.23	Linear	Quadratic	SEM
Metacarpal 3								
Bending moment, kg-cm	100.2	110.3	118.4	112. 9	120.0	0.003	0.24	4.36
Ash %	50.1	50.7	51.9	52.0	52.1	0.001	0.14	0.36
Metacarpal 4								
Bending moment, kg-cm	92.8	95.3	92.6	97.3	95.5	0.59	0.93	4.34
Ash %	51.2	51.6	51.8	52.7	53.3	0.001	0.48	0.52
Main effects of bone[b]								
Bending moment, kg-cm	96.5	103.3	105.5	105.1	107.7	0.04	0.41	3.50
Ash %	50.6	51.2	51.9	52.3	52.7	0.001	0.65	0.40

[a]Two pigs were randomly selected from each pen for harvest of bones, values represent the mean of nine observations per treatment.

[b]Values represent means combined Metacarpal 3 and 4 using repeated measures analysis of SAS.