THE IMPORTANCE OF CALCIUM AND PHOSPHORUS IN A SWINE RATION

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INTRODUCTION

For some time special importance has been attached, by both scientists and stockmen, to the feeding of calcium and phosphorus supplements to swine. Probably no other class of livestock is so often fed a ration consisting solely of cereal grains as is swine. All cereals, especially corn which is a chief constituent of many swine rations, are low in both calcium and phosphorus. The reasons for adding mineral supplements containing these elements are obvious; calcium and phosphorus being the most abundant mineral elements in the animal body. The body is composed of approximately 2% calcium and 1% phosphorus. Eighty five per cent of the mineral matter of bones and 75% of the ash of the entire body is calcium phosphate. The added strain on the skeleton, nervous system and other body parts, resulting from the increasing demand for earlier maturity and more rapid meat production in swine, enable you to attach a still greater significance to the addition of these minerals to a ration.

In support of the foregoing statements, and in order to set forth more clearly the importance of calcium and phosphorus in a swine ration, the author has made a thorough study of some of the more important literature; a condensed report of which follows.

REVIEW OF LITERATURE

BONE STRUCTURE

Orr[25] states that 10 to 25 per cent of living matter consists of organic compounds of which the colloidal material of the protoplasm is formed. The remaining 75 to 90 per cent consists of water and inorganic salts; calcium and phosphorus being important constituents of the latter.

These mineral elements are present in living matter, partly in chemical combination with and forming an integral part of organic compounds, and partly free or potentially free either in solution as salts or ions in the water of the protoplasm, or in a temporary loose union with the colloids. All forms of life depend ultimately upon the transformation of the energy of the sunlight into chemical energy. The power of carrying out this fundamental process, which can be regarded as the real origin of life, is possessed by inorganic salts in colloidal solutions. With the production of formaldehyde, which contains the trapped energy of the sun, photosynthesis arises from the action of sunlight and inorganic salts, with the aid of chlorophyll, on water and carbon dioxide.

Thus the beginning of life processes can be said to be a result of the action of radiant energy on inorganic salts. Changes in the concentration of the inorganic ions in the animal body can be correlated with changes in the functions of the organs.

The integrity of the functions of all organisms regulated by the central nervous system depend upon the maintenance of definite ratios of calcium, potassium and sodium in the fluids within the nerve tissues. Orr quotes Ringer as showing, in his experiments with the perfused heart, that minute changes in the concentrations of calcium in the perfusing fluids have a pronounced effect on the heart activity.

Both experimental and chemical evidence show that changes in the physiological balance are involved in many pathological conditions in which the symptoms can be associated with an excess or lack of specific ions. An example of this is a rachitic condition. In spite of the fact that there is considerable loss, of the mineral matter, in the excreta, the animal body is highly efficient in maintaining the balance. The bones act as a reservoir for a reserve amount which is deposited when the supply is ample, to be used in time of need. It is probable that this function of the bones, that is, regulating the supply of mineral elements to body fluids, is as important as the more obvious one of supplying a rigid framework for the body. This function might be considered even more fundamental, for, when the available mineral matter is insufficient to maintain both the physiological balance in the blood and the rigidity of the skeleton, the latter is sacrificed. Under experimental conditions it is possible to feed diets of marked deficiencies or excesses of some of the mineral elements, and produce a condition of malnutrition which is so definite and pronounced as to be called a disease. Such are rickets and anaemia. Not only must a sufficient amount be supplied but a correct balance must be maintained. With the increased demand for a greater capacity for growth, higher production etc., the mineral requirements for the modern types of animals have assumed a greater proportion. Orr concludes that serious pathological conditions develop when the supply of mineral elements in the ration does not meet the requirements of the animal.

In a series of experiments by McCollum and Simmonds[23] to determine the nature of the dietary deficiencies of cereal grains, part of the rats used in the experiments developed beaded ribs and collapsed thoraces. In a systematic effort to find a preventative they learned that no matter what other inorganic salts were added to supplement these cereal diets, these abnormalities of the skeleton could not be prevented without the addition of a calcium salt. McCollum states that Elliot, Crichton and Orr (1922) fed pigs on diets of bran and oatmeal, together with an abundance of vitamins A, B, and C and the pigs developed rickets in three months. Another series of pigs were fed the same foods under the same conditions but were supplied with calcium salts. These did not develop rickets.

For several years, previous to 1890, successful Wisconsin farmers had been advocating feeding hardwood ashes to hogs, especially where the chief concentrate was corn. Henry,[21] in an endeavor to determine the value of this practice and also to learn if there was any advantage to feeding bone meal with a corn ration, conducted a series of experiments using, in the first trial, 6 pigs from a litter which had been fed corn meal and skim-milk before weaning, and corn meal exclusively after weaning until the beginning of the trial.

At the age of 129 days they were divided into 3 lots of 2 pigs each. Lot I received a pinch of bone meal daily in the feed; lot II was supplied hard wood ashes in a separate trough and lot III received only corn meal. Rain water was furnished each lot for drink and all the salt they would consume without waste was given each lot.

In the second trial, the same number of pigs were fed under the same conditions, but were supplied with skim-milk both before and after weaning and consequently were more thrifty.

During the preceding year a similar experiment, having the same object as the one just mentioned, was conducted. The following table shows the results of the two experiments.

CORN MEAL ALONE VS. CORN MEAL AND HARD WOOD ASHES OR CORN MEAL AND BONE MEAL

Table I

	When Bone meal Was Fed	When Ashes Were Fed	When only Corn Meal Was Fed
Corn Meal Required to Produce 100# Gain:			
First Trial	519	549	853
Second Trial	426	417	466
Preceding Year . . .	518	515	568
Average . . .	487	491	629
Average Breaking Strength of Each Thigh Bone:			
First Trial . . .	417	340	306
Second Trial . . .	806	780	292
Preceding Year . . .	817	625	305
Average . . .	680	581	301
Total Ash of Thigh Bones:	Grams	Grams	Grams
First Trial . . .	109	97	88.9
Second Trial . . .	224.5	215.7	144.1
Preceding Year . . .	164	138.1	87.6
Average . . .	165.8	150.2	107

The preceding table shows plainly that corn alone cannot build strong bones or act as an economical feed in the production of pork. Calcium and phosphorus must be supplied in addition.

(1) The lots receiving bone meal and ashes consumed approximately 130# less of corn in the production of 100# of gain. This was a saving of about 28%.

(2) The strength of the thigh bones in the lot receiving neither bone meal or ashes was only about half that of the other two lots.

(3) The bones of the pigs in the lots receiving bone meal and ashes contained 50% more ash than the bones of the pigs in the lot receiving only corn meal.

At the Nebraska Experiment Station, Burnett[11] conducted two experiments designed to determine the relative strength of bones of pigs on different rations.

The first experiment, beginning October 13, 1906 and ending February 12, 1907 was composed of 4 lots of 4 pigs each. The initial weight of the pigs was 95# each and at the end of 17 weeks they weighed 232#.

Lot I received 100% corn meal, lot II, 75% corn meal and 25% shorts, lot III, 90% corn meal and 10% tankage and lot IV, 90% corn meal and 10% bone meal.

