University of Nebraska - Lincoln
DigitalCommons@University of Nebraska - Lincoln

Faculty Papers and Publications in Animal Science

Animal Science Department

1981

Effect of Level of Dietary Calcium-Phosphorus During Growth and Gestation on Performance, Blood and Bone Parameters of Swine

R. D. Nimmo
Allied Mills

E. R. Peo, Jr.
University of Nebraska-Lincoln

B. D. Moser
University of Nebraska-Lincoln

A. J. Lewis
University of Nebraska-Lincoln, alewis2@unl.edu

Follow this and additional works at: https://digitalcommons.unl.edu/animalscifacpub

Part of the Animal Sciences Commons

Nimmo, R. D.; Peo, Jr., E. R.; Moser, B. D.; and Lewis, A. J., "Effect of Level of Dietary Calcium-Phosphorus During Growth and Gestation on Performance, Blood and Bone Parameters of Swine" (1981). *Faculty Papers and Publications in Animal Science*. 656.
https://digitalcommons.unl.edu/animalscifacpub/656

This Article is brought to you for free and open access by the Animal Science Department at DigitalCommons@University of Nebraska - Lincoln. It has been accepted for inclusion in Faculty Papers and Publications in Animal Science by an authorized administrator of DigitalCommons@University of Nebraska - Lincoln.

Journal of Animal Science 52 (1981), pp. 1330-1342.
Copyright © 1981 American Society of Animal Science. Used by permission.

EFFECT OF LEVEL OF DIETARY CALCIUM-PHOSPHORUS DURING GROWTH AND GESTATION ON PERFORMANCE, BLOOD AND BONE PARAMETERS OF SWINE[1]

R. D. Nimmo[2], E. R. Peo, Jr., B. D. Moser and A. J. Lewis

University of Nebraska[3], Lincoln 68583

Summary

One-hundred and ninety-two crossbred weanling gilts (7.25 kg) were assigned to one of two treatments—(A) .65% Ca, .50% P or (B) .975% Ca, .75% P—and fed to an average weight of 92.8 kilograms. Average daily gain (.65 and .67 kg, respectively) and feed/gain were not affected by dietary treatment, but average daily feed intake was lower (P<.05) for gilts on treatment A (1.87 *vs* 1.95 kg). At the end of the growth phase, 96 gilts were slaughtered and bone strength parameters and physical characteristics were examined. Average peak force and bending moment of the third and fourth metatarsal bones were lower (P<.001) for gilts fed treatment A. However, no difference in maximum stress was observed between treatment groups. In phase 2, gilts from phase 1 were randomly allotted to two gestation treatments: (A) 13 g Ca, 10 g P/day, and (B) 19.5 g Ca, 15 g P/day. Gestation group A included 23 of the 45 gilts from growth treatment A (phase 1) while gestation group B contained the remaining 22 gilts from growth treatment A. The 46 gilts that had been fed growth treatment B were assigned to gestation groups in the same way. Gilts were individually fed until 109 days of gestation and given a lactation diet containing .75% Ca, .50% P for an average of 42 days. Analysis of the fourth metatarsal showed lower (P<.05) peak force values for gilts in gestation group A than for those in group B. Of the 23 gilts originally allotted to the combined growth-gestation treatment AA, seven had to be removed because they were unable to stand. These results suggest that levels of .65% Ca, .50% P from 7 to 93 kg and 13 g Ca, 10 g P/day during gestation are not adequate to meet Ca and P requirements of the gilt during growth and gestation.

(**Key Words**: Gilts, Calcium, Phosphorus, Swine.)

Introduction

The 1973 NRC, requirements of Ca and P for growing-finishing pigs (NRC, 1973) and the current (NRC, 1979) requirements are based primarily on the amounts necessary for optimum performance. The levels decline steadily with age and are .50% Ca, .40% P at 100 kilograms. Data from several sources (Chapman *et al.*, 1962; Combs *et al.*, 1962; Miller *et al.*, 1962, 1964; Libal *et al.*, 1969; Cromwell *et al.*, 1972; Stockland and Baylock, 1973) suggest that the Ca-P requirements for optimum performance are lower than those for maximal skeletal development. Furthermore, several reports (Chapman *et al.*, 1962; Miller *et al.*, 1964; Storts and Koestner, 1965; Brown *et al.*, 1966) have indicated crippling and occasional fractures among growing swine fed Ca and P levels similar to the suggested NRC requirements. As a result, gilts subject to possible selection as replacement gilts for the breeding herd probably do not possess the skeletal development necessary to withstand the severe and repeated drain on skeletal Ca-P that occurs during multiple parities.

Limited data are available for the assessment of Ca-P requirements of gilts during gestation. Kornegay *et al.* (1973) reported a number of fractured femurs when sows were fed low as well as high Ca-P levels for five parities. Harmon *et al.* (1974) reported that .5% P during one gestation and lactation cycle was adequate when sows were given dicalcium or Curacao

[1] Published as Paper No. 6082 Journal Ser. Nebraska Agr. Exp. Sta.

[2] Present address: Allied Mills, Libertyville, IL 60048.

[3] Dept. of Anim. Sci. Acknowledgment is made to Alice Teter for assistance with preparation of this manuscript and to Mary Barnes, Cecilia Stodd and Tom Crenshaw for laboratory and statistical counsel.

phosphate. Harmon *et al.* (1975) also reported that .45% P was the requirement during lactation for first litter sows with an *ad libitum* feed intake.

The objective of the experiments reported herein was to determine the effects of various levels of Ca and P during growth and gestation on skeletal development and on skeletal loss during the first lactation of gilts.

Experimental Procedure

Phase 1. One-hundred and ninety-two crossbred weanling gilts (7.25 kg) were randomly assigned to two levels of dietary Ca and P, with 12 replications of each treatment and eight gilts per pen (figure 1). Treatment A consisted of a 17% corn-soybean meal diet that contained .65% Ca and .50% P and met NRC (1973) requirements for young growing pigs. The treatment B diet contained .975% Ca and .75% P (table 1). The Ca to P ratio was maintained at 1.3:1.0 in both treatments. All gilts were fed *ad libitum* for 130 days (92.8 kg) in a modified open front, growing-finishing unit containing 24 1.52 × 5.49 m partially slotted pens. The animals were weighed biweekly, and average daily gain (ADG), average daily intake (ADFI) and feed conversion (F/G) were measured for the total feeding period. The pen was used as the experimental unit.

