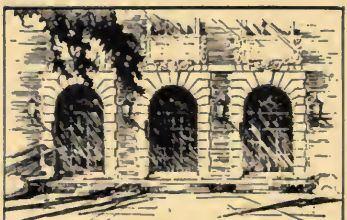

Calcium and Phosphorus Supplements for Growing Swine

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CONTENTS

General directions for the feeding of mineral supplements to swine and other classes of livestock are given in Circular 411, "The Feeding of Mineral Supplements to Livestock," 1933, in which the conclusions of the present study are embodied.

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Calcium and Phosphorus Supplements For Growing Swine

By H. H. MITCHELL, W. E. CARROLL, T. S. HAMILTON, W. P. GARRIGUS, and G. E. HUNT[a]

MINERALS needed by growing swine, except the sodium and chlorin readily supplied by common salt, are now known by nutrition specialists to be adequately provided by a proper selection of grain feeds and pastures. The requirements and functions of minerals in animal nutrition have been investigated sufficiently for predictions to be made, with a reasonable degree of assurance, as to which minerals will or will not be adequately provided for growing animals by a given combination of feeds. A review of the experimental work upon which this knowledge rests was published by Hamilton[14*] in 1932.

Not all practical swine rations, however, are so balanced as to supply all the minerals, besides common salt, needed by growing swine. If plentiful amounts of legume hay or pasture are not available, and if the protein is supplied entirely by vegetable concentrates, calcium is likely to be deficient. Whether, under such conditions, phosphorus also is deficient is a question upon which there is no unanimity of opinion; but when no protein concentrate is used in the ration, phosphorus is probably slightly deficient. Under certain conditions and in certain localities other minerals, particularly iron and iodin, may be lacking. But in Illinois iodin may be assumed to be present in sufficient amounts for growing swine unless definite symptoms of goiter or other thyroid disturbances are evident. And for pigs of weaning age or older, iron deficiencies in the ration have never been demonstrated. Furthermore, according to experiments conducted at the Illinois Station,[5, 6, 7*] neither iron nor iodin added to the rations of growing swine beyond the weaning age may be expected to improve the rate of growth or the health of the animals.

In the practical feeding of growing swine, consequently, the problem of supplying the needed amounts of minerals is not compli-

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*These numbers refer to literature citations listed on page 53.

cated. Common salt is, of course, always needed, and beyond that the problem is concerned mainly with calcium and phosphorus requirements and the utilization of these elements from feeds and minerals in which they are present in relatively abundant amounts. The experiments reported in this bulletin were therefore designed mainly to test the availability to growing pigs of the calcium and phosphorus in various mineral supplements commonly used in swine feeding.

But the experiments included also an inquiry into the need of swine for minerals other than calcium, phosphorus, and common salt as supplements to rations consisting mainly of corn. The impression still prevails in many quarters that the problems of mineral nutrition in practical livestock feeding are numerous and complicated, and that their solutions even now are obscure. This notion persists possibly because of the large number of mineral elements present in animal carcasses and known to be necessary for animal life, but it neglects to consider the fact that all these minerals are present in ordinary farm rations—the grains and the forages—and that usually most of these elements except the sodium and the chlorin may thus be provided in more than adequate amounts by properly balancing the rations with respect to nonmineral nutrients, especially protein.

This state of mind—the belief that mineral problems are numerous and complicated—is receptive to the proposition that farm animals should be fed mineral supplements generally, if only as a measure of safety; and that, in the absence of specific knowledge to the contrary, the safest course is to use complex mineral mixtures containing even as many as 14 to 16 ingredients. The sale of many commercial mineral mixtures is furthered by fostering this belief. Consequently comparisons of simple and complex mineral mixtures were included in these studies.

REVIEW OF LITERATURE

The investigations prior to 1932 on the availability to growing pigs of calcium and phosphorus in various mineral supplements were reviewed and evaluated by Maynard.[17*] His conclusions are well worth quoting:

"The evidence here reviewed suggests that when used under appropriate conditions and free from harmful impurities, various forms of calcium are equal from the standpoint of the chemical composition and strength of the bone formed. Neither soluble nor organic forms appear to have an advantage in this respect. On the other hand the question as to whether they are all equally efficient, as measured by percentage assimilation at minimum levels of intake, cannot be so definitely answered. A great preponderance of the evidence suggests an equality in this respect also. However, it is not entirely safe to conclude from the negative evidence reviewed that no differences exist. It is possible that many of the experiments may not have been sufficiently critical as regards minimum levels of intake and appropriate calcium-phosphorus ratios. From a physiological point of view this question could well be studied further . . . . "

In commenting on this same problem later, Rottensten and Maynard[24*] said that in very few of the comparisons made in preceding studies "could it be said with certainty that the level of intake was sufficiently low to bring out any difference in efficiency which might exist." In conducting experiments concerned with the detection and measurement of differences in the utilization by animals of calcium in minerals or in feeds, it is absolutely necessary to administer the calcium at a level incapable (or just capable) of supporting maximum calcium retention. Otherwise, if an excess of calcium is provided, any differences in calcium availability between the sources of the element being compared will be underestimated or may even be entirely obscured.

Since the publication of Maynard's review in 1932 only one report on the utilization of calcium supplements by swine has appeared. Ramsbottom[23*] in 1933 reported the results of experiments on growing pigs designed to measure the effect on growth, calcium retention, and bone composition of supplements of calcium carbonate, steamed bone meal, and a commercial preparation of dicalcium phosphate ("Dicapho"), added at different levels to rations which were adequate except for deficiencies in calcium and vitamin D. Quoting from the author's summary—

"When equivalent amounts of Ca, as present in ground limestone, steamed bonemeal, and Dicapho, were fed at low and high levels of intake to a low-Ca basal ration, the retention of Ca and P by all pigs so fed was similar, with one exception. On a high level of Ca supplementation one pig, which received the limestone supplement, had a less favorable Ca and P retention than the pigs which received the bone meal and Dicapho supplements. When the amount of P in the limestone supplemented ration was increased by the use of a neutral mixture of mono- and di-sodium phosphate to an amount similar to that found in the bonemeal ration, this pig's retention improved. Apparently, hog rations having a Ca:P ratio as wide as 2.13:1 and at the same time supplying minimum quantities of antirachitic are unsatisfactory for best results. Bone analyses were made on the femurs and humeri of one group of 4 pigs. The data collected indicate very small differences in the composition of the bones of the pigs which received ground limestone, steamed bonemeal, and Dicapho. The femurs and humeri of a check pig which was fed a low-Ca basal ration, were low in ash, Ca and P content."

In the following year, 1934, Rottensten and Maynard[24*] reported the results of a very careful comparison with growing rats, as well as with lactating female rats, of the assimilation of phosphorus in pure dicalcium and tricalcium phosphates, in commercial dicalcium phosphate, and in cooked bone meal. The mineral supplements were added at different levels to a basal ration, which was low both in calcium and in phosphorus and contained no vitamin-D concentrate. At all concentrations of supplements, the ratio of calcium to phosphorus was kept constant at about 1.5 to 1 by additions of the required amounts of calcium carbonate. The growth experiments were conducted according to the paired-feeding method or a modification of it involving triplicate feeding. The efficiency of the supplements for the growing rats was measured by the ash content of the bones; for the lactating females it was measured by the weight of the young weaned, the ash content of the femur, and the inorganic phosphorus of the blood. The conclusions from these experiments were, in the words of the authors:

"Throughout these three experiments such differences as were shown between the supplements under comparison generally favored a secondary phosphate over a tertiary product, but we are unwilling to consider this combined evidence as certain proof, because of the small differences involved and the variability of the individual data. It seems very unlikely that any differences which may actually exist are large enough to be of appreciable importance in the selection and use of mineral supplements in practice."

This conclusion is a conservative interpretation of the experimental data. The consistent advantage of the secondary phosphates over the tertiary phosphates seems statistically distinct, altho slight in magnitude.

PLAN OF THE EXPERIMENTS

The experiments reported in this bulletin, carried out with some interruptions during the period from the spring of 1929 to the fall of 1933, were concerned in part with an inquiry into the need of swine for minerals other than calcium, phosphorus, and common salt, but mainly with the problem of determining the comparative values of different calcium salts in promoting growth and calcification of the bones when added at low levels to calcium-poor rations. The extent of calcification of the bones was determined (1) by the analysis of selected bones, or (2) by calcium metabolism studies and the estimation of total calcium retention. These two methods are equivalent, since over 99 percent of the calcium in the body is located in the skeleton.[4*]

The paired-feeding method was used in most of the experiments, so that for any comparison of calcium supplements, or of a mineral supplement and no supplement, the amount of basal ration consumed was the same for the two pigs of each pair. Only under such conditions may the differences in growth or calcium retention observed be directly and entirely attributed to the differences in supplemental feeding. The pigs selected for each pair were of the same breed and sex, were within 4 pounds of each other in weight, and were litter mates whenever such a choice was possible.

The pigs were penned in a swine barn and had access to an outside concrete runway. At no time did the pigs have access to vegetation or dirt. They were fed twice daily in individual feeding crates adjacent to the concrete runway. Water was available at all times. Each pair was full-fed in so far as this could be done consistently with the paired-feeding plan. All corn used was yellow. The recorded initial and final weights were the averages of weights taken before feeding on three successive mornings. Individual weights were taken weekly thruout each test.

In contrast to many of the experiments relating to calcium metabolism reported in the literature on this subject, these experiments were conducted under conditions favoring the maximum utilization of calcium. Vitamin D, in particular, was provided to the experimental animals either by the incorporation of 1 percent of cod-liver oil in the basal rations or by assuring adequate solar irradiation. Since the experiments were conducted in the spring and summer, direct sunlight was available thruout most of the feeding period. The pens in which the pigs were confined were provided with outside concrete runways and those pigs whose basal ration did not carry cod-liver oil were forced to remain outdoors in the sunlight for at least 30 minutes at midday whenever the sun was shining. Besides promoting better utilization of calcium and phosphorus, vitamin D tends to prevent disturbances of mineral metabolism by variations in the ratio of Ca to P. This relationship between vitamin D, the ratio of Ca to P, and the rate of calcification has not been investigated systemmatically with swine, but it has been studied exhaustively with rats and chickens.

In all comparisons of the efficiency of the utilization of food materials with reference to any particular nutrient, the level of intake of that nutrient must be less than that required by the animal for maximum performance (see page 17), and furthermore the level of the nutrient in question must be the limiting factor in the nutritive value of the ration. In these experiments on the utilization of calcium, therefore, it was necessary to arrive at some estimate of the calcium requirements of growing swine. This estimate was made in the following manner.

From carcass analyses of pigs at different stages of growth it was concluded in an earlier publication from this department[19*] that the growing-fattening pig gaining about a pound daily actually uses for maintenance and growth from 2.5 to 3 grams of calcium each day. Assuming a utilization of dietary calcium of 50 percent,[12*] the 2.5 to 3 grams of net calcium are equivalent to 5 to 6 grams of dietary calcium. Other investigators have estimated about the same or slightly higher requirements. Dunlop[8*] compiled in 1935 the results of eight experiments from various laboratories in this country and Europe, from which he concluded that for pigs growing from a weight of 30 pounds to a weight of 200 pounds at a rate of 1 to 1.4 pounds daily, the ration should contain at least 45 hundredths of one percent of calcium on the dry-matter basis. This percentage is equal to about 2 grams of dietary calcium per pound of dry matter consumed, or 7 grams of dietary calcium daily for a daily gain of 1 pound and a feed cost of 3.5 pounds of feed per pound of gain. Møllgaard[20*] and Axelsson[2*] assessed the calcium requirements of growing pigs at even higher levels, while Spildo[25*] estimated a requirement of 5 grams of calcium daily for a body-weight gain of 500 grams a day, making no allowance for a maintenance requirement of calcium.