The second experiment, composed of 20 pigs divided into 5 lots, began August 2, 1907 and ended June 30, 1908. The initial weight of these pigs was 62# each and their final weight 230# each. At the close of the experiment they were slaughtered and hung in the cooler for 48 hours.

The humerus, radius, ulna, femur and tibia of each hog was removed, cleaned and broken in a testing machine. The following table shows the average breaking strength of the bones.

AVERAGE BREAKING STRENGTH PER 100# LIVEWEIGHT

OF BONES OF PIGS FED DIFFERENT RATIONS

1906-1907

Table II

LOT	RATION	Femur Lbs.	Tibia Lbs.	Humerus Lbs.	Radius and Ulna Lbs.	All Bones Lbs.
1	100% Corn Meal	244	269	326	285	281
2	75% Corn Meal 25% Shorts	264	274	381	326	311.75
3	90% Corn Meal 10% Tankage	376	353	522	402	413.75
4	90% Corn Meal 10% Bone Meal	454	375	530	504	467.75

1907-1908

Table II (continued)

LOT	RATION	Femur Lbs.	Tibia Lbs.	Humerus Lbs.	Radius and Ulna Lbs.	All Bones Lbs.
1	100% Corn Meal	276	252	434	341	325
2	75% Corn Meal 25% Shorts	343	309	555	376	396
3	25% Corn Meal 75% Skim-milk	462	360	685	529	509
4	90% Corn Meal 10% Tankage	559	409	740	611	580
5	90% Corn Meal 10% Bone Meal	646	465	898	715	681

A laboratory examination was made of the bones taken from the second experiment (1907-1908) and a marked difference was found in the thickness of the walls. The thickness of the bone wall was about 50% greater in the lot fed bone meal than in the lot fed corn meal alone. From an examination of the table it may well be assumed that skim-milk, tankage and bone meal contain some bone building substance which is lacking in corn. Burnett concludes that since the laboratory examination showed that the increased mineral matter was largely phosphate of lime, and since skim-milk, tankage and ground bone are each rich in phosphate of lime, it is fair to look upon the phosphates in these foods as the determining factor in the building up of the bones in the pigs.

Halverson and Nixon[20] observed that stockmen in limestone regions lying along side of or adjacent to non-calcareous areas produced stock of a better quality and possessing more vigor and vitality than stock coming from the non-calcareous regions. The difference is attributed to the fact that a greater amount of calcium is supplied to the animals in the limestone region. Since the pig is the most rapid grower of farm animals, has a small stomach, and subsists largely on concentrates rather than on roughages and bulk containing feeds, Halverson and Nixon found the calcium requirement of swine to be about .64 to .80% of the ration.

Water-extract of wheat bran contributed to the size and breaking strength of bones and to the development of the muscles, heart and lungs in swine, according to Forbes[16].

The muscles of pigs receiving bran extract were lower in phosphorus than muscles of pigs in other lots, though the pigs receiving this feed made the maximum increase in weight and muscle, and total protein in the muscle. The phosphorus of the bran was present mostly in the form of salts of phytic acid, a complex organic compound.

The addition of bone meal to a ration low in calcium and phosphorus, increased the ash and strength of the bones. The pigs receiving bone meal had muscles containing less ash and less phosphorus in the ash, but more ash in the protein, than the muscles of those pigs fed no bone meal and a ration lower in calcium and phosphorus. Although the bones of the pigs, fed a ration low in calcium and phosphorus, increased markedly in size, they decreased considerably in ash content.

The most urgent need of growing animals for a mineral supplement (aside from salt) is satisfied by calcium carbonate, according to Forbes, Halverson, Morgan and Schulz[18]. However, they determined that a further strengthening of the skeleton could be obtained by the addition of some phosphate or the feeding of calcium phosphate instead of calcium carbonate. In 1913, 30 growing swine were used in an experiment designed to compare a ration of cereal grains alone to a ration of cereal grains supplemented with mineral mixtures. Five pigs were killed as a control lot, while the remainder were fed in 5 lots of 5 pigs each. The basal ration was corn, linseed oil meal and wheat middlings. Mineral mixtures were fed to four lots supplying 5 grams of calcium to each pig each day. The pigs receiving mineral in the form of precipitated calcium carbonate or steamed bone meal had dense, strong bones not found in the other lots.

In 1919 a similar experiment was carried on in which the mineral supplements were supplied separately and the pigs were allowed to consume them at will. With the addition of limestone, steamed bone, whiting, precipitated bone, calcium carbonate and marl there was a marked and somewhat nearly equal increase in the strength of the bones. All of the pigs in the lot fed on a strict cereal ration possessed bones which were relatively poor in mineral constituents, other than magnesium.

Bohstedt, Bethke, Edgington, and Robison,[7] in an attempt to discover the factor, or combination of factors, causing rickets or partial paralysis in pigs, conducted the following experiment. Ten lots were used, each containing 8 Poland China pigs averaging 41# each in weight. The lots were 12 feet by 30 feet, paved with brick, and each contained a movable hog house. None of the pigs had access to green, growing vegetation or soil. They were fed from December 6, 1923 to May 14, 1924. The basal mixture was white corn, flour wheat middlings, linseed meal, and salt. This mixture was supplemented with various minerals, proteins, vitamins, and combinations of these.

The accompanying data represents the average daily gain, average daily feed consumption, economy of gains during the experimental period, and character of pigs at the end of the period.

A COMPARISON OF RATIONS FED IN AN EXPERIMENT TO DETERMINE THE FACTORS CAUSING RICKETS OR PARTIAL PARALYSIS IN PIGS

Table III

	Lot I	Lot II	Lot III	Lot IV	Lot V
	Basal 100#	Basal 100#; Calcium Carbonate 2#	Basal 100#; Di-Sodium Phosphate 2#	Basal 100#; Precipitated Bone-Flour 2#	Basal 100#; Casein 2#
Average Daily Gain Per Pig	0.41	0.38	0.42	0.55	0.60
Average Ration Per Pig	2.41	2.31	2.37	2.64	2.64
Feed Required Per 100# Gain	591	611	571	478	441
Character of Pigs at End of Experiment:					
Very thrifty	0	0	0	0	0
Fairly thrifty	1	0	2	2	1
Stunted	0	2	0	1	1
Lame*	3	1	2	1	1
Dead≠	4	5	4	4	5
Comments on pigs at end of period	Stary coat of hair, wrinkly hide, labored breathing	Extremely labored breathing, dwarfed, stary coat of hair, rough hide	Labored breathing	Fairly smooth coat of hair and hide	Rough coat of hair and hide

A COMPARISON OF RATIONS FED IN AN EXPERIMENT TO DETERMINE THE FACTORS CAUSING RICKETS OR PARTIAL PARALYSIS IN PIGS

Table III

	Lot VI	Lot VII	Lot VIII	Lot IX	Lot X
	Basal 100#; Casein 2#; Precipitated Bone Flour 2#	Basal Cod Liver Oil 1#	Basal 100#; Cod liver oil 1#; Precipitated Bone flour 2#	Basal 100#; aerated cod liver oil 1#; Precipitated Bone Flour 2#	Basal 100 #; Without Blood Meal
Average Daily Gain Per Pig	0.57	1.08	1.08	0.95	0.51
Average Ration Per Pig	2.58	4.37	3.91	3.57	2.71
Feed Required Per 100# Gain	450	405	361	376	530
Character of Pigs at End of Experiment:					
Very Thrifty	0	3	6	3	0
Fairly Thrifty	3	2	2	3	2
Stunted	2	2	0	2	2
Lame*	1	0	0	0	3
Dead/	2	1	0	0	1
Comments on pigs at end of period	Fairly Smooth Coat of Hair and Hide	Rapid average Growth But much variation 3 slightly stiff 1 piles, 1 crooked fore leg	Most uniform Growth, No Crampy nor Lame pigs	No crampy nor lame pigs	Less Lameness than in Lot I, which ate blood meal

/ Deaths were due to rickets, respiratory trouble, or effects of deficient rations generally.

