Phosphorus Excretion of Feedlot Cattle Fed Diets Containing Corn or Distillers Coproducts

A.S. Leaflet R2123

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Summary

Samples were analyzed from three metabolism trials to evaluate the effects of dietary phosphorus (P) intake on P excretion in beef steers fed corn-based finishing diets. In Experiment I, ten steers were fed ten diets that involved two processing methods, whole and dry rolled corn and five corn sources, commodity, white, high oil, high protein, and high-oil-high-protein corn. In Experiment II, six steers were fed three diets that included three variations of protein supplementation to meet 70, 80, and 100% of the degradable intake protein requirements for growing steers. In Experiment III, ten steers were fed five diets including control, 4% or 8% distillers solubles, and 10% or 20% wet distillers grains. For all experiments total urine and feces, feed intake, and feed refused were measured during a 5-d collection period, following 9, 10 and 14-d of dietary adaptation for the three respective experiments. Dietary P concentration (% DM) and dietary P intake (g/d) ranged from 0.31 to 0.36 and 21.5 to 27.2, 0.28 to 0.29 and 19.8 to 21.2 and 0.29 to 0.40 and 22.9 to 34.5 in the three respective experiments. Total P excretion was significantly related to P intake, but there was considerable variation among steers in partitioning excretion of P in urine or feces. Urinary P excretion (g/d) ranged from 3.0 to 7.4, 3.1 to 4.3 and 4.3 to 7.5 in the three studies, respectively. Replacing corn grain with corn processing co-products increased P intake but did not significantly change excretion patterns.

Introduction

The contribution of phosphorus (P) to eutrophication of surface water bodies and identification of intensive animal agriculture as a primary source of P in surface water has focused considerable attention on this required mineral. Dietary management is an essential component of strategies to reduce loss of nutrients from livestock operations. Recent research from the University of Nebraska indicated that the dietary P requirements of finishing yearling and calf-fed steers are lower than previously recommended, suggesting high-grain diets typically fed to finishing cattle contain P in excess of requirement. As production of ethanol co-product feedstuffs that contain high concentrations of P continues to increase and greater amounts of these co-products are fed to cattle, it is important to characterize the metabolism and excretion of P when excess P is fed. Since diet can affect route of P excretion in ruminants, the purpose of this study was to characterize excretion of P in cattle fed high-concentrate diets typically fed to beef cattle as well as diets containing corn processing co-products.

Materials and Methods

Three experiments were conducted in which feces and urine were separately collected from steers maintained in metabolism crates. The design of each experiment was a Latin square in which each steer was fed each diet during the course of the experiment. Each period ranged from 14 to 19 days with 9 or 14 days for adjustment to the new diet and five days for collection of samples. Samples of the diets were collected daily beginning the day prior to the first collection of feces and feed refusals were collected when necessary. Feces and urine were collected daily and a portion saved as a sample. Samples were pooled for each animal at the end of a collection period.

Experiment I

Ten crossbred Angus x Simmental steers with initial weight of 345 kg and average age of eight months were used in this experiment. Ten diets consisting of two processing methods of whole or dry rolled corn and five corn hybrids: commodity corn (C), white corn (W), high-oil corn (HO), high-protein corn (HP), and high-oil-high-protein corn (HOHP) were compared. Composition of the diets was similar for the two processing methods and shown in Table 1. Diets were formulated to be isonitrogenous at 13% CP and isocaloric for net energy for gain (NEg) at 1.4 Mcal/kg.

Experiment II

Six crossbred Angus x Charolais steers with an initial weight of 401 kg were used in this experiment. Treatments consisted of urea addition to the diets to meet 70, 80, and 100% of the degraded intake protein (DIP) requirements for growing steers. Combinations of corn gluten meal and urea were used to meet the metabolizable protein requirements of the steers fed the low DIP diet (Table 2). Diets were isocaloric for NEg at 1.43 Mcal/kg.

Experiment III

Ten crossbred Angus x Charolais steers with an initial weight of 386 kg were used in this experiment. Five diets (Table 3): control, 4% or 8% added corn distillers solubles and 10% or 20% added wet distillers grains plus solubles were compared. Diets were isocaloric for NEg at 1.43 Mcal/kg.

Table 1. Composition of diets fed in Experiment I (% DM basis).