In the experiments reported herein, the calcium supplements were fed in such amounts as to provide 2 to 5 grams of calcium daily. All the basal rations, mainly yellow corn and soybean oil meal in proportions varying with the weights of the pigs, were low in calcium and contained .5 to 1 percent of sodium chlorid and generally 1 or 2 percent of cod-liver oil.[a] In one experiment, in which it was desired to use a basal ration containing no more phosphorus than corn itself, commercial egg albumin was used as a protein concentrate in place of soybean oil meal. An analysis of these feeds is given in Table 1.

The bone meal used as supplement to the basal rations contained 81.42 percent ash and 31.28 percent calcium; the limestone, 38.43 percent calcium; the rock phosphate, 33.40 percent calcium and 3.83 percent fluorin; and the commercial dicalcium phosphate, sold under the name "Dicapho," 88.95 percent ash, 29.56 percent calcium, and 20.40 percent phosphorus.

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[a]The cod-liver oil used, put out by E. L. Patch and Company of Boston, Mass., for animal feeding, contained a guaranteed high potency in vitamins A and D.

TABLE 1.—PERCENTAGE COMPOSITION AND GROSS ENERGY CONTENT (SMALL CALORIES PER GRAM) OF FEEDS USED IN MINERAL FEEDING EXPERIMENTS

Experiment No.	Feed	Dry matter	Crude protein	Ether extract	Crude fiber	Ash	N-free extract	Gross energy	Calcium	Phosphorus
		perct.	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*sm.cals.*	*perct.*	*perct.*
2	Corn, yellow	85.75	7.88	3.08	3.17	1.11	70.51	3 810	....	.214
3	Corn, yellow	86.35	9.44	3.40	2.44	1.25	69.82	3 834	.015	.257
4	Corn, yellow	88.74	8.79	3.65	2.85	1.26	72.19	3 899	.005	.251
5	Corn, yellow	89.55	10.31	4.24	2.54	1.28	71.18	4 049	.007	.285
2	Soybean oil meal	90.15	43.13	5.30	7.53	5.78	28.23	4 416	....	.670
3	Soybean oil meal	90.89	43.25	6.82	8.69	5.70	26.43	4 438	.301	.683
5	Soybean oil meal	87.99	41.00	6.12	7.44	5.20	28.23	4 325	.261	.619
4	Dried egg albumin, Sample 1	86.12	78.25	.25	....	5.10	2.52	4 545	.066	.123
4	Dried egg albumin, Sample 2	86.90	79.19	.25	....	4.44	3.02	4 724	.061	.094

COMPLEX vs. SIMPLE MINERAL MIXTURES

(EXPERIMENT I)

Before the comparisons of the values of different calcium-containing minerals as supplements to swine rations were made, an experiment was conducted to throw some light on the question whether minerals other than common salt and calcium carbonate or phosphate are likely to be needed as supplements to swine rations properly provided with protein. In previous studies at this Station, no advantages were observed to follow the addition of iron or iodin supplements.[5, 6, 7*]

Basal Rations and Supplements

In this experiment a complex mineral mixture was studied as a supplement to two rations of different types, one containing soybean oil meal as a protein concentrate and the other tankage. To assure adequate amounts of calcium, phosphorus, sodium, and chlorin in the basal rations, .5 to 1 percent of common salt (sodium chlorid) and 1 percent of bone meal were incorporated in each. In a third test, designed to measure the effect on growth and bone calcification of a calcium supplement (limestone) added to a calcium-deficient diet, the basal ration consisted of yellow corn, soybean oil meal, and salt only. The basal rations used in this experiment are described in Table 2.

The complex mixture of mineral salts used in the first two tests was similar to that designed for the synthetic feeding of rats by Osborne and Mendel and modified by Hawk and Oser,[15*] except that in this test with swine the calcium salts were left out, because the purpose of the experiments was to test different calcium supplements. The complex salt mixture used contained the following ingredients:

TABLE 2.—BASAL RATIONS USED IN THE COMPARISON OF SIMPLE AND COMPLEX MINERAL RATIONS: EXPERIMENT I

Ingredients	Tankage rations, for pigs weighing—			Soybean oil meal rations, for pigs weighing—			Calcium-deficient rations, for pigs weighing—		
	Less than 100 lbs.	100 to 150 lbs.	Over 150 lbs.	Less than 100 lbs.	100 to 150 lbs.	Over 150 lbs.	Less than 100 lbs.	100 to 150 lbs.	Over 150 lbs.
	perct.	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*
Ground corn	83.5	87.5	93.5	74	82	90	75	83	91
Tankage	15.0	11.0	5.0	0	0	0	0	0	0
Soybean oil meal	0	0	0	24	16	8	24	16	8
Salt	.5	.5	.5	1	1	1	1	1	1
Bone meal	1	1	1	1	1	1	0	0	0

	Parts
Potassium citrate, $K_3C_6H_5O_7 \cdot H_2O$	88
Potassium sulfate, K_2SO_4	8.9
Potassium chlorid, KCl	55.7
Potassium phosphate, K_3PO_4	27.0
Sodium phosphate, $Na_3PO_4 \cdot 12H_2O$	81.8
Magnesium phosphate, $Mg_3(PO_4)_2 \cdot 8H_2O$	135.1
Ferric citrate, $FeC_6H_5O_7 \cdot 1.5H_2O$	6.34
Potassium iodid, KI	.020
Manganese sulfate, $MnSO_4$	.079
Sodium fluorid, NaF	.248
Potassium aluminum sulfate, $K_2Al_2(SO_4)_4$	.0245

Two of the three comparisons were made with groups of eight pairs of pigs each, and one with a group of seven pairs. The complex mineral mixture was fed at the rate of 5 grams per head daily to one pig in each pair in the first two comparisons; and the limestone was fed at the rate of 15 grams per head daily to one pig in each pair in the third comparison. The pigs were started on experiment at weights of 60 to 80 pounds each and carried generally to 175 pounds.

TABLE 3.—GAINS AND FEED CONSUMPTION OF CONTROL PIGS RECEIVING THE TANKAGE RATION AND OF THEIR PAIR MATES, THE TEST PIGS, RECEIVING THE SAME WITH A COMPLEX MINERAL SUPPLEMENT: EXPERIMENT I
(All weights expressed in kilograms)

	Pair 1		Pair 2		Pair 3		Pair 4	
	Control	Test	Control	Test	Control	Test	Control	Test
Final weight	83.0	83.9	60.8	68.9	80.3	82.1	71.2	81.6
Initial weight	29.0	31.3	31.7	34.0	34.0	31.7	29.5	29.9
Total gain	54.0	52.6	29.1	34.9	46.3	50.4	41.7	51.7
Average daily gain	.514	.501	.378	.453	.472	.514	.350	.435
Total feed consumed	180	180	116	116	171	171	184	184
Feed per kgm. gain	3.34	3.43	3.99	3.31	3.70	3.40	4.40	3.55
Days on feed	105	105	77	77	98	98	119	119
	Pair 5		Pair 6		Pair 7			
	Control	Test	Control	Test	Control	Test		
Final weight	81.2	76.2	79.8	78.0	78.9	76.2	....	....
Initial weight	28.1	28.6	30.8	30.4	29.9	29.0	....	....
Total gain	53.1	47.6	49.0	47.6	49.0	47.2	....	....
Average daily gain	.474	.425	.500	.486	.333	.321	....	....
Total feed consumed	189	189	167	167	208	208	....	....
Feed per kgm. gain	3.57	3.98	3.41	3.51	4.24	4.40	....	....
Days on feed	112	112	98	98	147	147	....	....

Results in Experiment I

Complex Mixture.—The very complete mineral mixture added to basal rations of yellow corn and tankage and yellow corn and soybean oil meal produced in the pigs no better growth or health than did the simple supplement of common salt and steamed bone meal (Tables 3 and 4). The inference may therefore be made from these tests that the basal rations in all probability were not deficient in iodin, iron, manganese, or most of the other elements required by animals in small amounts but present in farm feeds. And unless specific evidence to the contrary is obtained, it may also be inferred that practical swine rations are not, as a rule, deficient in these minerals.

It is significant that in experiments demonstrating the need of animals for mineral elements present in food materials in very small amounts, such as copper,[10*] manganese,[22*] and zinc,[26*] especially purified rations must be prepared. The content of the element under study must be reduced to a mere trace both by chemical methods and by the judicious selection of food materials from a restricted list. It is true that in certain areas of the earth, forage crops in particular are some-

TABLE 4.—GAINS AND FEED CONSUMPTION OF CONTROL PIGS RECEIVING THE SOYBEAN-OIL-MEAL RATION AND OF THEIR PAIR MATES, THE TEST PIGS, RECEIVING THE SAME WITH A COMPLEX MINERAL SUPPLEMENT: EXPERIMENT I
(All weights expressed in kilograms)

	Pair 1		Pair 2		Pair 3		Pair 4	
	Control	Test	Control	Test	Control	Test	Control	Test
Final weight	79.4	77.1	79.4	78.0	68.9	60.8	81.2	82.5
Initial weight	38.1	36.7	32.7	32.2	30.8	31.7	31.3	31.7
Total gain	41.3	40.4	46.7	45.8	38.1	29.1	49.9	50.8
Average daily gain	.393	.385	.445	.436	.286	.219	.475	.485
Total feed consumed	157	157	169	169	167	167	168	168
Feed per kgm. gain	3.81	3.90	3.62	3.69	4.38	5.75	3.37	3.31
Days on feed	105	105	105	105	133	133	105	105
	Pair 5		Pair 6		Pair 7		Pair 8	
	Control	Test	Control	Test	Control	Test	Control	Test
Final weight	71.2	82.1	68.5	64.4	66.2	49.4	65.8	67.1
Initial weight	29.5	31.3	29.9	29.0	31.7	31.7	29.9	30.4
Total gain	41.7	50.8	38.6	35.4	34.5	17.7	35.9	36.7
Average daily gain	.298	.363	.368	.337	.224	.115	.395	.403
Total feed consumed	180	180	131	131	161	161	122	122
Feed per kgm. gain	4.30	3.54	3.40	3.71	4.66	9.07	3.39	3.31
Days on feed	140	140	105	105	154	154	91	91

times found to be deficient in these "trace" minerals, notably iodin,[29*] iron,[3*] copper,[21*] and cobalt;[16*] but exceptional incidents afford no reasonable basis for the presumption that these deficiencies are likely to appear in any particular section of the country. In areas where endemic nutritional disorders have not been noted, the indiscriminate feeding of complex commercial minerals as a measure of insurance against such improbable occurrences would seem to be no less conservative than carrying insurance against property damage by meteorites.

