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PHOSPHORUS REQUIREMENTS IN THE RATION OF GROWING PIGS

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PHOSPHORUS REQUIREMENTS IN THE RATION OF GROWING PIGS

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STATEMENT OF PROBLEM

It has long been known that farm animals require minerals in their rations if they are to grow and have normal body development. It was believed quite generally, however, until recently, that any ration composed of ordinary farm feeds which supplied adequate amounts of proteins, carbohydrates, and fat to meet the requirements of the growing animal, would also meet the necessary mineral requirements of a normal healthy animal. As a result, workers in the mineral field have not devoted much time to determining the minimum amount of any specific mineral that an animal might require for normal growth. They have, however, devoted much effort to the study of mineral deficiency diseases.

Of the mineral elements determined to be necessary for farm animals, phosphorus is one of the most prominent because it enters deeply into nearly all the vital activities of the body. The body cells are rich in this mineral, for it is built into the nucleoproteins which constitute the nucleus. As an integral part of the phospholipins, phosphorus has much to do in maintaining a satisfactory functioning of the nerves; in fact, so closely is it allied with the nervous system that it has been referred to as the "brain building" material. Forming complexes with the carbohydrates it exerts an important influence on oxidation. As phosphocreatine, it serves as the storage battery of the muscle. In fact, phosphorus is intimately associated with numerous other physiological reactions which are important to the successful functioning of the body.

Phosphorus cannot be studied, however, without at the same time considering its relation to calcium. With calcium it combines in the building of the bones and teeth. The ions of these minerals form colloidal complexes and insoluble salts in neutral and alkaline solutions. Some of the phosphates thus formed help to maintain the slight alkalinity of the blood essential to its normal functioning. The close association of phosphorus with calcium also is shown by the fact that if there is a large excess of calcium in the body, it tends to depress the utilization of phosphorus.

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1. Contribution No. 115 from the Department of Animal Husbandry, No. 186 from the department of Chemistry, and No. 61 from the Department of Veterinary Medicine.

2. The material in this bulletin, with the exception of that pertaining to Experiment III, was presented by C. E. Aubel in partial fulfillment of the requirements for the degree of doctor of philosophy, University of Minnesota, 1935. He is indebted to Prof. W. H. Peters and to Dr. L. S. Palmer of the University of Minnesota for suggesting the problem and for their helpful criticism and suggestions in planning the investigation. He is also indebted to Dr. C. W. McCampbell and Profs. D. L. Mackintosh and W. E. Connell for aid during the progress of the experiments in handling and slaughtering the animals. To Prof. J. F. Merrill he is indebted for the chemical analyses of the feeds and bones, and to R. R. Roepke for the chemical analyses of the blood.

Phosphorus is also closely associated with vitamin D, a dietary factor that controls directly or through the parathyroid gland the concentration of the calcium and phosphorus ions in the blood. This influence is extremely important in that it aids in the assimilation of these minerals, and at the same time maintains an adequate and properly balanced supply of them. The ultra-violet rays, when animals are exposed to them, also have the power to help with this assimilation through the production of vitamin D.

It would seem, therefore, that phosphorus in the diet of farm animals must be available in some definite amount to satisfy these various activities. As a result, the rations of animals must be considered carefully and care must be taken to supply the necessary phosphorus. It is difficult to compile such a ration for some animals, especially those which derive much of their sustenance from forages and grains grown on soils deficient in phosphorus. Each year the soils of increasingly greater areas of the country are reported to be deficient in phosphorus. Actually, many of these soils are so deficient in phosphorus that the feeds grown thereon will not support normal growth and development when fed alone to animals. In fact, grave deficiency diseases arise, which often result in death, when only phosphorus-deficient feeds are available.

Because the animal has need of phosphorus and other minerals, and because of the lack of them in the feeds grown on deficient soils, recently workers in the field of animal nutrition have been recommending mineral mixtures to supplement the feeding ration for all classes of livestock where a possibility of a phosphorus deficiency exists. The mixtures that are recommended differ widely, but are all similar in that they provide for a large percentage of phosphorus. Since this mineral generally is the most expensive one in the mixture, it is of economic importance to incorporate in such a supplementary mineral feed only as much phosphorus as is necessary for the normal functioning of the animal body, and not to increase the cost of the mineral mixture by supplying a surplus of phosphorus.

With these points in mind, it seems important that a study be made of the specific minimum requirements of phosphorus for growing swine, since swine are subject quite as much as any animal to the increasing general recommendations being made for feeding mineral mixtures.

In order to find an answer to the exact requirements of phosphorus needed for the body activities in growing swine as supplied through the daily ration, the following specific questions may be raised:

1. What effect will deficient amounts of phosphorus in the ration have on the development of growing pigs?

2. What is the least amount of phosphorus in the daily diet of growing pigs that is necessary to support efficient feed utilization, normal growth of the body, and normal development, and composition of the blood and bone?

It was with the hope of throwing some light on these questions that the present investigation was undertaken. The study was not an attempt in any sense to consider the calcium-phosphorus ratio of the ration or its relation to vitamin D, for the amount of calcium was kept constant and a uniform supply of vitamin D was provided by giving cod-liver oil.

REVIEW OF LITERATURE

THE PHOSPHORUS PROBLEM IN THE NUTRITION OF ANIMALS

In reviewing the literature no attempt will be made to compile a complete list of the papers in which the question of phosphorus in rations of animals is reported. Such a list would be most extensive and would consist of many hundreds of references, a considerable number of which would have no bearing upon this investigation whatever, because they would involve problems considering phosphorus as an incidental issue only.

In this review of literature, it is of interest to note, however, that the deposition of phosphorus in the animal body has been a field of study for many years. As early as 1842 Chossat *(15)* studied the effect upon animals of rations low in minerals. At first he used pigeons in his investigations, but later included chickens, rabbits, and other animals *(16)*. Among other early investigators were: Boussingault *(11),* who in 1856 observed the effects of rations low in minerals upon the growth of the skeleton of pigs; Weiske and Wildt *(68)*, 1873, who used goats and lambs; Forster, *(50),* 1873, who employed pigeons, and later, dogs; Voit *(66),* 1880, who also used pigeons and dogs; and Aron and Sebauer *(3),* 1908, who worked upon rabbits and dogs. These workers demonstrated the necessity of minerals in the diet. They were not concerned specifically with low-phosphorus rations, rather they considered the mineral problem as a whole, although in the main, the rations they employed were deficient in calcium and phosphorus.

Following these early investigations, it was not long until attention was focused upon the effect of specific minerals in the ration. Even as early as 1873 Hofmeister *(41),* experimenting with lambs and low-phosphorus rations, noted an increase in phosphorus in the bones when he added precipitated bone phosphates to the basal ration. This work was followed by Henry *(38, 39)* in 1889-1890, who also demonstrated the favorable effect upon the bones of young pigs fed corn when the ration was supplemented with bone meal. Arnstadt *(2)* in 1893, also discusses the effect on the bones of cattle and other farm animals caused by a lack of phosphorus in the ration. Finally, Burnett, *(12, 13, 14)* in 1906 to 1910, showed more plainly than any of the earlier workers the fact that the mineral content of the bones of pigs may be modified in accordance with the composition of the ration. He fed as supplements to natural feeds, in order to demonstrate this, ingredients rich in phosphorus, such as bone meal and disodium phosphate.

Thus early investigators, while working with the mineral problem as a whole, had their attention immediately drawn to the importance of phosphorus in the ration as a specific problem. Since these early publications, many papers have appeared dealing in some manner or other with the effect of phosphorus in the rations of animals. It is interesting to observe that among these papers are reported ill effects of incorrect phosphorus feeding among many species.

Sherman and Pappenheimer *(60)* and McCollum and co-workers *(52)* have shown that rickets in rats can be produced by feeding rations low in phosphorus. Osborne and Mendel *(55)* have shown that the rat will not mature unless given sufficient minerals. Blum *(9)* has shown that when the amounts of phosphoric acid fed were below the minimum, the growth of the body and the bone development of the rat were below normal. Thus the rat suffers from a low-phosphorus ration.

Elliott *(23)* reported outbreaks of osteoporosis among horses in Hawaii. Singularly in horses, however, an excess of phosphorus in the diet brings about an injurious condition, as when bran is fed too liberally. This is known as Miller's disease or "bran disease." Law *(47)* refers to this disease as "a curious form of rickets." These reports indicate the need for a correct balance of phosphorus in the ration among horses.

Miles and Feng *(53)* indicate that osteomalacia is not confined to animals alone, but is common among women in northeastern China. They consider the cause to be a deficiency of calcium and phosphorus in the diet. Malan, Green, and DuToit *(48)* also report the same disease in the human.

In chickens, a condition known as "leg weakness" occurs when the ration lacks sufficient minerals. Hart, Halpin, and Steenbock *(35)* and Hughes and Titus *(45)* describe this as a form of rickets. Payne, Hughes, and Lienhardt *(57)* and Sherwood *(61)* refer to a "slipped tendon" condition in chicks when an excess of phosphorus is supplied in the ration. These reports indicate that the fowl is susceptible to different amounts of phosphorus in the diet. The requirements of phosphorus in the ration OF young chickens have been determined by Sherwood *(61)* to be between 0.65 and 0.87 percent.

Other workers report effects of low-phosphorus rations in dogs, goats, and rabbits. With the latter, however, the necessity for phosphorus is more difficult to demonstrate. In fact, Gilruth *(31)*, reporting on observations made in Australia, states that a deficiency of phosphorus in the feed is not so vital to rabbits running wild over the range as it is to breeding cattle and sheep. It would seem from this that rabbits apparently have a lower phosphorus requirement or else utilize phosphorus in their feed to better advantage. Gilruth also indicates that horses are similar to rabbits in this respect, which might explain the prevalence of Miller's disease.

There is a more extensive literature concerned with the subject of phosphorus feeding in ruminants than in any other class of livestock. The reason for this undoubtedly lies in the fact that attention is most readily drawn to them because they respond definitely to low-phosphorus rations. Ruminants often derive their entire sustenance from low-phosphorus feeds when they graze on pasture or eat dry forage which is grown on areas where the soil is deficient in this mineral. As a result a deficiency is readily manifested.

Sheep, as ruminants, have shown the effect of low-phosphorus rations. Du Toit, Malan, and Groenewald *(19)* show in this species that a low-phosphorus ration causes loss of appetite, inability to gain in weight, and a low inorganic phosphorus content of the blood. Bekker and Rossouw *(4)* show that in certain districts in South Africa sheep do not get enough phosphorus for physiological requirements and suffer from aphosphorosis.

But without doubt the most research on the subject of feeding low-phosphorus rations has been with cattle. No attempt will be made here to review the many references concerning it. This has been made available in three excellent reviews—one by Eckles, Becker, and Palmer *(20)*, and two others more recently by Theiler and Green *(64)* and by Eckles, Gullickson, and Palmer *(22)*.

It is well, however, to note that, with cattle, important contributions have been made in connection with several distinct phases of low-phosphorus feeding.

The first phase to be observed, and to which the bulk of the material on phosphorus feeding relates, has to do with the symptoms and causes of the deficiency diseases. Henry *(37)* describes the typical symptoms observed in cattle in Australia; namely: stiffness in the hindquarters, swelling of the joints, harsh, dry coat, dull eyes, unthrifty appearance, perverted appetite, and easily-broken leg and rib bones. Welch *(69)* has given a description of the symptoms of this disorder which he has observed in Montana. He emphasized the bone chewing and a craving for something not in the feed. Eckles, Becker, and Palmer *(20)* also describe this symptom as observed in cattle in Minnesota.

Although it has been recognized for a long time that normal cattle could not be grown on the veldt of the Union of South Africa and other regions, it was not until rather recently that light has been shed on the cause for this abnormal animal growth. Theiler, Green, and Du Toit *(65)* definitely established the significance of phosphorus in the rations of these cattle; while Eckles, Becker, and Palmer *(20)*, working independently in investigations practically paralleling those in South Africa, determined that a phosphorus deficiency was the cause of the nutritional disorder giving trouble in Minnesota. In late years the symptoms described and their connection with low-phosphorus rations have been established and reported from many areas in the United States.

A second important phase in cattle that has received much attention has been the utilization of feeds by animals suffering from a phosphorus deficiency. Theiler and Green *(64)* and Theiler and associates *(65)* concluded that phosphorus had much to do with growth and food consumption. They observed a marked increase in the rate of growth and fattening ability in South African range cattle when bone meal was added to phosphorus-deficient rations. In one experiment, the controls increased 21 percent in weight during a certain period, while the experimental group receiving bone meal as a supplementary feed gained 42 percent. This would indicate a need for phosphorus beyond that required for bone development. In fact Theiler *(63)* says, "Cattle on a phosphorus-deficient diet do not utilize their feed economically. Even if they eat a lot they waste it and do not give a profitable return in live weight for it." In a carefully controlled study of the feed requirements for dairy cows, Eckles and Gullickson *(21)* found that dairy cattle receiving a low-phosphorus ration actually lost weight. This loss occurred even though a sufficient amount of the feed was consumed to produce a gain if it had been properly supplemented with phosphorus.

A third phase important in the studies of low-phosphorus feeding in cattle has been that relating to digestion and metabolism. Riddell, Hughes, and Fitch *(58)* have come to the conclusion that a phosphorus deficiency does not depress the digestive functions of the lactating dairy cow. They were unable to demonstrate abnormal losses of energy between the feed consumed and the excreta in phosphorus-deficient animals. This shows that poor utilization of feed is not due to low digestion or loss through incomplete metabolism. They suggest that the poor utilization of feed is due to an increased rate of metabolism.

These phases are briefly indicated herewith in order to demonstrate the trend of investigations in low-phosphorus feeding. They also have considerable bearing on the questions involved in this investigation; for, should swine, feeding upon low-phosphorus rations, exhibit abnormal symptoms of disease, as evidenced in their behavior and abnormal food utilization, it could be interpreted that the ration therefore had not sufficient phosphorus to satisfy the requirements for normal functioning of the body.

