

2002

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Erickson, Galen; Klopfenstein, Terry; Milton, C. T.; Brink, Dennis; Orth, M. W.; and Whittet, K. M., "Phosphorus Requirement of Finishing Feedlot Calves" (2002). *Faculty Papers and Publications in Animal Science*. 459.
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Phosphorus requirement of finishing feedlot calves¹

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ABSTRACT: Dietary P supplied to feedlot cattle is important because an inadequate supply will compromise performance, whereas excess P may harm the environment. However, P requirements of feedlot cattle are not well documented. Therefore, 45 steer calves (265.2 ± 16.6 kg) were individually fed to determine the P required for gain and bone integrity over a 204-d finishing period. The basal diet consisted of 33.5% high-moisture corn, 30% brewers grits, 20% corn bran, 7.5% cottonseed hulls, 3% tallow, and 6% supplement. Treatments consisted of 0.16 (no supplemental inorganic P), 0.22, 0.28, 0.34, and 0.40% P (DM basis). Supplemental P was provided by monosodium phosphate top-dressed to the daily feed allotment. Blood was sampled every 56 d to assess P status. At slaughter, phalanx and metacarpal bones were collected from the front leg to determine bone ash and assess P resorption from bone. Dry

matter intake and ADG did not change linearly ($P > 0.86$) or quadratically ($P > 0.28$) due to P treatment. Feed efficiency was not influenced ($P > 0.30$) by P treatment and averaged 0.169. Plasma inorganic P averaged across d 56 to 204 responded quadratically, with calves fed 0.16% P having the lowest concentration of plasma inorganic P. However, plasma inorganic P concentration (5.7 mg/dL) for steers fed 0.16% P is generally considered adequate. Total bone ash weight was not influenced by dietary P for phalanx ($P = 0.19$) or metacarpal bones ($P = 0.37$). Total P intake ranged from 14.2 to 35.5 g/d. The NRC (1996) recommendation for these calves was 18.7 g/d, assuming 68% absorption. Based on performance results, P requirements for finishing calves is < 0.16% of diet DM or 14.2 g/d. Based on these observations, we suggest that typical grain-based feedlot cattle diets do not require supplementation of inorganic mineral P to meet P requirements.

Key Words: Cattle, Feedlots, Nutritional Requirements, Phosphorus

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J. Anim. Sci. 2002. 80:1690–1695

Introduction

Livestock producers are becoming increasingly aware of the challenges associated with nutrient management. Perhaps the largest challenge will be managing phosphorus inputs and outputs in livestock feeding operations. One method to help alleviate phosphorus mismanagement is decreasing dietary P to meet and not exceed requirements. However, P requirements are not well established for beef feedlot cattle weighing between 270 and 600 kg. Erickson et al. (1999) evaluated P requirements of yearling steers (380 kg) with typical feedlot gains (> 1.5 kg/d) and concluded that the requirement

was less than 0.14% of diet DM or 70% of NRC (1996) recommendations. Numerous studies have been conducted with lightweight calves (< 200 kg) that suggest calves have elevated requirements compared to large yearlings or mature cows (Wise et al., 1958; Miller et al., 1987; Jackson et al., 1988). Therefore, P requirements for typical feedlot calves (> 250 kg) fed high-energy diets need to be evaluated. Our objectives were to determine 1) the P requirement of finishing calves for maximum performance and 2) the impact of decreasing dietary P on bone mineral content as well as plasma inorganic P.

Materials and Methods

Diets

A base diet was formulated that would contain high concentrations of NE_m and NE_g and low concentrations of P. Only 34.5% of dietary DM consisted of high-moisture corn because corn contains $0.32 \pm 0.04\%$ P (NRC, 1996; Table 1). Brewers grits, which is primarily corn starch, and corn bran, the digestible fibrous component of corn, were added to provide a high-energy, low-P sub-

¹Published with the approval of the director as paper no. 13420, journal ser., Nebraska Agric. Res. Div.

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Received July 23, 2001.

Accepted January 11, 2002.