Limestone.—While the results obtained from the complex mineral-mixture supplement were quite negative in significance, those from limestone added to a calcium-poor basal ration were significantly positive. Six of the eight pigs receiving limestone gained faster than, and one of the others gained as fast as, the control mates (Table 5). The average difference in total gain between pair mates was 3.87 kilograms in favor of the limestone pigs; the standard deviation of differences was 4.93 kilograms, and the probability that a chance combination of uncontrolled factors common to both groups of pigs would produce a mean difference in gain as large as or larger than that ob-

TABLE 5.—GAINS AND FEED CONSUMPTION OF CONTROL PIGS RECEIVING A CALCIUM-DEFICIENT RATION AND OF THEIR PAIR MATES, THE TEST PIGS, RECEIVING THE SAME WITH A LIMESTONE SUPPLEMENT: EXPERIMENT I
(All weights expressed in kilograms)

	Pair 1		Pair 2		Pair 3		Pair 4	
	Control	Test	Control	Test	Control	Test	Control	Test
Final weight	78.0	80.3	76.7	80.3	78.9	79.8	74.8	82.5
Initial weight	32.7	32.2	30.4	28.1	31.7	32.2	34.5	35.4
Total gain	45.3	48.1	46.3	52.2	47.2	47.6	40.3	47.1
Average daily gain	.458	.486	.441	.497	.421	.425	.407	.476
Total feed consumed	162	162	172	172	171	171	156	156
Feed per kgm. gain	3.57	3.36	3.71	3.29	3.63	3.60	3.86	3.30
Days on feed	99	99	105	105	112	112	99	99
	Pair 5		Pair 6		Pair 7		Pair 8	
	Control	Test	Control	Test	Control	Test	Control	Test
Final weight	79.8	79.4	62.1	78.9	79.8	78.5	78.0	79.8
Initial weight	33.6	32.7	32.2	34.0	30.8	29.5	34.5	36.7
Total gain	46.2	46.7	29.9	44.9	49.0	49.0	43.5	43.1
Average daily gain	.471	.477	.203	.305	.333	.333	.414	.410
Total feed consumed	157	157	182	182	207	207	166	166
Feed per kgm. gain	3.39	3.36	6.08	4.05	4.22	4.22	3.80	3.84
Days on feed	98	98	147	147	147	147	105	105

TABLE 6.—WEIGHT AND COMPOSITION OF BONES OF CONTROL PIGS FED NO MINERAL SUPPLEMENT, AND OF THEIR PAIR MATES, THE TEST PIGS, FED LIMESTONE SUPPLEMENT

Pair No. and sex	Fresh weight of bones		Percentage of water in bones		Percentage of ash in dry fat-free bone		Percentage composition of ash				Ratio of calcium to phosphorus in bone	
							Calcium		Phosphorus			
	Control pig	Test pig	Control pig	Test pig	Control pig	Test pig	Control pig	Test pig	Control pig	Test pig	Control pig	Test pig
Weights and composition of the scapulas												
	gms.	gms.	perct.	perct.	perct.	perct.	perct.	perct.	perct.	perct.		
1 ♂	99	116	43.13	40.02	45.43	48.76	35.40	35.19	18.57	19.11	1.91	1.84
2 ♂	133	114	53.55	39.18	41.49	50.93	34.56	38.01	17.96	18.87	1.92	2.01
3 ♂	82	100	35.98	28.17	42.06	53.06	35.66	37.37	18.33	18.04	1.95	2.07
4 ♀	100	107	45.38	41.29	43.68	50.55	35.53	36.11	18.15	18.14	1.96	1.99
5 ♂	100	122	35.73	40.15	50.43	53.29	36.05	36.84	18.04	18.05	2.00	2.04
6 ♂	92	122	41.01	35.35	48.48	53.37	37.92	37.82	18.35	18.64	2.07	2.03
7 ♀[a]	...	...	.....	.....	.....	.....	.....	.....	.....	.....	....	....
8 ♀	84	99	34.93	32.83	45.27	52.79	36.16	36.68	18.80	18.64	1.92	1.97
Average	99	111	41.39	36.71	45.26	51.82	35.90	36.86	18.31	18.50	1.96	1.99
Weights and composition of the humeri												
1 ♂	185	199	37.34	36.82	49.97	55.06	36.72	37.83	17.73	18.81	2.07	2.01
2 ♂	222	221	46.30	36.10	44.88	52.38	35.85	37.38	18.46	18.63	1.94	2.01
3 ♂	177	194	35.31	30.87	48.37	56.20	36.88	37.40	18.54	18.36	1.99	2.04
4 ♀	178	198	40.85	37.14	47.94	52.68	36.30	36.14	18.63	18.19	1.95	1.99
5 ♂	203	213	32.10	33.91	55.06	55.48	37.45	38.05	18.80	19.21	1.99	1.98
6 ♂	198	233	36.11	30.95	49.36	56.67	36.14	36.24	17.95	18.65	2.01	1.94
7 ♀[a]	...	...	.....	.....	.....	.....	.....	.....	.....	.....	....	....
8 ♀	166	197	34.80	32.43	52.32	55.10	35.98	36.86	18.10	18.89	1.99	1.95
Average	190	208	37.54	34.03	49.70	54.80	36.47	37.13	18.32	18.68	1.99	1.99

[a]By mistake, the bones of these pigs were not saved for analysis.

served was only .039, according to Student's method[27, 28*] of assessing the significance of a mean. This probability is small enough to disregard. Hence it may be concluded that the limestone supplement to the calcium-deficient ration promoted more rapid gains in weight of the experimental pigs to which it was administered.

Bone Analyses.—At the termination of this experiment the pigs were slaughtered, and from each carcass one scapula and one humerus were taken for chemical analysis. The results of the chemical analyses are summarized in Table 6, and a statistical analysis of most of these results is given in Table 7.

TABLE 7.—STATISTICAL ANALYSIS OF DATA IN TABLE 6 SHOWING DIFFERENCES[a] BETWEEN PAIR MATES

Statistics	Fresh weight of bone	Water content of bone	Ash in dry fat-free bone	Calcium content of ash
		Scapulas		
	gms.	*perct.*	*perct.*	*perct.*
Mean	+12.9	−4.67	+6.56	+ .963
Standard deviation	14.5	5.31	2.82	1.29
Probability[b]	.036	.038	.007	.059
		Humeri		
Mean	+18.0	−3.51	+5.10	+ .654
Standard deviation	11.4	3.53	2.54	.513
Probability[b]	.004	.025	.001	.011

[a]A positive mean difference signifies a greater average measurement for the pigs receiving the limestone supplement over their pair mates receiving none. A negative sign has the contrary meaning.
[b]The probability, on a scale of 1, that chance alone would have produced the mean differences observed or larger ones of the same sign.

The calcium supplement (limestone) apparently increased the weight and the ash content, but decreased the water content of the bones. The percentage of calcium in the bone ash was increased, and evidently also the percentage of phosphorus, tho not to the same extent. The mean differences in the phosphorus content of the ash of the individual bones were not significant, but the mean difference computed for the two bones together seems quite significant. This difference was + .273 percent, the standard deviation of the fourteen differences was .461 percent, and the probability of a chance outcome only .026. The ratio of calcium to phosphorus in the bone ash was not appreciably disturbed by the limestone supplement.

COMPARATIVE VALUES OF BONE MEAL, LIMESTONE, AND ROCK PHOSPHATE AS CALCIUM SUPPLEMENTS

(EXPERIMENT II)

Basal Rations and Supplements

Three distinct tests were run in this experiment comparing (1) steamed bone meal and ground limestone; (2) tricalcium phosphate C.P., and rock phosphate containing 3.8 percent of fluorin; and (3) tricalcium phosphate C.P., and a mixture of the same salt with sufficient calcium fluorid to give the same fluorin content as that possessed by the rock phosphate used in the preceding comparison. The basal ration, the soybean-oil-meal ration described in Table 2 except that 1 percent of cod-liver oil replaced the same amount of bone meal, was the same in all three tests. This basal ration was quite evidently deficient in calcium. The *average*[a] basal rations consumed contained .05 percent calcium and .32 percent phosphorus. The ratios of calcium to phosphorus in the supplemented rations were as follows: for the limestone supplement, 1.18:1; for the rations in the second test, .81:1; and for the rations of the third test, .78:1.

The supplements were given daily to the individual pigs in amounts to provide 5 grams of calcium. The pigs, of Poland China or Duroc-Jersey breeds, were started on experiment at weights of 50 to 80 pounds. Only pigs of the same breed and approximately equal initial weights, and, where possible, of the same litter, were paired. Both the pigs in a pair were slaughtered as soon as one pig attained a weight of 175 pounds, except in the case of one pair on the rock phosphate test which was taken off at a lighter weight because of the poor condition of the rock-phosphate pig. From each carcass two bones, a scapula and a humerus from the same side, were taken for analysis.

Results in Experiment II

Rate of Growth.—The limestone pigs in five of the eight pairs gained in weight somewhat slower, on an average, than their pair mates getting bone meal (Table 8). This difference, however, was obviously of no statistical significance, and therefore cannot logically be attributed to the difference in composition of the supplements fed. The pig in Pair 6 that received the limestone supplement was definitely pathological towards the end of the experiment, which was terminated for this pair with the death of this pig. On post-mortem examination

[a]The soybean oil meal and corn were fed in different proportions according to the weight of the pigs.

TABLE 8.—GAINS AND FEED CONSUMPTION OF CONTROL PIGS RECEIVING BONE MEAL AND OF THEIR PAIR MATES, THE TEST PIGS, RECEIVING LIMESTONE, AS THE MINERAL SUPPLEMENTS:[a] EXPERIMENT II
(All weights expressed in kilograms)

	Pair 1		Pair 2		Pair 3		Pair 4	
	Control	Test	Control	Test	Control	Test	Control	Test
Final weight	79.8	80.7	82.5	79.4	80.7	78.0	84.4	78.9
Initial weight	24.0	24.5	25.4	27.2	25.9	27.7	30.8	27.7
Total gain	55.8	56.2	57.1	52.2	54.8	50.3	53.6	51.2
Average daily gain	.377	.380	.405	.370	.338	.310	.422	.403
Total feed consumed	227	227	223	223	230	230	215	215
Feed per kgm. gain	4.06	4.03	3.90	4.27	4.18	4.56	4.02	4.20
Days on feed	148	148	141	141	162	162	127	127

	Pair 5		Pair 6		Pair 7		Pair 8	
	Control	Test	Control	Test	Control	Test	Control	Test
Final weight	82.1	81.6	77.1	63.5	80.3	81.6	80.3	78.9
Initial weight	31.3	29.9	30.8	31.3	33.6	33.6	36.3	35.8
Total gain	50.8	51.7	46.3	32.2	46.7	48.0	44.0	43.1
Average daily gain	.450	.456	.389	.271	.345	.358	.346	.339
Total feed consumed	204	204	176	176	189	189	183	183
Feed per kgm. gain	4.02	3.95	3.80	5.45	4.05	3.94	4.15	4.24
Days on feed	113	113	119	119	134	134	127	127

[a]The basal ration was the soybean-oil-meal ration described in Table 2, except that 1 percent of the bone meal was replaced by cod-liver oil.

the pig was found to have a fractured femur and around the fracture a large hematoma.

In the second test, in which rock phosphate and pure tricalcium phosphate were compared, one pair of pigs was removed at the end of 35 days of feeding because of the development of pneumonia by the pig receiving the pure phosphate (Table 9). In six of the remaining seven pairs, the rock-phosphate pig gained at a slower rate than its pair mate. The one exception occurred in the pair which reached the final weight in the shortest time. For all pairs on test for as long as 24 weeks, the poorer growth of the rock-phosphate pigs was marked. In the later weeks of the experiment these pigs also appeared definitely less thrifty than their pair mates. It seems quite evident from these records that the rock phosphate was definitely toxic and that the toxic effects were cumulative, since with a constant daily dose, the symptoms (poor appetite, swellings on loin, scouring, stiffness, etc.) appeared only in the later stages of the feeding test.

In the third test, on the other hand, a mixture of CaF_2 and

TABLE 9.—GAINS AND FEED CONSUMPTION OF CONTROL PIGS RECEIVING TRICALCIUM PHOSPHATE AND OF THEIR PAIR MATES, THE TEST PIGS, RECEIVING ROCK PHOSPHATE, AS THE MINERAL SUPPLEMENTS:[a] EXPERIMENT II
(All weights expressed in kilograms)

	Pair 1		Pair 2		Pair 3		Pair 4	
	Control	Test	Control	Test	Control	Test	Control	Test
Final weight	27.2	27.2	77.6	71.7	82.5	77.6	84.4	60.3
Initial weight	25.9	24.0	27.2	27.2	27.7	28.6	27.7	27.2
Total gain	1.3	3.2	50.4	44.5	54.8	49.0	56.7	33.1
Average daily gain	.037	.091	.298	.263	.326	.292	.337	.197
Total feed consumed	24	24	242	242	251	251	225	225
Feed per kgm. gain	17.23	7.39	4.81	5.45	4.58	5.13	3.97	6.80
Days on feed	35	35	169	169	168	168	168	168

	Pair 5		Pair 6		Pair 7		Pair 8	
	Control	Test	Control	Test	Control	Test	Control	Test
Final weight	72.1	68.0	79.8	78.0	78.9	81.6	82.1	79.4
Initial weight	27.2	28.6	29.5	30.4	28.6	27.7	29.9	30.8
Total gain	44.9	39.4	50.3	47.6	50.3	53.9	52.2	48.6
Average daily gain	.266	.233	.357	.338	.375	.402	.370	.345
Total feed consumed	213	213	215	215	227	227	222	222
Feed per kgm. gain	4.75	5.40	4.26	4.50	4.50	4.20	4.25	4.57
Days on feed	169	169	141	141	134	134	141	141

[a]The basal ration was the soybean-oil-meal ration described in Table 2, except that 1 percent of the bone meal was replaced by cod-liver oil.