THE PHOSPHORUS PROBLEM IN SWINE FEEDING

A review of the literature of the problem of phosphorus feeding in swine discloses little difference from that portrayed in the literature for the other animals, unless it be said that the research as yet has not been so extensive, especially as to have delved so far into metabolism and digestion. It is similar, however, in that the initial conception of the problem in swine feeding is shown also to have begun with a study of the mineral problem as a whole, followed closely by a recognition of the specific problem of phosphorus.

The first work to be done with swine on the mineral problem is that of Boussingault *(11),* who in 1846 investigated the effects of feeds low in minerals on the growth of the skeleton of pigs. The specific phosphorus problem in swine nutrition was initiated by Henry *(38, 39)* who some years later, 1889 and 1890, working with the mineral problem, added bone meal to the ration of corn-fed pigs, and reported an increase in the ash content and the strength of the bones.

The work of Henry was soon followed by a series of experiments by Burnett *(12, 13, and 14),* 1906 to 1910, who showed that the mineral content and the breaking strength of the bones of the pig could be modified according to the composition of the ration. The strongest bones were produced when bone meal was added, while the next strongest bones were formed in the tankage-fed lots. Both supplements were rich in phosphorus and calcium. Alway and Hadlock *(2)*, feeding bone meal with a corn-alone ration, were able to increase the strength of the bones, but were unable to demonstrate a great difference in the relative proportions of the mineral matter therein.

Bohstedt and associates *(10)*, in a series of experiments designed to study the mineral and vitamin requirements of pigs, also showed that the bones of the pig varied in condition and composition of minerals with the kind of feed and different amounts of phosphorus that were fed in the ration.

Changes in the composition of the body other than the bones were indicated by experiments of others. Hart, McCollum, and Fuller *(34)* in a study of the blood of pigs fed different amounts and kinds of phosphorus compounds, showed a varying phosphorus content of the blood ranging from 0.24 to 0.33 percent phosphorus in the air-dry matter. They observed, also, a loss of control in the hindquarters of the pigs feeding on a low-phosphorus diet. Forbes and associates *(27)* and Bohstedt and associates *(10)* also found that the phosphorus of the blood varied markedly in accord with the character of the ration. In another series of experiments Forbes *(25, 26)* demonstrates the susceptibility of other parts of the body of the pig to changes of composition in water, protein, fat, ash, and phosphorus, as a result of the kind of feed used. He shows this change in the muscles, liver, and kidney, as well as the bones.

Similar results confirming the marked improvement in the condition of the bones, blood, and tissues of swine through the simple addition of bone meal or other phosphorus-containing supplement, have been reported in the literature from this country and elsewhere, but enough is presented here to indicate its bearing upon the scope of this investigation, since changes in the blood and character of the bones are used to demonstrate the insufficiency of phosphorus in the ration of the pigs.

THE REQUIREMENTS OF PHOSPHORUS

After the mineral problem in general and the specific influence of phosphorus in the ration had been once recognized, it was but natural that workers in the field of swine nutrition should turn to problems involving the actual requirements of phosphorus in the ration.

Kellner *(46)* was the first to contribute to this phase of the subject. He computed from the composition of a year's growth of a pig that the daily requirement is 12 grams each of lime and phosphoric acid. In arriving at this amount Kellner allows three times as much in the ration as the animal will store in the body. Hart, McCollum, and Fuller *(34)*, feeding rations containing only 0.112 percent of phosphorus, estimated that the daily phosphorus supply for a 50-pound pig should be at least 3 grams, and that a supply of 4 to 5 grams would be a safer quantity. Forbes and Keith *(29)* conclude from the experiments of Hart and associates *(34)* and from the experiments of Forbes and associates *(27)*, who fed rations containing 0.092 and 0.098 percent of phosphorus, that it was impossible to keep pigs alive indefinitely on rations so poor in this mineral. They recognized, however, that the rations they considered in drawing this conclusion were low in calcium. At any rate, a low minimum level of phosphorus in a ration is indicated from these computations.

As very little was known of vitamins at this time, the low-phosphorus basal ration of Forbes and associates, consisting of pearl hominy, blood albumin, wheat gluten, and corn bran, would seem to have been deficient in some of these essential elements also.

More specific evidence bearing on the requirements of phosphorus in the ration is limited; although Schittenhelm *(59)*, in the course of his investigations of nuclein metabolism in swine, conducted balance experiments which indicated phosphorus requirements. The intake of phosphoric acid per kilogram of body weight was 0.2 gram, which permitted a daily gain in body weight of 413 grams and a large storage of phosphorus.

Weiser *(67)* also indicated phosphorus requirements from balance experiments. On rations of corn alone he got negative balances on intakes of 0.057, 0.05, and 0.49 gram of phosphorus per kilogram of live weight, but by the addition of calcium carbonate the balance was changed to a positive one. Thus it seems that the cereal foods, at least the corn and barley which he used, contain sufficient phosphorus if enough calcium is supplied. Experiments of Forbes, Beegle, Fritz, and Mensching *(28)* also indicate that actual phosphorus requirements of growing swine are satisfied by corn and the supplementary feeds ordinarily fed with corn. Phosphorus was retained in their experiments on an intake of 48 milligrams per kilogram of live weight.

In 1933, after the investigations herein reported had been started, Spildo *(62)*, working in Denmark, reported the results of a series of metabolism trials with young pigs. From his experiments he estimated that for a pig gaining in weight 500 grams daily, one should feed 7 grams of lime and 13 grams of phosphoric acid daily for growth alone, and recommended that a little additional should be supplied for the maintenance of metabolism. While he does not give actual food consumption, these figures indicate that the ration should contain approximately 0.3 to 0.4 percent of phosphorus.

In the same year Bethke, Edgington, and Kick *(5)*, summarizing their work on the calcium-phosphorus relationship in the ration of pigs, state that there is evidence that the phosphorus content of a ration should be not less than approximately 0.6 percent for good growth and bone formation in the absence of vitamin D. Undoubtedly this would be more than is necessary if vitamin D is supplied, since Maynard, Goldberg, and Miller *(49)*, Bohstedt and associates *(10)*, and others have shown that the requirements of calcium and phosphorus are less in animals if cod-liver oil is supplied in the diet.[3]

From all this it would seem that the requirements of phosphorus for young swine have been more generally estimated than definitely determined, and with no more specific information available, especially when an adequate diet' including sufficient amounts of calcium and vitamin D is supplied, it would appear that an excellent field is open for study along these lines. Accordingly, the present investigation was planned in one of its phases to furnish definite information on this subject.

THE CALCIUM-PHOSPHORUS RATIO

Here again, with swine, the research work with the calcium-phosphorus relationship lags behind that of other animals. Yet a brief review of the accomplishments in this problem, affecting swine, should be presented here in order to make a more complete literature review of the phosphorus problem.

That there is a quantitative relation between calcium and phosphorus in the feed supply was demonstrated by McCollum and associates *(51)* and Sherman and Pappenheimer *(60)*. They showed it to be of great importance in the rat in determining whether an animal developed normal or pathological bones. There exists also a quantitative relation between vitamin D and calcium in affecting the utilization of the calcium, as shown in the work of Bethke, Steenbock, and Nelson *(8)*, who reported that the amount of the antirachitic factor required by rats on a synthetic ration containing 0.655 percent of phosphorus varied inversely with the calcium content of the ration. Recent observations of Bethke, Kick, and Wilder *(7)* show that the amount of vitamin D required by the rat is directly correlated with the calcium and phosphorus content of the ration, and the ratio in which these elements are present. Similar observations have been made by Bethke and associates *(6)* in the chick, and Haag and Palmer *(32)* showed the importance of a more or less balanced condition of calcium, phosphorus, and magnesium salts in the ration of the rat.

So far as the pig is concerned, however, it has been shown many

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3. Since this manuscript was prepared G. Dunlop has reported the results of his studies on the calcium, phosphorus, and vitamin D requirements in swine. However, his work indicates a phosphorus requirement slightly less than that suggested by Bethke. Dunlop emphasizes the importance of the calcium-phosphorus ratio. The results, which he has represented graphically, indicate clearly the importance of the minimum requirement of phosphorus and also show that without vitamin D no amount of calcium will produce normal results if the phosphorus is less than 0.6 percent. If this amount of phosphorus is in the ration the calcium can vary through a wide range without deleterious results. (See Jour. Agr. Science, Vol. 25:22-49. Jan., 1935.)

It is interesting to note that Dunlop estimates that no amount of vitamin D will give normal growth with growing pigs when added to diets containing less than 0.53 percent phosphorus. This amount is considerably above the minimum requirements established in this study.

times that ample quantities of calcium and phosphorus in the ration are important. Maynard, Goldberg, and Miller *(49)* showed that even when calcium and phosphorus were in abundance in the ration poor bone development frequently resulted, which could be corrected by supplying vitamin D or its equivalent. Bohstedt *et al.* *(10)* also observed that under certain conditions improperly calcified bones occurred, even though the ration in question was supplemented with what was generally considered to be sufficient quantities of calcium.

Recently Bethke, Edgington, and Kick *(5)* showed that the calcium-phosphorus ratio of the ration of the pig is decidedly a factor in growth and bone formation. For these body activities they found that best results were obtained with a calcium-phosphorus ratio between **1** and **2.** They observed that when the proportion of calcium to phosphorus was greater than 3 the pigs became rachitic and the requirements for vitamin D were increased. They further stated that the requirement of the pig for vitamin D could be minimized by properly adjusting the calcium and phosphorus content of the ration.

Spildo's *(62)* ideas in regard to the calcium-phosphorus ratio correspond quite closely with those of Bethke and associates *(5)*. He says, "A regulation of the rations, so that the P_2O_5:CaO quotient becomes about 1.6, and by letting the animals have plenty of sun and light, will certainly protect us against a great deal of discomfort and illness—perhaps even deadliness—at the piggeries."

Thus the findings and observations of workers on the calcium-phosphorus ratio are indicated, and although its importance is clearly evident, no more consideration can be devoted to it herewith, as the present investigation was not designed to consider this relationship in any way.

After studying the work which had been done as indicated by the foregoing literature, it was decided to divide the general plan of of this swine investigation into two phases:

1. A study of the effects of deficient amounts of phosphorus in the ration on the development of young pigs.
2. A determination of the minimum requirements of phosphorus in the ration.

EXPERIMENTAL METHODS

THE OBJECT OF THE STUDY

The object of this study was to determine the requirements of phosphorus in the ration of growing pigs. It was a study of the phosphorus requirements uncomplicated by the amount of calcium in the ration, or by the absence of any elements known to constitute an adequate diet. The limiting factor in the rations was phosphorus.

To accomplish this study it was the plan of the experiment to feed similar groups or lots of pigs 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 to indicate whether or not the animals were receiving a sufficient amount of phosphorus to meet the requirements for normal growth.

This seemed a reasonable method of approach to solve the problem since the only distinguishing difference in the rations was the phosphorus content. The first year three lots of six pigs each were fed. The lots were numbered 1, 2, and 3 and comprised Experiment I. The second year three other lots of six pigs each were fed. These lots were numbered 4, 5, and 6 and comprised Experiment II.

ANIMALS USED IN THE EXPERIMENTS

The pigs used in the experiments were bred and raised in the herd of a swine breeder living near Manhattan. They were all pure-bred Hampshires and closely related. (Fig. 1.) All were castrated males and were either half or full brothers, being sired by the same boar. When full brothers were in the experimental group they were divided as equally as possible among the lots. They were farrowed in the fall and after weaning at about 9 weeks of age, were placed on experiment. Their average weight was about 43 pounds. They were in a good average condition for weaned pigs. In uniformity, weight, growthiness, condition, and thrift, they were very similar, having been carefully selected from a large number, with the idea in mind of having the experimental lots as nearly alike at the beginning of the test as it was possible to make them. No pigs were included that were crooked in legs or weak in pasterns. At the time of purchase they had been running to self feeders of shelled corn, wheat shorts, and tankage. They were immunized for hog cholera and treated for round worms before being placed on experiment. They would be judged at least average pigs or better than average by swine breeders.

On their arrival they were divided into three lots of six each. (In Experiment III only ten pigs were used. See page 68.) No replacements were necessary after the original lotting nor during the progress of any one of the experiments.

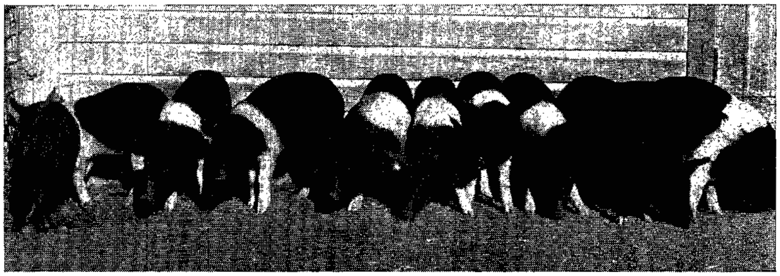

FIG. 1.—A group of 12 of the 18 pigs used in Experiment II at the beginning of the experiment. All the pigs used in both experiments were very similar at the beginning of the experimental period.

MANAGEMENT AND CARE OF THE ANIMALS

While on experiment each year twelve of the pigs were housed in one building, and six were housed in another. Both structures were well-ventilated, well-lighted, and provided with individual feeding pens (fig. 2), which were paved with concrete, and were 8 feet by 8 feet in dimension. These pens, with a feed alley on one side, extended the length of the barns which stand in an east and west direction. Each pen had an outside area to the south, 10 feet by 8 feet, paved with concrete, and fenced with wire. (Fig. 3.)