Table 1. Diet composition (% of diet DM) for calves fed varying levels of P for 204 d^a

Ingredient	% of Diet DM	Ingredient % P
High-moisture corn	33.5	0.32
Corn bran	20.0	0.08
Brewers grits	30.0	0.08
Cottonseed hulls	7.5	0.11
Fat	3.0	—
Supplement ^b	6.0	0.09
Finely ground corn	0.982	
Limestone	1.570	
Blood meal	0.647	
Potassium chloride	1.146	
Urea	0.906	
Salt	0.300	
Ammonium sulfate	0.250	
Tallow	0.100	
Trace mineral ^c	0.050	
Rumensin premix ^d	0.017	
Tylan premix ^e	0.013	
Vitamin premix ^f	0.020	

^aAt time of feeding, target levels of P were added as top-dress of NaH₂PO₄ to achieve added increments of 0.06% P.

^bSupplement was fed in three phases with decreasing amounts of blood meal to meet or exceed predicted metabolizable protein requirement.

^cPremix contained 10% Mg, 6% Zn, 4.5% Fe, 2% Mn, 0.5% Cu, 0.3% I, and 0.05% Co.

^dPremix contained 1,500 IU vitamin A, 3,000 IU vitamin D, 3.7 IU vitamin E per gram.

^ePremix contained 176 g/kg monensin.

^fPremix contained 88 g/kg tylosin.

stitute for corn. Dietary P treatments evaluated were 0.16 (no supplemental inorganic P), 0.22, 0.28, 0.34, and 0.40% of dietary DM. Dietary P was increased by addition of NaH₂PO₄ (SMC Corp., Philadelphia, PA) directly to each day's aliquot of feed in the bunk. Monosodium phosphate was "top-dressed" each morning after feed was placed in bunks. Therefore, P was replacing the entire diet, not the supplement carrier. Dietary Ca was formulated at 0.62% across all P treatments by supplementing limestone at 1.57% of diet DM, leading to calcium:phosphorus ratios ranging from 1.6 to 3.9 across the P levels fed. Diets were formulated to contain 29.9 mg/kg monensin and 11.4 mg/kg tylosin (DM basis; Elanco Animal Health, Greenfield, IN). Diets contained a minimum of 0.75% K.

A meal supplement was formulated to meet or exceed the metabolizable protein requirement of 272-kg calves (NRC, 1996). The supplement was changed three times during the experiment to ensure adequate metabolizable protein and degradable intake protein (**DIP**) while minimizing excess undegradable intake protein (**UIP**). Dietary concentrations of blood meal were decreased from 1.5 to 0% of diet DM to provide less UIP over the feeding period. The first supplement was fed for 58 d to calves with average BW of 305 kg. The second supplement, containing less blood meal, was fed for 44 d with calves averaging 385 kg. The final supplement was fed for the remaining 102 d. Composition of supplement provided in Table 1 is a weighted average of ingredient concentra-

tions based on days fed. Diet CP concentrations for the three phases were 13.0, 12.6, and 11.8% of diet DM.

Animals

Calves were purchased from one commercial ranch in Nebraska and uniformly managed prior to weaning. At weaning, calves were transported to the University of Nebraska Agricultural Research and Development Center near Mead, NE. Following arrival, calves had ad libitum access to a common diet for 25 d to acclimate and overcome any health-related problems. On January 10, 2000, calves were moved to barns equipped with Calan electronic gates (American Calan, Northwood, NH) and assigned to one of three pens with 15 steers per pen. Following a 14-d training to individual headgates, calves were limit-fed (5.4 kg·steer⁻¹·d⁻¹) a 50% alfalfa hay, 50% wet corn gluten feed (DM basis) diet for 7 d to minimize variation due to gastrointestinal tract fill. Initial weights were based on weights taken on three consecutive days in the morning prior to feeding.