$Ca_3(PO_4)_2$ containing the same fluorin content as the rock phosphate, exerted no obvious deleterious effects on growing pigs in contrast to the tricalcium phosphate alone, except possibly an impairment of appetite (Table 10). There were no significant differences in total gain between the pair mates of this test. In three pairs the fluorin pig made the greater gain and in five pairs the smaller gain.

In all three tests an account was kept of the food refusals, throwing light on the appetites of the pigs. The numbers given in Table 11 are the numbers of times that food was left in the feed boxes at the end of an experimental day, necessitating a decrease in the amount of food offered the following day.

It is clear that fluorin, ingested either as CaF_2 or as phosphate rock, depressed appetite. It is equally clear also that the fluorin in phosphate rock is more toxic than that in CaF_2, probably because of the different form in which it occurs.

Bone Weights and Analyses.—The bones removed from the carcasses of the pigs in this experiment were weighed and analyzed for

TABLE 10.—GAINS AND FEED CONSUMPTION OF CONTROL PIGS RECEIVING TRICALCIUM PHOSPHATE AND OF THEIR PAIR MATES, THE TEST PIGS, RECEIVING A MIXTURE OF TRICALCIUM PHOSPHATE AND CALCIUM FLUORID, AS THE MINERAL SUPPLEMENTS:[a] EXPERIMENT II
(All weights expressed in kilograms)

	Pair 1		Pair 2		Pair 3		Pair 4	
	Control	Test	Control	Test	Control	Test	Control	Test
Final weight	81.6	78.9	78.9	78.5	79.4	86.2	79.4	79.4
Initial weight	27.7	29.0	30.4	30.4	29.9	30.4	31.7	32.2
Total gain	53.9	49.9	48.5	48.1	49.5	55.8	47.7	47.2
Average daily gain	.382	.354	.344	.341	.306	.345	.356	.352
Total feed consumed	233	233	215	215	273	273	210	210
Feed per kgm. gain	4.32	4.67	4.43	4.47	5.53	4.90	4.42	4.46
Days on feed	141	141	141	141	162	162	134	134
	Pair 5		Pair 6		Pair 7		Pair 8	
	Control	Test	Control	Test	Control	Test	Control	Test
Final weight	85.3	70.8	79.8	82.5	81.6	82.5	80.7	78.9
Initial weight	31.7	33.1	31.7	32.2	36.3	35.8	36.7	36.3
Total gain	53.6	37.7	48.1	50.3	45.3	46.7	44.0	42.6
Average daily gain	.317	.223	.379	.396	.377	.389	.297	.288
Total feed consumed	229	229	210	210	202	202	223	223
Feed per kgm. gain	4.29	6.09	4.37	4.18	4.46	4.33	5.08	5.24
Days on feed	169	169	127	127	120	120	148	148

[a]The basal ration was the soybean-oil-meal ration described in Table 2, except that 1 percent of the bone meal was replaced by cod-liver oil.

moisture, fat, ash, calcium, and phosphorus. Only the results of the ash, calcium, and phosphorus analyses are tabulated here.

No effects of the mineral supplements were revealed in the bone weights (Table 12), except in the first test, made with bone meal and limestone; and no effects were observed on the moisture or fat contents. In fact, Tests 2 and 3, involving the feeding of fluorin supplements, resulted in no differences at all in bone composition between the various series of pair mates. In contrast to the effects on growth

TABLE 11.—FOOD REFUSALS IN EXPERIMENT II

	Test 1		Test 2		Test 3	
	Bone-meal	Lime-stone	$Ca_3(PO_4)_2$	Rock phosphate	$Ca_3(PO_4)_2$	$Ca_3(PO_4)_2$ + CaF_2
Number of refusals	21	24	6	49	18	51

TABLE 12.—WEIGHTS OF BONES ANALYZED FROM THE THREE SERIES OF PAIRED PIGS IN EXPERIMENT II
(All weights expressed in grams)

Pair No.	Series 1		Series 2		Series 3	
	Mineral supplements		Mineral supplements		Mineral supplements	
	Bone meal	Limestone	Tricalcium phosphate	Rock phosphate	Tricalcium phosphate	Tricalcium phosphate and calcium fluorid
Weights of scapulas						
1	120	110	...	...	135	123
2	132	109	132	109	123	120
3	128	107	132	129	104	134
4	134	118	159	98	124	127
5	150	164	117	120	133	108
6	126	110	105	121	137	140
7	120	131	105	116	136	138
8	134	112	131	128	147	131
Average	130	120	126	117	130	128
Weights of humeri						
1	224	207	...	...	238	230
2	235	210	251	201	212	225
3	219	190	249	218	198	250
4	237	214	249	208	237	240
5	240	221	188	202	227	219
6	205	200	204	210	214	226
7	222	218	200	207	233	226
8	224	198	227	222	237	229
Average	226	207	224	210	224	231

and appetite, no deleterious effects of fluorin were revealed by any of the analyses made on the bones.

On the other hand, the bones produced on the bone-meal supplement were quite definitely, tho only slightly, heavier than the bones produced on the limestone supplement. The scapulas of the bone-meal pigs were heavier than those of their pair mates in six of the eight pairs, averaging 130 grams as compared with 120 (Table 12). On statistical analysis, the probability that this was a fortuitous result is only .045. The humeri of the bone-meal pigs also were heavier in all pairs than those of their pair mates, averaging 226 grams as compared with 207 grams. In this case, the probability of a fortuitous outcome is only .0004. These results thus give high assurance that under conditions of sub-optimal mineral feeding, bone meal will produce heavier bones than will limestone.[a]

[a]The individual bone weights in this test were published in the Proceedings of the American Society of Animal Production, 1932.[18*]

TABLE 13.—COMPOSITION OF BONES OF CONTROL PIGS FED BONE MEAL AND OF THEIR PAIR MATES, THE TEST PIGS, FED LIMESTONE SUPPLEMENT

Pair No. and sex	Percentage of ash in dry fat-free bone		Percentage composition of ash			
			Calcium		Phosphorus	
	Control pig	Test pig	Control pig	Test pig	Control pig	Test pig
Composition of scapulas						
1 ♀	51.52	49.21	37.18	36.52	17.97	18.50
2 ♂	54.86	53.29	37.43	37.86	17.75	17.87
3 ♀	52.17	50.55	36.13	36.48	18.01	19.24
4 ♂	53.28	51.96	37.72	37.24	18.12	17.65
5 ♂	51.63	46.80	37.90	37.29	16.63	18.06
6 ♀	54.11	50.54	37.91	37.34	17.62	18.00
7 ♀	54.16	52.06	36.16	39.92	17.90	17.42
8 ♂	53.16	53.05	37.11	36.85	16.93	16.92
Average	53.11	50.93	37.19	37.44	17.62	17.96
Composition of humeri						
1 ♀	56.51	55.16	37.21	37.91	17.81	18.48
2 ♂	57.13	55.89	37.16	37.28	18.28	18.91
3 ♀	54.22	54.84	37.51	37.47	18.20	17.81
4 ♂	56.90	55.41	36.70	37.70	18.21	18.05
5 ♂	58.12	54.21	37.92	37.78	17.92	17.86
6 ♀	58.48	54.22	37.80	37.47	17.93	17.98
7 ♀	56.57	54.72	37.31	35.74	19.66	17.97
8 ♂	58.25	55.35	37.60	38.03	18.05	17.78
Average	57.02	54.98	37.40	37.42	18.26	18.10

The bone analyses, presented in summary form in Tables 13, 14, and 15, revealed no significant differences in bone composition among the three series of pair mates except, again, in the comparison of a bone meal and a limestone supplement. In all eight pairs in this test, the scapula of the pig receiving the bone-meal supplement had a greater percentage of ash on the dry fat-free (ether extracted) basis than that of the pig receiving the limestone supplement. With one exception, the same was true with reference to the humerus. The average difference in ash content between pair mates amounted to a little over 2 percent in each case. The probabilities that these average differences were the result merely of chance are so small that they may be neglected: .0018 for the scapula comparison and .0043 for the humerus comparison. While it thus seems clear that the bone-meal supplement promoted a more complete calcification of the bones than did the limestone supplement, the bones produced on the latter supplement were quite in line in ash content with those produced in the other two tests by the tricalcium phosphate supplement. They cannot be considered, therefore, as abnormal bones.

TABLE 14.—COMPOSITION OF BONES OF CONTROL PIGS FED TRICALCIUM PHOSPHATE AND OF THEIR PAIR MATES, THE TEST PIGS, FED ROCK PHOSPHATE

Pair No. and sex	Percentage of ash in dry fat-free bone		Percentage composition of ash			
			Calcium		Phosphorus	
	Control pig	Test pig	Control pig	Test pig	Control pig	Test pig
Composition of scapulas						
2 ♂	54.88	50.39	37.14	36.94	17.93	17.89
3 ♀	54.30	54.40	37.23	37.14	17.75	17.70
4 ♀	52.21	53.12	37.06	36.61	17.99	18.20
5 ♀	51.12	52.81	36.22	37.01	18.19	16.95
6 ♂	52.61	50.72	36.93	36.97	18.34	18.63
7 ♂	52.19	53.83	37.49	36.59	18.16	19.03
8 ♀	51.55	55.26	37.24	37.21	17.97	17.98
Average	52.69	52.93	37.04	36.92	18.05	18.05
Composition of humeri						
2 ♂	54.97	59.20	36.74	35.88	18.27	18.06
3 ♀	55.68	59.44	36.63	36.80	18.48	17.96
4 ♀	55.65	55.60	37.24	36.84	17.90	18.17
5 ♀	58.80	59.11	37.24	37.25	17.95	17.78
6 ♂	55.27	54.72	37.32	36.67	18.29	18.23
7 ♂	56.33	58.64	37.34	37.83	18.10	17.95
8 ♀	56.16	58.91	37.32	37.49	18.16	17.96
Average	56.12	57.95	37.12	36.97	18.16	18.02

None of the supplements used in these three tests appeared to have disturbed the proportions of calcium or phosphorus in the bone ash.

COMPARATIVE UTILIZATION OF PHOSPHATES AND NORMAL CARBONATE OF CALCIUM

(EXPERIMENT III)

When swine rations lack mineral supplements other than common salt, a calcium supplement is ordinarily required, but whether the supplement should be a phosphate of lime or the normal carbonate—the two classes of calcium salts most readily available on the farm—is not clear. If the ration lacking calcium is likely to be deficient also in phosphorus, a phosphate of calcium should be used; but if it is extremely unlikely that the basal rations are deficient in phosphorus, some source of calcium carbonate may be used. The calcium carbonate minerals, especially the limestones, are among the cheapest mineral supplements.