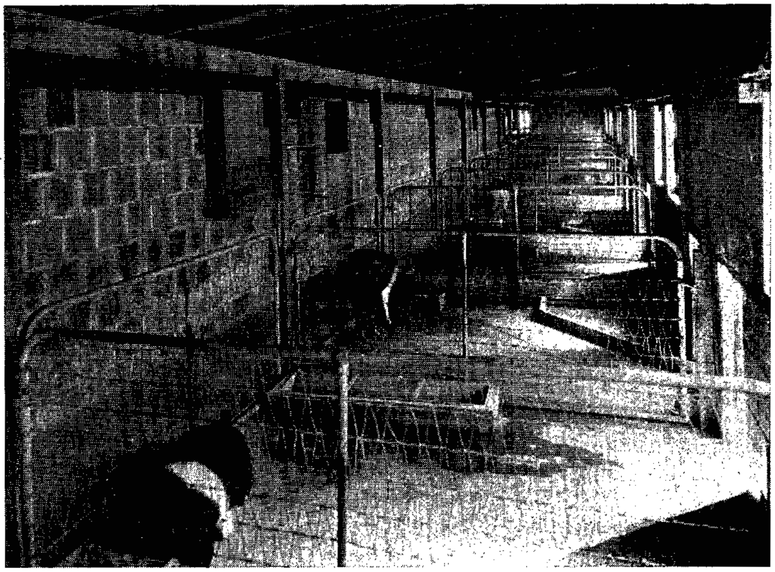

FIG. 2.—The inside of the house shown in figure 3. Note its good lighting and ventilation.

This outside area was in the nature of an exercise pen. Both enclosures were arranged so that the feces and urine could not get into adjoining pens. The outside area allowed the pigs access to the direct rays of the sun, and thus they were exposed to a considerable amount of ultra-violet rays. The animals remained in these pens, except once each 28 days, when they were driven the length of the barn, on concrete, to a scales. This constituted the only exercise they received except from moving about in their quarters. They were removed from the barn only at the time of slaughter.

All the animals were fed individually twice each day and handled and cared for in the same manner throughout both experiments, so that the rations consumed would constitute the only differences

FIG. 3.—The main house which accommodated 12 of the pigs each year. Note outside exercise pens. A similar structure was used each year for the other 6 pigs.

among the lots. In feeding the pigs the rations were fed dry. The feed for each animal was weighed to the tenth of a pound. The amount fed daily was changed from time to time, but each received the amount of feed he would clean up morning and evening. In case one pig refused feed a few times, the feed of the others was reduced, and then the reluctant one was fed enough to bring him up to the same consumption as the others. In this way all individuals received the same average amount of feed daily as computed at the end of each 4 weeks of feeding, so that if any significant differences in gains in weight and growth occurred they would not be due to a larger or smaller intake of food.

In order to study the effect of the different rations on the growth of these pigs, they were weighed individually and measured in height at the shoulders, in body length from base of ear to root of tail, and in the body girths at the heart, paunch, and flank, and the circumference of the left fore shin. These weights and body measurements were taken every 28 days throughout each experiment. The initial and final weights of each pig were taken on three successive days, and the average of the three weights was used as the initial and final weight, respectively. A single body measurement at the beginning of the experiment was used as the initial measurement and one at the end was used as the final measurement.

The pigs were watched closely for any abnormalities and unusual behaviors, and notes relating to their general appearance, health, unnatural cravings, and any other tendencies were recorded regularly.

Analyses were made of the blood for calcium and inorganic phosphorus at the beginning of the experiment and each 28 days throughout the experiment, in order to ascertain the effects of the ration upon the amount of these elements in the blood. The samples for these tests were taken by tail bleeding.

Two pigs for each lot were slaughtered at the end of 8 weeks of the experiment, two at the end of 16 weeks, and the last two pigs in the lot were slaughtered at the end of 24 weeks. This periodic slaughter during the progress of the experiment was planned so that the growth and development of the internal organs and bones could be followed closely. This was advisable since it was not known just when and on what level of phosphorus the pigs on feed might break down.

The last pigs slaughtered were about 8½ to 9 months old, and were thus well grown and of good market weight. It was thought that if a deficiency of phosphorus in the ration was to manifest itself it should be apparent by the end of this 6-month period of active growth.

At the time of slaughter, the appearance of the organs and carcass was carefully noted. The dressing percentages of the carcasses were ascertained, and weights were taken of the heart, liver, spleen, brain, and kidneys. The bones of each carcass were given special consideration.

Representative conditions of the skeleton of each pig were determined by removing the femur, humerus, sixth rib, and eleventh rib from the right side. These bones were selected because Neal and Palmer *(54)* showed that longitudinal sections of these bones constituted representative samples of the bovine skeletal structure. When removed, the bones were cleaned and breaking-strength tests were made, after which they were analyzed for ash, calcium, and phosphorus.

The bedding was wood shavings made from cottonwood timber. The more common straw was not utilized because it might introduce another variable. The shavings analyzed 0.0378 percent phosphorus and 0.362 percent calcium. At no time were the pigs observed eating the shavings. Consequently, if any was consumed it was undoubtedly in small amounts and the pigs received very little if any phosphorus from this source.

A picture was taken of each of the pigs at the beginning of the experiment, and at the end of each 8-week period until they were slaughtered. These pictures served to illustrate the growth and development of the body in progressive stages. Other pictures were taken of abnormal or interesting developments during the course of the experiments.

Water was regularly supplied the pigs twice a day, and when the weather was warm a third watering was made at noon. In this way fresh water was before the pigs at all times. The water was analyzed for calcium and phosphorus and found to contain 0.0095 percent calcium and 0.00004 percent phosphorus. The amount of calcium and phosphorus obtained from the water was consequently very small.

THE RATION USED IN THE EXPERIMENTS

Considerable difficulty was experienced in selecting a satisfactory ration, since it was necessary to select one that was low enough in phosphorus to demonstrate deficiencies and at the same time provide an adequate amount of all other necessary nutrients for growth. The ration selected must be palatable also, so that no difficulty would be experienced in having the pigs go off feed during the experiment. Another factor which complicated the selection of material for this ration was the fact that 4½ tons of feed would be necessary to feed the pigs in each experiment. For this reason many materials that might be used for small-animal feeding could not be considered as possible ingredients in the ration for this investigation because of their cost. Many feeds were given initial consideration because of some special qualification, but had to be discarded later when, upon further investigation, they were found to be too high in phosphorus, unpalatable, or inaccessible because of cost.

After considerable investigation a basal ration was adopted, which was made up as follows:

74 percent pearl hominy.
10 percent tapioca roots.
10 percent blood meal.
4 percent alfalfa-leaf meal.
1.5 percent dried brewers yeast.
0.5 percent iodized salt.
5 c.c. of cod-liver oil per pig per day.

The figures given in Table I show the average percentage composition of the ingredients used in the basal ration.

TABLE I.—COMPOSITION OF THE INGREDIENTS USED IN THE RATION

Ingredients.	Water.	Ash.	Crude protein.	Carbohydrates.		Ether extract.
				Crude fiber.	N-free extract.	
	Percent.	*Percent.*	*Percent.*	*Percent.*	*Percent.*	*Percent.*
Pearl hominy	10.46	0.63	9.56	0.57	77.56	1.22
Tapicoa roots	11.40	2.72	1.63	2.41	81.45	.39
Blood meal	15.32	3.92	78.56	.37	1.13	.70
Alfalfa-leaf meal	7.34	13.36	24.19	14.21	38.41	2.49
Dried brewers yeast	7.61	10.33	53.63	.30	28.00	.13

DISCUSSION OF THE BASAL RATIOS

The ration used contained 17.94 percent crude protein, 1.44 percent crude fiber, 67.4 percent nitrogen-free extract, and 0.86 percent fat. It also contained copper and iron. These figures do not express the digestible nutrients, but if these are computed by using the factors presented by Henry and Morrison *(40)* for these feeds or very similar ones, they would show that this ration, when fed in sufficient amounts for pigs, would satisfy in excess the requirements of the Morrison feeding standard *(40)* for growing and fattening pigs.

The protein requirements in this ration were of some concern. Although the quantity provided for was known to be well above the usual recommendations made for young swine, the quality might be open to question because the principal supply of protein was blood meal. Blood meal has a high percentage of protein, and was very desirable in the ration because it would furnish protein in large amounts without supplying at the same time any considerable amount of phosphorus. However, there was the question as to whether the proteins in blood meal were biologically adequate. Bohstedt and associates *(20)* are inclined to regard blood meal as an unsatisfactory source of protein for pigs. But Emmett and coworkers *(24)* and others have demonstrated it to be a satisfactory source when fed with yellow corn. Also, Riddell, Hughes, and Fitch *(58)* found blood meal to be a satisfactory protein supplement in their low-phosphorus studies in dairy cattle. Since there was evidence to show that it had been used effectively in other experiments as a protein supplement, it was decided to employ blood meal in this study, feeling that the protein therein, reinforced by that in the alfalfa, yeast, and other feeds, would prove to be adequate. The excellent gains made by the pigs later in actual feeding justified this assumption.

The vitamins were adequately supplied. Vitamin A was furnished in the 4 percent high-quality alfalfa-leaf meal and in the cod-liver oil. Vitamin B, although indicated as being unnecessary to add to normal swine rations by Bohstedt and associates *(10)*, was supplied as a matter of precaution in dried brewers yeast, in which it is abundant, as is also vitamin G. Vitamins B and C were also found in the alfalfa-leaf meal. Vitamin D was supplied in the cod-liver oil as a fortified product and in the almost daily exposure to sunshine. Vitamin C was not supplied, since Hughes, Aubel, and Lienhardt *(44)* showed it to be unnecessary in the feed of swine for growth and reproduction. Vitamin E is unnecessary also, except in reproduction. The ration therefore provides all the vitamins thought to be necessary for the well-being of pigs.

The minerals in the ration were adequate also. The ration contained all the elements known to be necessary for growth and development in swine, except phosphorus. The calcium was incorporated in the ration to the extent of about 0.8 percent. This amount was considered well above the requirements of swine, for

Hogan *(43)* found that brood sows should receive at least 0.4 percent of their ration as calcium. He also had stated earlier *(42)* that for young, growing gilts a ration of 0.25 percent calcium apparently was satisfactory. Dunlop *(18)* in England is reported as finding that 0.28 percent CaO was too low a level, but that 0.56 percent was satisfactory when fed with or without cod-liver oil. The levels recommended by these men are considerably below the amount incorporated in the ration for this investigation. Yet the level of 0.8 percent is not high enough to depress the utilization of phosphorus, at least when the vitamin D supply is ample.

The other mineral elements that should be considered in such a diet are copper, iron, and iodine. The ration contained 0.00773 percent copper and 0.0434 percent iron. Iodine was supplied in the salt, where it was present to the extent of 0.023 percent. The amounts of these elements in the ration undoubtedly provided an adequate supply in the diet as only small amounts of them are considered necessary to insure normal growth and development in an animal.

Enough of the materials used in this ration were purchased for a year's supply in order to reduce variations of composition in the rations. They are all commercial feeds procurable on the market except the blood meal used in Experiment II. The reason for having this special blood meal was that the meal purchased for Experiment I was found to vary among the different sacks. At the beginning of this experiment it was assumed that the blood meal purchased for it was uniform, therefore it was not all mixed together. It happened, however, that the sack selected for compounding the first mixture contained only 0.14 percent phosphorus. When the meal for the second mixture was analyzed the remaining sacks of blood meal mere found to contain 0.32 percent phosphorus. Although a search was made for blood meal of low-phosphorus content none could be found, so the higher-content meal had to be used. This accounts for the change of the phosphorus content of the first and the succeeding mixtures used in Experiment I.

The special blood meal was prepared for this experiment by Swift and Company, Kansas City, Mo., principally from the blood of cattle.[4]

There was a variation in the calcium and phosphorus content of the ingredients used in compounding the rations for Experiments I and II. The percentages of calcium and phosphorus in the feeds are found in Table II.

PREPARING THE CALCIUM AND PHOSPHORUS LEVELS IN RATIONS

The ingredients and their percentages in the ration having been decided upon, the next step was to prepare the rations with the different levels of phosphorus that had been selected and also to increase the calcium percentage so that it would be the same for all rations.

4. In this connection it is interesting to note that since Experiment II was started, Swift and Company have been able to produce a blood meal of 0.14 percent phosphorus.

TABLE II.—AVERAGE PERCENTAGE OF CALCIUM AND PHOSPHORUS IN THE INGREDIENTS USED IN THE RATIONS FOR EXPERIMENTS I AND II

Ingredients.	Calcium.		Phosphorus.	
	Expt. I.	Expt. II.	Expt. I.	Expt. II.
	Percent.	*Percent.*	*Percent.*	*Percent.*
Pearl hominy	0.05	0.006	0.11	0.10
Tapicoa roots	.13	.14	.04	.07
Blood meal	.41	.24	.32	.21
Alfalfa-leaf meal	1.53	1.46	.24	.20
Dried brewers yeast	.44	.41	1.90	1.90

This was accomplished by first preparing a basal ration which was mixed in the proper proportions in 1,000-pound lots in a mechanical mixer. After this mixture had been analyzed for calcium and phosphorus, it was determined how much phosphorus and calcium should be added to the ration for each lot to bring it to the desired level. The supplement added to raise the phosphorus levels was mono-calcium phosphate,[5] and the additional calcium necessary to bring it to the proper level was supplied in calcium carbonate. After these additions had been made the rations again were mixed and analyzed for their calcium and phosphorus content.

EXPERIMENT I

This experiment was begun January 2 and concluded June 19, 1933. It had as its plan the feeding of three groups of pigs on similar rations, but each on 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 requirements; another was to be an intermediate or medium level, approximately near the minimum requirements, whose adequacy was unknown. By comparing the results of the medium level with the low and high levels the adequacy was to be determined and the level then used as a known one to feed in another experiment.

In this way the requirements at the end of the experiment would be determined as being between two levels, which could be used as low and high levels in a succeeding experiment.

The levels decided upon for Experiment I were 0.15 percent in lot 1; 0.3 percent in lot 2; and 0.6 percent in lot 3.

The phosphorus content of the ration for lot 1 was as low as it was thought possible to get it in a practical ration. However, this was considered low enough from a consideration of the results of other experiments and it was thought that the pigs would exhibit defects from the deficiency.