Forty-five crossbred steer calves (British × Continental; 265 ± 16.6 kg) were randomly assigned to one of five levels of P, either 0.16, 0.22, 0.28, 0.34, or 0.40% of dietary DM. Steers were adapted to high-energy diets by limiting intake (3.6 kg DM initially) and gradually increasing DM offered at a rate of 0.23 kg/d until ad libitum intakes were achieved. This adaptation scheme required approximately 21 d. Steers were fed once daily and implanted d 1 with Synovex-S (Fort Dodge Animal Health, Overland Park, KS) followed by Revalor-S (Intervet Inc., Somerville, NJ) on d 84. Two-day weights were taken every 28 d for sampling and performance purposes. Steers were fed for 204 d and transported to a commercial abattoir (IBP Inc., West Point, NE). At slaughter, hot carcass weights were recorded, and the phalanx and metacarpal bones (lower front leg) were collected. After the carcass was chilled for 24 h, fat depth, longissimus area, and marbling measurements at the 12th rib were collected. Final weight was calculated from hot carcass weight divided by a common dressing percentage of 62%.

All animal procedures and protocols used in this experiment were approved by the University of Nebraska Institute for Animal Care and Use Committee, IACUC #98-04-021.

Sample Collection and Analysis

Feed ingredients were sampled weekly for DM determination, ground through a Wiley Mill (1-mm screen; Thomas Scientific, Philadelphia, PA), and composited by month for analysis. Orts were collected when necessary (minimum of weekly), dried in a 60°C forced-air oven for DM determination, composited by steer, and ground through a Wiley Mill (1-mm screen) for analysis. Composited feed ingredients and ort samples were analyzed for P following ash digest with weak acid and subsequent color development using the alkalimetric ammonium molybdophosphate method (400 nm; AOAC, 1996).

Blood samples were collected on d 0, 56, 112, 168, and 204. Blood was collected in heparinized tubes, transported to the laboratory on ice, and centrifuged ($1,850 \times g$) at 4°C for 15 min to separate plasma. Once separated, plasma was removed by pipetting and stored frozen at -80°C until analysis. Plasma samples from calves fed 0.16 and 0.40% P from d 0, 56, 112, and 204 were transported to Michigan State University and osteocalcin concentrations in plasma were determined using ELISA (NovoCalcin, Metra Biosystems, Mountain View, CA) according to manufacturer's instructions. Although the kit was designed for analysis of human serum, bovine osteocalcin was used to generate the primary antibody, making the kit appropriate to use for cattle as well. Plasma samples, stored at -80°C until analyzed, were diluted 1:15 for the assay. The samples and standard curves were read at 405 nm optical density on a Spectra Max 340 plate reader (Molecular Devices Corp., Sunnyvale, CA). All samples had an intraassay coefficient of variation under 10%. Once osteocalcin analysis was complete, those samples were returned to Nebraska for plasma inorganic P analysis. Plasma samples from all days and treatments were analyzed for inorganic P using a colorimetric procedure (no. 670; Sigma Diagnostics, St. Louis, MO).

Statistical Analysis

Animal performance, bone characteristics, plasma P, and osteocalcin level were analyzed using PROC GLM procedures of SAS (SAS Inst. Inc., Cary, NC) for one-way analysis of variance. The statistical model included P concentration in the diet as a fixed effect. Steer was the experimental unit because individual feed intakes were collected. There were nine replications per treatment, and the experimental design was a completely randomized design. Orthogonal linear, quadratic, cubic, and lack of fit effects were tested to assess variation due to dietary P treatment. Plasma samples were analyzed using PROC MIXED procedures of SAS as a repeated measure, and time \times P treatment interactions were evaluated. If an interaction between P treatment and time existed, data were tested for simple effects of treatment

within time. Treatments were evaluated for d 56, 112, 168, and 204. Plasma P on d 0 was not significantly different ($P > 0.10$) across treatments, and therefore d 0 was not included as a covariate.

Results

Two calves were removed from data analysis for this experiment. One calf had an injured shoulder after 28 d on test. The calf was on the 0.34% P treatment and was removed from the study because treatment for the injury was not available. Another calf on the 0.16% P treatment did not perform because of health-related problems. This calf was handled similarly to the rest of the calves in the experiment but only gained 1.04 kg/d with a DMI of 6.4 kg/d, which was a feed efficiency similar to that of the other steers.

