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EFFECT OF DIETARY CALCIUM AND PHOSPHORUS LEVEL UPON CALCIUM, PHOSPHORUS AND NITROGEN BALANCE IN SWINE¹

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Summary

Three metabolism trials were conducted to determine the effects of dietary calcium and phosphorus level upon calcium, phosphorus and nitrogen balance in growing swine. The nine pigs in each trial averaged 22.6, 25.2 and 26.5 kg initially for trials 1, 2 and 3, respectively. The diets contained three levels of calcium and three levels of phosphorus and were rotated among the pigs in the three trials. Feed intake was adjusted to metabolic size.

Within the limits of the calcium and phosphorus levels used in this experiment, calcium to phosphorus ratios were not as important in the utilization of these two elements as dietary levels *per se*. The optimum calcium to phosphorus ratio varied with the level of calcium and with the level of phosphorus in the diet. The utilization of calcium appears to be less affected by calcium to phosphorus ratios than is the case with phosphorus utilization.

Urinary calcium decreased while calcium retention increased as dietary phosphorus increased. Varying dietary calcium level had the same effect on phosphorus utilization. The calcium phosphorus interaction was significant for phosphorus digestibility and retention.

Nitrogen retention was affected more by dietary phosphorus level than by calcium. Increasing dietary calcium level without also

increasing dietary phosphorus resulted in a decrease in nitrogen retention.

Introduction

Many studies concerning the dietary requirements of calcium and phosphorus for growing swine have been reported. However, there is still considerable disagreement among researchers as to the true requirement for these two elements. Traditionally, investigators have measured growth rate, feed efficiency, bone composition and strength, and blood components in assessing the dietary levels of calcium and phosphorus required. All of these methods of evaluating the calcium and phosphorus status of the animal show a common weakness of not being sensitive enough to discriminate between small dietary changes in these nutrients. Balance studies, which yield information concerning digestibility, retention and excretion of nutrients, offer a means of more accurately assessing the true mineral requirement. Such studies also yield information concerning nutrient interaction.

The purpose of the research presented in this paper was to determine the effects of various levels of dietary calcium and phosphorus upon calcium and phosphorus utilization by the growing pig as determined by mineral balance studies and to obtain data which would help to more accurately determine the dietary calcium and phosphorus requirement.

Experimental Procedure

A total of 27 Hampshire Yorkshire crossbred barrows were used in three metabolism trials. The nine pigs in each trial were selected from three litters (average initial weight 22.6, 25.2 and 26.5 kg for trials 1, 2 and 3,

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respectively) and were divided into three groups by litter and by weight.

The treatments employed were: (A) 0.25% Ca, 0.25% P; (B) 0.25% Ca, 0.50% P; (C) 0.25% Ca, 0.75% P; (D) 0.50% Ca, 0.25% P; (E) 0.50% Ca, 0.50% P; (F) 0.50% Ca, 0.75% P; (G) 0.75% Ca, 0.25% P; (H) 0.75% Ca, 0.50% P; (I) 0.75% Ca, 0.75% P.

The trials were divided into three periods. Each period consisted of 8 days, 3 days for the pigs to adjust to their respective diets and 5 days for the collection period. Diets (shown in table 1) A, B and C in trial 1; D, E and F in trial 2; and G, H and I in trial 3 were randomly assigned to one of the three groups in each period. Each group was fed a different diet in each of the three periods.

Prior to starting the trials, the pigs were placed in circular metal metabolism crates located in a environmentally controlled unit and fed a standard corn-soybean meal diet until feed intake stabilized. The daily feed allowance during the experimental period was determined by multiplying their metabolic size ($Wkg^{.75}$ Kleiber, 1947) by a factor of .09. Pigs were fed one-half their daily ration at 7 am and the rest at 4 pm. Water was offered free choice.

The metabolism crates were designed to allow separation of the urine and feces. The entire daily fecal collections were frozen fresh for later analysis. The daily urine collection was

measured, brought to a constant volume with distilled water and samples from each pig were pooled and frozen until analyzed.

Approximately 6 ml of blood were withdrawn from each pig before being placed on the test ration and on the last day of the collection period. Blood samples were collected approximately 2 hr. after feeding. The plasma was separated by centrifugation and stored frozen.