For lot 3 a ration of 0.6 percent phosphorus was selected with

5. Mono-calcium phosphate is a commercial product used for animal feeding, containing 17 percent calcium and 19.81 percent phosphorus.

the feeling that this was well above the optimum requirements, since at the time this experiment was started no investigators had reported deficiency effects in any animals when the phosphorus was so fully supplied. McCollum and associates *(50)* had shown that in rats the optimum amount was 0.41 percent phosphorus, and Riddell, Hughes, and Fitch *(58)* in dairy cattle reported that their 0.34 percent phosphorus ration was adequate for their control animals. After this investigation had been started, Bethke and associates *(5)* and Spildo *(62)* recommended a minimum level of phosphorus that should be contained in a desirable ration in swine. Bethke set his percentage at 0.6 when the pigs were not receiving cod-liver oil. Spildo's recommendation was 0.3 to 0.4 percent if vitamin D was supplied.

The ration for lot 2 was to contain 0.3 percent phosphorus. This was an intermediate level whose effects it was hoped would prove, by comparison with the effects of the other levels, to be either above the phosphorus requirements or below them, and therefore could be used as one of the known levels in a succeeding experiment.

In compounding the rations for Experiment I, 1,000 pounds of feed of each level was prepared. This furnished feed from the beginning of the experiment until February 15, 1933, a period of 7 weeks, after which second rations were prepared in sufficient quantity to complete the experiment.

The rations first prepared (A) analyzed 0.15 percent phosphorus for lot 1, 0.29 percent for lot 2, and 0.59 percent for lot 3. In calcium the analysis was 0.79 percent for lots 1 and 2, and 0.77 percent for lot 3. After the second rations (B), with which the experiment was completed, had been prepared and analyzed they were found to contain 0.18 percent phosphorus for lot 1, 0.33 percent for lot 2, and 0.59 percent for lot 3. The phosphorus content of the rations of lots 1 and 2 in finishing the experiment was thus increased 0.03 percent from that fed the first 7 weeks. This increase in lot 1 was undoubtedly due to the higher phosphorus content of the blood meal that was used in mixing the rations. In lot 2 the increase was due to an inaccuracy in adding the mono-calcium phosphate. The calcium content of the second rations showed little difference from that in the first. It analyzed 0.77 percent in lots 1 and 3, and 0.78 percent in lot 2.

The percentage of calcium and phosphorus in these rations is shown in Table III.

TABLE III.—PERCENTAGES OF CALCIUM AND PHOSPHORUS IN THE RATIONS FED IN EXPERIMENT I

Rations.	Weeks fed.	Calcium.			Phosphorus.		
		Lot 1.	Lot 2.	Lot 3.	Lot 1.	Lot 2.	Lot 3.
		Percent.	*Percent.*	*Percent.*	*Percent.*	*Percent.*	*Percent.*
A.	7	0.79	0.79	0.77	0.15	0.29	0.59
B.	17	.77	.78	.77	.18	.33	.59

RESULTS OF THE EXPERIMENT

In order to get information on the minimum requirements of phosphorus in rations and the effect of low-phosphorus rations on the development of pigs, observations were made and data collected on the influence of the rations employed upon the consumption and utilization of feed and upon a number of developments in the body.

EFFECT OF RATIONS UPON CONSUMPTION AND UTILIZATION OF FEED

A consideration of the results from the standpoint of the amount of feed consumed daily and the amount consumed per 100 pounds gain brings out some striking differences between pigs fed a low level of phosphorus and those fed on higher levels.

TABLE IV.—DAILY FEED CONSUMED AND FEED REQUIRED FOR 100 POUNDS GAIN
Average per pig by 28-day periods

Period (28 days).	Number of pigs (*a*).	Feed consumed daily.			Feed required for 100 pounds gain.		
		Lot 1.	Lot 2.	Lot 3.	Lot 1.	Lot 2.	Lot 3.
		Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
1	6	2.5	2.5	2.5	347.2	308.6	294.1
2	6	3.1	3.1	3.1	418.9	322.9	313.1
3	4	3.9	3.9	3.9	367.9	357.7	336.1
4	4	4.5	4.5	4.5	391.3	357.1	375.0
5	2	5.5	5.9	5.9	743.2	418.4	450.3
6	2	5.7	5.9	5.9	445.3	393.3	398.6
Weighted average	....	3.7	3.7	3.7	417.1	344.6	341.0

(*a*) Of the original six pigs, two were slaughtered at the end of the second period; two at the end of the fourth; and two at the end of the sixth.

A review of the data in Table IV discloses that the amount of feed per pig consumed daily was exactly the same for the first four periods. This was in accordance with the plan of the experiment, which was to have all pigs on the same intake of food. However, in the last two periods there was a slight decrease in the amount of feed consumed daily by lot 1, compared with that consumed by the pigs in lots 2 and 3.

The reason for this was that the effect of the phosphorus on the appetite began to show up about the end of the second period, but by careful handling it was possible to get the pigs to consume their ration. By the beginning of the fifth period the loss of the appetite was so marked that the pigs would no longer consume their ration in the dry form. From this time on, advantage was taken of the increased thirst, and by withholding the drinking water and mixing the feed with it, a thin slop was made which they consumed more readily. In this way it was possible, in a sense, to force feed the lot 1 pigs during the fifth and sixth periods. Even then in order to have them consume a satisfactory amount of the ration, it was necessary to make the thin slop available more than twice during the day.

Toward the end of the experiment, in the last period, water and feed were given the pigs as many as six times a day. The evening feed that was not consumed at night was also consumed with the morning feed during the day.

Table IV also shows that lot 1, the low-phosphorus group, had during each period of the experiment the largest feed consumption per 100 pounds gain. It is interesting to note that the consumption fluctuated from period to period and that it was exceptionally high in period 5. The fluctuations varied as the average daily gains varied, and the very high requirement of feed in period 5 also corresponded with the low average daily gain in the same period. No explanation can be offered for this unless the change from a dry-feeding method to a thin-slop method might have caused temporarily a poor utilization of feed. In period 6 the gains again were fairly good. Lots 2 and 3 had very similar feed requirements throughout the six periods. Lot 3 was a little more efficient the first three periods, while lot 2 was the more efficient the last three periods. The differences in feed consumption between lots 2 and 3 were within the experimental error.

This would indicate on the basis of the utilization of feed that lot 1, receiving 0.18 percent phosphorus, did not have a sufficient supply of phosphorus in the ration and also that lot 2, receiving 0.33 percent, had as good a utilization of feed as lot 3 receiving 0.59 percent.

EFFECT OF RATIONS UPON BODY GROWTH AND DEVELOPMENT

A consideration of the results from the standpoint of growth and development brings out even more striking differences than the utilization of feed between pigs fed a low level of phosphorus and those fed on higher levels. Especially is this true in regard to the effect on the body weight and daily gains.

BODY WEIGHT AND DAILY GAINS

Data (Table V) in this connection show that the average final weights of the pigs in lots 2 and 3 at the close of the experiment were 36.5 and 34 pounds, respectively, more than in lot 1, the low-phosphorus-fed pigs. Lots 2 and 3 had almost the same average final body weight. Lots 2 and 3 also had almost the same gains each month of the experiment, and the gains were considerably more than those made by lot 1. They were slightly higher in lot 3 the first three periods and were slightly higher the last three periods in lot 2. Both lots were considerably higher than lot 1 throughout the experiment. The weighted average daily gain for lot 1 was 0.9 pound, for lot 2, 1.07 pounds, and for lot 3, 1.08 pounds. All three lots made consistently higher gains each succeeding period except lot 1 in the fifth, when a considerable reduction took place. The possible cause of this inconsistency has been discussed previously as probably due to the change from dry to slop feeding.

TABLE V.—BODY WEIGHT AND DAILY GAIN

Average per pig by 28-day periods

Period (28 days).	Number of pigs.	Body weight.			Daily gain.		
		Lot 1.	Lot 2.	Lot 3.	Lot 1.	Lot 2.	Lot 3.
		Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Initial	6	46.6	45.6	44.5	....	....	....
1	6	67.0	68.5	68.3	0.72	0.81	0.85
2	6	87.8	95.5	96.0	.74	.96	.99
3	4	117.7	126.0	128.5	1.06	1.09	1.16
4	4	149.7	161.5	162.2	1.15	1.26	1.20
5	2	170.5	201.0	199.0	.74	1.41	1.31
6	2	206.5	243.0	240.5	1.28	1.50	1.48
Weighted average	....	....	....	....	.90	1.07	1.08

A further comparison of the body weights of the pigs as affected by the different levels of phosphorus in the ration may be gained by plotting growth curves and comparing them with the growth curve of normal pigs.[6]

Such a method of comparison shows that the curves of the body gains made by the pigs of lots 2 and 3 fall a little below the curve of normal animals. In spite of this the gains may be considered as being satisfactory.[7] However, the curve of the body weight of the low-phosphorus pigs in lot 1 falls considerably below the curves for the pigs of lots 2 and 3, and therefore indicates a deficiency in the ration.

It is evident from these data that the 0.18 percent phosphorus received in lot 1 was inadequate for normal gains. The fact that lot 2, receiving 0.33 percent phosphorus, and lot 3, receiving 0.59 percent, were so nearly alike in their gains would indicate that the percentage of phosphorus in lot 2 was as efficient as the percentage in lot 3. The numerical data obtained affecting the body weight and daily gain are presented in Table V and graphically in figure 4.

6. The curve for normal pigs was drawn from unpublished data supplied by Prof. E. F. Ferrin of the Division of Animal Husbandry of the University of Minnesota. It is the average of the records of 134 pigs of Record of Performance litters. The pigs included all breeds and were self-fed an excellent ration.

7. The experimental pigs of lots 2 and 3 may be expected to be smaller rather than larger at any period of the trial for they were all Hampshire-bred and hand fed. In addition they were never on a full feed, for it was always necessary to restrict their ration so they would not eat more than the poorest-eating pigs which were in the low-phosphorus lot.

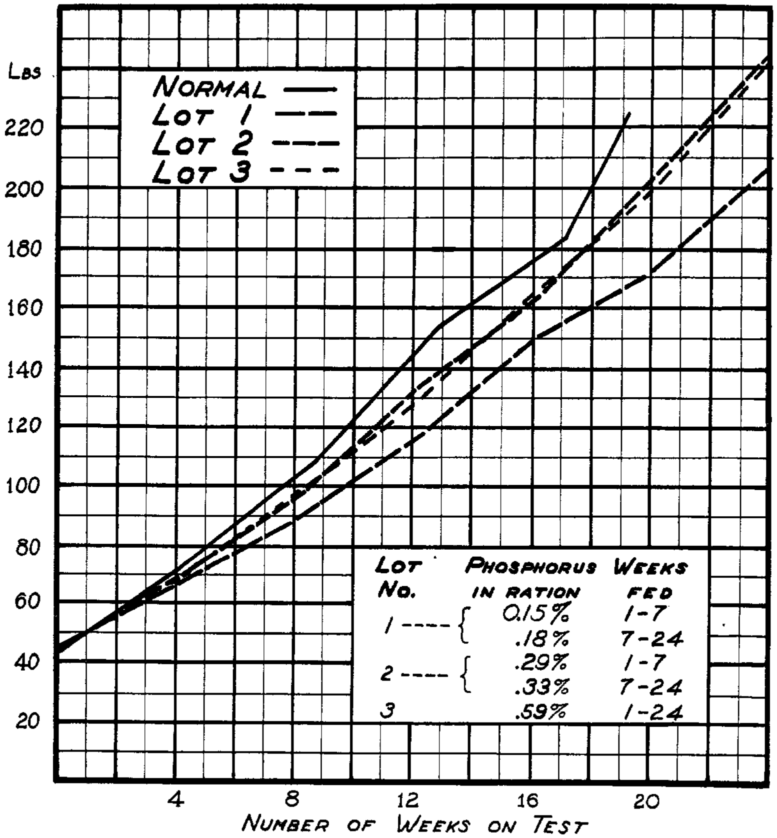

FIG. 4.—Graphs representing the body growth, in weight, of lots of pigs receiving varying percentages of phosphorus in their ration and a graph representing the body growth, in weight, of normal pigs.

BODY HEIGHT, LENGTH, GIRTHS, AND SHIN MEASUREMENTS

The effect of the rations on the growth and development of the body is further shown by a consideration of the measurement of the height of the pig at shoulders; the length of body, from base of ear to root of tail; the girths of the body at heart, paunch, and flank; and the circumference of the left fore shin.

A review of the data, Tables VI and VII, shows that the rate of growth as determined by the various body measurements was very similar in lots 2 and 3. It further shows that the growth in lot 1, receiving the low level of phosphorus, was almost as large. The greatest difference was observed in the length of the animals in lot 1, when compared with the lengths in lots 2 and 3. Singularly little difference was measured in the circumference of the left fore shins. A greater difference was shown in the heights at shoulder, yet this difference was not very great.

TABLE VI.—HEIGHT AT SHOULDERS, LENGTH OF BODY FROM BASE OF EARS TO ROOT OF TAIL, AND CIRCUMFERENCE OF THE LEFT FORE SHIN

Average per pig by 28-day periods

Period (28 days)	Num. of pigs.	Height at shoulders.			Length of body.			Circumference of left fore shin.		
		Lot 1.	Lot 2.	Lot 3.	Lot 1.	Lot 2.	Lot 3.	Lot1.	Lot 2.	Lot 3.
		Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
Initial...	6	15.9	15.7	15.9	27.1	26.9	26.9	4.5	4.4	4.5
1.......	6	18.4	18.5	18.5	29.8	30.5	30.2	4.8	4.8	4.9
2.......	6	19.7	20.3	20.1	32.1	32.4	32.4	5.0	5.1	5.2
3.......	4	21.3	21.7	21.6	37.5	37.9	37.7	5.5	5.6	5.6
4.......	4	23.5	24.1	24.1	40.3	41.7	41.8	5.9	6.1	6.1
5.......	2	24.5	25.5	25.3	42.1	44.5	44.1	6.1	6.3	6.1
6.......	2	26.0	27.2	27.2	44.0	48.0	47.7	6.1	6.7	6.5

TABLE VII.—CIRCUMFERENCE OF BODY AT HEART, PAUNCH, AND FLANK GIRTHS

Average per pig by 28-day periods

Period (28 days)	Num. of pigs.	Heart circumference.			Paunch circumference.			Flank circumference.		
		Lot 1.	Lot 2.	Lot 3.	Lot 1.	Lot 2.	Lot 3.	Lot 1.	Lot 2.	Lot 3.
		Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
Initial...	6	25.1	24.4	24.5	28.1	27.3	27.5	24.9	24.4	24.5
1.......	6	28.5	29.0	28.8	30.4	31.7	31.8	28.1	28.5	29.1
2.......	6	31.7	32.1	31.5	34.8	34.3	34.3	31.5	31.1	31.7
3.......	4	36.3	36.3	36.0	39.7	40.1	40.4	36.7	37.3	36.0
4.......	4	39.3	39.0	39.8	42.2	42.3	42.6	39.0	39.8	40.2
5.......	2	41.1	44.5	43.1	44.8	47.6	45.1	40.1	43.7	43.7
6.......	2	44.7	48.5	47.3	48.9	51.2	50.7	43.0	47.2	47.5

A further comparison of body growth and development as affected by the different levels of phosphorus in the ration may be ascertained by plotting curves and comparing them with the curves of normal pigs.[8]

Such curves (fig. 5) show that the growth in height at shoulders of the pigs in lots 2 and 3, receiving the higher percentages of phosphorus, is quite similar and that they compare very satisfactorily with the curves of normally grown pigs. However, the curves of the pigs in lot 1, receiving 0.18 percent of phosphorus, fall below the curves for the normal pigs and for those in lots 2 and 3.