Based on DMI and P concentration in diets vs orts samples, P intake ranged from 14.2 to 35.5 g/d. Gain, DMI, and feed efficiency were not different across P treatments (Table 2). Final weights were not influenced by P treatment. No relationship between grams of P intake per day and feed efficiency was detected ($r^2 < 0.01$; data not shown), indicating that feed efficiency was not influenced by dietary P concentrations fed in this experiment. Carcass traits measuring fat depth, longissimus area, and marbling score were also unaffected ($P > 0.42$) by dietary P treatment (Table 2).

Phalanx bone ash expressed as total grams was not influenced by dietary P treatment (Table 3). However, concentration of phalanx ash per unit of hot carcass weight tended ($P = 0.08$) to respond quadratically to P additions, with percentage ash being lowest for the 0.16 and 0.40% P treatments. Expressing mineral content of these bones as a percentage of carcasses should minimize any effects of bone size due to frame or BW differences. Metacarpal bone ash, expressed as either total grams or as a percentage of carcasses, was not influenced by dietary P treatment.

On d 0, plasma inorganic P across all treatments was not different ($P = 0.41$) and averaged 7.5 mg/dL. A significant interaction between P treatment and time was detected for plasma P concentration. At d 56, P treat-

Table 2. Effects of dietary P on finishing performance and carcass characteristics for calves fed varying levels of P

Item	Phosphorus, % of DM ^a					SE	Linear ^a	Quadratic ^a
	0.16	0.22	0.28	0.34	0.40			
P intake, g/d	14.2	20.2	23.4	31.7	35.5	0.7		
Initial wt, kg	268	265	264	264	264	6	0.61	0.75
Final wt, kg	579	578	538	592	564	11	0.69	0.33
DMI, kg/d	8.9	9.0	8.2	9.3	8.8	0.2	0.92	0.32
ADG, kg/d	1.52	1.53	1.34	1.61	1.47	0.04	0.86	0.28
ADG:DMI	0.171	0.171	0.163	0.174	0.166	0.004	0.65	0.79
Fat depth, cm	0.97	1.28	1.16	1.17	1.17	0.12	0.41	0.25
Longissimus area, cm ²	112.0	110.0	105.4	106.0	108.1	2.7	0.19	0.21
Marbling ^b	529	533	516	566	571	31	0.25	0.57

^aLinear and quadratic orthogonal contrast for dietary P level.

^bMarbling score, where slight 50 = 450, small 50 = 550.

Table 3. Effect of dietary P on phalanx and metacarpal bone ash from carcasses of calves fed varying levels of P

Item	Phosphorus, % of DM					SE	Linear ^a	Quadratic ^a
	0.16	0.22	0.28	0.34	0.40			
Phalanx bone								
Total ash, g	27.8	29.3	27.8	30.9	27.6	1.1	0.72	0.23
Ash, mg/kg HCW ^b	80	82	84	85	80	2	0.87	0.08
Metacarpal bone								
Total ash, g	242	238	232	249	227	8	0.48	0.65
Ash, mg/kg HCW ^b	700	671	702	684	656	20	0.23	0.51

^aLinear and quadratic orthogonal contrast for dietary P level.

^bAsh is percentage bone mineral expressed as mg/kg of hot carcass weight.

ment resulted in a quadratic response for plasma P, with calves on the 0.16% P treatment having the lowest ($P < 0.05$) plasma P concentrations (4.6 mg/dL; Figure 1). However, plasma P concentration for calves fed 0.16% P did increase over the course of the experiment. On d 112, plasma P concentrations responded quadratically ($P < 0.05$) with calves fed 0.16% P having the lowest plasma P. Despite subtle differences in plasma P concentrations, all concentrations were above 5.5 mg/dL for all treatments after d 112.