	Diets[a]				
Ingredient	C	W	HO	HP	HOHP
Dry rolled corn	79.84	80.66	80.67	80.82	83.92
Chopped alfalfa hay	11.00	11.00	11.00	11.00	11.00
Corn gluten meal	2.21	1.39	1.38	1.23	1.13
Soybean meal	3.00	3.00	3.00	3.00	
Cane molasses	2.00	2.00	2.00	2.00	2.00
Ground limestone	1.00	1.00	1.00	1.00	1.00
Urea	0.50	0.50	0.50	0.50	0.50
Sodium chloride	0.30	0.30	0.30	0.30	0.30
Vitamin A premix[b]	0.080	0.080	0.080	0.080	0.080
Trace Mineral premix[c]	0.024	0.024	0.024	0.024	0.024
Ionophore premix[d]	0.020	0.020	0.020	0.020	0.020
Elemental sulfur	0.030	0.030	0.030	0.030	0.030
Chemical analysis					
Dry matter, %	89.8	91.0	91.6	90.6	90.4
Crude protein, % DM	13.70	13.60	13.42	13.47	13.72
Phosphorus, % DM	0.33	0.32	0.36	0.31	0.35

[a]C = Commodity corn; W = white corn; HO = high oil corn; HP = high protein corn; HOHP = high oil high protein corn.
[b]Vitamin A premix contained 5 million IU/kg.
[c]Trace mineral premix contained: Ca 13.2%, Co 0.10%, Cu 1.5%, Fe (ferrous) 10.0%,Fe (ferric) 0.44%, I (as EDDI) 0.20%, Mn 8.0%, S 5.0% and Zn 12.0%.
[d]Premix contained 176 g monensin sodium/kg.

Analysis

Samples were dried, ground and analyzed for P using a calibrated standard solution of phosphorus. Apparent P digestibility was calculated as ((P intake – fecal P excretion) / P intake) * 100. Phosphorus retention as a percentage of intake was calculated as ((P intake – fecal P excretion – urinary P excretion) / P intake) * 100.

Statistical Analyses

Total P excreted (g/d), urine P (g/d), fecal P (g/d), retained (g/d) and apparent digestibility of P (%) were analyzed as a Latin square using PROC GLM procedures of SAS with a model that included period, animal, and diet. When the overall *F*-value for treatment was significant using the residual mean square as the error term, means were separated using the PDIFF option of SAS. Orthogonal coefficients were generated for treatments and for all observations (n = 168) using REG option of SAS.

Results and Discussion

Experiment I

There were no effects of source of corn on feed intake (Table 4); however P intakes ranged from 21.5 to 27.2 g/d with differences among sources of corn because of differences in dietary P concentrations. The concentration of P in the HP diet (0.31%) was lower than in the C, HO, and HOHP diets. The HOHP diet contained higher concentrations of P compared with diets containing C, W, and HP corns. These differences were presumably due to differences in P concentration in the sources of corn. The higher concentration of P in the HO and HOHP hybrids could be explained by increased germ size relative to kernel size. Processing the corn grain did not affect DMI or P intake. Dry rolling corn, however resulted in significantly higher apparent digestibility, higher urinary excretion and lower fecal excretion of P. Steers fed the diet containing rolled HOHP had the lowest fecal excretion (8.2 g/d) and the highest urinary excretion (7.4 g/d). There was a

Table 2. Composition of diets fed in Experiment II.

	Diets[a]		
Ingredient	70%	80%	100%
Dry rolled corn	80.60	82.00	81.37
Corn silage	15.00	15.00	15.00
Corn gluten meal	1.96		
Cane molasses	0.75	0.75	0.75
Urea		.54	1.15
Ground limestone	0.98	0.98	0.98
Sodium chloride	0.30	0.30	0.30
Potassium chloride	0.29	0.29	0.29
Vitamin A premix[b]	0.080	0.080	0.080
Trace mineral premix[c]	0.024	0.024	0.024
Ionophore premix[d]	0.020	0.020	0.020
Elemental sulfur		0.017	0.037
Chemical analysis			
Dry matter, %	81.0	80.8	80.7
Crude protein, % DM	9.46	10.16	12.11
Phosphorus, % DM	0.29	0.29	0.28

[a]70% = 70% of DIP requirement; 80% = 80% of DIP requirement; 100% = 100% of DIP requirement.
[b, c, d]See Table 1.

significant linear relationship between P intake and total P excretion: P excretion (g/d) = 11.68 – 0.32 * P intake (g/d) + 0.0175 * (P intake)^2, (r^2 = 0.62). Only a small portion of the variation in urinary excretion could be explained by total intake: Urinary P excretion (g/d) = - 0.401 + 0.229 * P intake (g/d), (r^2 = 0.11). As apparent digestibility of P increased there was an increase in urinary P excretion: Urinary P excretion (g/d) = -5.816 + 0.178*Apparent digested P (% intake), (r^2 = 0.51). Phosphorus retention and percentage of dietary P retained were similar across sources of corn. All steers were in positive P balance with an average value of 9.63 g/d.