Whether or not a ration is deficient in phosphorus as well as calcium, the use of a calcium phosphate supplement in place of the

Table 15.—Composition of Bones of Control Pigs Fed Tricalcium Phosphate and of Their Pair Mates, the Test Pigs, Fed a Mixture of Tricalcium Phosphate and Calcium Fluorid

Pair No. and sex	Percentage of ash in dry fat-free bone		Percentage composition of ash			
			Calcium		Phosphorus	
	Control pig	Test pig	Control pig	Test pig	Control pig	Test pig
Composition of scapulas						
1 ♂	51.31	50.66	37.02	35.83	18.21	18.90
2 ♂	51.88	51.26	37.84	37.30	18.99	17.98
3 ♂	50.69	51.32	37.10	37.64	18.37	17.14
4 ♂	52.52	51.60	37.10	36.95	17.96	18.04
5 ♀	53.15	54.16	36.77	37.39	18.27	18.04
6 ♀	52.13	52.78	36.22	36.48	18.77	17.34
7 ♀	51.13	47.51	35.20	36.74	18.50	18.18
8 ♀	50.49	51.86	37.05	36.44	18.42	18.44
Average	51.66	51.39	36.79	36.85	18.44	18.01
Composition of humeri						
1 ♂	56.05	55.54	37.08	36.93	18.02	18.26
2 ♂	55.68	55.37	37.42	36.70	19.44	18.25
3 ♂	52.62	55.12	37.28	37.30	19.00	18.43
4 ♂	50.72	53.00	36.72	36.95	18.45	19.29
5 ♀	57.02	54.70	37.57	36.03	18.05	18.20
6 ♀	54.81	57.78	37.04	36.75	18.44	18.07
7 ♀	57.37	55.88	37.77	37.57	18.47	18.12
8 ♀	55.14	56.10	37.41	37.34	18.46	18.06
Average	54.93	55.44	37.29	36.95	18.54	18.34

carbonate might still be advisable if the calcium in the phosphate were much more readily available to the pig than the calcium in the carbonate.[a] There might be some grounds for discrimination also among the different calcium phosphates if there were a relationship between the solubility of a calcium supplement and its utilization in the animal body. It has been argued that salts of calcium insoluble in weak acids, such as citric acid, are less available than those that are soluble. At the present time a dicalcium phosphate is being sold as a mineral supplement for livestock largely on the claim that it is much more soluble in the digestive juices, and hence more digestible, than the tricalcium phosphate found in bone meal. While this argument is evidently carried over bodily from the field of plant nutrition, it can be judged finally only on the basis of animal experimentation.

[a]The difference between the availability of the phosphates that can be recommended for animal feeding and of the carbonate (limestone) would have to be considerable in order to compensate for the normal differences in price.

First Test: Food Consumption and Gains

Basal Rations and Supplements.—The first test in the present experiment was a comparison by the paired-feeding method of the value of a commercial dicalcium phosphate, sold under the trade name "Dicapho," with the value of steamed bone meal, as supplements to a calcium-deficient ration. The basal ration consisted of mixtures of yellow corn and soybean oil meal, varying in proportions according to the weights of the pigs, with 1 percent of sodium chlorid in all rations. For pigs weighing up to 100 pounds, the ration contained 79 percent corn and 20 percent soybean oil meal, and analyzed .072 percent calcium. For pigs weighing from 100 to 150 pounds, the basal ration contained 86 percent of corn and 13 percent of soybean oil meal and analyzed .052 percent calcium. And for pigs weighing over 150 pounds, the ration was composed of 91 percent corn and 8 percent soybean oil meal, and contained only .038 percent calcium.

Six pairs of Chester White and two pairs of Duroc-Jersey pigs were used. The pigs were fed from weights of approximately 70 pounds each to final weights of about 175 pounds.

Equal amounts of the basal ration were fed to the two pigs of each pair twice daily in individual feeding crates. To the ration of one pig of each pair there was added enough bone meal once daily to provide 2 grams of calcium, while the other pig of each pair was given 2 grams of calcium daily in the form of commercial dicalcium phosphate. All pigs were kept in direct sunlight for about 30 minutes at midday whenever sunlight was available. At the conclusion of the feeding period, the pigs were slaughtered and two bones from the same half of each carcass, the scapula and the humerus, were taken for weighing and analysis.

Rate of Growth.—No consistent differences in rate of gain were observed between pair mates receiving the different calcium supplements (Table 16). In three pairs the pig receiving the dicalcium phosphate gained faster than its pair mate receiving an equal amount of calcium in bone meal; in four pairs the reverse was true; while in one pair the gains were equal.

The bones from the pigs fed the commercial dicalcium phosphate were, on the average, slightly richer in ash than the bones from the pigs that received equal amounts of calcium in bone meal, but of the fifteen comparisons between pair mates, only 9 favored the dicalcium phosphate (Table 17). This difference is far from possessing any statistical significance. Also no significant differences were discovered between the bones of pair mates with reference to the calcium or the

TABLE 16.—GAINS AND FEED CONSUMPTION OF CONTROL PIGS RECEIVING BONE MEAL AND OF THEIR PAIR MATES, THE TEST PIGS, RECEIVING DICALCIUM PHOSPHATE, AS THE MINERAL SUPPLEMENTS:[a] EXPERIMENT III
(All weights expressed in kilograms)

	Pair 1		Pair 2		Pair 3		Pair 4	
	Control	Test	Control	Test	Control	Test	Control	Test
Final weight	79.4	79.8	66.2	77.1	74.8	82.5	80.7	78.0
Initial weight	33.1	32.2	31.3	32.2	31.3	32.2	32.2	31.3
Total gain	46.3	47.6	34.9	44.9	43.5	50.3	48.5	46.7
Average daily gain	.367	.378	.262	.338	.366	.423	.433	.417
Total feed consumed	189	189	178	178	182	182	181	181
Feed per kgm. gain	4.07	3.96	5.09	3.96	4.19	3.62	3.73	3.88
Days on feed	126	126	133	133	119	119	112	112

	Pair 5		Pair 6		Pair 7		Pair 8	
	Control	Test	Control	Test	Control	Test	Control	Test
Final weight	80.3	75.3	78.0	77.6	79.8	80.7	81.6	76.7
Initial weight	30.8	30.8	34.0	31.7	32.7	34.5	33.6	32.7
Total gain	49.5	44.5	44.0	45.9	47.1	46.2	48.0	44.0
Average daily gain	.354	.318	.299	.312	.449	.440	.429	.393
Total feed consumed	206	206	207	207	168	168	172	172
Feed per kgm. gain	4.18	4.65	4.70	4.52	3.56	3.63	3.57	3.90
Days on feed	140	140	147	147	105	105	112	112

[a]Basal rations were mixtures of yellow corn and soybean oil meal, varying in proportions according to the weights of the pigs, with 1 percent of sodium chlorid in all rations.

phosphorus content of the ash. And inasmuch as no significant or consistent differences between pair mates were revealed by the weights of bones, the data on bone weights are not tabulated here.

The experiment thus produced no evidence of any difference in the value of bone meal and dicalcium phosphate as supplements to a calcium-deficient ration, neither in promoting the growth of pigs and in maintaining health, nor in favoring calcification of the bones. It should be remembered in this connection that the supplemental amounts of calcium fed in these experiments were less than the amounts required for maximum growth and calcification, a condition deliberately imposed in order to reveal small differences in utilization.

Second Test: Metabolism Trials

Rations and Method of Feeding.—The second test in this experiment consisted of a series of metabolism trials on five young Hampshire pigs, in which comparisons were made among calcium carbonate, tricalcium phosphate, dicalcium phosphate, and monocalcium phos-

TABLE 17.—COMPOSITION OF BONES OF CONTROL PIGS FED BONE MEAL AND OF THEIR PAIR MATES, THE TEST PIGS, FED DICALCIUM PHOSPHATE

Pair No. and sex	Percentage of ash in dry fat-free bone		Percentage composition of ash			
			Calcium		Phosphorus	
	Control pig	Test pig	Control pig	Test pig	Control pig	Test pig
Composition of scapulas						
1 ♂	47.67	52.81	37.45	37.55	18.55	18.36
2 ♂	53.56	53.94	37.22	36.78	18.38	18.05
3 ♀	51.21	51.53	37.34	37.30	18.68	18.16
4 ♀	49.33	48.95	36.60	35.43	18.58	19.22
5 ♂	49.65	51.48	38.37	36.60	19.41	18.46
6 ♀	50.26	51.36	36.44	37.05	18.39	18.64
7 ♂	49.49	48.82	37.91	36.81	18.14	18.90
8 ♀	51.04	51.14	37.97	37.17	18.39	18.70
Average	50.28	51.25	37.41	36.84	18.57	18.56
Composition of humeri						
1 ♂	53.09	55.54	37.84	37.37	18.51	18.99
2 ♂	52.34	58.11	36.77	37.03	18.40	18.26
3 ♀	50.98	56.28	37.17	38.24	18.60	18.40
4 ♀	.....	53.42[a]	.....	38.51[a]	.....	18.74[a]
5 ♂	53.08	52.98	37.53	37.13	18.82	18.55
6 ♀	57.09	55.60	38.01	36.83	18.78	18.30
7 ♂	51.62	51.47	38.01	36.82	18.79	19.10
8 ♀	54.50	54.40	38.41	37.17	19.10	19.35
Average	53.24	54.91	37.68	37.23	18.71	18.71

[a]Not included in the average.

phate with reference to the retention in the body of calcium and phosphorus and also to any possible differential effect of the mineral upon the retention of nitrogen.[a] The salts used were the best that could be obtained, and were fed daily in amounts to provide 2 grams of calcium for each 1,000 grams of ration consumed. The basal ration, designed to be seriously inadequate in calcium and to contain about as much phosphorus as that in corn, contained 91 percent corn (yellow), 6 percent dried egg albumin, 2 percent cod-liver oil, and 1 percent common salt. This ration, presumably adequate in vitamin D, contained an average of 12.94 percent crude protein, .0125 percent calcium, and .255 percent phosphorus. It was fed to the pigs at the rate of 4 pounds per 100 pounds body weight, or as near this rate as the appetites of the pigs would permit.

The six metabolism periods of the main test were of 10 days du-

[a]Grateful acknowledgment is made to W. T. Haines, Laboratory Technician in Animal Husbandry, for his assistance in conducting these metabolism trials. The responsibility of the care of the pigs and of the collection, weighing, and sampling of the excreta was his.

ration each and were preceded by preliminary periods of at least 4 days during which the same amounts of feed and supplement were consumed as in the following experimental periods. No feces markers were used.

The metabolism periods were so planned as to compare dicalcium phosphate with each of the other supplements in turn. In Periods A and B, the secondary and tertiary phosphates were compared; in Periods C and D, the secondary phosphate and the carbonate; and in Periods E and F, the secondary phosphate and the primary phosphate. In the first period of each comparison two of the pigs received one of the mineral supplements and three pigs the other. In the second period the supplemental feeding was reversed. In this way it was hoped to counteract any time-effect on nitrogen, calcium, and phosphorus metabolism.

The pigs were confined in metabolism crates similar in design to those described by Forbes.[11*]

At the termination of the principal experiment, consisting of Periods A to F inclusive, an attempt was made to determine the maintenance requirements of the pigs by measuring their output of nitrogen, calcium, and phosphorus while subsisting on a ration very low in these elements. The ration contained 94 percent starch, 1 percent yeast, 4 percent salt mixture free of calcium and phosphorus, and 1 percent cod-liver oil. On analysis this ration was found to contain .144 percent nitrogen, .0171 percent calcium, and .0318 percent phosphorus. After a four- or five-day period of preliminary feeding, collections of feces and urine were made for two consecutive periods, G and H, each being three or four days in length. For Pig 4 only one such period, lasting five days, could be secured. During Periods G and H the pigs were fed as much of the ration as they would clean up consistently.

Results.—The results of the metabolism experiments are presented by periods in Tables 18, 19, and 20, and the data on calcium and phosphorus retention are summarized in Table 21. The average nitrogen balances and digestion coefficients are summarized in Table 22.