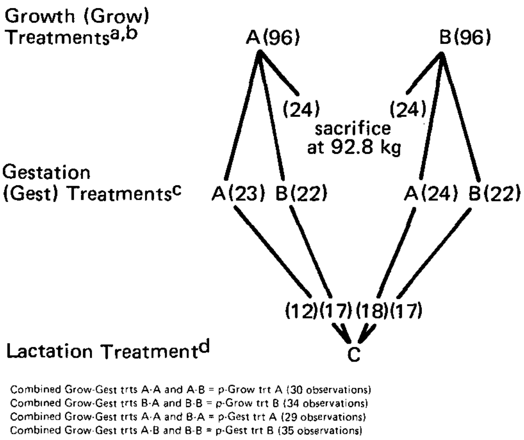

Figure 1. Experimental design. Number of gilts (a) involved in each phase is shown by the values in parenthesis. Ca and P levels fed during the growth phase (b) were .65%, .50% (treatment A) and .975% and .75% (treatment B), respectively. Initial weight of the pigs was 7.25 kilograms. During gestation, (c), gilts were fed either 13 g Ca, 10 g P (treatment A) or 19.5 g Ca, 15.0 g P (treatment B) from 92.8 kilograms to parturition. During lactation (d), all animals were fed *ad libitum*. The diet contained .75% Ca and .50% P.

TABLE 1. COMPOSITION OF DIETS (TRIAL 1)

Ingredient, %	Diet A	Diet B
Ground yellow corn (IFN 4-02-931)	73.25	71.50
Soybean meal (IFN 5-04-612)	23.35	23.75
Dicalcium phosphate (IFN 6-01-080)	.85	2.20
Calcium carbonate (IFN 6-01-069)	.95	.95
Salt (iodized) (IFN 6-04-152)	.50	.50
Trace mineral premix[a]	.10	.10
Vitamin and antibiotic premix[b]	1.00	1.00
	100.00	100.00

	Calculated		Actual	
	Diet A	Diet B	Diet A	Diet B
% protein	17.0	17.0	17.57	17.81
% Ca	.65	.975	.62	.99
% P	.50	.75	.51	.77

[a]Contributed the following in ppm of diet: Zn, 200; Fe, 100; Mn, 55; Cu, 10; Co, 1; I, 1.5.

[b]Contributed the following per kilogram of diet: vitamin A, 3,300 IU; vitamin D_3, 440 IU; riboflavin, 4.4 mg; pantothenic acid, 26.4 mg; niacin, 35.2 mg; choline chloride, 220 mg; vitamin B_{12}, 44 ug ethoxyquin, 8.8 mg; menadione sodium bisulfite, 4.4 mg; vitamin E, 44 IU; chlortetracycline, 110 mg; sulfamethazine, 110 mg; procaine penicillin, 55 milligrams.

Blood samples were collected at 0, 4, 9, 13 and 18 weeks from the brachial region of four gilts in each pen (48 per treatment) that had been randomly selected at the initiation of the trial. The 0-week bleeding was used to adjust for possible differences in initial levels of serum Ca, P and alkaline phosphatase. The 4-, 9-, 13- and 18-week bleedings constituted bleeding periods 1 to 4. Analyses of serum Ca and P concentrations in each pig were performed by an automated procedure adapted from the simultaneous procedure of Kessler and Wolfman (1964). Serum alkaline phosphatase was determined by an automated procedure adapted from Morgenstern *et al.* (1965) and Frankel *et al.* (1970). Treatment differences were pooled by period, and statistical tests for linear, quadratic and cubic responses of serum parameters, pooled by treatments, were determined. Because the period spacing for bleedings was

uneven, orthogonal coefficients for linear, quadratic and cubic responses were adjusted accordingly (Snedecor, 1958).

Four gilts from each pen (48 per treatment) were selected for slaughter 1 day after the end of the trial, and the third and fourth metatarsal bones were collected. Procedures for the assignment of soundness scores, collection, storage and preparation for subsequent bone fracture have been described by Nimmo *et al.* (1980b). The following relative strength indices and physical characteristics of the bones were measured: weight in grams; length, centimeters; two outside and two inside micrometer-determined diameters (OD1, OD2, ID1, ID2) measured at the midpoint of the shaft perpendicular to each other, centimeters, guage length (length of fulcrum points that the bone rested on), centimeters; circumference = OD1−(4 × OD1)/9.42477; extension measurement (EXT) = length of travel of crosshead required to fracture bone, centimeters; peak force (PF) = kilograms of force required to fracture bone; bending moment (BM) = (peak × gauge)/4, kilograms/centimeter; moment of inertia (MI) = (.0549 × $OD2^3$ × OD1)−(ID2 × $ID1^3$), $centimeters^4$; maximum stress = (PF × gauge × C)/(4 × MI) measured in kilograms/square centimeter; modulus of elasticity (ME) = (PF × $gauge^3$)/(48 × MI × EXT) kilograms/square centimeter; average outside diameter (AVOD) = (OD1 + OD2)/2, centimeters, and average inside diameter (AVID) = (ID1 + ID2)/2, centimeters. Treatment differences were pooled by bone for statistical analysis. Bone comparisons pooled by treatment and treatment × bone interactions were also tested.

Phase 2. The remaining 91 gilts from phase 1 were allotted to two gestation treatments. Twenty-three of the 45 gilts that had been on growth treatment A (.65% Ca, .50% P) were assigned to gestation treatment A (13.0 g Ca, 10.0 g P/day), while the other 22 gilts were allotted to gestation treatment B (19.5 g Ca, 15.0 g P/day; table 2). The 46 gilts from growth treatment B (phase 1) were similarly assigned to gestation treatments A and B. The combined growth-gestation arrangements and numbers of gilts beginning the gestation trial were: A-A, 23; A-B, 22; B-A, 24; B-B, 22. All gilts were exposed to boars during a 30-day breeding period 70 days after the termination of phase 1. Any gilts that failed to conceive during one estrous cycle were eliminated from the trial, so all gilts were bred to farrow during a 30-day period.