8. Ferrin, E. F. (*loc. cit.*), p. 26.

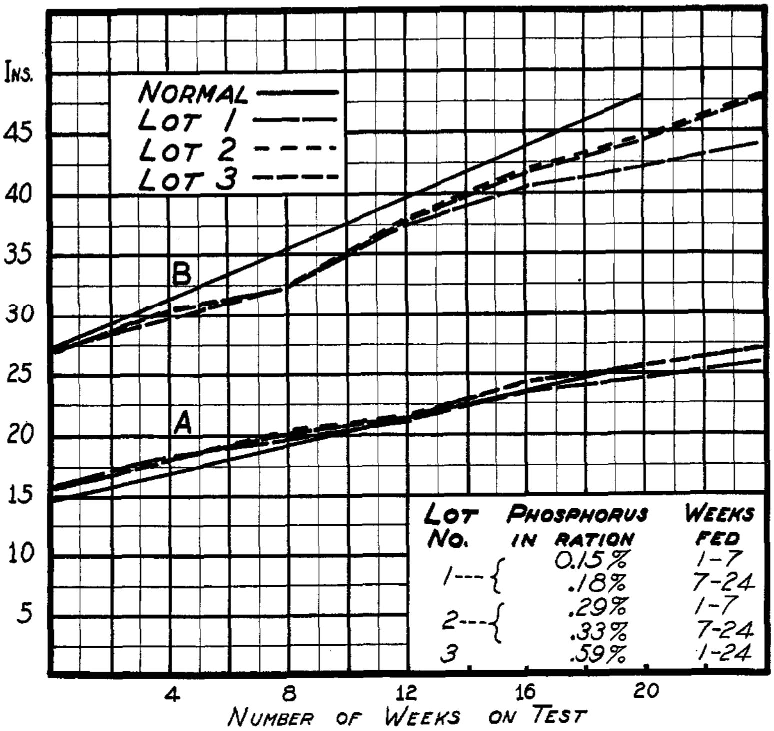

FIG. 5.—Graphs representing the body growth, in height at shoulders (A) and length of body (B), of lots of pigs receiving varying percentages of phosphorus in their ration compared to curves for normal pigs.

It is evident, therefore, from these data that a low-phosphorus ration of 0.18 percent did not restrict the growth in height at shoulders and the circumference of the left fore shin so much as it restricted growth in length of body. Yet at the same time it must be recognized that the ration in lot 1 was inadequate in phosphorus, for the growth and development of the pigs were not so satisfactory as they were in lots 2 and 3. The fact that lot 2, receiving 0.33 percent phosphorus, and lot 3, receiving 0.59 percent phosphorus, were so nearly alike in their gains would indicate that the percentage of phosphorus in lot 2 was as efficient as the percentage in lot 3.

A description of the pigs in the three lots receiving different levels of phosphorus might help to supplement the information given by the measurements and graphs and to picture more accurately the growth and development as affected by these rations.

The pigs in lot 1, receiving 0.18 percent phosphorus, failed to grow and develop as satisfactorily as the pigs on the higher levels of phosphorus. Some pigs in this lot began to show ill effects from the ration as early as the seventh week. Typical ill effects were low back, crooked legs, and weak pasterns. One of the pigs slaughtered at the end of the first two periods had difficulty in walking. This condition became more aggravated in the pigs as the experiment progressed. The legs were so badly deformed and weak that pig No. 13 (fig. 6) could scarcely walk. It was necessary to haul him with his lot mate to the slaughter house at the close of the experiment. These pigs were also markedly short in length of body.

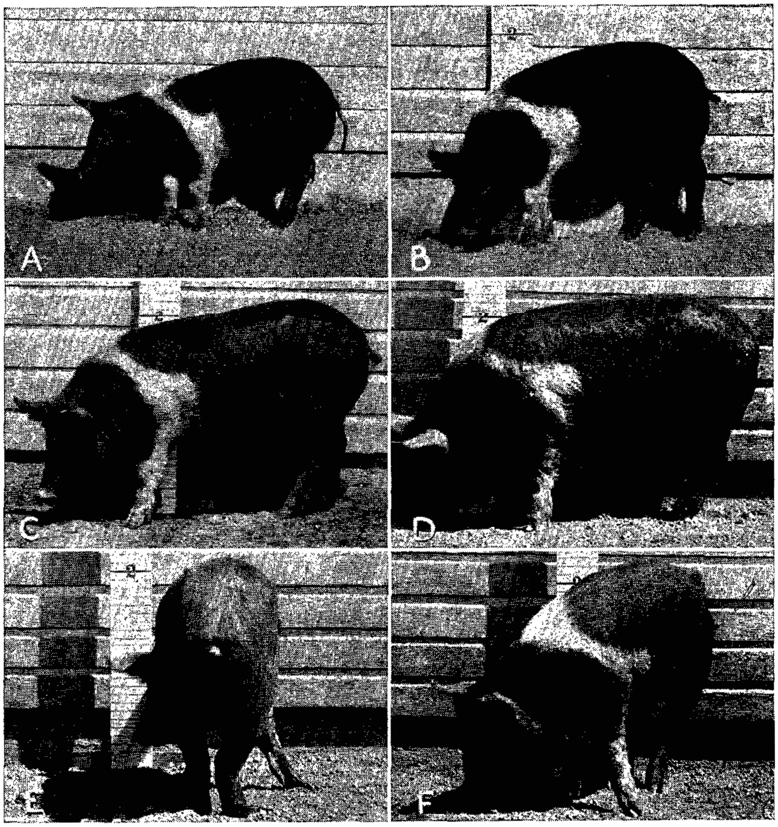

FIG. 6.—Several views of pig No. 13, lot 1, in successive 8-week stages of development. This pig received 0.18 percent phosphorus in his ration. Note crooked legs, weak pasterns, and low back. (A) At beginning of experiment; (B) at 8 weeks; (C) at 16 weeks; (D, E, and F) different views at end of experiment, 24 weeks. This amount of phosphorus was inadequate to insure normal development.

The pigs in lot 2, receiving the 0.33 percent phosphorus, and the pigs in lot 3, receiving the 0.59 percent, developed normally from the beginning of the experiment until the end. They had straight legs and strong pasterns and carried a well-arched back. (Fig. 7.) They were well grown and thrifty in appearance at all times and walked and moved about in a normal manner.

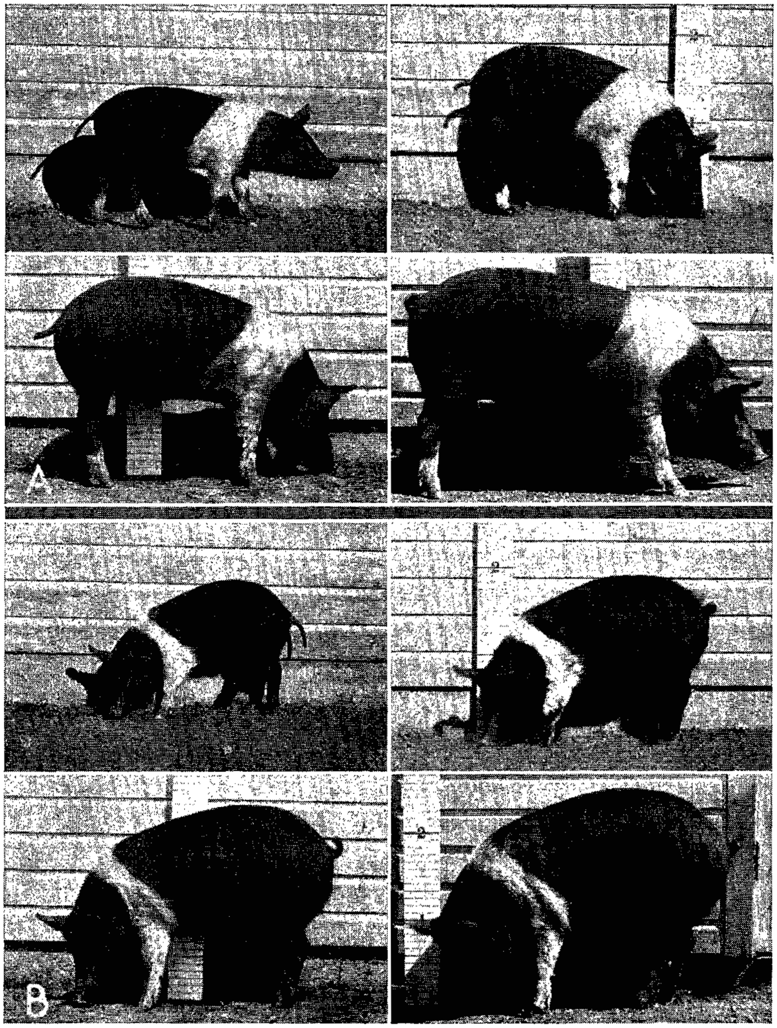

FIG. 7.—(A) Pig No. 16, lot 2, at successive 8-week stages of development. (B) Pig No. 17, lot 3, at successive 8-week stages of development.

Pig No. 16 (A) received 0.33 percent phosphorus in his ration. Pictures at the beginning of the experiment, and at 8, 16, and 24 weeks are shown in 1, 2, 3, and 4, respectively. Note the straight legs, strong pasterns, well-arched back, and thrifty appearance of the pig. The amount of phosphorus fed in lot 2 was as efficient in growing and developing the pigs as the 0.59 percent fed in lot 3.

Pig No. 17 (B) received 0.59 percent phosphorus in his ration. Pictures at the beginning of the experiment, and at 8, 16, and 24 weeks are shown in 1, 2, 3, and 4, respectively. Note the straight legs, strong pasterns, well-arched back, and thrify appearance of the pig. The amount of phosphorus fed in lot 3 was no more efficient in growing and developing the pigs than the 0.33 percent fed in lot 2.

EFFECT OF RATIONS UPON CONSUMPTION OF WATER

Shortly after the experiment had been started it was observed that the pigs of the different groups were consuming varying amounts of water. It was decided to determine the average amounts consumed by the pigs. Accordingly, water consumption was determined on the 15th and the 25th of each calendar month throughout the experiment, and an average made of the two days' consumption to represent the daily intake for a pig.

TABLE VIII.—WATER CONSUMED DAILY

Average per pig by 28-day periods (*a*)

Period (28 days).	Number of pigs.	Water consumed daily.		
		Lot 1.	Lot 2.	Lot 3.
		Lbs.	*Lbs.*	*Lbs.*
1	6	10.5	8.1	7.3
2	6	20.0	15.7	12.3
3	4	19.7	18.1	14.6
4	4	24.6	22.3	18.2
5	2	(*b*)	27.1	25.2
6	2	(*b*)	34.9	31.1

(*a*) Calculated from the water consumption for two days of each month.
(*b*) No data were secured for lot 1 for periods 5 and 6.

The data in Table VIII show the results of the determination of the water consumed. The low-phosphorus group, lot 1, consumed during each period more water than either lots 2 or 3; also lot 2, which received less phosphorus than lot 3, consumed more water than lot 3. In the fourth and fifth periods the consumption of water could not be accurately determined for lot 1 because the pigs had to be slopped five or six times per day in order to get them to eat their ration. However, it was observed that the water consumption of the pigs in lot 1 at this time was materially higher than for the pigs of the other two lots.

The observations indicate that rations low in phosphorus have a distinct tendency to develop abnormal thirst in pigs.

EFFECT OF RATIONS UPON COMPOSITION OF THE BLOOD

In the present investigation it was planned to check symptoms of aphosphorosis with analyses of the blood. The inorganic phosphorus was determined by the method of Youngburg and Youngburg *(70)*, while the blood calcium was determined by the Clark and Collip *(17)* method, on a single day's sample of blood drawn on the last day of each period. The data are presented in Table IX.

TABLE IX.—CALCIUM AND INORGANIC PHOSPHORUS CONTENT OF THE BLOOD

Average per pig by 28-day periods

Period (28 days).	Number of pigs.	Calcium (mg. per 100 c. c. serum).			Inorganic phosphorus (mg. per 100 c. c. whole blood).		
		Lot 1.	Lot 2.	Lot 3.	Lot 1.	Lot 2.	Lot 3.
Initial (a)	6	11.9	11.9	11.7	4.3	5.5	6.6
1	6	12.8	12.3	11.1	3.9	4.9	6.1
2	6	13.3	12.4	11.8	3.4	4.8	5.4
3	4	13.7	12.9	12.3	3.7	4.8	5.9
4	4	14.9	12.8	12.1	2.9	4.8	6.1
5	2	13.3	12.1	12.4	3.2	5.1	6.0
6	2	12.9	12.1	11.6	3.3	5.8	6.8

(a) The blood samples for this analysis were taken about two hours after the second feed of the experimental ration had been given the pigs.