Nitrogen determination of the feed, feces and urine was in accordance with methods outlined in the A.O.A.C. (1965). Calcium levels of feed, feces, urine and plasma were determined by atomic absorption. Phosphorus levels were determined colorimetrically as outlined by Sumner (1944).

The data were analyzed as one experiment by analysis of variance methods as outlined by Steel and Torrie (1960). Trial effects were assumed to be unimportant since they are confounded with the effects of levels of calcium.

Results and Discussion

The effects of varying dietary calcium and phosphorus levels upon calcium utilization are presented in table 2 and figure 1. Dietary intake, expressed as milligrams per kilogram of metabolic size (mg/kg M.S.) was essentially the same for all pigs fed the same dietary level of

TABLE 1. COMPOSITION OF DIETS

Ingredient	Treatments								
	A	B	C	D	E	F	G	H	I
Corn (%)	72.7	72.7	72.7	72.7	72.7	72.7	72.7	72.7	72.7
50% SBM (%)	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2
Blood meal (%)	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Molasses	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Corn starch	6.1	5.1	4.1	5.4	5.0	4.0	4.6	4.4	4.0
Dicalcium phosphate	-	-	-	-	1.3	1.8	-	1.0	2.2
NaH ₂ PO ₄	-	1.0	2.0	-	-	0.7	-	-	-
Iodized salt	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
CaCO ₃	0.5	0.5	0.5	1.1	0.3	-	1.9	1.1	0.3
Vitamin-Antibiotic ^a	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Trace mineral ^b	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
					<u>Calculated</u>				
Calcium (%)	.25	.25	.25	.50	.50	.50	.75	.75	.75
Phosphorus (%)	.25	.50	.75	.25	.50	.75	.25	.50	.75
					<u>Analyzed</u>				
Calcium (%)	.29	.28	.29	.54	.53	.52	.75	.73	.70
Phosphorus (%)	.26	.48	.70	.26	.52	.68	.30	.52	.74

^aComposition per kilogram diet: Vit. A, 3,168 IU; Vit. D₂, 475 IU; Riboflavin, 2.11 mg; Pantothenic acid, 7.90 mg; Niacin, 21.1 mg; Choline chloride, 132 mg; Vit B₁₂, 13 mcg; Chlortetracycline 44 milligrams.

^bComposition (%) Mn, 10.0; Fe, 10.0; Cu, 1.0; Co, 0.10; I, 0.30; Zn, 10.0. Calcium Carbonate Company, Quincy, Ill.

TABLE 2. THE EFFECTS OF VARYING DIETARY CALCIUM AND PHOSPHORUS LEVELS UPON CALCIUM UTILIZATION

Item	Treatments								
	A	B	C	D	E	F	G	H	I
Dietary Ca (%)	.25	.25	.25	.50	.50	.50	.75	.75	.75
Dietary P (%)	.25	.50	.75	.25	.50	.75	.25	.50	.75
Calcium:									
Intake mg/kg									
M.S. ^a	251	250	251	468	456	449	700	694	692
Retained Mg/kg									
M.S. ^{b,c,d,e,f}	87	139	151	138	290	290	293	405	455
Retained (%) ^{b,c,d,e}	35	56	60	29	63	65	42	58	65
C.O.D. ^g									
(%) ^{b,c,d}	56	57	62	54	67	66	63	66	68
Feces mg/kg									
M.S. ^{b,c,d}	110	107	96	215	150	154	256	234	223
Urine mg/kg									
M.S. ^{b,c,d,e}	55	4	3	116	14	4	150	55	17

^aMilligrams per kilogram of metabolic size.

^bSignificant linear effect of phosphorus level ($P < .01$).

^cSignificant linear effect of calcium level ($P < .01$).

^dSignificant calcium x phosphorus interaction ($P < .01$).

^eSignificant quadratic effect of phosphorus level ($P < .01$).

^fSignificant quadratic effect of calcium level ($P < .01$).

^gCoefficient of digestibility.