All gilts were individually fed 1,816 g of a 14% crude protein corn-soybean meal-based diet in gestation stalls for 50 days and then switched to an intake level of 1,589 g until day 109 g gestation, when beet pulp (20.0%) was added to the diet. The beet pulp diet was fed until parturition at a rate of 1,816 g/day. Gilts that were unable to stand after 40 days of pregnancy and gilts that aborted were removed from the experiment.

Phase 3. Gilts were placed in individual farrowing stalls in environmentally controlled rooms (12 sows per room). Twnety-four hours after parturition, all gilts, regardless of prior treatment, were placed on the same lactation diet (table 3). The lactation diet contained .75% Ca, .50% P (NRC, 1979) and was fed to approximate *ad libitum* intake four times daily within 7 days postpartum. Pigs were offered creep feed from 10 days postpartum to weaning in order to simulate practical management conditions. The pigs were weaned at an average age of 42 days. Sows were slaughtered 24 hr thereafter, and the third and fourth metatarsal bones were collected.

Bone characteristics and relative strength indices measured were the same as in phase 1. Combined growth-gestation treatments groups AA and AB were pooled, creating pooled growth treatment group A (p-grow A), and growth-gestation treatments groups BA and BB made up pooled growth treatment group B (p-grow B). Pooled gestation treatment groups (p-gest A, p-gest B) were B-A, A-A and A-B, B-B, respectively. Analyses of p-grow A *versus* p-grow B, p-gest A *versus* p-gest B and p-grow × p-gest treatment interactions were performed with data for bones from the sows on each treatment.

Statistical analysis was conducted by procedures designed and implemented by Steel and Torrie (1960) and Barr *et al.* (1976).

Results and Discussion

The performance of gilts (phase 1) fed the two levels of dietary Ca and P is summarized in table 4. There were no differencs ($P > .05$) in average daily gain or feed/gain between treatment groups. Gilts on treatment B (.975% Ca, .75% P) consumed more feed per day ($P < .05$) than gilts on treatment A (.65% Ca, .50% P; 1.95 *vs* 1.87 kg). These results are similar to those reported by Liptrap *et al.* (1970) for development gilts fed for 16 weeks, although

TABLE 2. COMPOSITION OF DIETS (TRIAL 2)

Ingredient, %	Early Gestation		Mid Gestation		Late Gestation	
	Treatment A	Treatment B	Treatment A	Treatment B	Treatment A	Treatment B
	1,816 g/day		1,589 g/day		1,816 g/day	
Ground yellow corn (IFN 4-02-931)	82.40	80.50	80.70	78.70	61.35	59.55
Soybean meal (IFN 5-04-612)	13.85	14.30	15.40	15.85	15.35	15.75
Beet pulp (IFN 4-00-669)	...	...	...	...	20.00	20.00
Dicalcium phosphate (IFN 6-01-080)	1.25	2.70	1.50	3.05	1.30	2.70
Calcium carbonate (IFN 6-01-069)	.90	.90	.75	.75	.35	.35
Salt (iodized) (IFN 6-04-152)	.50	.50	.50	.50	.50	.50
Trace mineral premix[a]	.10	.10	.10	.10	.10	.10
Vitamin and antibiotic premix[b]	1.00	1.00	1.00	1.00	1.00	1.00
Se premix[c]	...	...	.05	.05	.05	.05
	100.00	100.00	100.00	100.00	100.00	100.00

[a]Contributed the following in ppm of diet: Zn, 200; Fe, 100; Mn, 55; Cu, 10; Co, 1; I, 1.5.

[b]Contributed the following per kilogram of diet: vitamin A, 3,300 IU; vitamin D_3, 440 IU; riboflavin, 4.4 mg; pantothenic acid, 26.4 mg; niacin, 35.2 mg; choline chloride, 220 mg; vitamin B_{12}, 55 ug; ethoxyquin, 8.8 mg; menadione sodium bisulfite, 4.4 mg; vitamin E, 44 IU; chlortetracycline, 110 mg; sulfamethazine, 110 mg; procaine penicillin, 55 milligrams.

[c]Contributed the following per kilogram of diet: Se, .1 milligram.

TABLE 3. COMPOSITION OF DIETS (TRIAL 3)

Ingredient, %		Diet
Ground yellow corn (IFN 4-02-931)		57.55
Soybean meal (IFN 5-04-612)		14.30
Beet pulp (IFN 4-00-669)		20.0
Wheat bran (IFN 4-05-190)		2.5
Alfalfa dehy (IFN 1-00-023)		2.5
Dicalcium phosphate (IFN 6-01-080)		1.0
Calcium carbonate (IFN 6-01-069)		.55
Salt (iodized) (IFN 6-04-152)		.50
Trace mineral premix[a]		.10
Vitamin premix[b]		1.0
		100.00
	Calculated	Actual
% protein	14.0	14.4
% Ca	.75	.78
% P	.50	.51

[a]Contributed the following in ppm of diet: Zn, 200; Fe, 100; Mn, 55; Cu, 10; Co, 1; I, 1.5.

[b]Contributed the following per kilogram of diet: vitamin A, 3,300 IU; vitamin D_3, 400 IU; riboflavin, 4.4 mg; pantothenic acid, 26.4 mg; niacin, 35.2 mg; choline chloride, 220 mg; vitamin B_{12}, 44 ug; ethoxyquin, 8.8 mg; menadione sodium bisulfite, 4.4 mg; vitamin E, 44 IU.

those authors noted a decrease in average daily gain among gilts fed Ca at 1.2% and P at .51% of the diet. Cromwell *et al.* (1970) noted a linear increase in gains and a linear decrease in feed/gain of gilts fed .34, .45 and .56% P with Ca held constant. A wealth of research has been reported assessing the Ca and P requirements of growing-finishing pigs based on performance, but most of the data are pooled across sexes. Hines (1966) reported differences in performance between gilts and barrows. Most of the data used to establish Ca and P requirements for growing-finishing pigs have been averages for the two sexes, and the response criteria have been gains and feed conversion. Practical management conditions dicatate that barrows and gilts be group-fed. Under normal conditions, performance would not be affected by the feeding of marginal levels of dietary Ca and P to market swine, but replacement gilts are often selected from market swine groups. Thus, there is a possible risk of inadequate skeletal development in these gilts.