An inspection of these data clearly shows that the pigs in lot 1 quickly developed a state of phosphorus deficiency which became more marked as the experiment progressed. Of the three lots, lot 1 had the least amount of inorganic phosphorus in the blood. Lot 3 had the highest percentage, while the amount in lot 2 was between that of the other two lots. Since each lot received a different level of phosphorus in its ration and since each lot had a distinctly separate level of inorganic phosphorus in the blood, it is clearly evident that the amount of phosphorus in the feed readily reflects itself in the blood.

This fact is shown further by the initial analysis of the blood of the pigs. Through an oversight at the time of starting the experiment, blood was not drawn for analysis until after the second feed of the experimental ration had been consumed. In this short time the amount of phosphorus in these two feeds affected the inorganic phosphorus of the blood of the pigs in the three lots so that three distinct levels resulted, corresponding to three definite levels in the rations.

The data of the blood analysis in regard to the serum calcium show that this factor was slightly higher at the end of the experiment in lot 1, receiving the 0.18 percent phosphorus, than in lot 2, receiving 0.33 percent, and that lot 2 was slightly higher than lot 3, which received 0.59 percent.

It is seen, therefore, that the amount of calcium and phosphorus in the feed is clearly indicated in the blood, and that a low inorganic phosphorus content of the blood is associated with low-phosphorus rations and retarded growth and development in pigs.

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EFFECT OF RATIONS UPON INTERNAL ORGANS AND THE CARCASSES

Among the observations it was planned to make to determine the influence of rations upon various developments in the body, were those pertaining to the effect on the internal organs and on the carcasses. Accordingly the weights of the heart, liver, spleen, brain, and kidneys of each carcass were determined.

An inspection of the figures obtained, comparing the weight of the organs with the dressed carcass weight, shows no significant difference between the different groups of pigs except in the weights of the brains and kidneys.

The brains of the pigs in lot 1, receiving 0.18 percent phosphorus, were as large or larger at each two-month interval during the progress of the experiment than the brains of the pigs in the lots receiving 0.33 percent or 0.59 percent.

The average figures also show that the low-phosphorus group of pigs had considerably larger kidneys. In some cases these organs were one third larger than those in the groups of pigs receiving the higher percentages of phosphorus. This is interesting in view of the fact that the low-phosphorus pigs were possessed with an abnormal thirst and consumed a greater amount of water daily than the pigs receiving a larger percentage of phosphorus in the ration.

Although an inspection of the data shows no significanct difference in the dressing percentage of the carcasses, a physical inspection of them showed that the low-phosphorus pigs at each slaughter were considerably shorter in length and were somewhat thicker and plumper. The low-phosphorus carcasses appeared also to carry a thicker covering of fat.

The numerical data obtained from the calculations based on the weights of the organs are presented in Table X and the carcasses are shown in figure 8.

TABLE X.—DRESSING PERCENTAGE AND WEIGHT OF THE BODY ORGANS COMPARED TO THE DRESSED BODY WEIGHT

Average of two pigs at 56-day periods

Period (28 days).	Lot No.	Percentage of dressed body weight.					Dressing percentage.
		Heart.	Liver.	Spleen.	Brain.	Two kidneys.	
2	1	0.61	2.93	0.38	0.37	0.81	70.70
	2	.49	2.25	.33	.29	.53	74.35
	3	.48	3.22	.32	.30	.59	69.30
4	1	.38	1.72	.23	.16	.52	81.15
	2	.38	2.22	.25	.16	.48	80.30
	3	.35	1.91	.21	.16	.38	79.20
6	1	.34	1.85	.22	.13	.52	78.85
	2	.30	1.60	.20	.10	.31	80.25
	3	.29	1.90	.22	.11	.31	80.50

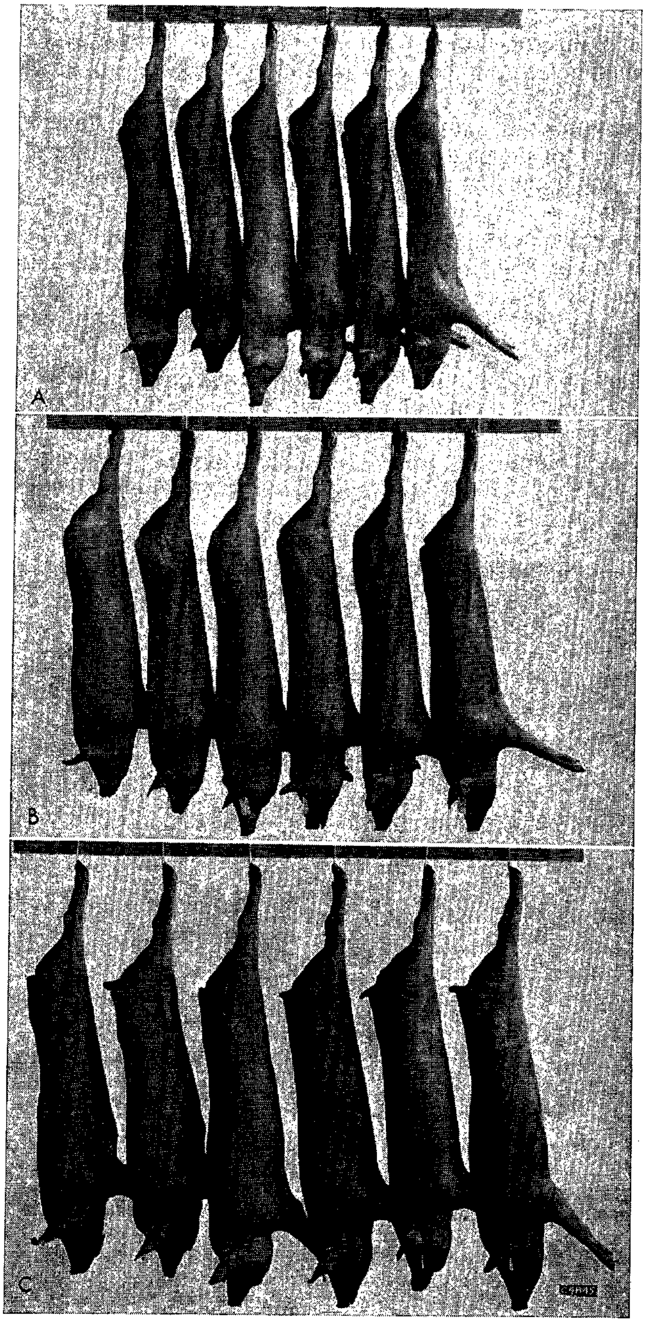

FIG. 8.—The carcasses of the pigs in Experiment I. (A) At the end of 8 weeks; (B) at the end of 16 weeks; (C) at the end of the experiment. Note the length and thickness of the carcasses. The two carcasses on the left in each group are from lot 1; the next two carcasses in each group are from lot 2; and the two on the right in each group are from lot 3.

PATHOLOGICAL INSPECTION OF THE CARCASSES

At each slaughter an inspection was made of the carcasses for lesions that might have been produced by phosphorus-deficient rations.

An examination of the carcasses of the pigs fed a low-phosphorus ration at the end of 8 weeks showed suppurative alveolar periostitis and soft teeth. When the bones of the vertebral columns of these pigs were split, the interior was so soft as to be readily punctured by the thumb nail. (Fig. 9.) Accompanying the apparent lack of calcification was a pronounced reddish color. The cerebellum exhibited numerous red points on section, indicating a slight hyperemia. In addition sub-epyndemal hemorrhages were present in the lateral ventricles.

Pigs of the medium- and high-phosphorus groups showed no changes in the brain. One of the pigs on a medium-phosphorus ration exhibited a suppurative alveolar periostitis and soft teeth. The carcass of the other pig appeared normal in every respect. One of the pigs on the high-phosphorus ration showed soft teeth and the other showed a well developed caries.

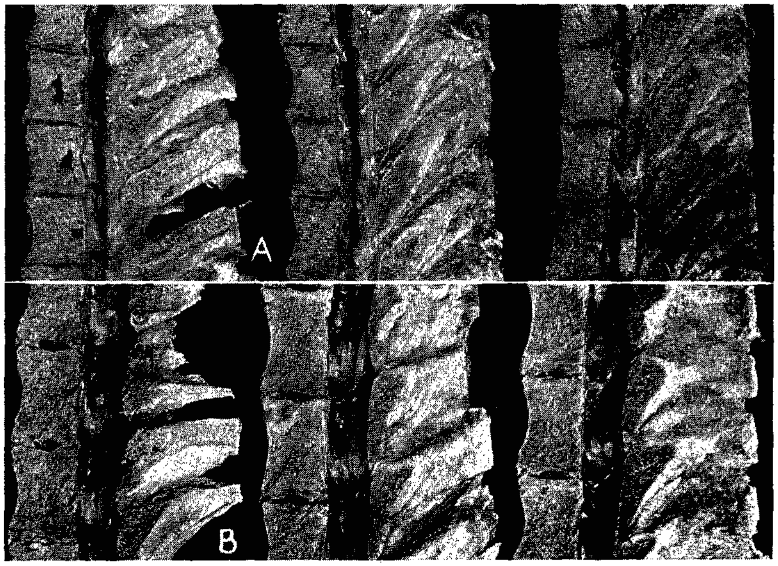

FIG. 9.—(A) Longitudinal sections of the thoracic vertebrae of a pig from each of lots 1, 2, and 3 (left to right) at the end of 8 weeks. Note the poor calcification of the bones of pig the from lot 1—low-phosphorus group. Note also the looseness of structure of these vertebrae as compared with the vertebrae of the pigs from the other lots.

(B) Longitudinal sections of the thoracic vertebrae of a pig from each of lots 1, 2, and 3 at the end of 16 weeks. Again note the poor calcification of the bones and the looseness of vertebral structure of the pig from the low-phosphorus lot.

The vertebrae of the medium- and high-phosphorus fed pigs were somewhat soft, yet were much harder and less red than the vertebrae of the pigs fed the low-phosphorus ration.

Examination of the carcasses of the low-phosphorus fed pigs at the end of 16 weeks of feeding, showed the same general condition except that the alveolar periostitis was almost absent. The teeth were still soft. The vertebrae were red, but the bone was not so soft as those at the first slaughter. The cerebral hyperemia still existed but was not so intense. In addition, the kidneys showed evidence of hyperemia, slight swelling, and slight evidence of degeneration.

The carcasses of the medium- and high-phosphorus fed pigs showed no abnormalities and presented bones that were harder than those in the low-phosphorus group of pigs and were pink instead of red in color.

At the end of the experiment the same changes were again observed relating to the teeth, bones, and brain that were noted in the carcasses at the previous slaughter. The vertebrae of the carcasses of the pigs on the low level of phosphorus were still soft; a distinct difference, however, was observed in the hardness of the vertebrae of the other pigs on the higher levels.

The kidneys of the low-phosphorus fed pigs were distinctly enlarged and light in color, presenting the appearance of a "large white kidney." Microscopically this organ showed evidence of a chronic diffuse nephritis of the parenchymatous type, and presented widened glomerular spaces around the glomerular tufts and also widely distended uriniferous tubules with flattened epithelial cells. A slight degeration was evident in some of the epithelial cells, and a granular debris was present in some of the tubules.

It is significant that the impaired kidney was consistent with the excessive urination and accompanying thirst observed during the progress of the experiment.

EFFECT OF RATIONS UPON THE BONES

At the end of the second, fourth, and sixth periods, when two pigs from each lot were slaughtered, four bones were removed from the right side of each carcass for a determination of the effect of the ration upon the physical measurements and chemical composition of the skeleton. The bones removed were two leg bones, the humerus and femur, and two rib bones, the sixth and eleventh.

PHYSICAL MEASUREMENTS

In order to study the physical composition, the bones were cleaned and data were secured to calculate the specific gravity. The length of the bone and the diameter at the breaking point were measured. After the bones had been subjected to a breaking-pressure test, the average thickness of the bone wall at the point of breaking was measured.

An inspection of the data, Table XI, shows the specific gravity of the bones to be considerably less in the lot 1 pigs on the low-phosphorus level than in the pigs in lots 2 and 3. The specific gravities of the bones of the pigs in lots 2 and 3 are very similar.

TABLE XI.—SPECIFIC GRAVITY, BREAKING STRENGTH, LENGTH, DIAMETER, AND THICKNESS OF WALL OF THE GREEN LEG AND RIB BONES

Average of two pigs for each of lots 1, 2, and 3 by 56-day periods

Period (28 days).	Bones.	Specific gravity.			Breaking pressure.			Length of bones (*a*).			Diameter of bones (*b*).			Thickness of wall (*c*).		
		Lot 1.	Lot 2.	Lot 3.	Lot 1.	Lot 2.	Lot 3.	Lot 1.	Lot 2.	Lot 3.	Lot 1.	Lot 2.	Lot 3.	Lot 1.	Lot 2.	Lot 3.
					Lbs.	*Lbs.*	*Lbs.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*
2........	Humerus...	1.102	1.241	1.234	305	575	635	5.49	5.57	5.57	0.660	0.713	0.725	0.094	0.138	0.133
	Femur.....	1.098	1.233	1.223	190	595	590	6.31	6.52	6.46	.636	.647	.675	.103	.153	.169
	6th rib.....	1.076	1.200	1.170	25	78	79	5.33	5.62	5.67	....	....	....	....	....	....
	11th rib....	1.091	1.226	1.155	16	64	65	5.18	5.47	5.58	....	....	....	....	....	....
4........	Humerus...	1.124	1.221	1.237	420	745	910	6.57	6.78	6.67	.744	.825	.825	.120	.168	.184
	Femur.....	1.108	1.225	1.219	427	945	975	7.03	7.73	7.81	.745	.822	.797	.115	.191	.187
	6th rib.....	1.042	1.159	1.193	61	157	157	6.67	6.97	7.16	....	....	....	....	....	....
	11th rib....	1.071	1.216	1.211	50	156	153	6.48	7.00	7.02	....	....	....	....	....	....
6........	Humerus...	1.167	1.339	1.386	500	1,435	1,380	6.95	7.32	7.14	.852	.992	.877	.111	.206	.182
	Femur.....	1.167	1.338	1.345	585	1,490	1,455	7.72	8.41	8.23	.895	.937	.877	.086	.206	.179
	6th rib.....	1.121	1.398	1.395	60	370	390	7.52	7.72	7.71	....	....	....	....	....	....
	11th rib....	1.193	1.483	1.455	55	345	345	7.53	7.73	7.62	....	....	....	....	....	....