The various mineral supplements did not exert any appreciable effect on the digestion or the metabolism of nitrogen (Table 22). None of the differences between the corresponding averages for the secondary phosphate and the other elements approach statistical significance.

In the utilization of calcium and phosphorus, as measured by the amounts retained daily, no significant differences were observed between the secondary phosphate and the other supplements (Table 21).

TABLE 18.—DAILY NITROGEN METABOLISM OF PIGS IN EXPERIMENT IV

Pig No.	Body weight	Calcium supplement	Food intake	Nitrogen intake	Fecal nitrogen	Urinary nitrogen	Nitrogen balance
	kgs.		*gms.*	*gms.*	*gms.*	*gms.*	*gms.*
		Period A					
1	25.2	Secondary phosphate.....	900	18.27	3.04	8.95	6.28
2	46.1	Secondary phosphate....	1 625	32.99	5.73	16.52	10.74
3	47.0	Tertiary phosphate......	1 625	32.99	5.18	16.36	11.45
4	26.9	Tertiary phosphate......	900	18.27	2.65	8.40	7.22
5	48.2	Tertiary phosphate......	1 625	32.99	4.64	17.13	11.22
		Period B					
1	30.3	Tertiary phosphate......	1 060	22.37	3.01	11.56	7.80
2	57.0	Tertiary phosphate......	1 950	41.14	5.52	21.67	13.95
3	58.5	Secondary phosphate....	1 995	42.09	6.33	21.19	14.57
4	32.8	Secondary phosphate....	1 135	23.95	3.11	12.03	8.81
5	59.7	Secondary phosphate....	2 020	42.62	5.76	22.35	14.51
		Period C					
1	35.4	Secondary phosphate....	1 110	22.66	2.89	12.27	7.50
2	67.1	Secondary phosphate....	2 100	43.26	6.84	24.40	12.02
3	68.8	Carbonate..............	2 140	44.08	7.16	22.96	13.96
4	39.4	Carbonate..............	1 200	24.72	2.69	13.19	8.84
5	72.0	Carbonate..............	2 200	45.32	6.18	25.08	14.06
		Period D					
1	42.7	Carbonate..............	1 290	27.09	2.80	14.04	10.25
2	76.7	Carbonate..............	2 003	41.97	5.48	26.11	10.38
3	81.5	Secondary phosphate....	2 160	45.36	6.79	23.69	14.88
4	48.1	Secondary phosphate....	1 440	30.24	2.76	15.58	11.90
5	82.5	Secondary phosphate....	2 246	47.16	4.59	27.96	14.61
		Period E					
1	48.9	Secondary phosphate....	1 330	26.73	2.79	16.13	7.81
2	84.0	Secondary phosphate....	1 831	36.80	3.94	22.62	10.24
3	89.2	Primary phosphate......	2 110	42.41	6.34	24.96	11.11
4	55.6	Primary phosphate......	1 510	30.35	2.96	16.23	11.16
5	89.4	Primary phosphate......	2 040	41.00	4.54	27.14	9.32
		Period F					
1	55.0	Primary phosphate......	1 500	32.10	3.25	17.59	11.26
2	88.0	Primary phosphate......	1 300	27.17	2.64	17.27	7.26
3	99.4	Secondary phosphate....	1 415	29.57	2.58	17.56	9.43
4	63.1	Secondary phosphate....	1 730	37.02	2.94	22.26	11.82
5	97.8	Secondary phosphate....	1 361	28.38	2.64	17.87	7.87
		Period G					
1	54.5	None..................	738	1.06	.97	3.63	− 3.54
2	87.6	None..................	600	.86	.69	6.00	− 5.83
3	99.9	None..................	1 000	1.44	.54	3.99	− 3.09
4	64.5	None..................	860	1.24	.76	12.71	−12.23
5	96.7	None..................	400	.58	.25	5.20	− 4.87
		Period H					
1	54.5	None..................	600	.86	.53	3.09	− 2.76
2	87.6	None..................	600	.86	.78	5.00	− 4.92
3	99.9	None..................	1 000	1.44	.21	3.46	− 2.23
5	96.7	None..................	400	.58	.09	4.28	− 3.79

Altho in each of the three comparisons the *average* calcium retention of the pigs on the dicalcium phosphate supplement was the higher, in none of the comparisons did all five pigs show a higher retention for the dicalcium phosphate. In the comparison of the secondary and tertiary phosphates in Periods A and B, three of the pigs retained more calcium on the secondary phosphate, but two retained more on the tertiary. In the comparison of secondary phosphate and carbonate, the division was again 3 to 2 in favor of the former, while for secondary and primary phosphates it was 3 to 2 in favor of the latter.

TABLE 19.—DAILY CALCIUM METABOLISM OF PIGS IN EXPERIMENT IV

Pig No.	Calcium supplement	Calcium intake			Fecal calcium	Urinary calcium	Calcium balance	
		Feed	Suppl.	Total			Total	Percent of intake
	Period A	*gms.*	*gms.*	*gms.*	*gms.*	*gms.*	*gms.*	
1	Secondary phosphate......	.16	1.80	1.96	.87	.05	1.04	53.1
2	Secondary phosphate......	.28	3.25	3.53	1.79	.12	1.62	45.9
3	Tertiary phosphate........	.28	3.25	3.53	1.61	.09	1.83	51.8
4	Tertiary phosphate........	.16	1.80	1.96	.97	.04	.95	48.5
5	Tertiary phosphate........	.28	3.25	3.53	1.73	.16	1.64	46.5
	Period B							
1	Tertiary phosphate........	.12	2.12	2.24	.80	.05	1.39	62.1
2	Tertiary phosphate........	.23	3.90	4.13	1.91	.07	2.15	52.1
3	Secondary phosphate......	.23	3.99	4.22	1.78	.11	2.33	55.2
4	Secondary phosphate......	.13	2.27	2.40	1.11	.04	1.25	52.1
5	Secondary phosphate......	.24	4.04	4.28	1.98	.10	2.20	51.4
	Period C							
1	Secondary phosphate......	.12	2.22	2.34	.70	.03	1.61	68.8
2	Secondary phosphate......	.24	4.20	4.44	1.87	.10	2.47	55.6
3	Carbonate................	.25	4.28	4.53	1.67	.15	2.71	59.8
4	Carbonate................	.14	2.40	2.54	.92	.19	1.43	56.3
5	Carbonate................	.25	4.40	4.65	1.79	.29	2.57	55.3
	Period D							
1	Carbonate................	.17	2.58	2.75	.77	.59	1.39	50.5
2	Carbonate................	.03	4.20	4.23	1.56	.13	2.54	60.0
3	Secondary phosphate......	.29	4.32	4.61	1.47	.08	3.06	66.4
4	Secondary phosphate......	.19	2.88	3.07	.85	.04	2.18	71.0
5	Secondary phosphate......	.25	4.52	4.77	2.44	.11	2.22	46.5
	Period E							
1	Secondary phosphate......	.15	2.66	2.81	.64	.04	2.13	75.8
2	Secondary phosphate......	.21	3.96	4.17	1.62	.07	2.48	59.5
3	Primary phosphate........	.24	4.22	4.46	1.68	.15	2.63	59.0
4	Primary phosphate........	.17	3.02	3.19	1.11	.05	2.03	63.6
5	Primary phosphate........	.23	4.28	4.51	2.09	.17	2.25	49.9
	Period F							
1	Primary phosphate........	.18	3.00	3.18	.83	.06	2.29	72.0
2	Primary phosphate........	.13	2.60	2.73	1.31	.04	1.38	50.5
3	Secondary phosphate......	.14	2.83	2.97	.83	.05	2.09	70.4
4	Secondary phosphate......	.21	3.46	3.67	.88	.05	2.74	74.7
5	Secondary phosphate......	.09	2.85	2.94	1.15	.04	1.75	59.5
	Period G							
1	None.....................	.13	0	.13	.36	.041	−.27	....
2	None.....................	.10	0	.10	.30	.058	−.26	....
3	None.....................	.17	0	.17	.17	.043	−.05	....
4	None.....................	.15	0	.15	.18	.045	−.08	....
5	None.....................	.07	0	.07	.17	.028	−.13	....
	Period H							
1	None.....................	.10	0	.10	.16	.042	−.10	....
2	None.....................	.10	0	.10	.40	.060	−.36	....
3	None.....................	.17	0	.17	.04	.073	+.06	....
5	None.....................	.07	0	.07	.03	.031	−.01	....

On the basis of the percentage of calcium intake that was retained, the verdicts of the individual pigs were 3 to 2 in favor of the secondary over the tertiary phosphate, 3 to 2 in favor of the secondary phosphate over the carbonate, and 5 to 0 in favor of the secondary over the primary phosphate. Only the last result is statistically significant, the mean difference between the two results on each of the five pigs being + 8.8 percent, the standard deviation of differences, 3.2, and

TABLE 20.—DAILY PHOSPHORUS METABOLISM OF PIGS IN EXPERIMENT IV

Pig No.	Calcium supplement	Phosphorus intake			Fecal phosphorus	Urinary phosphorus	Phosphorus balance	
		Feed	Suppl.	Total			Total	Percent of intake
	Period A	*gms.*	*gms.*	*gms.*	*gms.*	*gms.*	*gms.*	
1	Secondary phosphate......	2.31	1.29	3.60	1.73	.97	.90	25.0
2	Secondary phosphate......	4.18	2.33	6.51	3.36	1.37	1.78	27.3
3	Tertiary phosphate........	4.18	1.80	5.98	2.85	1.18	1.95	32.6
4	Tertiary phosphate........	2.31	.99	3.30	1.69	.62	.99	30.0
5	Tertiary phosphate........	4.18	1.80	5.98	3.17	1.24	1.57	26.3
	Period B							
1	Tertiary phosphate........	2.85	1.17	4.02	1.88	.77	1.37	34.1
2	Tertiary phosphate........	5.25	2.16	7.41	3.85	1.49	2.07	27.9
3	Secondary phosphate......	5.37	2.87	8.24	3.58	2.18	2.48	30.1
4	Secondary phosphate......	3.05	1.63	4.68	2.16	1.19	1.33	28.4
5	Secondary phosphate......	5.43	2.90	8.33	3.72	2.30	2.31	27.7
	Period C							
1	Secondary phosphate......	2.78	1.72	4.50	2.08	1.41	1.01	22.4
2	Secondary phosphate......	5.31	3.25	8.56	4.20	2.65	1.71	20.0
3	Carbonate................	5.41	0	5.41	3.79	.06	1.56	28.8
4	Carbonate................	3.04	0	3.04	1.97	.04	1.03	33.9
5	Carbonate................	5.57	0	5.57	3.64	.08	1.85	33.2
	Period D							
1	Carbonate................	3.35	0	3.35	1.99	.05	1.31	39.1
2	Carbonate................	5.19	0	5.19	3.40	.19	1.60	30.8
3	Secondary phosphate......	5.62	3.34	8.96	3.95	2.65	2.36	26.3
4	Secondary phosphate......	3.74	2.23	5.97	2.19	1.65	2.13	35.7
5	Secondary phosphate......	5.83	3.49	9.32	4.05	2.74	2.53	27.1
	Period E							
1	Secondary phosphate......	3.25	2.05	5.30	2.16	1.61	1.53	28.9
2	Secondary phosphate......	4.47	3.06	7.53	3.13	2.19	2.21	29.3
3	Primary phosphate........	5.15	6.97	12.12	5.38	5.40	1.34	11.1
4	Primary phosphate........	3.68	4.99	8.67	2.72	3.61	2.34	27.0
5	Primary phosphate........	4.98	7.07	12.05	4.28	5.09	2.68	22.2
	Period F							
1	Primary phosphate........	3.84	4.96	8.80	2.80	3.89	2.11	24.0
2	Primary phosphate........	3.20	4.30	7.50	2.27	3.54	1.69	22.5
3	Secondary phosphate......	3.48	2.19	5.67	2.12	1.95	1.60	28.2
4	Secondary phosphate......	4.43	2.67	7.10	2.53	2.20	2.37	33.4
5	Secondary phosphate......	3.33	2.20	5.53	2.12	1.95	1.46	26.4
	Period G							
1	None....................	.23	0	.23	.82	.512	−1.10	....
2	None....................	.19	0	.19	.42	.552	− .78	....
3	None....................	.32	0	.32	.29	.439	− .41	....
4	None....................	.27	0	.27	.46	.599	− .79	....
5	None....................	.13	0	.13	.20	.552	− .62	....
	Period H							
1	None....................	.19	0	.19	.38	.199	− .39	....
2	None....................	.19	0	.19	.57	.366	− .75	....
3	None....................	.32	0	.32	.06	.215	+ .05	....
5	None....................	.13	0	.13	.06	.458	− .39	....

the probability of a fortuitous outcome only .0028. Therefore, measured by the percentage of the calcium intake retained, the secondary phosphate, altho markedly less soluble than the primary phosphate, was better utilized in the metabolism of the growing animal.