* Pigs previous to coming down with rickets or paralysis were in some cases very thrifty.

The basal mixture:

For pigs weighing up to 100#

Ground white corn	. . .	70#
Flour wheat middlings	. . .	15#
Linseed oil meal	. . .	10.5#
Blood meal	. . .	4.0#
Salt	. . .	.5#

The tables show that an insufficiency of either minerals or vitamins will not permit proper development.

With the coming of livestock production on a more intense scale a long list of diseases in animals has become prominent states Bohstedt[5]. Important among these are rickets and osteoporosis, and since they are not given any consideration in earlier literature it appears that intensity of culture and management has imposed conditions on livestock, particularily swine, which set real limitations on their development. The depositing of calcium salts in the body, which is necessary for the complete ossification of bone, is an important part of the metabolism of the animal. The presence of rickets indicates a failure in this respect. On the other hand osteoporosis occurs in bones more or less completely developed, and consists of decalcification without the proliferative processes characteristic of rickets. Bohstedt lists some of the symptoms of these bone softening diseases as follows:

Stiffness of body

Disinclination to move from the lying position

Fear at being approached

Pain at being touched

Stilted, staggering gait

Rough, stary coat of hair

Wrinkly skin

Paralysis of hind quarters

Broken bones

Broken down in the back

Lameness

Quoting Bohstedt[5],

> "More thoroughly established than any other possible cause of abnormal bone formation is a deficient and unbalanced diet. A deficiency of calcium in the feed was early suspected of causing rickets."

Quoting Hutyra and Marek (19th century) he also makes the statement,

> "A low calcium content of drinking water might be a factor in the incidence of rickets, and above all, the relationship between the lime salts and phosphoric acid appears to be of importance."

In 1921, Bohstedt and Robison[10] found that an addition of limestone to a swine ration consisting of corn, flour wheat middlings, linseed meal and salt caused a greater gain in weight.

A similar experiment the following year yielded the same result. The breaking strength of the bones of the pigs fed limestone was much greater than those of the pigs fed the basal ration alone. In both experiments the basal ration was supplied as follows:

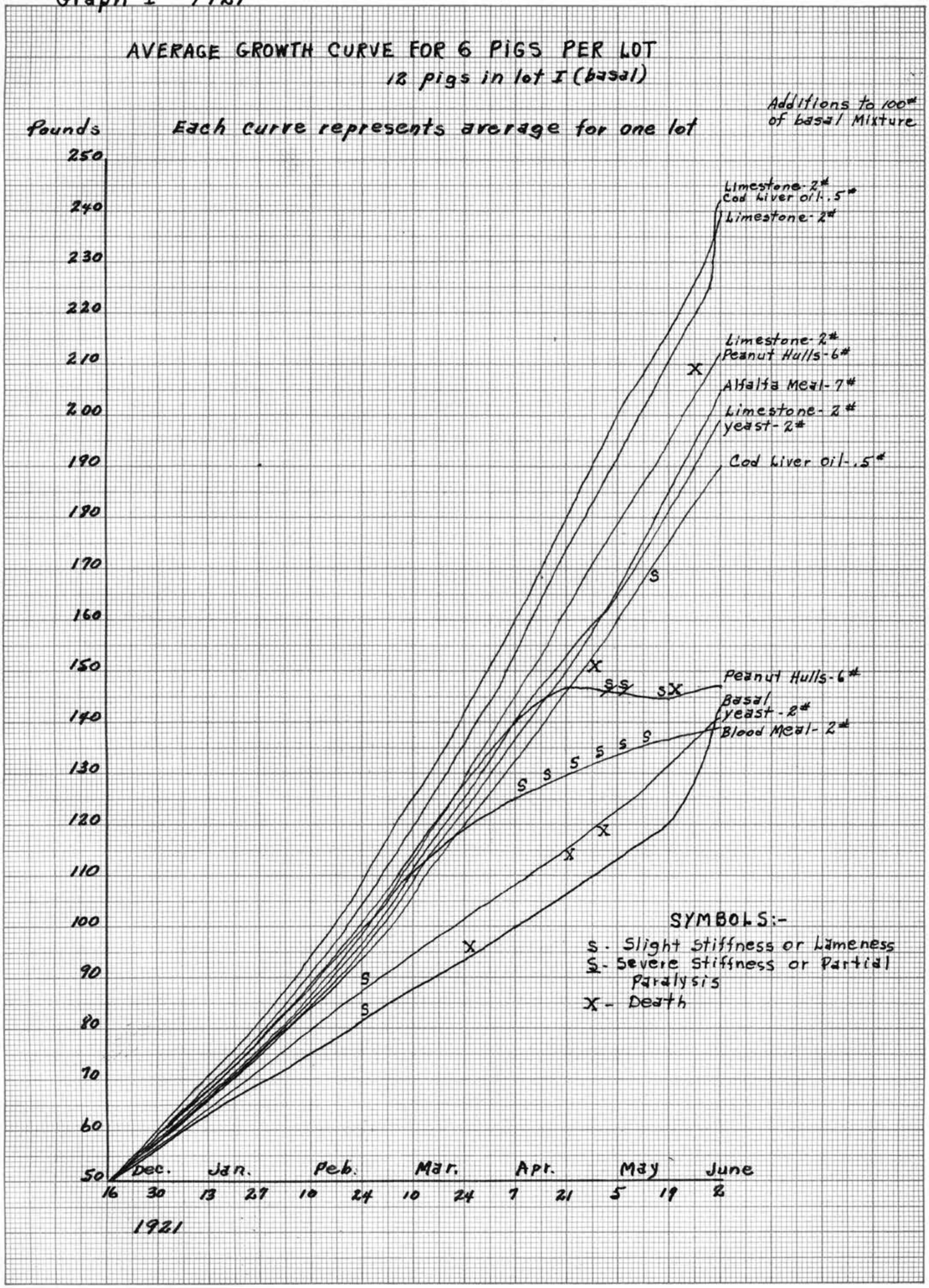
	For Pigs Weighing-		
	0-100#	100-150#	above 150#
Ground White Corn	75	75	75
Flour Wheat Middlings	9	14	17
Linseed Meal	15	10	7
Salt	1	1	1
	100#	100#	100#

All pigs were hand fed inside the barn.