(*a*) Leg bones, length over all. Ribs shortest distance from head to end of shaft.
(*b*) Average of smallest and greatest diameter at breaking point.
(*c*) Average of smallest and greatest thickness of wall at breaking point.

The data also show very marked differences in the strength of the bones as evidenced by the breaking pressure. The lot 1 pigs had decidedly the weakest bones. The breaking pressure in the bones of the lot, 2 and lot 3 pigs differed very little, and some breaks required much more pressure for the bones of the pigs of lot 2 than for lot 3.

There was some difference in the length and diameter of the bones, showing that growth was not so satisfactory in lot 1, but there was little difference between the bones of the pigs in lots 2 and 3.

The data indicating the thickness of the wall of the bones conform very closely with the specific gravity and the breaking-pressure data. They show the thinnest wall to be in the lot 1 pigs and little difference in the thickness of the walls of the bones in the lots 2 and 3 pigs.

The difference in the thickness of wall and the length and diameter of the bones between the lot 1 pigs and the lots 2 and 3 pigs was clearly apparent to the eye. (Fig. 10.)

Therefore, concerning the effects of the rations on the physical measurements of the bones, the evidence collected indicates clearly that the amount of phosphorus in the ration of lot 1, which received 0.18 percent, was not enough to develop normal bone, and that since the data for the bones of the pigs comprising lot 2, which received 0.33 percent of phosphorus, were very similar to the data for the bones of the pigs comprising lot 3, which received 0.59 percent, it would indicate that 0.33 percent phosphorus in the ration was as efficient as 0.59 percent in developing normal bone.

CHEMICAL COMPOSITION

After the bones had been measured to determine the specific gravity and crushed to determine the breaking pressure, the entire femur and humerus bones were ground together in a bone grinder, the fat extracted with alcohol and ether, and the remainder dried. The two rib bones were treated similarly and after drying were combined for analysis. The ash, calcium, and phosphorus were then determined separately on fractions of both the leg and rib bones.

The data relating to physical measurements of the bones disclosed poorly-developed bone resulting from the feeding of 0.18 percent phosphorus in the ration, as compared with 0.33 and 0.59 percent fed other pigs.

The chemical analysis of the bones (Table XII) disclosed data supporting the evidence of the physical measurements. In lot 1, the low-phosphorus group, receiving 0.18 percent phosphorus, the percentage of ash, calcium, and phosphorus in the bones was much less than the percentages in the lot 2 group, receiving 0.33 percent, and the lot 3 group, receiving 0.59 percent. The percentages of ash, calcium, and phosphorus in lots 2 and 3 differ very little and indicate that the amount of phosphorus in the ration of lot 2, which received 0.33 percent, was as adequate for normal bone development as that supplied in lot 3, which received 0.59 percent.

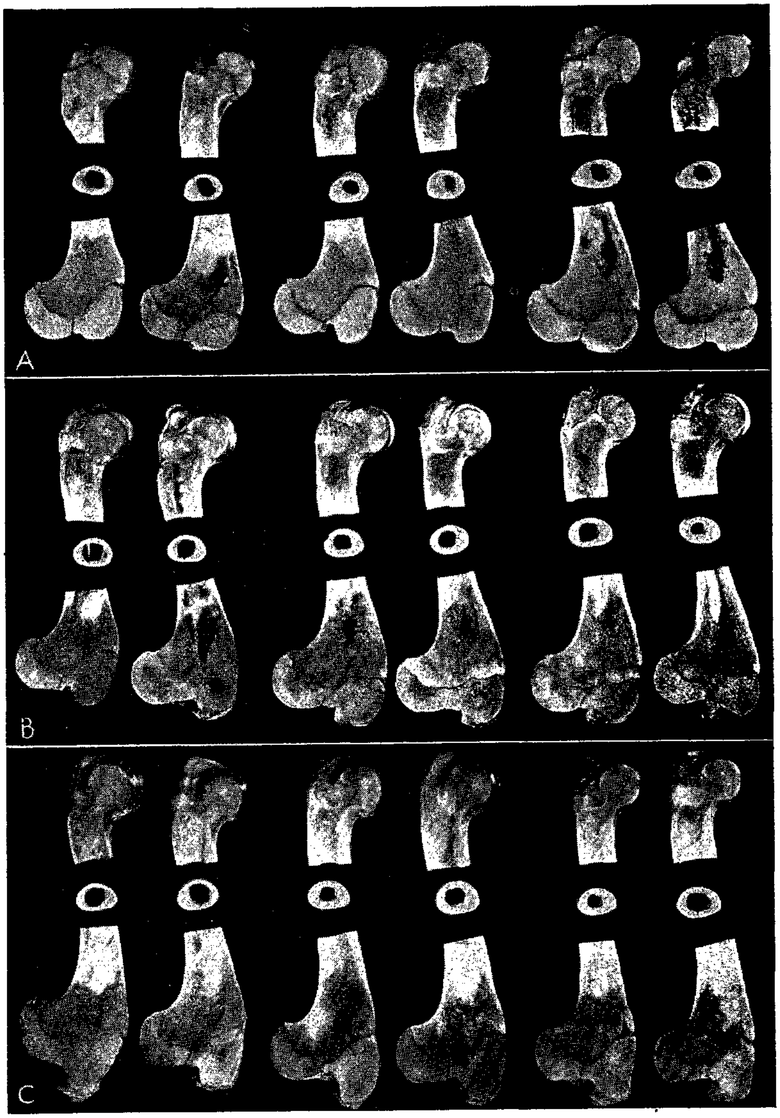

FIG. 10.—Longitudinal sections and cross-section rings of the left humeri of: (A) Pigs slaughtered at the end of 8 weeks; (B) pigs slaughtered at the end of 16 weeks; and (C) pigs slaughtered at the end of 24 weeks. The two bones on the left in each group are from the low-phosphorus pigs receiving only 0.18 percent phosphorus in their ration. The middle two bones in each group are from pigs receiving 0.33 percent phosphorus in the ration, and the two on the right in each group are from pigs receiving 0.59 percent phosphorus in their ration. Note the short length and the thin walls of the bones of the low-phosphorus pigs as compared with the bones of the other two groups. There is little difference in bone development between the pigs of the medium-phosphorus and the high-phosphorus groups.

TABLE XII.—ASH, CALCIUM, AND PHOSPHORUS IN THE DRY FAT-FREE LEG AND RIB BONES

Average of two pigs from each lot at 56-day periods

Period (28 days).	Bones.	Ash.			Calcium.			Phosphorus.		
		Lot 1.	Lot 2.	Lot 3.	Lot 1.	Lot 2.	Lot 3.	Lot 1.	Lot 2.	Lot 3.
		Percent.	*Percent.*	*Percent.*	*Percent.*	*Percent.*	*Percent.*	*Percent.*	*Percent.*	*Percent.*
2	Femur and humerus	48.14	57.35	59.64	18.35	21.93	22.70	8.69	10.58	10.82
	6th and 11th ribs	53.08	60.03	60.32	20.29	22.94	23.17	9.34	10.87	11.02
4	Femur and humerus	52.72	59.63	61.08	20.19	22.76	23.29	9.25	10.73	11.17
	6th and 11th ribs	52.29	58.80	60.97	20.48	22.75	23.37	8.85	10.63	11.22
6	Femur and humerus	54.16	62.29	62.82	21.32	24.06	23.87	9.51	11.27	11.42
	6th and 11th ribs	52.88	61.04	61.84	20.38	23.82	23.74	9.12	10.98	11.22

REQUIREMENTS OF PHOSPHORUS DETERMINED FROM EXPERIMENT I

Considering the results on the development of growing pigs from feeding the different levels of phosphorus it is clearly apparent that the levels of 0.59 percent and 0.33 percent were similar in their ability to produce normal development in pigs, while the low level of 0.18 percent was undoubtedly too low to insure normal development, Therefore, it can be said that under the conditions of this experiment the requirement of phosphorus in the ration for growing pigs lies between 0.18 and 0.33 percent.

Considering the amount of phosphorus ingested per unit of body weight, it is clear that since the percentage of phosphorus remained constant while the relative food consumption became less as the hog increased in body weight, the grams of phosphorus fed per 100 pounds of body weight gradually decreased.

These calculations are presented in Table XIII and show the amount of phosphorus fed daily in the different lots and the daily requirement of phosphorus established in this experiment per 100 pounds live weight of pig. The requirement in the first period of feeding for the pigs in lot 2, receiving 0.33 percent phosphorus, when their average weight was 57 pounds, was 5.75 grams. The requirement per 100 pounds live weight for these pigs in the third period when their average weight was 110.7 pounds, was 5.26 grams, and in the sixth period when they weighed 222 pounds, 3.97 grams.

TABLE XIII.—BODY WEIGHT, DAILY GAIN, PHOSPHORUS FED DAILY, AND PHOSPHORUS CONSUMED DAILY FOR 100 POUNDS LIVE WEIGHT

Average per pig for each period

Period (28 days).	Num. of pigs.	Body weight.			Daily gain.			Phosphorus fed daily.			Phosphorus consumed daily for 100 pounds live weight.		
		Lot 1.	Lot 2.	Lot 3.	Lot 1.	Lot 2.	Lot 3.	Lot 1.	Lot 2.	Lot 3.	Lot 1.	Lot 2.	Lot 3.
		Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*
1..........	6	56.5	57.0	56.4	0.72	0.81	0.85	1.70	3.28	6.69	3.00	5.75	11.86
2..........	6	77.4	82.0	82.1	.74	.96	.99	2.20	4.21	8.29	2.84	5.13	10.09
3..........	4	102.7	110.7	112.2	1.06	1.09	1.16	3.18	5.83	10.43	3.09	5.26	9.29
4..........	4	133.7	143.7	145.3	1.15	1.26	1.20	3.67	6.73	12.04	2.74	4.68	8.28
5..........	2	160.1	181.2	180.6	.74	1.41	1.31	4.48	8.83	15.78	2.79	4.87	8.73
6..........	2	188.5	222.0	219.7	1.28	1.50	1.48	4.65	8.83	15.78	2.46	3.97	7.18

EXPERIMENT II

This experiment was begun December 5, 1933, and concluded May 22, 1934. The pigs employed were similar to those used in Experiment I (fig. 1), being purebred Hampshires and possessing the same breeding, age, weight, and general thrift, for they were purchased from the same breeder.

This experiment was conducted in precisely the same manner as Experiment I and also had as its plan the feeding of three lots of pigs on similar rations, but each on a different level of phosphorus. The feeds constituting the rations were the same as those employed in the former experiment. The levels of phosphorus were a low, an intermediate, and a high, and were fed to lots 4, 5, and 6, respectively. It was decided to feed levels of phosphorus of 0.15 percent in lot 4, for the low group, of 0.23 percent in lot 5, for the intermediate group, and of 0.3 percent for the high group in lot 6.

These levels were decided upon because in Experiment I it was clearly demonstrated that the levels of 0.59 percent and 0.33 percent were similar in their ability to produce normal development in pigs, while the low level of 0.18 percent was undoubtedly too low to insure normal development.

It was thought that using the two levels, 0.15 percent and 0.3 percent, in Experiment II would tend to check the results of the former experiment in which approximately these levels were fed, and that an intermediate level in this experiment of 0.23 percent would help ascertain the minimum requirements of a ration.

The rations for Experiment II were compounded as they were for Experiment I, with the exception that enough feed was prepared at the beginning of the experiment to feed the pigs throughout the entire experiment. This obviated any variations in the feed. (Table XIV.)

Through some error the calcium content of the rations in this experiment was only about 0.7 percent. It had been planned to feed a calcium level of 0.8 percent, similar to that used in Experiment I, but after 4½ tons of feed were mixed and the analyses made, it was found to contain only 0.7 percent calcium. Although this percentage was lower than that used in Experiment I, it was decided to feed the pigs on this level, for the percentage was well above that reported by workers in the field of nutrition as being necessary for the normal development of swine.

TABLE XIV.—PERCENTAGES OF CALCIUM AND PHOSPHORUS IN THE RATIONS FED IN EXPERIMENT II

Calcium.			Phosphorus.		
Lot 4.	Lot 5.	Lot 6.	Lot 4.	Lot 5.	Lot 6.
Percent. 0.71	*Percent.* 0.69	*Percent.* 0.7	*Percent.* 0.15	*Percent.* 0.23	*Percent.* 0.3

RESULTS OF THE EXPERIMENT

The effect of different levels of phosphorus on the development of the pigs was determined in Experiment II as in Experiment I. Accordingly, observations were made and data compiled pertaining to the same general developments in the body.

EFFECT OF RATIONS UPON CONSUMPTION AND UTILIZATION OF FEED

A review of the data, Table XV, pertaining to the effect on consumption of feed shows that the amount of feed consumed daily by each lot was the same throughout the experiment.

TABLE XV.—DAILY FEED CONSUMED AND FEED REQUIRED PER 100 POUNDS GAIN

Average per pig by 28-day periods

Period (28 days).	Number of pigs.	Feed consumed daily.	Feed required per 100 pounds gain.		
		Lots 4, 5, and 6.	Lot 4.	Lot 5.	Lot 6.
		Lbs.	*Lbs.*	*Lbs.*	*Lbs.*
1	6	2.7	415.3	325.3	296.7
2	6	3.3	407.4	330.0	311.3
3	4	3.5	406.9	333.3	294.1
4	4	4.4	505.7	328.3	312.0
5	2	5.7	404.2	354.0	351.8
8	2	6.0	571.4	468.7	472.4
Weighted average,	....	3.7	439.1	342.6	321.7

The effect of phosphorus on the appetite in this test was observed as early as the middle of the second period. Some difficulty was experienced at this time in having the pigs eat their full allowance of feed, but by careful handling, by making a thin slop of their feed, and withholding drinking water, thus force feeding them as in Experiment I, the pigs were all kept on the same intake of food throughout the feeding trial. There was, however, more difficulty in this experiment than in the former and more care had to be exercised in the feeding. In order to get the low-phosphorus pigs to consume their allowance of feed toward the end of the experiment the slop had to be stirred constantly while the pigs were drinking. Otherwise much of the feed would settle to the bottom and the pigs would drink off the water and leave considerable feed.