Altho the experiment was not designed to obtain valid comparisons of the utilization of phosphorus in the various supplements or supplemented rations, the same kind of calculations that were made from the

TABLE 21.—SUMMARY OF UTILIZATION OF CALCIUM AND PHOSPHORUS IN THE DIFFERENT RATIONS AND SUPPLEMENTS

Pig No.	Period	Body weight, kilograms	Food intake, grams	Ca intake, grams	P intake, grams	Calcium balance		Phosphorus balance	
						Grams	Percent of intake	Grams	Percent of intake
				Secondary phosphate					
1	A.......	25	900	1.96	3.60	1.04	53	.90	25
2	A.......	46	1 625	3.53	6.51	1.62	46	1.78	27
3	B.......	58	1 995	4.22	8.24	2.33	55	2.48	30
4	B.......	33	1 135	2.40	4.68	1.25	52	1.33	28
5	B.......	60	2 020	4.28	8.33	2.20	51	2.31	28
Average......		44.4	.....	3.28	6.27	1.69	51.4	1.76	27.6
				Tertiary phosphate					
1	B.......	30	1 060	2.24	4.02	1.39	62	1.37	34
2	B.......	57	1 950	4.13	7.41	2.15	52	2.07	28
3	A.......	47	1 625	3.53	5.98	1.83	52	1.95	33
4	A.......	27	900	1.96	3.30	.95	48	.99	30
5	A.......	48	1 625	3.53	5.98	1.64	46	1.57	26
Average......		41.8	.....	3.08	5.34	1.59	52.0	1.59	30.2
				Secondary phosphate					
1	C.......	35	1 110	2.34	4.50	1.61	69	1.01	22
2	C.......	67	2 100	4.44	8.56	2.47	56	1.71	20
3	D......	81	2 160	4.61	8.96	3.06	66	2.36	26
4	D......	48	1 440	3.07	5.97	2.18	71	2.13	36
5	D......	82	2 246	4.77	9.32	2.22	46	2.53	27
Average......		62.6	.....	3.85	7.46	2.31	61.6	1.94	26.2
				Carbonate					
1	D......	43	1 290	2.75	3.35	1.39	50	1.31	39
2	D......	77	2 003	4.23	5.19	2.54	60	1.60	31
3	C.......	69	2 140	4.53	5.41	2.71	60	1.56	29
4	C.......	39	1 200	2.54	3.04	1.43	56	1.03	34
5	C.......	72	2 200	4.65	5.57	2.57	55	1.85	33
Average......		60.0	.....	3.74	4.51	2.13	56.2	1.47	33.2
				Secondary phosphate					
1	E.......	49	1 330	2.81	5.30	2.13	76	1.53	29
2	E.......	84	1 831	4.17	7.53	2.48	59	2.21	29
3	F.......	99	1 415	2.97	5.67	2.09	70	1.60	28
4	F.......	63	1 730	3.67	7.10	2.74	75	2.37	33
5	F.......	98	1 361	2.94	5.53	1.75	59	1.46	26
Average......		78.6	.....	3.31	6.23	2.24	67.8	1.83	29.0
				Primary phosphate					
1	F.......	55	1 500	3.18	8.80	2.29	72	2.11	24
2	F.......	88	1 300	2.73	7.50	1.38	50	1.69	22
3	E.......	89	2 110	4.46	12.12	2.63	59	1.34	11
4	E.......	56	1 510	3.19	8.67	2.03	64	2.34	27
5	E.......	89	2 040	4.51	12.05	2.25	50	2.68	22
Average......		75.4	.....	3.61	9.83	2.12	59.0	2.03	21.2

TABLE 22.—AVERAGE NITROGEN BALANCES AND DIGESTION COEFFICIENTS

Calcium salt	Periods	Average daily N balance	Average digestibility of N
		gms.	*perct.*
Secondary phosphate	A and B	10.98	84.9
Tertiary phosphate	A and B	10.33	85.8
Secondary phosphate	C and D	12.18	87.5
Carbonate	C and D	11.50	87.2
Secondary phosphate	E and F	9.43	90.6
Primary phosphate	E and F	10.02	88.9

results of the calcium study have also been made from the results of the phosphorus study. Certain conditions in the phosphorus study tended to invalidate the data. These were (1) the wide variations in phosphorus intake depending upon the chemical constitution of the various supplements, and (2) the fact that a very considerable fraction of the phosphorus intake was derived from the basal ration.

No clear-cut differences between the utilization of the phosphorus in the rations supplemented with dicalcium-phosphate and in those supplemented with the other minerals were evident in the phosphorus balances in Table 21 altho, as with the calcium, some slight advantage not statistically significant rested with the dicalcium phosphate. On the basis of percentage retention of phosphate, the tertiary phosphate and the carbonate were higher than the secondary phosphate, but the secondary phosphate was higher than the primary phosphate.

The results of the low-calcium and low-phosphorus feeding Periods G and H, in which it was hoped to get some measure of the daily output of calcium and phosphorus on a ration extremely poor in these elements, were so variable as to possess little definite significance, except possibly when averaged together. In all probability, less variable results would have been secured if feces markers had been used, altho the purpose of feces markers is only partly served when the nutrients to be traced are excreted into the intestinal lumen from the blood. The average loss of calcium per kilogram of body weight for all 5 pigs and for both periods was only 1.6 milligrams. The average loss of phosphorus on the same basis was 7 milligrams. These small losses may approximate the minimum maintenance requirements of swine for calcium and phosphorus, altho much larger figures for these requirements are sometimes quoted in the literature on the subject. The greater loss of phosphorus than of calcium should not be surprising in view of the more active role that phosphorus assumes in animal metabolism.

In discussing the calcium requirement for maintenance—and the remarks apply equally well to phosphorus—Ellis and Mitchell[9]* concluded that, in growing animals at least, there may be no integral requirement at all:

> "In the adult, the maintenance requirement for calcium may well represent merely a leakage of calcium ions through the kidney and the walls of the intestinal tract, due entirely to physico-chemical processes. Calcium ions liberated in the course of catabolism from functional combinations in the tissues and body fluids are probably just as available for the reconstruction of such combinations as are calcium ions picked up from the intestinal tract. In the young growing animal these 'used' ions as well as the calcium ions coming directly from the alimentary tract may be absorbed and retained by the developing bones and the growing tissues at such a rapid rate that, at low levels of calcium feeding, the threshold of excretion by the kidneys and the intestines is never reached."

PHOSPHORUS NOT LIKELY TO BE DEFICIENT IN SWINE RATIONS

(EXPERIMENT IV)

Whether the rations usually fed to swine are ever likely to be deficient in phosphorus is an extremely practical question. The most readily available minerals that carry both phosphorus and calcium are either relatively expensive, as are various bone preparations and dicalcium phosphate, or, as the rock phosphates, are toxic when used indiscriminately, especially in the self-feeder. On the other hand, the various forms of calcium carbonate, such as limestone, wood ashes, marl, oyster and mussel shells, and marble dust, are cheap, readily available, and innocuous.

In the experiment described in the foregoing section a supplement of pure calcium carbonate added to a calcium-deficient diet induced in growing pigs retentions of calcium not to be distinguished in magnitude from the retentions induced by dicalcium phosphate. This result might be taken to indicate that the basal diet, consisting largely of corn, was not deficient in phosphorus. However, in an earlier experiment with practically the same basal diet, a bone-meal supplement produced a somewhat larger and better calcified bone than a supplement of limestone containing an equal amount of calcium (Tables 11 and 15). These results are somewhat difficult to reconcile. It may be that the calcium of bone meal is utilized only slightly better by the growing animal—so slightly that a long-continued feeding period is required to demonstrate the difference. Or it may be that the basal ration was only slightly deficient in phosphorus. It is possible also that the calcium of pure calcium carbonate is utilized better than that of limestone. To throw some light upon this question the paired-feeding experiment described below was carried out.

Basal Rations and Supplements

Six pairs of Chester White pigs, one pair of Hampshire pigs, and one pair of Duroc-Jersey pigs were selected at initial weights ranging from 60 to 70 pounds. All were fed a ration composed mainly of corn, fairly well balanced, and containing no more phosphorus than corn itself. It was composed of 92.5 percent corn (yellow), 5 percent soybean oil meal, .5 percent cod-liver oil, 1.5 percent marble dust, and .5 percent salt. This ration contained only 11.58 percent protein (undoubtedly deficient for maximum growth), .754 percent calcium, and .340 percent phosphorus. The phosphorus content was but little higher than that cited by Henry and Morrison for the average phosphorus content of corn, .302 percent. The pigs were housed in the swine barn and had access to an adjacent concrete runway outdoors.

Thruout the feeding period of 16 to 24 weeks one pig in each pair received daily a supplement of sodium phosphate (Na_3PO_4) containing 1 gram of phosphorus. Otherwise the pair mates received the same kind and amount of feed and the same treatment. Water was available at all times. Body weights were taken weekly, while both the initial and the final weights were averages of weights for three consecutive days. The experiment on each pair was terminated, except for two pairs, when one pair mate attained a weight of approximately 175 pounds. Two pairs grew so slowly that this weight was not attained in 24 weeks. At the termination of the feeding period all the pigs were slaughtered, and two bones, a scapula and a humerus, were taken from each pig for chemical analysis in order to determine the effect of the phosphate supplement on calcium and phosphorus retention.

The experiment started May 26, 1933. During the month of August the appetites of the pigs were so poor and the gains so slow that from August 28 to September 8, a period of 10 days, all pigs were given a daily supplement of 4 pounds of skim milk. This departure from the plan of the experiment could have no serious effect upon the results, since the phosphorus content of the total ration consumed was raised thereby only from .340 to .349 percent.