Indications are made on the graphs as to the supplements supplied each lot, the rate and amount of gain and the physical characteristics of the pigs in each lot. Each curve represents the average for one lot of pigs.

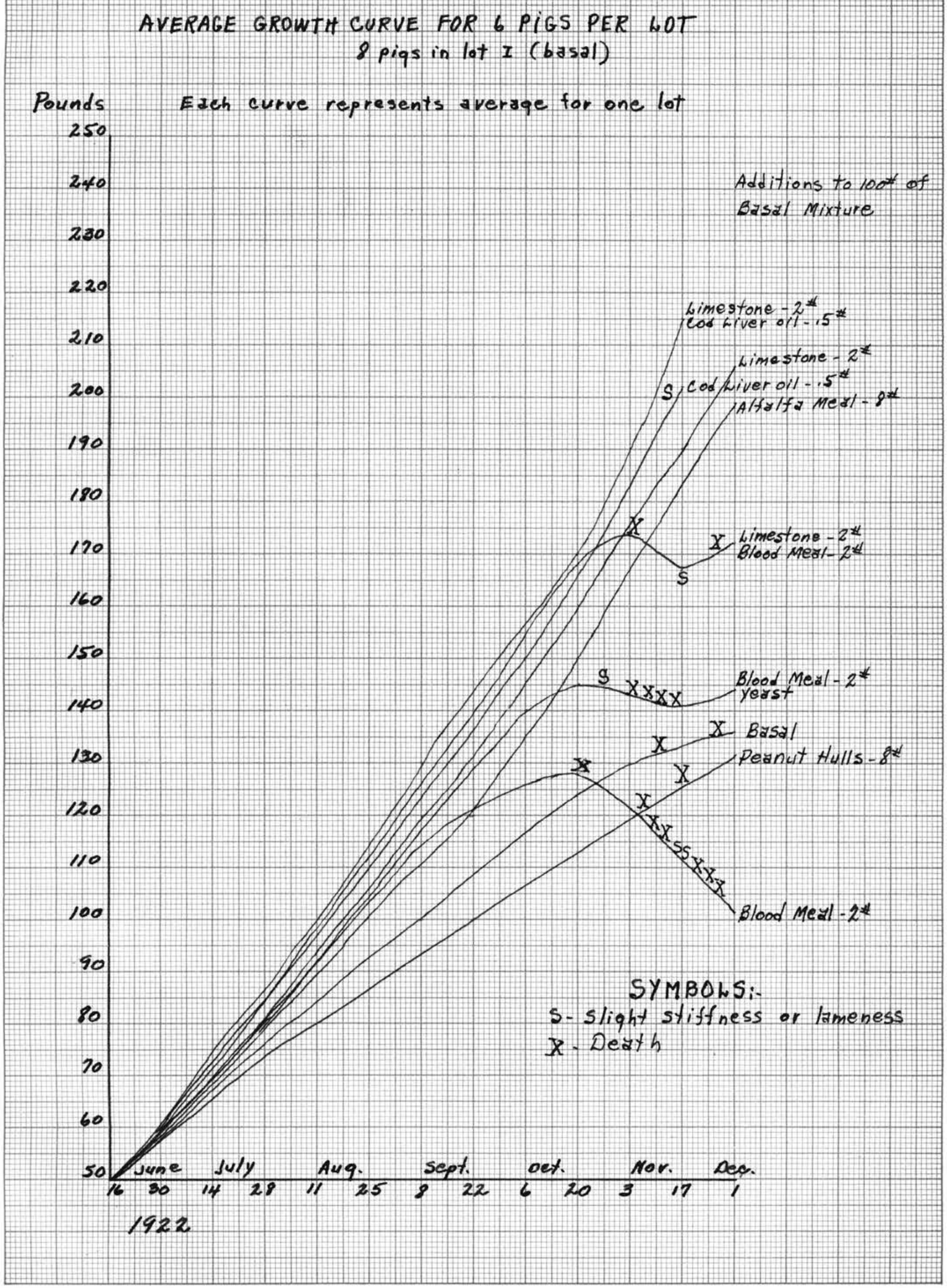
More than any other one thing, these experiments, from the clinical manifestations of the pigs and incidentally from such hints as were furnished by the breaking strength of the bones, prove the adverse effects of rations low in ash.

Graph I 1921



AVERAGE GROWTH CURVE FOR 6 PIGS PER LOT
12 pigs in lot I (basal)
Each curve represents average for one lot
Additions to 100# of basal Mixture
Pounds
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
Limestone-2# Cod Liver oil-.5#
Limestone-2#
Limestone-2# Peanut Hulls-6#
Alfalfa Meal-7#
Limestone-2# yeast-2#
Cod Liver oil-.5#
Peanut Hulls-6#
Basal
yeast-2#
Blood Meal-2#
SYMBOLS:-
S. Slight stiffness or Lameness
S. Severe stiffness or Partial paralysis
X - Death
Dec.
Jan.
Feb.
Mar.
Apr.
May
June
16
30
13
27
10
24
10
24
7
21
5
19
2
1921

Graph II 1922



In 1921 and 1923, Maynard, Goldberg and Miller [24] conducted experiments to determine whether calcium and vitamin C had any effect upon stiffness in pigs.

The rations for the 1921 experiment were as follows:

	A	B	C
Yellow hominy feed	200	200	200
Wheat middlings	100	100	100
Casein	4	4	4
Pasteurized skim-milk	322	0	0
Raw skim-milk	0	322	322
Precipitated bone meal	4	4	0
Calcium carbonate	4	4	0

Twelve pigs were placed on ration A and 6 on each of rations B and C. At the end of 90 days the pigs on ration A had each gained about 0.84# daily and showed no signs of stiffness. The pigs on ration B had gained about 0.81# daily and showed no stiffness.

Early in the experiment 1 pig was removed and 1 died in the pen fed ration C. (In neither case was the ration at fault, however) The remaining pigs developed stiffness during the third month. Pig number 5, stiff in all four legs and losing weight, was transferred to ration B with extra bone meal and calcium carbonate furnished ad libitum. Seven weeks later when he was killed, all stiffness had disappeared and growth had been resumed.

In 1923 a similar experiment was run using the following rations:

	A	B	C	D
Yellow corn meal	200	200	200	200
Wheat Middlings	100	100	100	100
Oil Meal	30	30	75	75
Pasteurized skim-milk	365	365	0	0
Steamed bone meal	5	0	6	0
Ground limestone	5	0	6	0

5 pigs were fed on each of the 4 rations; A, B, C and D. At the end of 90 days the pigs in lot A had gained an average of 1# per day and showed no stiffness. At the end of 80 days 1 was stiff in lot B and the rest gained an average of .97# each daily. At the end of 120 days there was no stiffness in lot C and they gained an average of .67# each daily. One in lot D became stiff in 90 days while the rest gained .7# daily. An examination of the bones of the pigs not stiff in the mineral deficient lots showed them to be poorly developed in comparison to those in lots fed mineral.

Results from a later experiment (1923-24) show that an addition of calcium salts produced bones of a strong nature and high in ash, while the bones from pigs fed a diet low in calcium were low in calcium and phosphorus content.