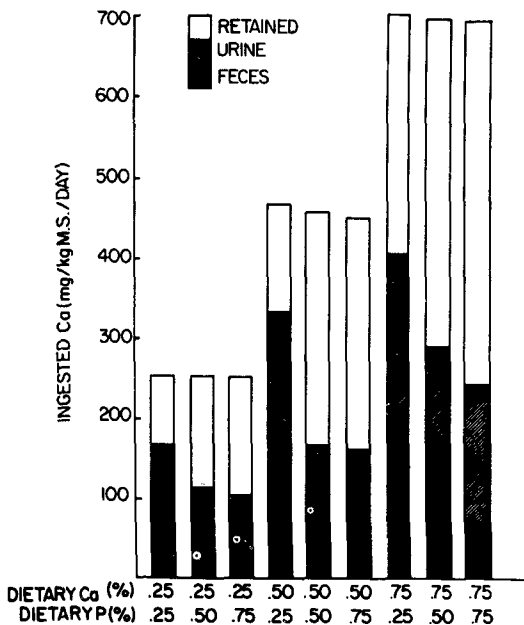


Figure 1. Distribution of ingested calcium in pigs fed various levels of Ca & P.

calcium. The linear and quadratic effects of both calcium and phosphorus level were highly significant ($P < .01$) for calcium retention (mg/kg M.S.; figure 2) but the linear effect was of greater magnitude. While the effect of dietary calcium and phosphorus on percent calcium retention was not consistent, the percentage calcium retained when diets containing 0.25% phosphorus were fed was only about one-half that observed when the higher dietary phosphorus levels were employed. Similar results were reported by Miller *et al.* (1964) using the baby pig.

Fecal calcium increased linearly ($P < .01$) with each increment of dietary calcium and decreased ($P < .01$) with each increment of dietary phosphorus. An important calcium level phosphorus level interaction ($P < .01$) was obtained for urinary calcium excretion. Urinary calcium excretion (figure 3) was quite low when dietary phosphorus levels were equal to or higher than the dietary calcium levels and increased as dietary calcium levels exceeded the level of dietary phosphorus. The latter observation does not agree with previous reports by Hansard, Lyke and Crowder (1961) and Miller *et al.* (1962, 1964) which indicated that there

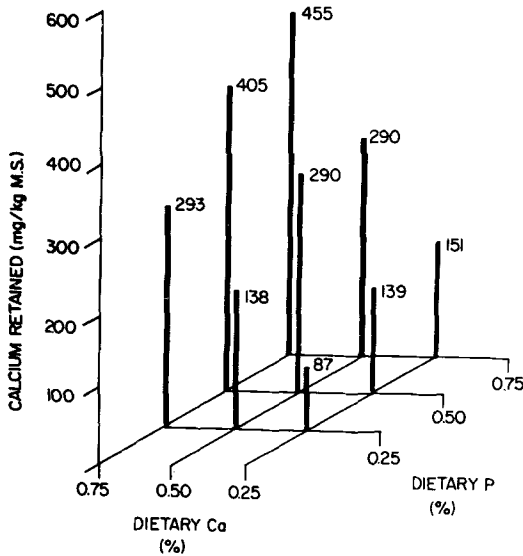


Figure 2. Effect of various levels of dietary Ca & P on daily calcium retention.

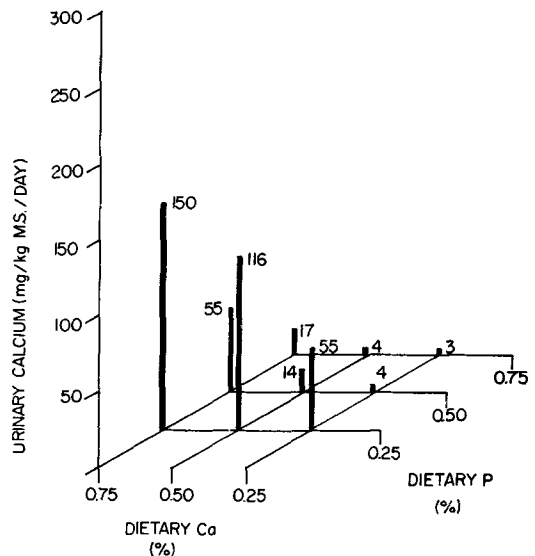


Figure 3. Effect of various levels of dietary Ca & P on urinary calcium excretion.

was little dietary phosphorus effect on urinary calcium excretion.