Results in Experiment IV

Rate of Growth.—The growth of the pigs was evidently not accelerated by the phosphorus supplement, since in four pairs the control pig receiving no additional phosphorus gained faster than his pair mate (Table 23). One test pig that did not attain a weight of 100 pounds in 24 weeks was obviously pathological. The average daily gains, excluding this pig and his pair mate, were .75 pound for the control pigs and .78 pound for the test pigs. In spite of these slow gains, which, however, do not invalidate the comparison in the slightest, the feed cost of gains was not excessive. For the control pigs 414 pounds and for the test pigs 398 pounds of feed were required to

TABLE 23.—GAINS AND FEED CONSUMPTION OF CONTROL PIGS RECEIVING NO MINERAL SUPPLEMENT AND OF THEIR PAIR MATES, THE TEST PIGS, RECEIVING A SODIUM PHOSPHATE SUPPLEMENT TO A BASAL DIET CONTAINING ADEQUATE CALCIUM:[a] EXPERIMENT IV

(All weights expressed in kilograms)

	Pair 1		Pair 2		Pair 3		Pair 4	
	Control	Test	Control	Test	Control	Test	Control	Test
Final weight	65.6	44.8	69.2	62.9	75.6	81.0	79.7	78.7
Initial weight	34.4	30.3	29.9	29.4	30.3	33.0	32.1	31.2
Total gain	31.2	14.5	39.3	33.5	45.3	48.0	47.6	47.5
Average daily gain	.19	.09	.23	.20	.38	.40	.43	.42
Total feed consumed	152	152	179	179	179	179	172	172
Feed per kgm. gain	4.87	10.48	4.55	5.34	3.95	3.73	3.61	3.62
Days on feed	168	168	168	168	119	119	112	112
	Pair 5		Pair 6		Pair 7		Pair 8	
	Control	Test	Control	Test	Control	Test	Control	Test
Final weight	72.0	81.0	78.3	78.7	65.6	80.1	79.2	77.8
Initial weight	30.8	32.1	29.0	29.4	27.2	29.0	30.3	31.2
Total gain	41.2	48.9	49.3	49.3	38.4	51.1	48.9	46.6
Average daily gain	.31	.37	.35	.35	.24	.32	.44	.42
Total feed consumed	186	186	199	199	187	187	171	171
Feed per kgm. gain	4.51	3.80	4.04	4.04	4.87	3.66	3.50	3.67
Days on feed	133	133	140	140	161	161	112	112

[a]The basal ration consisted of 92.5 percent yellow corn, 5 percent soybean oil meal, .5 percent cod-liver oil, 1.5 percent marble dust, and .5 percent salt.

produce 100 pounds of gain. No difference in the appetites of test and of control pigs, as measured by the food refusals, was noted.

The data on weights of fresh bones did not reveal any statistically adequate evidence of an effect of the phosphate supplement, and consequently are not tabulated here. Of the sixteen bone comparisons, only ten favored the supplement. The average weights of scapulas were 106 and 109 grams for the basal and the supplemented ration respectively, while the average weights of humeri were 217 and 219 grams, in the same order.

Bone Analyses.—The bone analyses also revealed no advantages from the phosphorus supplement (Table 24). Of the sixteen comparisons between the phosphate-supplement pigs and the control pigs for the calcification of the two bones analyzed, eight favored the control pigs and eight the test pigs. The degree of calcification of the bones is measured by the percentage of total ash on the dry fat-free basis. The average percentages of ash for the control and for the test

TABLE 24.—COMPOSITION OF BONES OF CONTROL PIGS FED NO SUPPLEMENT AND OF THEIR PAIR MATES, THE TEST PIGS, FED A SUPPLEMENT OF SODIUM PHOSPHATE

Pair No. and sex	Percentage of ash in dry fat-free bone		Percentage composition of ash			
			Calcium		Phosphorus	
	Control pig	Test pig	Control pig	Test pig	Control pig	Test pig
Composition of scapulas						
1 ♂	57.17	53.33	35.66	37.08	17.43	18.07
2 ♂	56.35	55.77	37.12	37.02	18.15	17.92
3 ♀	55.15	54.50	37.56	37.39	18.74	18.31
4 ♂	53.53	56.19	37.44	37.68	17.85	18.35
5 ♂	52.70	56.50	37.10	37.29	18.20	18.36
6 ♀	56.31	55.96	36.19	37.13	18.43	18.39
7 ♂	54.52	57.01	36.82	37.06	17.88	18.08
8 ♀	55.17	54.54	37.46	36.72	18.09	18.69
Average	55.11	55.48	36.92	37.17	18.10	18.27
Composition of humeri						
1 ♂	59.22	55.48	35.28	37.06	17.72	18.27
2 ♂	58.51	59.93	37.65	37.16	18.14	18.60
3 ♀	60.09	59.62	36.94	37.53	18.56	18.22
4 ♂	56.13	57.13	37.19	37.41	18.06	18.33
5 ♂	54.59	58.57	37.69	37.38	18.18	18.25
6 ♀	58.26	58.08	37.46	37.64	18.21	19.07
7 ♂	57.18	58.54	37.21	36.95	18.12	18.71
8 ♀	55.86	58.41	37.83	36.65	18.12	18.70
Average	57.48	58.22	37.16	37.22	18.14	18.52

pigs were 55.11 and 55.48 percent respectively for the scapulas, and 57.48 and 58.22 percent respectively for the humeri. These results thus gave no evidence that additional phosphorus, over and above the concentration found in corn, improved the utilization of the calcium when present in abundance or promoted a more rapid calcification of the bones.

The phosphate supplement did apparently have a slight tendency to produce a greater proportion of phosphorus in the bone ash without disturbing the percentage of calcium (Table 24). The phosphorus in the ash of the scapulas averaged 18.10 percent for the control pigs and 18.27 percent for the test pigs; and the phosphate supplement was associated with the higher phosphorus percentage in five of the eight pairs. For the humeri the averages were 18.14 and 18.52 percent, in the same order; and in seven of the eight pairs the higher percentage of phosphorus was observed in the humerus of the pig receiving the phosphate supplement. The probabilities, according to Student's method of analysis, that these were chance results are .12 for the scapulas, but only .012 for the humeri. The latter probability, but not the former, is so small that it may be ignored. The conclusion may be drawn, therefore, that at least with the humerus the phosphate supplement definitely, tho only slightly, raised the phosphorus content of the ash, probably by lowering the percentage of carbonates. That this change in ash composition of the bones would be beneficial in any way is open to question, since Forbes and Schultz[13*] found that the carbonate content of bones is positively correlated with hardness, the bones lowest in carbonate being the softest. Thus the phosphate supplement may actually have produced a softer bone by lowering the carbonate content of the bone ash.

The results of this experiment point to the conclusion that .34 percent of phosphorus in a ration predominantly made up of corn is adequate for growing swine when vitamin D is adequately provided. It may be argued in opposition that this conclusion should apply only to the slow rate of growth that obtained in this test. If all indispensable nutrients other than phosphorus were present in the basal ration in concentrations adequate for maximum growth and bone calcification, this objection would have no force, since with a basal ration containing a concentration of phosphorus inadequate for maximum performance, a phosphate supplement at any level of intake should induce greater growth or more rapid calcification of the bones, or both. However, if some nutrient other than phosphorus is limiting growth, the argument would be valid.

In the present experiment there is good reason to believe that the protein content of the basal ration was a limiting factor, since it amounted to less than 12 percent. Accordingly the above-stated conclusion—that .34 percent of phosphorus is sufficient in a ration adequately supplied with vitamin D—may be restricted in its application to less than maximal growth. The practical significance of this conclusion would not, however, seem to be impaired in so far as it implies that no phosphorus-containing mineral supplement is needed with a ration predominantly composed of corn. For if the protein in the basal ration had been raised from 12 percent to a level permitting maximum growth by the use of any available protein supplement for swine, the phosphorus content of the ration would have been increased as well, since protein supplements as a class are much richer in phosphorus than is corn.

Altho, for the reason just given, the results of this experiment do not prove that in a ration predominantly made up of corn a level of .34 percent of phosphorus will promote maximum calcification of the bones, other evidence in favor of some such minimum may be cited. Forbes and associates[12*] obtained as good bone development from calcium carbonate added to a calcium-poor basal ration containing 75 percent of corn and .398 percent of phosphorus as they obtained from a supplement of bone meal. And in an excellent, well-controlled study of the phosphorus requirements of growing swine Aubel and Hughes[1*] proved that for the basal ration they used the minimum requirement of phosphorus for normal body and bone development lay between .27 and .30 percent. The basal ration they fed contained no whole corn, but it did contain 74 percent pearl hominy and less than .15 percent of phosphorus. The phosphorus content was varied by additions of monocalcium phosphate. Cod-liver oil was given each pig daily in doses of 5 cc. Both of these investigations thus support the indications of the Illinois tests, namely that the percentage of phosphorus required in swine rations is not appreciably higher than that in corn, and that rations made up predominately of corn and properly balanced with respect to protein will most certainly contain enough phosphorus for growing swine.

SUMMARY AND CONCLUSIONS

Paired-feeding experiments with 115 growing pigs during the period from 1929 to 1933 were made in order to determine the most likely mineral deficiencies of practical swine rations consisting mainly of corn, and to compare the value of different mineral supplements in correcting such deficiencies. With all of the rations used in the tests vitamin D was adequately provided. The supplements were judged according to the rate of growth of the pigs, the effect upon the bones as determined by weights and chemical analyses, and the retention of minerals and nitrogen as determined by metabolism studies.

The data from these tests, subjected to statistical analysis, brought forth the following facts and led to the following conclusions.

1. The addition of a very complete mineral mixture to two basal rations of corn and tankage, and corn and soybean oil meal, promoted no better growth or health than a simple supplement of common salt

and steamed bone meal. In all probability, therefore, the basal rations were not deficient in mineral elements other than sodium, chlorin, calcium, and phosphorus. Accordingly, unless specific evidence to the contrary is obtained, it is reasonable to assume that practical swine rations are not deficient in iodin, iron, manganese, or any of the elements required by animals in small amounts but widely distributed in farm feeds. This conclusion is supported by the results of other investigations with mineral supplements.

2. A calcium supplement added to a calcium-deficient ration for growing swine produced heavier bones containing less moisture and more mineral matter. It also increased somewhat the percentage both of calcium and of phosphorus in the bone ash. Correcting calcium deficiencies in rations are thus clearly advantageous.

3. Steamed bone meal proved somewhat superior to limestone as a supplement to a ration deficient in calcium, as judged by the weight and the ash content of the bone produced. The bones produced on limestone cannot fairly be described as abnormal, however. The rate of gain produced on limestone was not to be distinguished from that produced on bone meal.

4. Rock phosphate fed in an amount sufficient to provide 5 grams of calcium daily as a supplement to a calcium-deficient diet exerted definite toxic effects on pigs after variable periods of feeding. This toxicity was cumulative and was greater than that produced by a mixture of pure tricalcium phosphate and calcium fluorid providing daily the same amounts of calcium and flourin. In the composition of the bones, however, no detrimental effect of rock phosphate or of calcium fluorid was observed under the conditions of these experiments.

5. In comparisons of calcium carbonate, and mono-, di-, and tricalcium phosphates as supplements to a calcium-deficient ration during ten-day metabolism periods, no significant differences were found in the retentions by pigs of calcium from calcium carbonate, dicalcium phosphate, and tricalcium phosphate. The retention from monocalcium phosphate was distinctly, tho slightly, less.

6. The average losses of calcium and phosphorus from the bodies of five young pigs subsisting on a ration of starch, yeast, a calcium-and-phosphorus-free mineral mixture and cod-liver oil was only 1.6 milligrams and 7.0 milligrams respectively per kilogram of body weight. These values may be considered approximations to the maintenance requirements of pigs for calcium and phosphorus, tho it is possible that the integral requirements of young animals are not measurable by the methods used in these tests.

7. A supplement of sodium phosphate added to a basal ration composed largely of corn and containing .75 percent of calcium and .34 percent of phosphorus did not improve the power of the ration to promote growth or bone calcification in young pigs. The supplement did, however, increase slightly the phosphorus content of the bone ash without disturbing the calcium content, probably as a result of a reduction in the carbonates in the bone. There is no reason to believe that this is an advantageous modification in bone composition brought about by the phosphate supplement.

8. From this and other experiments with phosphate supplements it seems safe to conclude that, in the presence of adequate vitamin D and calcium, a concentration of phosphorus at .30 to .35 percent in a ration composed predominantly of corn is adequate for maximum growth and bone development. In view of the high phosphorus content of all available protein supplements for swine, evidently no phosphorus in the form of a mineral supplement need be added to swine rations consisting mainly of corn adequately balanced with respect to protein, when vitamin D is present in adequate amounts in the ration or, much more commonly, is provided by exposure to sunlight. Under such conditions the only mineral supplements needed are salt and, if vegetable protein concentrates are used, limestone or some other mineral containing calcium carbonate.

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