A total of 95 pigs were used in these experiments, 23 of which developed stiffness. In three out of four of the times when stiffness was produced it was on a ration below the optimum in calcium content. In two out of three cases tried, the stiffness so produced was alleviated by the addition of limestone and bone meal.

Aubel and Hughes [2] conducted a study to determine the requirements of phosphorus of growing pigs when fed a ration deficient in vitamin D. It was a study of phosphorus requirements, uncomplicated by the amount of calcium in the ration, or by the absence of any elements known to constitute an adequate diet, except vitamin D. The limiting factor in the ration was phosphorus.

Three groups of pigs, similar in age, size and breeding, were fed on identical rations, which contained the same amounts of digestible nutrients, minerals and vitamins but which contained different percentages or levels of phosphorus. The manner in which the pigs of each group reacted in body and bone growth, utilization of feed and blood composition was taken as the criterion for determining whether or not the animals were receiving a sufficient amount of phosphorus to meet the requirements for normal development.

All animals were fed individually twice each day. The amount fed daily was changed from time to time. The plan was to feed so that each pig ingested the same amount of feed so that if any significant difference in gains in weight and growth occurred the cause would not be attributed to a larger or smaller intake of food. Each pig was fed the amount the one of the series eating the least would clean up morning and evening. There were four pigs in Lot I; four in lot II; and three in lot III.

Pigs were weighed and measured each 28 days. Analyses were made of the blood, drawn from the tail, for calcium and for inorganic phosphorus, at the beginning of the experiment, each 28 days throughout the experiment and at the time of slaughter in order to ascertain the effects of the ration upon the amount of these elements in the blood. The experiment ran for 22 weeks when the animals were killed and a pathological inspection was made of the carcasses. Femurs and costochondral junctions were saved for examination.

The basal ration consisted of 74% pearl hominy, 10% tapioca roots, 10% blood meal, 4% dehydrated alfalfa meal, 1.5% dried brewer's yeast and 0.5% iodized salt. Calcium carbonate was added to these ingredients to bring the calcium content up to the required level for each experiment and mono-calcium phosphate was used to raise the phosphorus content. The three groups were to be fed on the same basal ration, but each was to receive a different level of phosphorus. One level was to be low enough so that phosphorus deficiencies would be manifested. Another was to constitute a level high enough to be above the requirement, while the third was to be an intermediate level, the adequacy of which was unknown.

The levels decided upon were; 0.24% of the ration in lot I; 0.51% of the ration in lot II; and 0.79% of the ration in lot III. The level of calcium in all three lots was to be 0.79% of the ration. Observations were made and data collected on the influence of the rations upon the consumption and utilization of feed and upon a number of developments in the body.

The following table shows the data pertaining to this experiment and also includes the data of a lot of 4 pigs (lot 9 of a previous experiment) fed the same ration that the pigs received in this test. The level of phosphorus for the lot 9 was 0.30%, and for calcium it was 0.84%. The pigs had access to sunshine and received 5 cc of cod liver oil per pig daily. This was the level of phosphorus that gave the best gains, feed utilization, and blood and bone formation for young pigs in a series of earlier experiments by Aubel and Hughes[1] and Aubel, Hughes and Lienhardt[3].

These data for lot 9 are included here for comparison with the different lots of pigs fed in which vitamin D was omitted from the ration.

COMPARISON OF PIGS FED THE SAME RATION WITH DIFFERENT LEVELS OF PHOSPHORUS

Table IV

Lot No.	No. pigs in lot	Ca in ration	P in ration	Average initial weight	Average final weight	Average daily gain	Average daily feed	
Vit. D		Per-cent	Per-cent	Pounds	(a) Pounds	Pounds	Pounds	
9	3	0.84	0.30	41.1	236.3	1.17	4.26	
No. Vit. D							12 wks.	10 wks.
1	4	0.78	0.24	44.2	159.5	0.75	3.17	3.81
2	4	0.79	0.51	44.5	194.3	0.97	3.16	4.67
3	3	0.79	0.75	44.0	123.0	0.51	3.02	3.31

(b) (c)
Blood analysis

Lot no.	No. pigs in lot	Feed required for 100 pounds gain		Ca in serum	Inorganic P in serum	Avg. specific gravity femurs	Avg. breaking strength femurs	Average ash in femurs and humeri
Vit. D. (d)		Pounds		Mg.	Mg. (f)		Pounds	Percent
9	3	359		11.8	6.1	1.28	1303	63.1
No. Vit. D		12 wks.	10 wks.					
1	4	405	539	10.9	5.9	1.09	482	51.9
2	4	407	387	10.4	8.4	1.21	960	56.6
3	3	456	992	(e) 8.0	(e) 8.6	1.15	606	54.8

(a) 24 weeks
(b) At end of experiment
(c) Mg. per 100 cc.
(d) Data from lot 9 in earlier experiment as mentioned
(e) Two pigs
(f) Whole blood

The table shows that on the basis of daily gains, feed consumption and utilization of feed, lot II, receiving 0.51% phosphorus, was receiving a more favorable calcium-phosphorus ratio, in the absence of vitamin D.

The results of the blood analysis show that the lowest inorganic phosphorus in the serum was found in lot I, and that lots II and III did not vary much from each other. The percentage of serum calcium found in lot III is hard to explain. However, the averages shown for lot III are from 2 pigs only. The other pig died 10 hours previous to the time of slaughter. One of the pigs from which these averages were made yielded blood that clotted rapidly and a satisfactory calcium determination was not made.

The results of the bone analysis showed that the best bone was developed by the pigs in lot II. These pigs seemed to walk normally and with ease and at the time of slaughter no beaded ribs were found among them. The pigs of lot I were badly affected with rickets and exhibited beaded ribs. Two of the pigs of lot III were undoubtedly rickety and had beaded ribs. The third pig showed little beading of the ribs but could have been rickety.

Under conditions of this investigation, Aubel and Hughes[2] conclude that the pigs in lot II, receiving a ration containing 0.51% phosphorus and 0.79% calcium, a phosphorus-calcium ratio of 1 to 1.5, had the best appetite, made the best gain in weight, had the best utilization of feed, and formation of bone of any of the lots of pigs.

Bohstedt[6] says nutrition experiments from the earliest years of experimental work have proved the need for calcium in swine rations if these rations consisted of cereals that were balanced in respect to protein with by-products of cereals or seeds. All of these feeds, while fairly rich in phosphorus, are low in lime.

Experiments in swine mineral feedings have shown that 1½ parts of calcium for every 1 part of phosphorus in the ration was very nearly an optimum Ca:P ratio. Excellent growth and calcification of bones have been obtained in rations with a calcium content of .50 to .75% and a phosphorus content of .33 to .50%.

BREEDING AND LACTATION

According to Sherman,[27] the calcium and phosphorus content of the body of the young mammal at the end of the suckling period represents a very important added nutritional demand which the mother has been called upon to meet partly during the period of pregnancy and partly during lactation.