Phosphorus utilization data are presented in table 3 and figure 4. Phosphorus retention (mg/kg M.S.) decreased as dietary calcium was increased when diets containing 0.25% phosphorus were fed, but increased with each

increase in dietary calcium, when the two higher dietary phosphorus levels were employed (figure 5). Phosphorus retention increased quadratically ($P < .01$) with each increment of dietary phosphorus irrespective of dietary calcium level. The low digestibility of the phosphorus in the 0.25% phosphorus diets confirms

TABLE 3. THE EFFECTS OF VARYING DIETARY CALCIUM AND PHOSPHORUS LEVELS UPON PHOSPHOROUS UTILIZATION

Item	Treatments								
	A	B	C	D	E	F	G	H	I
Dietary Ca (%)	.25	.25	.25	.50	.50	.50	.75	.75	.75
Dietary P (%)	.25	.50	.75	.25	.50	.75	.25	.50	.75
Phosphorus:									
Intake mg/kg									
M.S. ^a	230	424	607	230	424	605	226	425	605
Retained mg/kg									
M.S. ^{b,c,d}	80	137	135	37	165	210	35	214	263
Retained (%) ^{b,c,d,e}	35	32	22	16	39	35	15	50	43
C.O.D. ^f (%) ^{b,c,d,e}	36	53	59	15	50	61	16	51	59
Feces mg/kg									
M.S. ^{b,c,d}	147	200	249	196	214	238	190	209	248
Urine mg/kg									
M.S. ^{b,c,d}	1	87	223	1	45	157	1	1	94

^aMilligrams per kilogram of metabolic size.

^bSignificant linear and quadratic effect of phosphorus level ($P < .01$).

^cSignificant linear effect of calcium level ($P < .01$).

^dSignificant calcium x phosphorus interaction ($P < .01$).

^eSignificant quadratic effect of calcium level ($P < .01$).

^fCoefficient of digestibility.

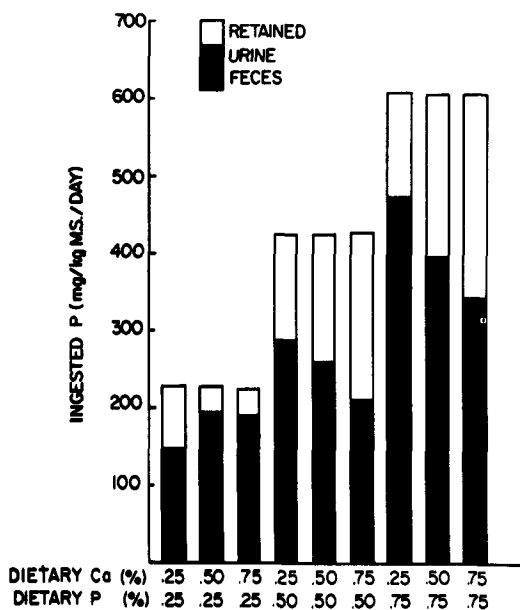


Figure 4. Distribution of ingested phosphorus in pigs fed various levels of Ca & P.

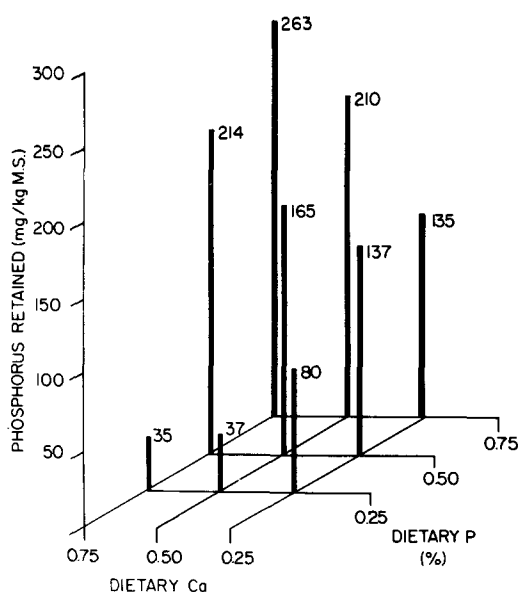


Figure 5. Effect of various levels of dietary Ca & P on daily phosphorus retention.

earlier reports (Chapman *et al.*, 1955; Besecker *et al.*, 1967; Bayley and Thomson, 1969; Libal *et al.*, 1969) that plant phosphorus is largely unavailable to swine. The increase in utilization of phosphorus from the low phosphorus diet which also contained a low level of calcium (diet A) also confirms reports by Chapman *et al.* (1962), Zimmerman *et al.* (1963) and Cromwell *et al.* (1970) that the calcium to phosphorus ratio becomes more critical when low levels of dietary phosphorus are fed.