Discussion

The P requirement predicted from NRC (1996) recommendations using actual performance of calves in this study was 18.7 g/d, or 3,815 g over the 204-d finishing period. This calculation assumed the maintenance requirement was 16 mg/kg BW and the requirement for

gain was 3.9 g of P per 100 g retained protein. Based on retained energy calculations using ADG and average BW over the feeding period, retained protein was equal to 155 g/d. Therefore, 6.7 g/d of P for maintenance and 6.0 g/d for gain was the predicted requirement for these calves based on NRC (1996) guidelines. The NRC (1996) assumed a 68% absorption rate, which means that dietary P requirements are projected as 18.7 g/d. Despite utilizing unique feed ingredients that are low in P (i.e., brewers grits and corn bran), P intakes in this experiment were in the range of 76 to 190% of NRC recommendations for P. Intake of P in this study was 62 to 156% of requirements predicted for these calves using AFRC (1991) guidelines. The AFRC system is quite different from NRC and assumed maintenance requirements are related to DMI, not BW, and the calculation for gain is based on mature size, current BW, and ADG. Based on the average performance of calves in this study, AFRC

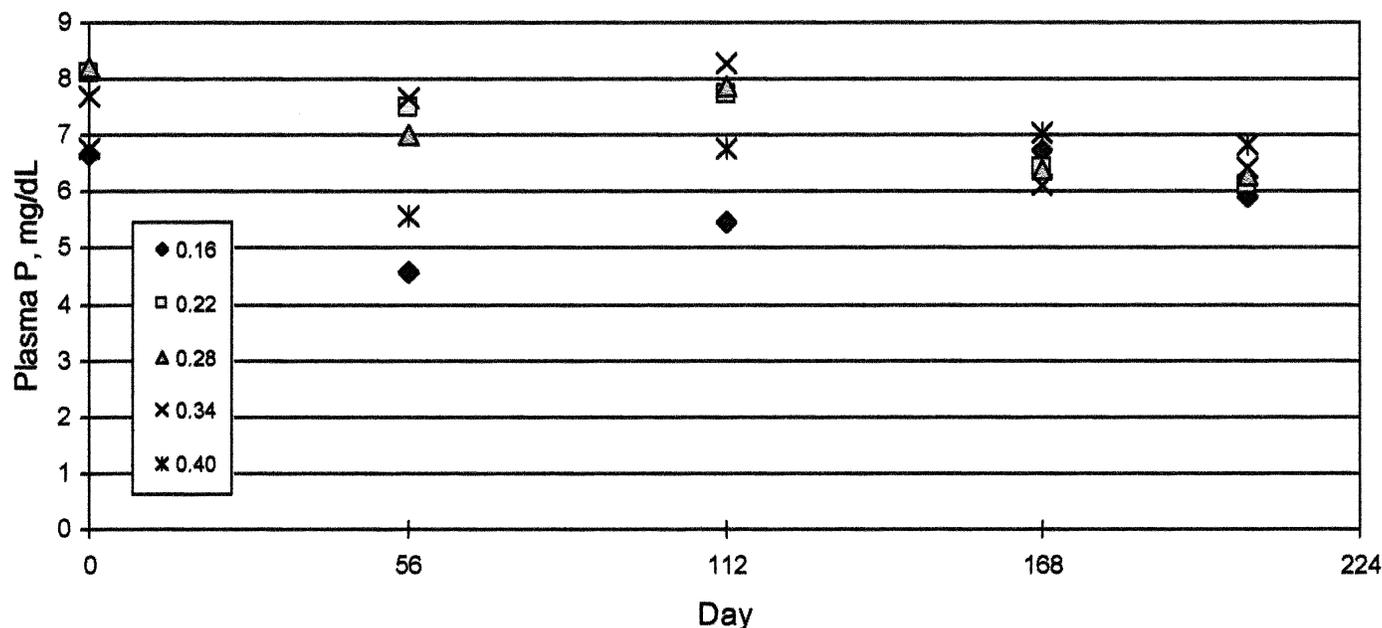


Figure 1. Change in plasma P concentration measured on d 0, 56, 112, 168, and 204 as influenced by P concentration of feedlot cattle diets. Standard errors for treatment across time were 0.21 mg/dL. Linear (L) and quadratic (Q) contrasts were $P < 0.05$ at d 0: Q; d 56: L, Q; d 112: L, Q; d 168: Q; and d 224: L.