Experiment II

Steers fed the low-DIP diet tended to consume less feed, but there were no differences in P intakes among the three diets (Table 5). The concentration of P was higher in the low DIP diet most likely due to the inclusion of corn gluten meal. While P concentration was higher in the 70% diet, DMI of the other two diets was numerically higher, which resulted in similar P intakes for all diets. Apparent digestibility, total and urinary excretion, quantity and percentage of dietary P retained were similar for all diets. Excretion of P in the feces did vary among diets. There is no obvious explanation for the observed variation in excretion of P in the feces related to diet in this experiment. The relationship between P intake and total P excretion was linear: P excreted (g/d) = 2.5618 + 0.467 * P intake (g/d), (r^2 = 0.58). In this experiment there was not a linear increase in urinary P excretion with increased P intake, but overall urine excretion accounted for 31% of total P excretion. As apparent digestibility increased there was an increase in urinary P excretion: Urinary P excretion (g/d) = -6.011 + 0.165*Apparent digested P (% intake), (r^2 = 0.55, $P < 0.01$).

Experiment III

Feed intake varied among diets, ranging from 7.6 to 8.7 kg/d (Table 6). Diet did affect P intake, ranging from 22.9 (control) to 34.5 g/d (8% solubles). The average P concentrations in distillers solubles and distillers grains were 1.14% and 0.83% of DM, respectively with total P concentrations in the diets ranging from 0.29 to 0.40% of dietary DM. Steers fed 20% wet distillers grains consumed less dry matter than steers fed 4% or 8% distillers solubles. The quantity of P retained and apparent digestibility of dietary P were not different among diets and averaged 10.5 g/d and 57.0%, respectively. There was a linear relationship between P intake and total P excretion: P excretion (g/d) = -1.505 +0.688*P intake (g/d), (r^2 = 0.72). A small portion of the variation in urinary excretion could be explained by total intake: Urinary P excreted (g/d) = 0.200 + 0.197*P intake (g/d), (r^2 = 0.14). There was a significant positive

Table 3. Composition of diets fed in Experiment III (% DM basis).

	Diets[a]				
Ingredient	Control	4%	8%	10%	20%
Dry rolled corn	86.23	82.67	79.10	77.08	67.65
Corn silage	5.00	5.00	5.00	5.00	5.00
Chopped grass hay	5.00	5.00	5.00	5.00	5.00
Distillers solubles		4.00	8.00		
Distillers grains + solubles				10.00	20.00
Urea	1.29	.99	.68	.52	
Ground limestone	1.00	1.00	1.00	1.00	1.00
Cane molasses	0.75	0.75	0.75	0.75	0.75
Sodium chloride	0.30	0.30	0.30	0.30	0.30
Potassium chloride	0.21	0.11		0.19	0.15
Vitamin A premix[b]	0.040	0.040	0.040	0.040	0.040
Trace mineral premix[c]	0.024	0.024	0.024	0.024	0.024
Ionophore premix[d]	0.020	0.020	0.020	0.020	0.020
Vitamin mix[e]	0.063	0.063	0.063	0.063	0.063
Elemental sulfur	0.044	0.032	0.022	0.017	
Chemical analysis					
Dry matter, %	82.4	77.9	74.8	69.8	61.6
Crude protein, % DM	12.05	12.42	12.01	12.26	13.14
Phosphorus, % DM	0.29	0.31	0.35	0.33	0.38

[a]When corrected for dry matter of ingredients diets contained 0, 3.84 and 7.79% solubles and 10.7 and 20.9% distillers grains with solubles.

[b, c, d]See Table 1.