Most of the variation in phosphorus retention could be accounted for by the variation in urinary phosphorus excretion. Similar findings were reported by Miller *et al.* (1962) in the baby pig and by Vipperman *et al.* (1969) in sheep. From the graph presented in figure 6 it can be noted that urinary phosphorus increased linearly as dietary phosphorus was increased in the diets containing the two lower levels of calcium and increased quadratically as the dietary phosphorus was increased in the diets containing 0.75% calcium. It can also be noted that urinary phosphorus decreased linearly as dietary calcium was increased in the diets containing the two higher levels of phosphorus and that urinary phosphorus excretion was practically nil when dietary calcium exceeded dietary phosphorus levels.

It can be seen from table 4 that increasing dietary calcium resulted in quadratic response in nitrogen retention when the diets contained 0.25% phosphorus. However, there was very little effect of dietary calcium level on nitrogen retention when the two higher dietary phosphorus levels were employed. Nitrogen retention increased ($P < .01$) as dietary phosphorus increased. In most cases, 0.50% dietary phosphorus was sufficient to support maximum nitrogen retention. While there was some increase in nitrogen digestibility when rations containing 0.75% calcium were fed, this advantage was offset by an increase in urinary nitrogen excretion.

The data presented in table 5 and figures 6 and 7 indicate that plasma calcium and phosphorus levels are poor indicators of dietary adequacy of these two minerals. Dietary phosphorus levels appear to have a greater effect on both plasma calcium and inorganic phosphorus concentrations than does dietary calcium. In general, when the dietary level of calcium was higher than dietary phosphorus, post-treatment plasma calcium concentration was higher than the initial value while the reverse was true when the dietary phosphorus was higher than the dietary calcium.

TABLE 4. THE EFFECTS OF VARYING DIETARY CALCIUM AND PHOSPHORUS LEVELS UPON NITROGEN UTILIZATION

Item	Treatments								
	A	B	C	D	E	F	G	H	I
Dietary Ca (%)	.25	.25	.25	.50	.50	.50	.75	.75	.75
Dietary P (%)	.25	.50	.75	.25	.50	.75	.25	.50	.75
Nitrogen									
Intake mg/kg M.S. ^a	1.99	1.98	1.99	2.03	2.05	2.04	2.04	2.05	2.06
Retained mg/kg M.S. ^{b,e}	937	996	999	885	999	986	910	972	998
Retained (%) ^{b,c,e}	47	50	50	44	49	48	45	47	48
C.O.D.g(%) ^{b,c,e,f}	72	75	76	72	75	73	79	80	80
Feces mg/kg M.S. ^{b,c,e,f}	551	491	487	570	520	559	430	409	412
Urine mg/kg M.S. ^{b,c,d,e,f}	506	496	492	557	506	490	700	666	634

^aMilligrams per kilogram of metabolic size.

^bSignificant linear effect of phosphorus level ($P < .01$).

^cSignificant linear effect of calcium level ($P < .01$).

^dSignificant calcium x phosphorus interaction ($P < .05$).

^eSignificant quadratic effect of phosphorus level ($P < .01$).

^fSignificant quadratic effect of calcium level ($P < .01$).

^gCoefficient of digestibility.

It is interesting to note that there was a slight increase in plasma calcium concentration from the initial values when diet A (0.25% Ca, 0.25% P) was fed. This together with the increase noted in excretion of calcium in urine, would indicate that the plasma calcium level is being maintained from body stores.