Front and rear feet and leg soundness scores are presented in table 4. Gilts on treatment B had higher (P<.05) rear feet and leg soundness scores than gilts on treatment A. A similar trend (P<.1) was noted when the front and rear feet and leg scores were pooled and compared between treatments. Similar results were reported for boars fed the same dietary Ca and P levels as these gilts from 3 to 11 weeks of age (Nimmo *et al.*, 1980b).

Serum Ca,P and aklaline phosphatase concentrations for each treatment group are presented in table 5. No differences (P>.05) in serum Ca were observed between treatment groups when data were pooled by periods. A treatment × period interaction (P<.05) was observed for serum Ca. No explanation for this response is

TABLE 4. EFFECTS OF DIETARY CALCIUM-PHOSPHORUS LEVELS ON PERFORMANCE OF GROWING GILTS[a] (TRIAL 1)

	Criterion[b]					
Treatment[c]	ADG, kg	ADFI[d], kg	F/G	Front foot score	Rear foot[d] score	Avg foot score[e]
A	.65 ± .01	1.87 ± .04	2.86 ± .04	6.09 ± .22	5.90 ± .17	6.00 ± .17
B	.67 ± .01	1.95 ± .04	2.95 ± .02	6.29 ± .21	6.42 ± .11	6.36 ± .14

[a]Starting weight, 7.25 kg; termination weight, 92.82 kilograms.

[b]Average daily gain = ADG; average daily feed intake = ADFI; feed per gain = F/G; foot scores on a scale of 1 to 10, where 1 = worst, 10 = best.

[c]Treatment A = .65% Ca, .50% P; treatment B = .975% Ca, .75% P. Performance means equal 24 pen averages with eight gilts per pen. Feet scores equal 24 pen averages with four gilts per pen.

[d]Difference (P<.05) between treatments A and B.

[e]Difference (P<.1) between treatments A and B.

TABLE 5. EFFECTS OF DIETARY CALCIUM-PHOSPHORUS ON SERUM CALCIUM, PHOSPHORUS AND ALKALINE PHOSPHATASE LEVELS, BY PERIOD[a] (TRIAL 1)

		Period				
Item	Treatment[c]	1	2	3	4	Avg
Serum Ca, mg/100 ml	A[de]	10.47 ± .18	10.73 ± .12	10.56 ± .17	10.82 ± .12	10.65 ± .07
	B[de]	10.12 ± .16	10.49 ± .08	10.95 ± .18	10.67 ± .12	10.56 ± .07
Serum P, mg/100 ml	A[fghi]	7.98 ± .17	8.90 ± .29	7.94 ± .18	7.94 ± .10	8.22 ± .10
	B[fghi]	8.90 ± .25	9.59 ± .24	8.41 ± .11	7.64 ± .13	8.65 ± .11
Serum alkaline phosphatase, IU/100 ml	A[ghij]	15.94 ± .76	11.72 ± .42	10.15 ± .35	8.30 ± .23	11.53 ± .31
	B[ghij]	15.57 ± .63	12.00 ± .41	10.31 ± .34	8.44 ± .23	11.58 ± .28

[a]Serum Ca, P and alkaline phosphatase were determined at 0, 4, 9, 13 and 18 weeks on test. The 0-week bleeding was used to adjust for differences in initial serum levels. Periods 1 to 4 are the remaining four bleedings.

[b]Orthogonal coefficients for linear, quadratic and cubic comparions were adjusted for unequal period intervals.

[c]Treatment A = .65% Ca, .50% P, B = .975% Ca, .75% P.

[d]Treatment × period interaction (P<.05).

[e]Period linear (P<.005).

[f]Treatment 1 *vs* treatment 2 pooled by period (P<.025).

[g]Period linear (P<.001).

[h]Period quadratic (P<.001).

[i]Period cubic (P<.001).

[j]Treatment × period interaction (P<.1).

apparent. Serum Ca increased (P<.005) linearly when data were pooled by treatment, although the net increase was small. The large number of observations per period and relatively low standard error were probably the reasons for the significant linear response. Ullrey *et al.* (1967) reported that serum Ca concentrations decreased slightly (1 mg/100 ml) from 2 to 5 months of age in barrows and gilts fed .71% Ca and .54% P. Harmon *et al.* (1970) reported increasing serum Ca concentrations as the level of P in the diet increased. Although the trends were not significant, the data reported herein appear to correspond to the results of Harmon.

Serum P was higher (P<.025) in gilts on treatment B than in those on treatment A when data were pooled by period (8.65 *vs* 8.22 mg/100 ml). The linear increase in serum P concentrations was similar to increases observed by Miller *et al.* (1964), Cromwell *et al.* (1970), Harmon *et al.* (1970), Reinhard *et al.* (1976) and Nimmo *et al.* (1980b). Serum P was highest at the second sampling (12 weeks of age) and decreased thereafter. Ullrey *et al.* (1967) reported maximum serum P concentrations at approximately 2 weeks of age for pigs fed .54% P, followed by a steady decrease through 5 weeks and a level of 7.0 mg/100 ml at 5 months of age.