(1991) recommendations indicate 22.8 g/d of P required by each steer.

Performance in this experiment was not influenced by dietary P treatment despite diets that contained 76% of NRC recommendations for P (NRC, 1996). In a similar experiment with yearling steers (BW = 385 kg), supplementation of P did not improve performance (Erickson et al., 1999). Dietary P fed to yearlings in that study ranged from 0.14 to 0.34% of diet DM, with individual intakes of 16 to 36 g/d equating to a range of 71 to 162% of NRC recommendations (Erickson et al., 1999). Similarly, Call et al. (1978) fed growing heifers 66 or 174% of NRC-predicted requirements for P during a 2-yr study without adverse effects on gain, BW, or reproduction. Few data are available for beef cattle weighing between 250 and 600 kg fed high-energy finishing diets. Most research has focused on young calves weighing less than 250 kg, which would be expected to have higher P requirements than typical feedlot cattle fed today.

The NRC (1996) recommendations on P requirements are higher than data from this experiment and other published work (Call et al., 1978; Erickson et al., 1999). Three possible reasons exist for disagreement between experimental data and NRC (1996) recommendations. The first reason is that maintenance requirements for P were overestimated by NRC (1996). The P maintenance requirements have been fairly well documented due to the ease of feeding cattle maintenance diets low in P and results support NRC recommendations (Ternouth et al., 1996; Challa and Braithwaite, 1988; Challa et al., 1989). A second reason is that gain requirements were overestimated by NRC (1996). The NRC (1996) cites only one study for estimating requirement for gain. Ellenberger et al. (1950) conducted an elaborate experiment in which 132 dairy cattle ranging in age from developing fetus to 12-yr-old cows were used to determine P retention during growth and development. Although that experiment is extremely valuable, there are inherent problems with basing the requirement for gain on a single study. The cattle used for whole-body analysis by Ellenberger et al. (1950) were quite different in breed, body weight, age, and genetic potential than beef feedlot cattle fed today. The third area that may cause inaccurate predictions of dietary requirements is the assumption that dietary P is only 68% absorbed. Evidence exists that apparent P absorption is related to P intake (Challa et al., 1989) because of changes in salivary flow of P (Wadsworth and Cohen, 1976). However, at low P intakes, true absorption of P from dietary ingredients may increase above 68%. On high-grain diets, phytate-P is hydrolyzed (Morse et al., 1992), and true dietary P absorption may be higher than 68% (Ternouth et al., 1996) despite low apparent absorption rates.

In this study, bone mineral content was not different among P treatments, suggesting that calves were not mobilizing P to meet their requirements for maintenance and gain. However, bones were collected at the end of the feeding period when P requirements are probably lowest relative to supply. Therefore, calves may have

mobilized P from bone stores early in the feeding period when requirements were highest and replenished those stores once dietary supply was adequate to meet requirements. Although bone mineral content is a critical assessment of P status of animals (Crenshaw et al., 1981), osteocalcin in plasma is a marker of bone turnover and(or) formation (Lian and Gundberg, 1988). This protein is usually elevated in plasma during bone formation and high turnover. Of importance is that net accretion or depletion of bone mineral is the balance between continuous bone formation and resorption. The bone matrix is actually quite active, and considerable turnover normally occurs (Loveridge, 1999). Figure 2 illustrates the osteocalcin detected in plasma for calves on the 0.16 and 0.40% P treatments. Osteocalcin concentrations in plasma were not significantly different on d 0, 56, 112, or 204, suggesting that bone turnover was not affected by dietary P treatment. Combining the osteocalcin data with bone ash data, we conclude that dietary P was adequate to meet the requirements for maintenance and gain without calves mobilizing P stores in bone.

Dietary calcium was kept constant in this study at 0.62% of diet DM. Because the percentage of P varied from 0.16 to 0.40, calcium:phosphorus ratios ranged from 1.6 to 3.9. Other research has demonstrated that cattle can tolerate Ca:P ratios between 1:1 and 7:1, assuming both calcium and phosphorus are included at or above requirements (Wise et al., 1963; Ricketts et al., 1970). Calcium was kept constant in this study because previous research demonstrated no interaction of P level when yearlings were fed two levels of Ca (Erickson et al., 1999).