In connection with a study of the influence of age, growth and feed upon the calcium and phosphorus content of the body (in rats), referred to above, it was found that the bearing and suckling of young resulted in a very appreciable lowering of the mother's store of calcium and phosphorus. This was true even when the mother was supplied with a diet rich enough in calcium and phosphorus to meet all requirements of even the most rapid periods of growth. This is also true in farm animals. When these requirements are not covered by the intake, in the form of an added supplement, the deficit must be covered by drafts upon the mineral stored in the body. Most of this comes from the bones. He quotes Meltzer as saying,

> "Calcium is capable of correcting the disturbances of the inorganic equilibrium in the animal body, whatever the direction the deviation from the normal may be. Any abnormal effect which sodium, potassium or magnesium may produce, whether the abnormality be in the direction of increased irritability or of decreased irritability, calcium is capable of reestablishing the normal equilibrium."

Davidson,[12] recognizing calcium as an important constituent in the development of the embryo, investigated the effect of a calcium deficiency in rations of breeding sows.

Three lots were fed the following rations respectively:

Lot I - Control
Lot II- Protein deficient ration
Lot III-Calcium deficient ration

The rations consisted of:

	Control (Parts)	Protein Deficient (Parts)	Ca. Deficient (Parts)
Barley Meal	188	188	188
Maize Meal	188	188	188
Bean Meal	16	16	16
Blood Meal	28	--	28
Ground Limestone	7	7	--
Salt	2	2	2
Mineral Mixture	--	1.0555	--

All groups received the following per head per day: Cod liver oil - ¼ ounce; Fresh Orange pulp:

Pigs weighing 40# - 20 cc.
40-200# - 100 cc.
Sows - 150 cc.

The following table shows the calcium requirements for pigs gaining 1# weight per day, with the amounts of these constituents supplied in the experimental rations.

CALCIUM REQUIREMENTS, AND AMOUNTS SUPPLIED IN EXPERIMENTAL RATIONS, FOR PIGS GAINING ONE POUND WEIGHT PER DAY

Table V

Live Wt. (lbs)	50	100	150	200	250	300	350 & over
Lbs. Meal Fed Per Head Daily	3.0	4.5	5.25	5.5	6.0	6.25	6.75
Calcium Supplied as CaO Requirement	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Control	0.024	0.036	0.042	0.044	0.048	0.050	0.054
Protein Deficient	0.024	0.036	0.042	0.044	0.048	0.050	0.054
Calcium Deficient	0.002	0.002	0.003	0.003	0.003	0.003	0.003

Each of the original gilts was served by the same boar. Four out of the six head in each group were slaughtered when they were three months in pig. The remaining two gilts were allowed to farrow and an additional group of six was selected from these gilts. They were fed the same ration, served, four were slaughtered when three months in pig, and two were allowed to farrow as before.

When the plan was fully developed there should have always been four sows, six store gilts and six gilt pigs in each group.

Investigation of the calcium deficient group during the experiment indicates the following:

(1) The failure of the milk supply became more acute with each generation.

(2) Sows failed to develop a normal udder at farrowing time.

(3) The pigs appeared underfed and the average weight at weaning time became less with each generation.

In later stages of the experiment the pigs died within two days following birth, probably from complete lack of milk. Several in the calcium deficient group died from rachitic conditions, became crippled, took peritonitis or came down with a broken spine or thigh bones.

When the investigation ended in 1928 the control group had bred regularily twice a year and had reached the first litter of the third generation at two and one half years. At the close there were two sows, two gilts in pig, five store gilts and five young gilts, with a total of fourteen gilts instead of sixteen.

The calcium deficient group had only reached the third litter of the second generation at the end of three years and there were only two sows in pig, and two gilts for service. The rest had died or had been slaughtered on account of acute and painful leg and spine trouble.

In a summary Davidson concludes that a ration deficient in calcium does not produce an immediate effect upon breeding sows due to their ability to store lime in the body. Definite evidence was obtained that a calcium deficient diet leads to a considerable increase in still born pigs. Combining: failure of sows to milk, pigs born dead, and fatal accident, it is evident that a group of pigs fed solely on this ration will eventually be exterminated.

Evans[13] extended the work of Davidson and studied the conditions affecting the fecundity of swine by variations in the calcium content of the ration. Two groups of gilts were used; one being placed on a low calcium diet and one on a high calcium ration. They were bred and allowed to farrow several litters. In the group fed a ration high in calcium the advancement of gestation was accompanied by a decrease in the amount of lime retained.

The balance results from the calcium deficient sows showed that they had attained lime equilibrium on an intake of less than 2 grams of Ca O per day. This is evidence supporting the fact that lime from the bones of the mother is used for the development of the foetus. The sows of the calcium deficient group had insufficient milk and showed a definite condition of anaemia when they farrowed.

According to Fraser,[19] rations which formerly seemed adequate, because the rate of growth and feed requirements in the semi-wild state were of minor importance, now require special supplementation in order to procure optimum gains under the present, rather artificial conditions.

Calcium occupies a prominent place and is needed in greater amounts under the present system of handling livestock. Calcium is necessary for the coagulation of blood and the automaticity of the heart is partially dependent upon the presence of calcium in the blood stream. Fraser indicates three periods in an animal's life as being times when an especially generous supply is essential.

(1) Period of growth - during this period calcium is necessary for the building of bone and tissue.

(2) Period of pregnancy - if a greater supply is not given, too great an amount of stored calcium will be taken from the bones of the mother to meet the great demand for the formation of bone in the foetus.

(3) Period of lactation - milk is relatively high in calcium for the purpose of supplying the growing young. A deficiency in the mother's ration will result in a necessary withdrawal of too much calcium from her skeleton.

As a result of experiments with swine he concluded that all calcium compounds fed, including limestone with a high calcium carbonate content, calcium sulfate, bone derived and bone meal promote better growth in fall pigs than rations containing none of the above mentioned substances.

GENERAL HEALTH AND UTILIZATION OF FEED

Orr[25] states that the condition of malnutrition due to disordered mineral metabolism occurs most readily in animals growing the fastest. An excess or deficiency of one mineral element may not, only interfere with the absorption but with the utilization of the other.

Because of their physical or physico-chemical properties, the mineral salts play an important part in the vital processes of the animal cell, according to Forbes[16]. Certain chemical reactions in the body constitute the physical basis of life. These take place between substances in solution and it is by means of the electrical charges carried by the particles in solution that reactions are brought about. An enormous increase in the power to conduct electrical currents can be brought about by very small amounts of the mineral salts, acids or alkalies in water. Orr gives the uses of calcium and phosphorus as follows:

(1) Calcium and phosphorus are used in the formation of essential structures in the body.

(2) The control of both voluntary and involuntary muscles is accomplished through the proportion of calcium, magnesium, sodium and potassium salts acting upon them.

(3) The salts in foodstuffs act as laxatives and also effect the action of secreting glands; they also assist in the preservation of normal physical conditions within the cells by regulating their distention by liquids. Gordon, Hart and Patten, of the New York Station, are quoted as say-

ing that wheat bran, freed of mineral constituents is constipating.

(4) Calcium is essential to blood coagulation.

(5) Phosphorus, which has an essential connection with many of the body structures and processes, exists in the body in many compounds belonging to at least four groups:

1. Inorganic phosphates existing in solution in body fluids and in solid substances in the bones.
2. Lecithins-found in all plant and animal cells.
3. Phospho-proteins and-
4. Nucleo-proteins-both being constant cell components.