Serum Ca appeared to increase and serum P to decrease by period when data were pooled by treatment, and, conversely, serum Ca appeared to decrease as dietary Ca increased, whereas serum P increased with higher levels of dietary P. Serum alkaline phosphatase (SAP) did not differ between treatment groups when data were pooled by period, but the linear component pooled by treatment was significant (P<.001). In addition, a treatment × period interaction (P<.1) was noted. Normally, SAP is fairly sensitive to changes in graded levels of dietary Ca and P to levels at or slightly below those required for maximum calcification of bones. Increases in SAP levels have been reported in diseases such as osteomalacia and rickets (Kay, 1930), and increases in this enzyme are typical when diets are fed that contain Ca and P below levels required for maximum skeletal development (Nimmo *et al.*, 1980a,b). Except during period 1, SAP values were consistently higher for gilts on treatment A than for those on treatment B. The steady decrease in SAP with

each period for both treatment groups is consistent with findings reported by others (Hoekstra *et al.*, 1967; Cromwell *et al.*, 1970; Liptrap *et al.*, 1970; Reinhard *et al.*, 1976; Nimmo *et al.*, 1980a,b). This pattern of higher SAP levels appears to indicate that the degree of mineralization of bones may have been lower for gilts on treatment A. Posen (1967) reported that an absence of large differences in SAP is not surprising, since the enzyme is derived from a number of locations other than the skeleton, and that levels appear to fluctuate due to a number of factors.

A summary of bone strength parameters is presented in table 6. PF (kilograms) and BM (kilograms/centimeter) were greater (P<.001) for bones from gilts fed treatment diet B than for bones from gilts on treatment A (148.4 *vs* 124.9 kg and 116.9 *vs* 98.4 kg-cm, respectively). The PF, BM and MI values for the third metatarsal were consistently higher than those for the fourth metatarsal when pooled by treatment. Since PF was measured in kilograms of force required to fracture the bones, with no compensation for any other physical characteristics, large differences in absolute values were observed. Similar treatment differences in PF values of bones from boars fed the same diets as these gilts were reported by Nimmo *et al.* (1980b). BM is a measurement similar to PF, since PF is utilized to derive the value. Maximum stress (kilograms/square centimeter) values pooled by bone were the same for both treatment groups, but the third metatarsal had higher (P<.005) maximum stress values than the fourth metatarsal when values were pooled across treatments. A similar response was observed for ME (kilograms/square centimeter), with the third metatarsal having a larger (P<.001) value than the fourth metatarsal. Maximum stress values are used for determining the force the bone will withstand per unit area, while ME is a measure of the force a bone will withstand per unit area per unit of deformation. In theory, the mass density of bones is similar per unit of area of the bones, since any differences between treatment groups in total area of the bones has been eliminated. The same relationship exists for ME, including elimination of the variable of deformation per unit area. Crenshaw (1980) has provided a detailed description and analysis of these bone force parameters and their relationship among certain bones in swine.

The physical characteristics of bones from phase 1 are summarized in table 7. Gilts fed treatment diet B had longer (8.13 *vs* 8.06 cm) and heavier (23.87 *vs* 23.11 g) bones (P<.001) than gilts fed treatment diet A. In addition, the fourth metatarsal was longer and heavier (P<.001) than the third metatarsal when data were pooled by bone across treatments. No differences due to treatment were noted in the AVID and AVOD of bones, but the third metatarsal was larger (P<.005) in both inside and outside diameters than the fourth metatarsal when compared by bone across treatments. Although AVID of both bones from gilts in treatment group B were identical, some variation existed in AVID of the third and fourth metatarsals from gilts fed treatment diet A.

A summary of the bone force and related parameters of bones from gilts following one lactation is presented in table 8. P-grow A *versus* p-grow B treatments and p-gest A *versus* p-gest B treatments resulted in lower (P<.05) PF and BM values for the fourth metatarsal. No differences in PF and BM of the third metatarsal were observed in either the p-grow or p-gest treatment group comparisons. A trend for lower maximum stress values (P<.1) for the third and fourth metatarsals was apparent in both the growth and gestation treatment group comparisons. The results indicate that the maximum stress required to fracture the bones from gilts in both the p-grow A and p-gest A treatment group was less than that for bones from animals in the B treatment groups. Also, the results suggest that changes in the differential between accretion and resorption rate of bones from p-grow A and p-gest A gilts may have altered the density per unit area of bone. Since no differenes in AVID and AVOD (table 9) were observed in the p-grow and p-gest treatment comparisons, the differences found for maximum stress lend support to the hypothesis that bones from animals on the growth A and gestation A treatments were less dense per unit area. Doige *et al.* (1975) reported similar results for pigs fed several different Ca-P levels; those authors observed no differences in thickness of cortical bone, but found that in pigs fed low Ca-P, porosity of bones resulted from the formation of numerous resorption spaces. The fourth metatarsal from gilts on p-grow B weighed more (P<.06) than the third metatarsal, and the third metatarsal from p-grow A gilts was shorter (P<.05) than its treatment B counterpart.

The number of gilts beginning phase 2, the

TABLE 6. EFFECTS OF DIETARY CALCIUM-PHOSPHORUS LEVELS ON BONE TRAITS OF GROWING GILTS[a] (TRIAL 1)

		Trait				
Treatment[b]	Bone[c]	Peak force[de], kg	Bending moment[de], kg-cm	Maximum stress[f], kg/cm^2	Modulus of elasticity[e], kg/cm^2	Moment of inertia[d], cm^4
A	3	128.9 ± 3.18	101.6 ± 2.50	605.0 ± 16.59	1,750.8 ± 86.75	.124 ± .004
	4	120.9 ± 3.28	95.20 ± 2.59	570.2 ± 17.07	1,522.3 ± 65.29	.122 ± .004
	Avg	124.9 ± 2.31	98.39 ± 1.82	587.6 ± 11.97	1,636.6 ± 55.25	.123 ± .002
B	3	154.0 ± 3.18	121.3 ± 2.51	641.2 ± 15.34	1,872.6 ± 85.44	.142 ± .005
	4	142.9 ± 3.80	112.5 ± 2.99	614.4 ± 19.55	1,652.5 ± 82.55	.138 ± .005
	Avg	148.4 ± 2.53	116.9 ± 1.99	627.8 ± 12.44	1,762.6 ± 60.16	.140 ± .003

[a]Gilts sacrificed at an average of 92.82 kilograms. Means represent 48 observations per bone. Treatment means are averages of 96 observations ± SEM.

[b]Treatment A = .65% Ca, .50% P; treatment B = .975% Ca, .75% P.

[c]Bone 3 = third metatarsal; 4 = fourth metatarsal.

[d]Treatment A *vs* B ($P<.001$).