There is little doubt that dietary calcium level had an effect on plasma inorganic phosphorus concentration when the values obtained with the 0.25% calcium diets fed in combination with either 0.25% P or 0.50% P are compared to those obtained with the two higher dietary calcium levels (figure 8). The

lowest level of dietary phosphorus also had a definite effect on plasma phosphorus concentration. However, on comparing the phosphorus retention data obtained from the pigs which received diets containing 0.25% calcium and 0.50% phosphorus (137 mg phosphorus retained/kg M.S.; plasma phosphorus concentration = 12.6 mg/100 ml) to those which received the diets containing 0.75% calcium and 0.50% phosphorus (214 mg phosphorus retained/kg M.S.; plasma phosphorus concentration = 10.5 mg/100 ml) one can again see how misleading plasma constituent concentration can be in assessing the dietary needs of the animal. This is

TABLE 5. EFFECT OF VARYING DIETARY CALCIUM AND PHOSPHORUS LEVELS UPON PLASMA Ca AND INORGANIC P CONCENTRATION

Item	Treatments								
	A	B	C	D	E	F	G	H	I
Dietary Ca, %	.25	.25	.25	.50	.50	.50	.75	.75	.75
Dietary P, %	.25	.50	.75	.25	.50	.75	.25	.50	.75
Initial plasma Ca, mg/100 ml	10.6	10.8	11.1	13.0	14.2	12.7	11.5	11.3	13.0
Post treatment plasma Ca ^{a,b,c,e} , mg/100ml	11.1	10.6	10.7	14.2	13.4	11.4	13.9	11.7	11.3
Initial plasma inorganic P, mg/100 ml	12.4	12.7	10.0	11.0	8.1	10.3	9.8	11.3	8.1
Post treatment plasma inorganic pa, d, mg/100 ml	8.1	12.6	12.0	6.8	10.5	10.6	6.9	10.4	11.7

^aSignificant linear effect of phosphorus level ($P < .01$).

^bSignificant linear effect of calcium level ($P < .01$).

^cSignificant calcium x phosphorus interaction ($P < .01$).

^dSignificant quadratic effect of phosphorus level ($P < .01$).

^eSignificant quadratic effect of calcium level ($P < .01$).

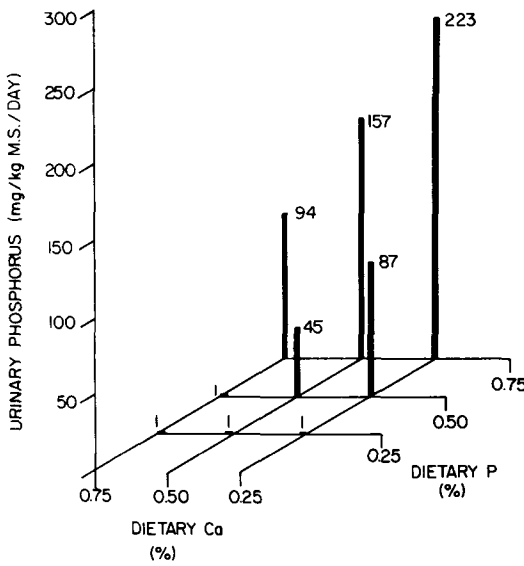


Figure 6. Effect of various levels of dietary Ca & P on urinary phosphorus excretion.

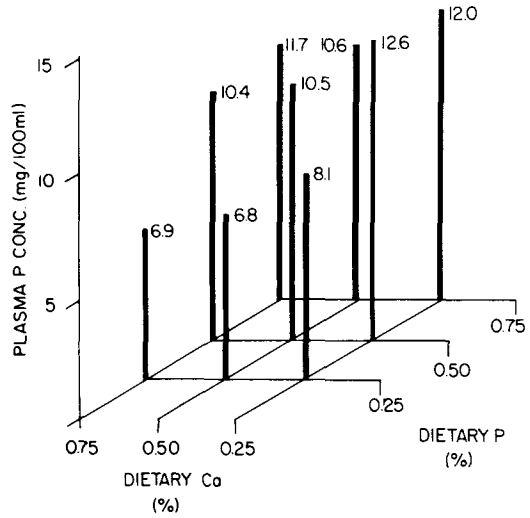


Figure 8. Effect of dietary level of Ca & P on plasma inorganic P concentrations.

not surprising when one considers the many mechanisms of homeostasis.