[e]Multi-vitamin premix contained vitamin A 454,000 IU/g, vitamin D_3 90,900 IU/kg, vitamin e 454 IU/kg and vitamin K (menadione) 182 mg/kg.

linear relationship between P excretion in the urine and apparent digestibility of dietary P: Urinary P excretion (g/d) = - 2.170 + 0.141*Apparent P digested (% of intake), (r^2 = 0.39). Urinary P comprised 32.4, 28.8, 32.4, 32.1, and 34.8% of total P excreted for the control, 4%, 8%, 10%, and 20% diets, respectively. Steers fed the diet containing 8% solubles consumed the most P (34.5 g/d), excreted more P (23.3 g/d), had the lowest digestibility (53.0%) and retained less of the consumed P (31.2%) than steers fed the other diets.

Combined data

There was a positive quadratic relationship (r^2 = 0.74,) between P excretion and P intake when data from the 168 collections made in the three experiments were combined (Figure 1A). The relation between P excretion in the feces and intake also was quadratic (r^2=0.41). Excretion of P in the urine was linearly related to P intake with considerable variation (r^2 = 0.14) and on average accounted for one-third of the P excreted. Apparent digestibility of dietary P averaged 60% and there did not seem to be a trend for change in apparent digestibility with increased intake of P (data not shown). It is commonly believed that ruminants excrete excess P in the feces, but our results with cattle fed high-grain diets clearly show that significant quantities of P were excreted in the urine. As shown in Figure 2 there was a positive relationship between apparent digestibility of dietary P and urinary P excretion. In all three experiments there were significant differences among animals for quantity of P excreted in the urine or feces and the apparent digestibility of dietary P.

Phosphorus is concentrated several fold in saliva of ruminants compared with blood. Overall P homeostasis of ruminants involves salivary-P secretion and subsequent reabsorption or loss as fecal endogenous P. It is estimated that cattle secrete 30 to 90 g of P/d in the saliva of which 75 to 80% is reabsorbed from the small intestine with the remaining excreted in the feces. With higher concentrations of P in saliva more P is absorbed, but a greater portion of the total is excreted in the feces suggesting that fecal