[e]Bone 3 *vs* 4 ($P<.001$).

[f]Bone 3 *vs* 4 ($P<.005$).

number remaining at the completion of phase 3 and the causes of elimination are presented in table 10. Of the 24 gilts removed from the gestation treatments, 14 failed to conceive after exposure to a boar during estrus. Four gilts aborted, possibly because of infection from bladder catheters utilized during the gestation metabolism trial. At approximately 40 days of pregnancy, six gilts were removed because they were unable to stand in the gestation stall. All six gilts had been fed treatment diet A (.65% Ca, .50% P) during gestation and five of the six gilts were on gestation treatment A (13.0 g Ca, 10.0 g P/day) when removed from the trial. In addition, two other gilts were removed during phase 3. One suffered a broken femur immediately after being removed from the farrowing crate following lactation, and the other sustained a similar bone fracture just before slaughter. These seven gilts on growth-gestation treatments A-A represented slightly over 30% of the total number of gilts subjected to the lower Ca and P levels during phases 1 and 2. Of the 68 gilts on the other dietary treatments in phase 2, only one was unable to stand after 40 days of pregnancy. That gilt had been fed growth treatment A in phase 1. These results suggest that the probability of a gilt on growth-gestation treatment A-A encountering some form of physical disability, such as inability to stand up during gestation or failure to avoid fractures of bones after one lactation, is greater than that for gilts fed other growth-gestation treatments. Since seven of the initial 23 gilts fed growth-gestation treatments A-A were removed during phases 2 and 3, the bone force and physical measurement parameters for the remaining gilts may have provided an inflated estimation, as the values for the gilts that were removed might have decreased the group averages.

The 1968 and 1973 NRC requirements for bred gilts and sows (NRC 1968, 1973) were 15.0 g Ca and 10.0 g P/day, but the 1979 recommendations (NRC, 1979) show a reduction in Ca (13.5 g/day) and a slight increase in P (10.8 g/day). The results reported herein indicate that gestation Ca-P levels similar to those suggested by NRC (1979) do not support maximal skeletal development, particularly if the gilts are fed .65% Ca and .50% P during the growing-finishing period starting at 21 days of age. Although these results show no large numerical differences in mean PF and maximum stress of bones from gilts on growth-gestation treatments A-B and B-A, it is important to recognize that there was a clear difference between growth treatment A and growth treatment B. Any compensatory mineral

TABLE 7. EFFECTS OF DIETARY CALCIUM-PHOSPHORUS LEVELS ON PHYSICAL CHARACTERISTICS OF BONES FROM GROWING GILTS[a] (TRIAL 1)

Treatment[b]	Bone[c]	Parameter			
		Weight[de], g	Length[de], cm	Avg outside diameter[f], cm	Avg inside diameter[fg], cm
A	3	21.52 ± .44	7.89 ± .06	2.07 ± .01	1.52 ± .01
	4	22.81 ± .45	8.23 ± .06	2.04 ± .01	1.47 ± .01
	Avg	22.16 ± .32	8.06 ± .04	2.06 ± .009	1.49 ± .01
B	3	23.11 ± .38	7.96 ± .05	2.09 ± .01	1.44 ± .02
	4	24.62 ± .47	8.31 ± .05	2.08 ± .01	1.44 ± .02
	Avg	23.87 ± .31	8.13 ± .04	2.08 ± .09	1.44 ± .09

[a]Gilts sacrificed at an average of 92.82 kilograms. Means represent 48 observations per bone. Treatment means are averages of 96 observations ± SEM.

[b]Treatment A = .65% Ca, .50% P; B = .975% Ca, .75% P.

[c]Bone 3 = third metatarsal; 4 = fourth metatarsal.

[d]Treatments A *vs* B (P<.005).

[e]Bones 3 *vs* 4 (P<.001).

[f]Bones 3 *vs* 4 (P<.005).

[g]Treatment × bone interaction (P<.005).

TABLE 8. EFFECTS OF PREVIOUS DIETARY CALCIUM-PHOSPHORUS LEVELS ON BONE TRAITS OF SOWS FOLLOWING ONE LACTATION[a] (TRIAL 3)

Treatment[bc]			Parameter				
Growth	Gestation	Bone[d]	Peak force[ef], kg	Bending moment[ef], kg-cm	Maximum stress[gh], kg/cm²	Modulus of elasticity, kg/cm²	Moment of inertia, cm⁴
A	A	3	152.5 ± 8.2	120.1 ± 6.4	422.8 ± 32.5	1,131 ± 137.9	.224 ± .01
		4	149.3 ± 7.6	117.5 ± 6.0	450.3 ± 28.0	1,389 ± 99.8	.222 ± .01
		Avg	150.9 ± 5.5	118.8 ± 4.3	436.5 ± 21.1	1,260 ± 87.5	.233 ± .01
A	B	3	166.2 ± 8.0	130.9 ± 6.3	491.9 ± 22.9	1,328 ± 85.6	.220 ± .007
		4	173.5 ± 9.3	136.6 ± 7.4	504.8 ± 29.3	1,438 ± 104.7	.228 ± .01
		Avg	169.8 ± 6.1	133.7 ± 4.8	498.3 ± 18.4	1,383 ± 67.3	.224 ± .006
B	A	3	174.6 ± 7.3	137.5 ± 5.7	523.3 ± 24.7	1,444 ± 135.6	.220 ± .01
		4	180.1 ± 8.8	141.8 ± 7.0	532.6 ± 32.2	1,322 ± 101.6	.227 ± .01
		Avg	177.3 ± 5.6	139.6 ± 4.4	527.9 ± 20.0	1,383 ± 84.1	.224 ± .008
B	B	3	183.2 ± 7.4	144.3 ± 5.9	527.0 ± 28.9	1,461 ± 108.0	.229 ± .01
		4	203.9 ± 8.3	160.6 ± 6.5	571.2 ± 35.3	1,552 ± 138.8	.244 ± .02
		Avg	193.6 ± 5.7	152.4 ± 4.5	549.1 ± 22.8	1,507 ± 86.9	.237 ± .01

[a]Sows sacrificed approximately 24 hr after weaning. Means for groups AA, AB, BA and BB represent 12, 17, 18 and 17 observations per bone, respectively, ± SEM.