The data presented in tables 2 and 3 indicate that no one calcium to phosphorus ratio favors calcium and/or phosphorus utilization. Rather, the optimum calcium to phosphorus ratio varies with the level of calcium and phosphorus in the diet. In general, lower calcium to phosphorus

ratios favor both calcium and phosphorus retention for any given level of dietary calcium fed while the higher calcium to phosphorus ratios favor both calcium and phosphorus retention for any given level of dietary phosphorus used except when the 0.25% phosphorus level was employed.

The retention of calcium appears to be less affected by calcium to phosphorus ratios than does the retention of phosphorus. For example, calcium retention was the same for diets E, F and G having calcium to phosphorus ratios of 1.0, .67 and 3.0, respectively. The phosphorus retention was 165, 210 and 35 mg phosphorus/kg M.S. for diets E, F and G, respectively.

The emphasis which has been placed on calcium to phosphorus ratios tends to create confusion in that it leads to the assumption that, if the correct ratio is used, the animal's requirement will be met. The data presented support the contention that an optimal calcium to phosphorus ratio is valid when and only when the dietary levels of these two elements are supplied in the correct amounts.

If one assumes the maximum retention of a nutrient to be the requirement for that nutrient, then, among the levels tested, .75% calcium and .75% phosphorus would come closest to meeting the growing pig's requirement for these two minerals. However, many reports (Brown, Krook and Pond, 1966; Chapman *et al.*, 1969; Rutledge, Hanson and Mead, 1961) indicate

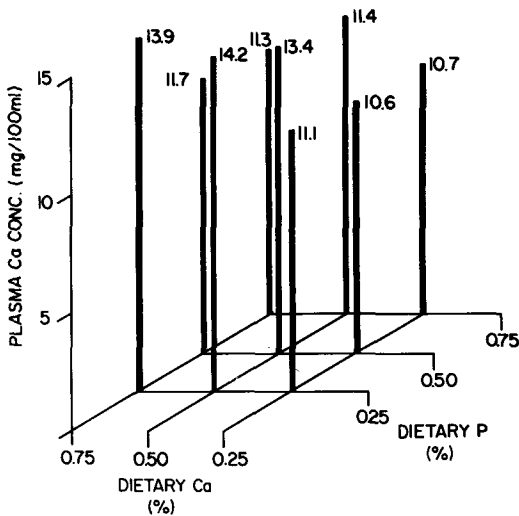


Figure 7. Effect of dietary level of Ca & P on plasma Ca concentration.

that the levels of calcium and phosphorus required for optimal skeletal development may be greater than that required for optimal growth. Therefore, it can be assumed that calcium and phosphorus continue to be stored in bone after the dietary need for other vital functions of calcium and phosphorus have been met.

There is also ample documentation that one of the functions of bone is to serve as a storage center for calcium and phosphorus and that the animal can draw upon these stores during periods of dietary inadequacy (Campbell, 1965; Harrison and Fraser, 1960; McLean and Urist, 1961).

The question now becomes one of how much bone does a pig need to supply adequate support if the diet contains adequate calcium and phosphorus for the other body functions. It is reasonable to assume that the animal is capable of storing more calcium and phosphorus in bone than is needed for adequate skeletal support. Therefore, the actual requirement for calcium and phosphorus by a normally developing animal with adequate skeletal support may be below that required for maximum bone mineralization and, hence, below that required for maximum retention. More research in this area would certainly seem warranted.

When excretion data are considered along with the retention data, it would appear that .75% calcium and .50% phosphorus would be a closer estimate of the true need of the growing pig. The data obtained from this experiment are inadequate to determine the exact requirement.

The data presented support earlier reports (Bayley and Thomson, 1969; Besecker *et al.*, 1967; Chapman *et al.*, 1955; Libal *et al.*, 1969) that phosphorus from plant sources is largely unavailable to swine. Therefore, it would be more logical to state the requirement in terms of available phosphorus.

The observed sensitivity of calcium and phosphorus retention and excretion to changes in dietary levels of these two minerals indicate studies of this nature can be useful in the determination of the true requirement of growing swine for these two minerals provided that a method of determining "adequate" skeletal development can be found.

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