(6) Phosphorus then is necessary to supply inorganic phosphorus.

(7) Smaller amounts are needed to support the muscles, nervous tissue, gland cells, milk, and reproductive substances.

A metabolism experiment, conducted by Forbes, Beegle, Fritz and Mensching,[17] involving eight, ten day collection periods, separated by seven day intervals yielded some interesting data. Five pigs from the same litter were used. Corn alone was fed in periods I and VII; corn supplemented with soy beans, linseed oil meal and wheat middlings in periods II, III and IV and a ration of rice polish and wheat bran in period VIII. During periods V and VI the pigs were fed skim-milk and meat meal. These feeds supply calcium. During these periods they stored 9 to 10 times as much calcium as during any of the other periods.

Evans,[14] found that sows fed a diet deficient in calcium suffer periodically from loss of appetite and refuse to clean up food as well as sows on a ration containing a sufficient amount of calcium.

For some time the presence of kidney worms had been thought to cause paralysis in pigs. In an attempt to learn the true cause, Bohstedt, Bethke, Edgington and Robison,[8] conducted four experiments involving the addition of minerals and vitamins to a ration. Some interesting data were also obtained as to gain and utilization of feed.

A total of 56 pigs were used in the experiments and were fed an average of 156 days. An average of four experiments in which a comparison of the results obtained from feeding a grain mixture alone and a grain mixture supplemented with ground limestone brought the following results:

RESULTS OF FEEDING GRAIN MIXTURES ALONE AND GRAIN MIXTURES SUPPLEMENTED WITH GROUND LIMESTONE

Table VI

RATION	Avg. daily gain	Feed required per 100# gain	Mortality	Strength of thigh bone
	Lbs.	Lbs.	No.	Lbs.
Grain Mixture	0.66	548	9	447
Grain Mixture Ground Limestone	1.00	454	1	1041

The addition of two pounds of limestone to every 100# of grain mixture enabled the pigs to gain 0.34# more daily, to save 94# of feed for every 100# increase in liveweight and to escape severe stiffness or paralysis as well as lameness.

An average of four experiments in which both minerals and vitamins were added to the grain mixture showed results as follows:

RESULTS FROM ADDING MINERALS AND VITAMINS TO GRAIN MIXTURE

Table VII

RATION	Avg. daily gain	Feed required per 100# gain	Mortality	Lameness stiffness and paralysis	Strength of thigh bone
	Lbs.	Lbs.	No.	No.	Lbs.
Grain Mixture	0.41	688	10	3	201
Grain Mixture Ground limestone or Calcium carbonate Cod Liver Oil	0.98	422	0	0	619

The addition of limestone, or calcium carbonate, and cod liver oil to the grain mixture enabled the pigs to gain 0.57# more daily, to save 266# of feed for every 100# increase in Weight and to escape lameness or stiffness.

Forbes, Halverson, Morgan and Schulz[18] made investigation of the metabolism of swine on cereal rations as affected by the addition of the following supplements: (1) pulverized limestone, (2) precipitated bone flour, (3) raw rock phosphate floats, (4) "special" steamed bone flour, (5) precipitated calcium carbonate.

Some of the prominent characteristics of the metabolism of swine on a ration of corn, linseed oil meal and wheat middlings (with common salt) were loss of calcium, and sub-normal retention of magnesium and phosphorus.

An increased intake of precipitated carbonate or pulverized limestone caused a very noticeable increase in calcium, magnesium and phosphorus retention. Pulverized limestone, precipitated bone flour, and steamed bone meal were equally efficient in this respect. Phosphorus retention was increased by all of the calcium supplements. The digestibility of the ration was not affected by the addition of any of these supplementary minerals.

Robison,[26] found minerals to be beneficial with corn and soybeans or corn and soybean oil meal for pigs both in dry lot and on rape pasture. In one of the soybean trials on forage, the addition of limestone resulted in 7% faster gains and each pound fed saved 3.5 pounds of corn and 0.5 pound of soybeans. In the other there was practically no difference in the gains but 7.6 pounds of corn were saved by each pound of limestone and bonemeal fed.

What applies to supplements of plant origin may not apply to tankage and similar protein feeds. These are not only high in ash or minerals but also high in protein, and so make up a smaller percentage of the ration.

Three experiments were used: Two on clover and one on rape pasture, in which a mineral mixture was fed, both with corn alone and with corn and tankage.

In one trial the minerals consisted of salt, 19.37; limestone, 38.8; anhydrous copper sulfate, 0.2; and potassium iodide, 0.03. In the others a similar mixture was fed except that it contained 5% of Glauber's salts and no copper sulfate. In each trial by mixing the minerals, or the tankage and minerals with ground corn, the pigs were forced to take the various feeds in definite proportions. Minerals constituted 2.5% of the ration when fed with corn alone. When fed with tankage they made up 2.5% of the total feed in one trial and 1.5% in the others. Since older pigs need less protein than younger ones, the percentage of tankage was reduced when an average weight of 120-125 pounds was reached. The pigs were hand-fed in one and self-fed in two of the experiments. When added to corn alone, each pound of mineral fed, exclusive of the salt, saved 5.9 pounds of corn. When added to corn and tankage, each pound of mineral fed, exclusive of the salt, saved 2.6 pounds of corn and 0.4 pound of tankage.

According to Becker,[4] calcium, phosphorus and magnesium are found primarily in the skeleton. Relatively small decreases in the ionic calcium available in the blood have marked effects upon nervous response. Milk fever is caused by a sudden depression in available calcium in the blood. A shortage of phosphorus, which is contained in every cell in the body, does not affect the digestibility of a given ration, but does affect utiliza- of the nutrients after they are digested. Prolonged deficiency of phosphorus in the ration delays oestrum and affects the composition of the bones.

In an effort to determine the value of finely powdered gypsum in comparison to powdered limestone as a source of calcium, McCampbell and Aubel[22] fed 4 groups of pigs for 112 days. All pigs were fed individually and each pig was fed the same basal ration. This basal ration consisted of 0.6 pound of linseed oil meal daily, 1 pound of wheat shorts daily and shelled corn equal to the amount the least consuming pig would eat. This corn consumption averaged 2.52 pounds per head daily. Each pig also received one table-spoonful of cod liver oil daily.

Two pens were fed limestone in the same proportion the other two pens were fed gypsum. Analysis showed 38.34% calcium in the limestone and 23.54% in the gypsum. Data relative to chemical analysis of the bones were destroyed in a fire. The average daily gain per pig for the limestone groups was 1.0075 pounds; for the gypsum groups 0.9975 pound.

The comparison indicates the possibility of using calcium sulfate in the form of finely powdered gypsum as a source of calcium in swine rations. Adding about 1.5# of ground limestone or the combination of 1# of limestone and 1# of steamed bone meal to 100# of grain mixture brought about the favorable proportion.

Forbes[15] states that if corn alone is to be used as the principal food for animals, the greatest success can be hoped for only by feeding with the corn, supplements that are richer in protein, calcium and phosphorus. He found that swine fed corn alone produced small, weak bones, and that their digestive organs were so poorly developed and small as to be out of proportion to the rest of their body.