Plasma inorganic P was decreased by feeding the 0.16% P diet, which suggests that less P was absorbed from the gastrointestinal tract. Cattle require a threshold concentration of plasma P for optimal growth. Numerous reports suggest that the threshold concentration is between 4.5 and 5.0 mg/dL (Kincaid, 1993; Ternouth et al., 1996; Underwood, 1966). Based on average concentrations from d 56 to 204 for the 0.16% P treatment, cattle were not deficient in P. However, because plasma P was 4.6 mg/dL on d 56 for the lowest level of P fed, those calves may have been marginally deficient. Because P was lower for the 0.16 and 0.40% P treatments, a quadratic response across P levels was observed for d 56 and 112. The plasma concentration for calves on the 0.16% treatment did increase past d 56 of the experiment, which suggests that dietary supply relative to requirement was increasing. As requirements become lower relative to supply after 56 d, plasma P increased above threshold concentrations (5.0 mg/dL). Performance and bone data for the entire 204 d suggest calves were not deficient. However, performance and bone data represent the entire 204 d and do not give insight into the P status early in the experiment when P requirements are presumably highest. Plasma P data were quite variable in response to dietary treatment after the first 112 d. Interestingly, plasma collected on d 56 and 112 from calves on the highest level of P (0.40%) contained less P than intermediate P treatments.

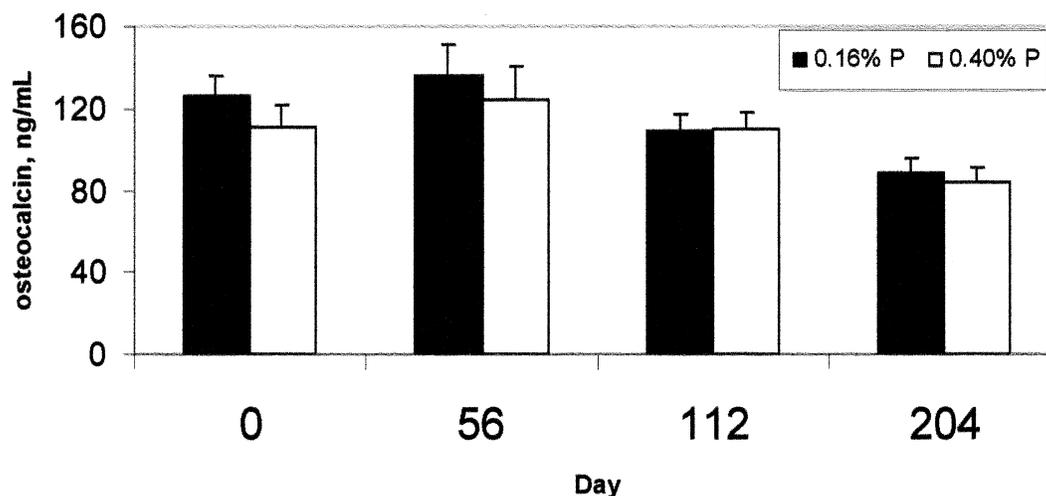


Figure 2. Osteocalcin concentration (ng/mL) in plasma from calves fed either 0.16 or 0.40% P during the 204-d finishing experiment. Bars denote standard errors. The treatment \times time interaction was not significant ($P = 0.81$), main effects of time were significant ($P < 0.01$), and there was no effect of P treatment ($P = 0.49$).

Implications

The results of this study suggest that P requirements for finishing calves are lower than previous estimates. Plasma P, performance, and bone characteristics indicate that P requirements are less than 0.16% of diet DM. NRC-predicted requirements appear to be too high and should be modified. Given the relatively large amount of P that grain-based finishing diets contain, determining the P requirement for feedlot cattle may be unimportant. Supplementation of mineral P in finishing diets is an unnecessary economic and environmental cost for beef feedlot producers and should discontinue.

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