[b]Date fed growth A and growth B treatments were pooled by bone and compared. The same comparisons were made for gestation treatments and the growth X gestation interaction.

[c]Growth A = .65% Ca, .50% P; B = .975% Ca, .75% P fed to an average weight of 92.82 kg. Gestation A = 13.0 g Ca, 10.0 g P/day; B = 19.5 g Ca, 15.0 g P/day fed from an average weight of 92.82 kg until parturition.

[d]Bone 3 = third metatarsal; 4 = fourth metatarsal.

[e]Grow A *vs* Grow B ($P<.05$) (Bone 4).

[f]Gest A *vs* Gest B ($P<.05$) (Bone 4).

[g]Grow A *vs* Grow B ($P<.1$) (Bone 3).

[h]Grow A *vs* Grow B ($P<.1$) (Bone 4).

TABLE 9. EFFECT OF PREVIOUS DIETARY CALCIUM AND PHOSPHORUS LEVELS ON PHYSICAL CHARACTERISTICS OF BONES FROM SOWS FOLLOWING ONE LACTATION[a] (TRIAL 3)

Treatment[bc]			Trait			
Growth	Gestation	Bone[d]	Weight[e], g	Length[f], cm	Avg outside diameter, cm	Avg inside diameter, cm
A	A	3	32.50 ± 1.31	8.97 ± .08	2.43 ± .04	1.72 ± .04
		4	34.26 ± 1.24	9.40 ± .09	2.35 ± .04	1.66 ± .03
		Avg	33.38 ± .90	9.18 ± .07	2.39 ± .03	1.69 ± .03
A	B	3	32.80 ± .69	9.11 ± .09	2.37 ± .02	1.69 ± .03
		4	34.01 ± .88	9.49 ± .12	2.38 ± .03	1.69 ± .04
		Avg	33.40 ± .56	9.30 ± .08	2.37 ± .02	1.69 ± .02
B	A	3	34.94 ± .84	9.25 ± .08	2.38 ± .03	1.70 ± .04
		4	36.08 ± .90	9.67 ± .09	2.38 ± .03	1.68 ± .04
		Avg	35.51 ± .61	9.46 ± .07	2.38 ± .02	1.69 ± .03
B	B	3	34.74 ± .90	9.33 ± .08	2.38 ± .03	1.65 ± .05
		4	36.65 ± .99	9.51 ± .11	2.39 ± .04	1.63 ± .05
		Avg	35.70 ± .68	9.42 ± .10	2.38 ± .03	1.64 ± .03

[a]Sows sacrificed approximately 24 hr after weaning. Means for groups AA, AB, BA and BB represent 12, 17, 18 and 17 observations per bone, respectively, ± SEM.

[b]Data for growth A and growth B treatments were pooled by bone, and compared. The same comparison was made for gestation treatments and the growth × gestation interaction.

[c]Growth A = .65% Ca, .50% P; B = .975% Ca, .75% P fed to an average weight of 92.82 kilograms. Gestation A = 13.0 g Ca, 10.0 g P/day; B = 19.5 g Ca, 15.0 g P/day fed from an average weight of 92.82 kg until parturition.

[d]Bone 3 = third metatarsal; 4 = fourth metatarsal.

[e]Grow A *vs* Grow B ($P<.06$) (Bone 4).

[f]Grow A *vs* Grow B ($P<.05$) (Bone 3).

TABLE 10. GILT OUTCOME FROM INITIATION OF TRIAL 2 THROUGH COMPLETION OF TRIAL 3

	Item					
Treatment[a]	No. started on trial 2	Reproductive failure[c]	Unable to stand[d]	Weaned[e]	Lost after weaning[f]	Total remaining[g]
A-A	23	4	5	14	2	12
A-B	22	3	1	18	0	18
B-A	24	7	0	17	0	17
B-B	22	4	0	18	1	17
Total	91	18	6	67	3	64

[a]Treatment during growth = left letter, gestation treatment = right letter. Growth treatment A = .65% Ca; .50% P, B = .975% Ca, .75% P. Gestation treatment A = 13.0 g Ca, 10.0 g P/day; B = 19.5 g Ca, 15.0 g P/day.

[b]Number of gilts placed on gestation diets immediately following termination of trial 1.

[c]Includes number of gilts that failed to conceive after one cycle and gilts that aborted.

[d]Number of gilts that were unable to stand on their own after 40 days of pregnancy.

[e]Number of sows that weaned their litter to an average of 42 days without any obvious inability to stand in lactation crate.

[f]Number of sows that were either unable to load for transport to slaughter (because of fracture of femur) or animals lost at packing plant.

[g]Number of sows utilized for analysis of third and fourth metatarsals.

deposition that might have occurred during gestation in the gilts fed treatment diet B did not overcome the numerical differences between growth-gestation groups A-B and B-A, even though the absolute differences were small.

More attention should be focused on physical strength and integrity of the skeletal system as gilts are developing, as well as during gestation, and on the subsequent lactation drain on the skeletal reserves of Ca and P. Although bone ash values may be relatively accurate indices of skeletal development in the young, rapidly growing pig, no measure of the strength of the bone or of the apparent indication of bone density per unit area is evident from this criterion.

Literature Cited

Barr, A. J., J. H. Goodnight, J. P. Sall and J. T. Helwig. 1976. A User's Guide to SAS. SAS Institute Inc., Raleigh, NC.

Brown, W. R., L. Crook and W. Pond. 1966. Atrophic rhinitis in swine. Etiology, pathogenesis and prophylaxis. Cornell Vet. (Supp. No. 1) 56:1.

Chapman, H. L. Jr., J. Kastelic, D. V. Catron, V. W. Hays and V. C. Speer. 1962. Calcium and phosphorus requirements of growing-finishing swine. J. Anim. Sci. 21:112.

Combs, G. E., J. M. Vandepopuliere, H. D. Wallace and M. Koger. 1962. Phosphorus requirement of young pigs J. Anim. Sci. 21:3.