Grain rations that are balanced with soybean oil meal and used for pigs, have interested nutrition workers for a number of years. Some very interesting results have been secured at the Ohio Experiment Station by Bohstedt, Fargo and King,[9] where the question of favorable levels of calcium and phosphorus has been under scrutiny.

It seemed desirable to extend this inquiry to find out whether pigs fed practical rations under conditions of abundant and limited sunlight, both in dry lot and on pasture, might not indicate varying optimum levels and proportions of calcium and phosphorus in their rations. This investigation was also made to include grain rations that were balanced with the combination of linseed meal and wheat middlings which are richer in phosphorus than is soybean oil meal.

The very practical question was also asked in this set-up whether pigs fed strictly grain or cereal rations, where homegrown grain was supplemented with soybean oil meal or with linseed meal and wheat middlings, would consume enough ground limestone, when access was given in separate mineral boxes.

To four dry-lot rations of corn, soybean oil meal, ground alfalfa hay and iodized salt, were added 1.25, 1.50, 1.75, and 2.00 percent, respectively, of ground limestone having a calcium content of 38.5 per cent. This resulted in a Ca:P ratio of 1.9, 2.2, 2.6 and 2.9. The average daily gains in weight of the four lots were 1.20, 1.20, 1.15, and 1.11 pounds, the feed requirement per 100 pounds gain, 401, 406, 411, and 422 pounds, and the ash content of the second rib of the pigs was 54, 55, 54, and 55 per cent, respectively.

Thus it appears that the smallest addition, 1.25 per cent of ground limestone, which gave the lowest Ca:P ratio of the lot, gave as good gains, feed economy, and nearly as good calcification of bones as any of the others.

The addition of 1.5 per cent steamed bone meal, resulting in a Ca:P ratio of 1:1.1, brought about the largest gain, 1.31 pounds daily per pig, the best feed economy, 380 pounds, and the rather high ash content of 59 per cent. Adding 1.5 per cent of a mixture of equal parts ground limestone and steamed bone meal, resulting in a Ca:P ratio of 1:5.1, did not, in this case, do quite as well, for the average daily gain of the pigs so fed was 1.22 pounds, with a feed economy of 404 pounds, and an ash content of ribs of 60 per cent. However, this mixture compared favorably in rate of gain and economy with the 1.5 per cent of limestone alone and produced a higher ash content. Of particular interest is the fact that bone meal gave a higher ash content of ribs although the calcium content of the ration was lower than in most of the rations containing ground limestone.

The gains and economy of gains of pigs who had an opportunity of eating ground limestone, or both ground limestone and bone meal, free choice, compared favorably with those of the pigs fed definite amounts of the minerals in their rations.

In an experiment, similar in all respects to the first except that the pigs were on rape pasture instead of in a dry lot, it appeared that the pigs were fully as responsive to the differences in mineral supplementations as were the pigs in the dry lots. As in the dry lot experiment the pigs receiving the smallest amount of limestone made the most rapid and economical gain. Furthermore, the highest ash content was obtained by the pigs that received bone meal additions.

A third experiment was conducted using linseed meal and wheat middlings as protein supplements to corn in dry lot rations. These two protein concentrates are considerably higher in phosphorus than is soybean oil meal. Minerals were supplied the same as in the two previous soybean oil experiments.

These data show that smaller amounts of ground limestone than 2.0% may be preferable. The 1.5 per cent bone meal addition resulted in the largest and most economical gains, also in a high ash content of bones.

In a review of these experiments, Bohstedt, Fargo and King state that less than 2.0 per cent of high calcium limestone gave the best results where limestone was the only mineral addition outside of salt. A Ca:P ratio of less than 2:1 proved better than where the calcium level exceeded that proportion.

Bone meal additions were beneficial in all cases.

Pigs self-fed corn, ground alfalfa hay and salt, apparently ate sufficient amounts of either ground limestone or ground limestone and bone meal, when they had free access to these minerals.

DISCUSSION

A lack of sufficient calcium and phosphorus in the ration can be the cause of varied diseases and physiological disturbances in swine.

Calcium is most likely to be deficient and rickets and osteoporosis are diseases resulting from this deficiency. The presence of these bone softening diseases is manifested by lameness, stiffness, paralysis of the hind quarters, pain at being touched, disinclination to move, wrinkly skin and rough, stary coat of hair.

Breeding sows fed a ration deficient in calcium are poor milkers. They fail to develop a normal udder at farrowing time and their pigs appear underfed and below average weight at weaning time.

Milk fever is caused by a sudden depression in available calcium.

A shortage of calcium has an adverse effect upon the control of voluntary and involuntary muscles.

Vitamin D is essential for calcium absorption and vitamin C seems to be necessary for its proper utilization.

Phosphorus is also essential for proper bone formation and for the proper development of muscles.

A shortage of phosphorus has an adverse effect upon nervous responses.

A prolonged deficiency of phosphorus delays oestrum.

Calcium and phosphorus in foodstuffs act as laxatives and affect the action of secreting glands.

A deficiency of either of these two minerals appears to lessen the rate of gain and to interfere with the proper utilization of feed.

Since a lack of either calcium or phosphorus or both has a rather pronounced effect upon the physiological processes of swine, this may be the thing that is responsible for a number of the so called "poor doers" among pigs. The supply of these minerals may be sufficient to prevent any outward manifestations but still the pigs gain very slowly on account of the limited supply. Some pigs may be able to assimilate these minerals to a better advantage than others because of individual differences or because of variations in the vitamin supply in the ration.

Calcium can be added to cereal rations with ground limestone, ground oyster shell or hard wood ashes. Finely powdered gypsum is also a possible source.

Phosphorus can be supplied in the form of bone meal or mono-calcium phosphate.

Protein supplements, derived from plants, will not provide these minerals in sufficient quantities. However, tankage and skim-milk, protein supplements derived from animals, are good sources of these minerals.

The desirable level of calcium can be placed at from .64 to 1.5 per cent of the ration and the phosphorus level at from .30 to .51 per cent.

None of the literature studied listed harmful results from feeding an excess of calcium and phosphorus as long as they were in a ratio of slightly less than two parts of calcium to one part of phosphorus and providing there was plenty of vitamin D present in the ration.

Since these mineral supplements are inexpensive, it seems that the producer should make certain a sufficient amount of these minerals are included in the swine ration.

SUMMARY

This study, which is a review of literature and experimental results, attempts to evaluate the importance of calcium and phosphorus in swine rations.

Special significance is attached to their function in regard to general health, utilization of feed, bone structure, breeding and lactation periods.

Cereal grains contain little calcium and phosphorus. Since swine are largely fed on such concentrates their rations are frequently low in calcium and phosphorus and must be supplemented with these minerals.

In all cases the addition of such a mineral mixture brought about the following: (1) Better calcification of bones, (2) More rapid and economical gains, (3) A liberal supply of milk during lactation, (4) Better general health.

These experimental results place the desirable level of calcium at from .64 to 1.5 per cent of the ration, and the phosphorus level at from .30 to .51 per cent.

The more favorable results were obtained when the Ca:P ratio was slightly less than 2:1.

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