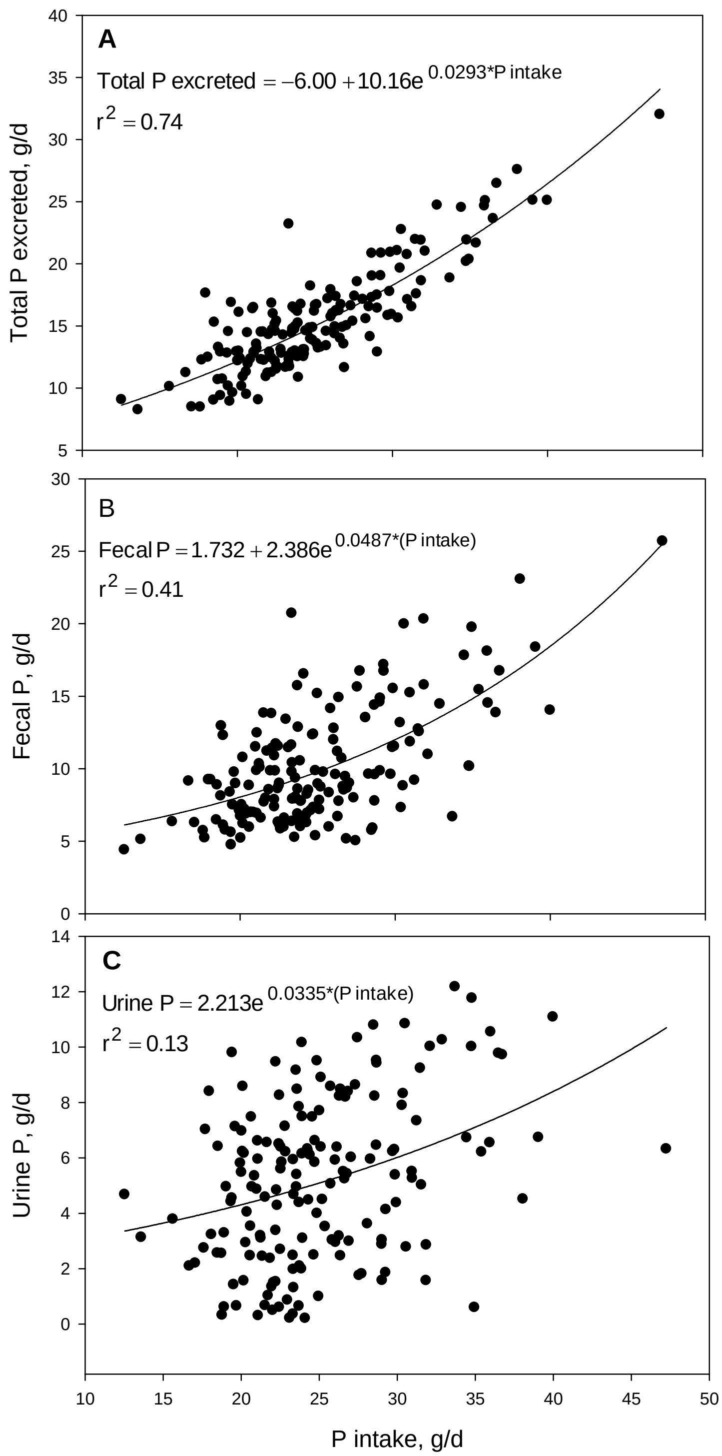

Figure 1. Relationship of P excretion to P intake in steers fed high-concentrate diets in three digestion and metabolism experiments, n = 168 collection periods. A: Relation of total P excretion to intake (P < 0.01). B: Excretion of P in feces in relation to intake (P < 0.01). C: Excretion of P in urine in relation to intake (P < 0.01).

Table 4. Phosphorus metabolism in steers fed whole or dry rolled genetically diverse sources of corn (Experiment I).

	Diets										Statistics		
	Whole corn					Dry rolled corn							
Item	C	W	HO	HP	HOHP	Cr	Wr	HOr	HPr	HOHPr	SEM	Diet[a]	Proc[b]
Diet P, %	0.33	0.32	0.36	0.31	0.36	0.33	0.32	0.36	0.31	0.35	0.005	<0.01	0.98
DMI, kg/d	7.0	6.8	7.5	7.4	7.1	7.4	7.2	7.1	7.0	6.9	0.27	0.23	0.63
P Intake, g/d	23.4	21.5	27.2	23.3	25.4	24.6	22.5	25.6	22.1	24.2	1.01	<0.01	0.70
P Excreted g/d	14.0	12.1	16.9	13.0	16.2	14.3	13.0	15.5	13.1	15.6	0.88	<0.01	0.98
Urine P, g/d	4.1	3.0	5.1	4.0	6.2	5.7	4.6	6.4	4.3	7.4	0.65	<0.01	<0.01
Fecal P, g/d	9.9	9.1	11.8	9.0	10.0	8.5	8.3	9.1	8.8	8.2	0.91	0.01	<0.01
Apparent Digestibility, %	57.8	57.2	56.8	60.5	60.4	64.6	63.6	64.9	60.0	66.3	0.31	0.02	<0.01
Retained P, g/d	9.5	9.4	10.3	10.3	9.2	10.3	9.6	10.1	9.0	8.6	0.95	0.59	0.63

[a]Comparison of diets.
[b]Comparison of the whole and rolled corn.

excretion of excess P becomes more significant with increased salivary secretion of P. The role of saliva and intestinal reabsorption of P might be compromised in ruminants fed high-concentrate diets due to reduced volume of saliva secreted. If grain-fed cattle secrete less saliva and thereby reduce recycling of P from the blood to the digestive tract, concentration of P in blood will likely increase to the threshold of clearance by the kidney.

Retention of P ranged from 8.6 to 10.3, 7.5 to 9.3, and 9.6 to 11.2 g/d for the cattle in each of the respective experiments with an overall average retention of 9.75 g/d (average 430 kg weight). There was a difference in P retention among collection periods ($P < 0.01$ for experiment I, $P < 0.31$ for experiment II and $P < 0.05$ for experiment III), with a trend towards greater retention as the steers increased in weight. The data in Figure 1A indicate total P excretion was increasing at an increasing rate when intake exceeded 15 g/d that might be related to the dietary requirement. Using 68% true absorption (NRC) this would correspond to 10 g/d net requirement. The calculated net P requirement for growing cattle according to NRC equations is about 12 g of P for a 400 kg steer gaining 1 kg/d. The lower estimate derived from these P balance experiments is in agreement with the feeding trials at Nebraska that indicated P requirement of growing and finishing cattle to less than estimated NRC requirements.