Crenshaw, T. D. 1980. Physical and biological factors affecting bone integrity in swine. Ph.D. Dissertation. Univ. of Nebraska, Lincoln.

Cromwell, G. L., V. W. Hays, C. H. Chaney and J. R. Overfield. 1970. Effects of dietary phosphorus and calcium level on performance, bone mineralization and carcass characteristics of swine. J. Anim. Sci. 30:519.

Cromwell, G. L., V. W. Hays, C. W. Scherer and J. R. Overfield. 1972. Effects of dietary calcium and phosphorus on performance and carcass, metacarpal and turbinate characteristics of swine. J. Anim. Sci. 34:746.

Doige, C. E., B. D. Owens and J.H.L. Mills. 1975. Influence of calcium and phosphorus on growth and skeletal development of growing swine. Can. J. Anim. Sci. 55:147.

Frankel, S., S. Reitman and A. C. Sonnenwirth (Ed.). 1970. Gradwohl's Clinical Laboratory Methods and Diagnosis (7th Ed.). 1:355.

Harmon, B. G., C. Liu, S. Cornelius, J. Pettigrew, D. H. Baker and A. H. Jensen. 1974. Efficacy of different phosphorus supplements for sows during gestation and lactation. J. Anim. Sci. 39:1117.

Harmon, B. G., C. Liu, A. H. Jensen and D. H. Baker. 1975. Phosphorus requirement of sows during gestation and lactation. J. Anim. Sci. 40:660.

Harmon, B. G., J. Simon, D. E. Becker, A. H. Jensen and D. H. Baker. 1970. Effect of source and level of dietary phosphorus on structure and composition of turbinate and long bones. J. Anim. Sci. 30:742.

Hines, R. H. 1966. The interaction of restricted feed intake and sex on swine performance and carcass quality. Ph.D. Thesis. Michigan State Univ., East Lansing.

Hoekstra, W. G., E. C. Falton, C. W. Lin, H. F. Roberts and R. H. Grummer. 1967. Zinc deficiency in reproducing gilts fed a diet high in calcium and its effect on tissue zinc and blood serum alkaline phosphatase. J. Anim. Sci. 26:1348.

Kay, H. O. 1930. Plasma phosphatase II. The enzyme in disease, particularly in bone disease. J. Biol. Chem. 89:249.

Kessler, G. and M. Wolfman. 1964. An automated procedure for the simultaneous determination of calcium and phosphorus. Clin. Chem. 10:686.

Kornegay, E. T., H. Thomas and T. Meacham. 1973. Evaluation of dietary calcium and phosphorus for reproducing sows housed in total confinement on concrete or in dirt lots. J. Anim. Sci. 37:493.

Libal, G. W., E. R. Peo, Jr., R. P. Andrews and P. E. Vipperman, Jr. 1969. Levels of calcium and phosphorus for growing-finishing swine. J. Anim. Sci. 28:331.

Liptrap, D. O., E. R. Miller, D. E. Ullrey, K. K. Keahey and J. A. Hoefer. 1970. Calcium level for developing boars and gilts. J. Anim. Sci. 31:540.

Miller, E. R., D. E. Ullrey, C. L. Zutaut, B. V. Baltzer, D. A. Schmidt, J. A. Hoefer and R. W. Luecke. 1962. Calcium requirements of the baby pig. J. Nutr. 77:7.

Miller, E. R., D. E. Ullrey, C. L. Zutaut, B. V. Baltzer, D. A. Schmidt, J. A. Hoefer and R. W. Luecke. 1964. Phosphorus requirements of the baby pig. J. Nutr. 82:34.

Morgenstern, S., G. Kessler, J. Auerbach, R. V. Flor and B. Klein. 1965. An automated p-nitrophenylphosphate serum alkaline phosphatase procedure for the autoanalyzer. Clin. Chem. 11:876.

Nimmo, R. D., E. R. Peo, Jr., B. D. Moser, P. J. Cunningham, T. D. Crenshaw and D. G. Olson. 1980a. Response of different genetic lines of boars to varying levels of dietary calcium and phosphorus. J. Anim. Sci. 51:112.

Nimmo, R. D., E. R. Peo, Jr., B. D. Moser, P. J. Cunningham, D. G. Olson and T. D. Crenshaw. 1980b. Effect of various levels of dietary calcium and phosphorus on performance, blood and bone parameters in growing boars. J. Anim. Sci. 51:100.

NRC, 1968. Nutrient Requirements of Domestic Animals, No. 2. Nutrient Requirements of Swine. National Academy of Sciences—National Research Council, Washington DC.

NRC. 1973. Nutrient Requirements of Domestic Animals, No. 2. Nutrient Requirements of Swine. National Academy of Sciences—National Research Council, Washington DC.

NRC. 1979. Nutrient Requirements of Domestic Animals, No. 2. Nutrient Requirements of Swine. National Academy of Sciences—National Research Council, Washington DC.

Posen, S. 1967. Alkaline phosphatase. Ann. Internat'l Med. 67:183.

Reinhard, M. K., D. C. Mahan, B. L. Workman, J. H.

Cline, A. W. Fetter and A. P. Grifo, Jr. 1976. Effect of increasing dietary protein level, calcium and phosphorus on feedlot performance, bone mineralization and serum mineral values with growing swine. J. Anim. Sci. 43:770.
Snedecor, G. W. 1958. Orthogonal coefficients for unequal intervals. Biometrics 14:287.
Steel, R.D.G. and J. H. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill Book Co., New York.
Stockland, W. L. and L. Blaylock. 1973. Influence of dietary calcium and phosphorus levels on the performance and bone characteristics of growing-finishing swine. J. Anim. Sci. 37:906.
Storts, R. W. and A. Koestner. 1965. Skeletal lesions associated with dietary calcium and phosphorus imbalance in the pig. Amer. J. Vet. Res. 26:280.
Ullrey, D. E., E. R. Miller, B. E. Brent, B. L. Bradley and J. A. Hoefer. 1967. Swine hematology from birth to maturity. IV. Serum calcium, magnesium, sodium, potassium, copper, zinc and inorganic phosphorus. J. Anim. Sci. 26:1024.