Implications

Results from this study indicate urinary P excretion accounts for a significant portion of total P excreted in finishing beef steers fed high-grain diets that could impact P concentration in liquid runoff from confined cattle yards. Replacing corn grain with corn processing co-products resulted in greater total P excretion and with higher inclusion rates, greater amounts of urinary P excretion. It appears that corn-based diets fed to finishing cattle furnish more than adequate P.

Acknowledgements

Materials were supplied as follows: Rumensin, Elanco Products, Indianapolis, Ind.; Implants, VetLife, Overland park, Kan.; and Vitamin A, Roche Animal Nutrition and Health, Paramus, N.J. The assistance of Rod Berryman, research farm superintendent; Julie Roberts, Beef Center secretary; and the animal caretakers at the ISU Beef Nutrition and Management Research Center is appreciated.

Table 5. Phosphorus metabolism of steers fed varying quantities of urea to satisfy the requirement for degradable intake protein (Experiment. II).

	DIP supplied[a]			Statistics	
Item	70%	80%	100%	SEM	Diet[b]
Diet P, %	0.29	0.28	0.28	0.002	0.01
DMI, kg/d	6.9	7.5	7.5	0.17	0.08
P Intake, g/d	19.8	21.2	20.8	0.42	0.12
P Excreted g/d	12.4	12.4	11.8	0.47	0.65
Urine P, g/d	4.1	3.1	4.2	0.36	0.12
Fecal P, g/d	8.3	9.3	7.6	0.36	0.03
Apparent Digestibility, %	59.1	56.0	63.9	2.46	0.13
Retained P, g/d	7.5	8.8	9.0	0.80	0.38

[a]Percentage of requirement for degradable intake protein.
[b]Comparison of diets.

Table 6. Phosphorus metabolism of steers fed diets containing distillers corproducts (Experiment III).

	Control	Distillers solubles		Wet distillers grains		Statistics	
tem		4%	8%	10%	20%	SEM	Diet[a]
Diet P, %	0.29	0.33	0.40	0.34	0.38	0.005	<0.01
DMI, kg/d	8.00	8.7	8.6	8.4	7.6	0.23	0.01
P Intake, g/d	23.0	29.0	34.5	28.5	28.6	0.94	<0.01
P Excreted g/d	13.2	18.5	23.3	17.3	19.0	0.70	<0.01
Urine P, g/d	4.3	5.3	7.5	5.5	6.6	0.44	<0.01
Fecal P, g/d	8.9	13.1	15.8	11.7	12.4	0.63	<0.01
Apparent Digestibility, %	61.2	55.0	53.0	58.6	57.1	2.41	0.16
Retained P, g/d	9.7	10.6	11.2	11.2	9.6	0.98	0.63

[a]Comparison of diets

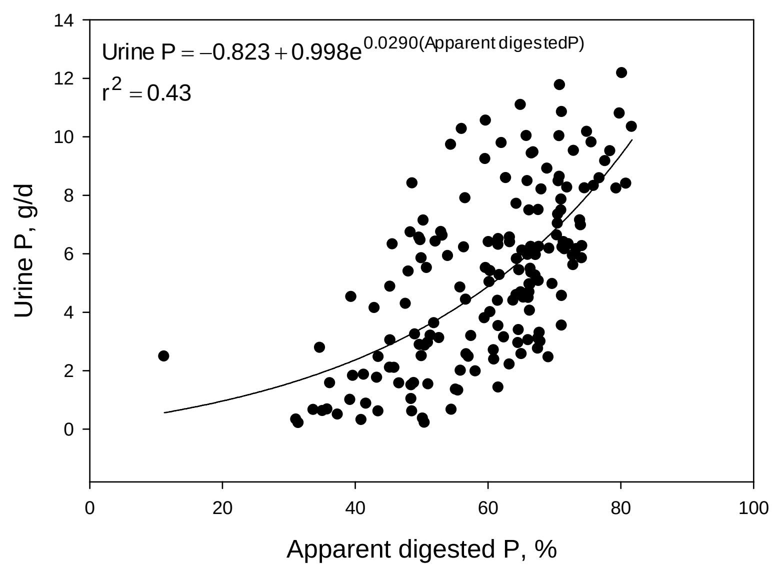

Figure 2. Relationship of apparent P digestibility of dietary P and urinary P excretion in steers fed high-concentrate diets, n = 168 collection periods (P < 0.01).