A review of the data, Table XV, also shows that lot 4, the low-phosphorus group, had the largest food consumption per 100 pounds gain during each period of the experiment. The next largest consumption was in lot 5, lot 6 having the smallest consumption of the three.

On the basis of feed utilization it is evident from the data in this experiment that the 0.15 percent phosphorus received by lot 4 in their ration was not adequate for normal nutrition. The fact that lot 5, receiving the 0.23 percent phosphorus, did not utilize their feed quite so well as lot 6, receiving the 0.3 percent phosphorus, would indicate that 0.23 percent phosphorus in a ration is below the required amount necessary for the normal functioning of an animal.

EFFECT OF RATIONS UPON BODY GROWTH AND DEVELOPMENT

The effect of the rations on body growth and development was determined as in Experiment I. The data collected included that pertaining to the body weight and daily gains, and the body height, length, girths, and shin measurements. These data are presented in Tables XVI, XVII, and XVIII.

TABLE XVI.—BODY WEIGHT AND DAILY GAIN

Average per pig by 28-day periods

Period (28 days).	Number of pigs.	Body weight.			Daily gain.		
		Lot 4.	Lot 5.	Lot 6.	Lot 4.	Lot 5.	Lot 6.
		Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Initial	6	41.6	41.6	41.8	....	....	....
1	6	60.0	65.0	67.5	0.65	0.83	0.91
2	6	82.8	93.1	97.1	.81	1.00	1.06
3	4	107.0	122.5	130.5	.86	1.05	1.19
4	4	131.5	160.2	170.0	.87	1.34	1.41
5	2	171.0	205.5	215.0	1.41	1.61	1.62
6	2	200.5	241.5	251.0	1.05	1.28	1.27
Weighted average	....	....	....	....	.85	1.09	1.16

TABLE XVII.—HEIGHT AT SHOULDERS, LENGTH OF BODY FROM BASE OF EARS TO ROOT OF TAIL, AND CIRCUMFERENCE OF THE LEFT FORE SHIN

Average per pig by 28-day periods

Period (28 days)	Num. of pigs.	Height at shoulders.			Length of body.			Circumference of left fore shin.		
		Lot 4.	Lot 5.	Lot 6.	Lot 4.	Lot 5.	Lot 6.	Lot 4.	Lot 5.	Lot 6.
		Ins.	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*
Initial	6	17.1	16.5	16.8	27.9	27.4	27.7	4.1	4.1	4.1
1	6	18.2	17.9	18.3	30.4	31.0	30.9	4.4	4.7	4.7
2	6	19.3	19.2	19.9	33.5	34.9	35.2	4.8	5.1	5.3
3	4	20.3	21.9	22.6	35.9	37.6	39.3	5.0	5.5	5.7
4	4	21.6	23.7	24.1	39.7	42.1	43.7	5.3	5.7	6.0
5	2	23.5	25.5	26.2	42.2	44.5	48.0	5.8	6.3	6.4
6	2	24.4	26.6	27.6	44.1	47.1	51.0	6.0	6.5	6.7

TABLE XVIII.—CIRCUMFERENCE OF BODY AT HEART, PAUNCH, AND FLANK GIRTHS

Average per pig by 28-day periods

Period (28 days)	Num. of pigs.	Heart circumference.			Paunch circumference.			Flank circumference.		
		Lot 4.	Lot 5.	Lot 6.	Lot 4.	Lot 5.	Lot 6.	Lot 4.	Lot 5.	Lot 6.
		Ins.	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*
Initial...	6	24.5	24.4	24.5	26.1	25.8	25.8	24.9	24.3	24.5
1.......	6	28.9	29.1	29.6	31.0	31.1	31.2	28.4	28.6	28.5
2.......	6	32.6	33.6	33.3	34.0	35.0	34.8	31.5	32.0	32.3
3.......	4	35.2	36.4	37.1	37.2	37.8	39.1	34.1	34.8	36.8
4.......	4	37.6	39.7	40.6	39.2	42.0	43.1	35.4	39.1	39.9
5.......	2	41.8	43.7	44.5	43.8	46.5	47.3	40.2	43.2	43.2
6.......	2	45.5	46.9	49.1	46.9	50.5	51.5	44.5	45.7	48.1

From an inspection of these data it is clear that the 0.15 percent phosphorus received by lot 4 was inadequate, as was the 0.18 percent in lot 1, Experiment I. It is also evident that lot 5, receiving the 0.23 percent phosphorus, did not make quite so good body development as shown by the measurements as lot 6, which received the 0.3 percent phosphorus. This would indicate that the 0.23 percent level is below the amount required for normal growth and development.

The data concerning the effects of the different levels of phosphorus on the body weight and the growth of body in height and length, are expressed graphically in figures 11 and 12. In these figures, curves for the three lots may be compared with normal growth curves. The curves for the three lots show that lot 4 made an unsatisfactory growth when compared with either lot 6 or with normal pigs represented by the normal growth curve. It is also evident that lot 5 made a development somewhat less satisfactory than lot 6 but more satisfactory than lot 4.

Figures 13 and 14 provide pictorial evidence of the effects of the different levels of phosphorus on body growth.

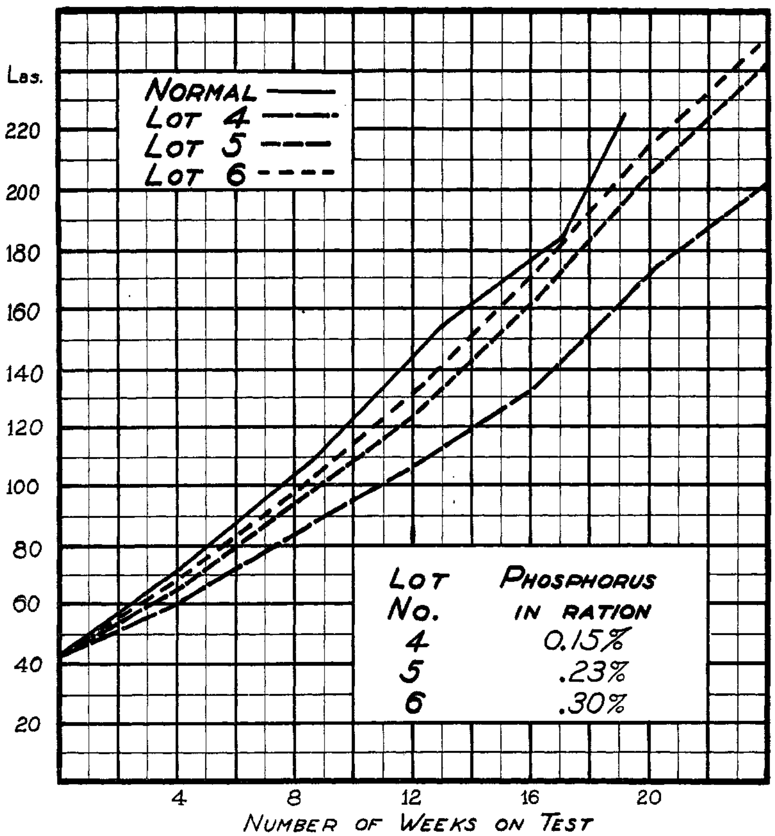

FIG. 11.—Graphs representing the body growth, in weight, of lots of pigs receiving varying percentages of phosphorus in their ration and a graph representing the body growth, in weight, of normal pigs.

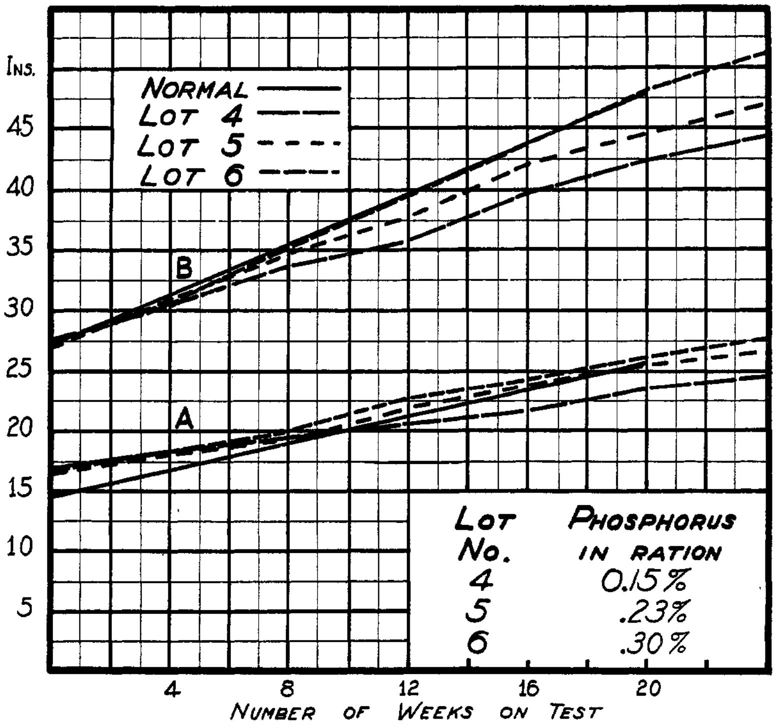

FIG. 12.—Graphs representing the body growth, in height at shoulders (A) and length of body (B), of lots of pigs receiving varying percentages of phosphorus in their ration compared to curves for normal pigs.

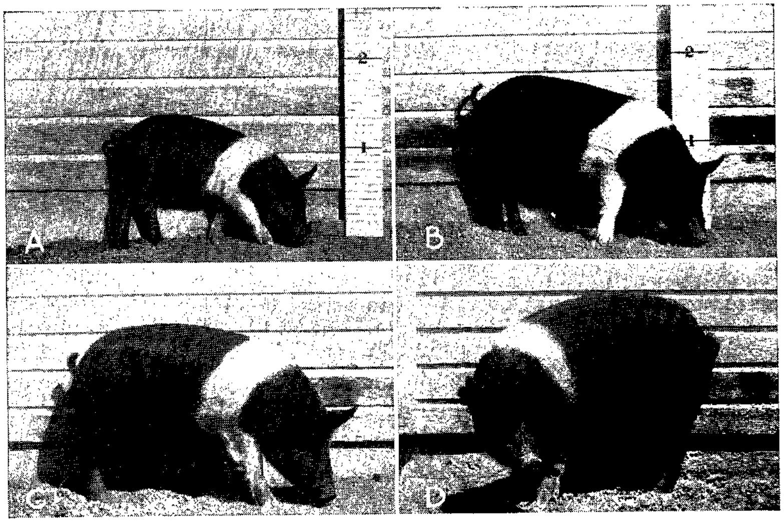

FIG. 13.—Pig No. 13A, lot 4, successive 8-week stages of development. This pig received 0.15 percent phosphorus in his ration. Pictures taken at the beginning of the experiment and at 8, 16, and 24 weeks are shown in A, B, C, and D, respectively. Note the crooked legs, weak pasterns, and low back. This amount of phosphorus was inadequate to insure normal development.

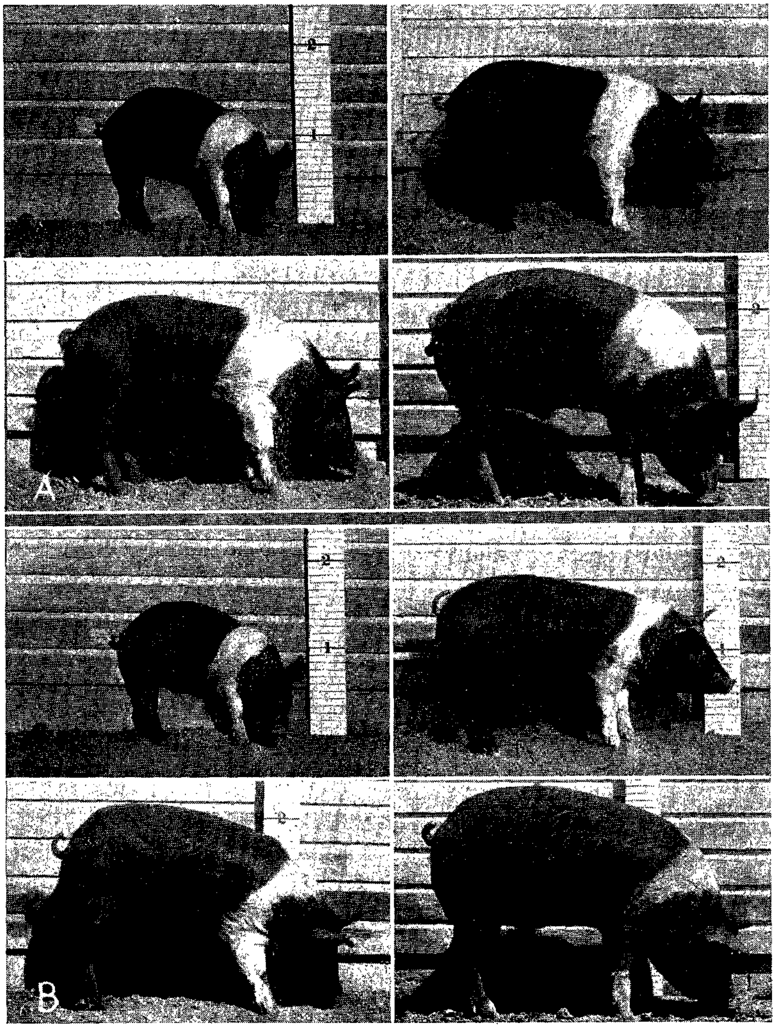

FIG. 14.—(A) Pig No. 15A, lot 5, at successive 8-week stages of development. (B) Pig No. 18A, lot 6, at successive 8-week stages of development.

Pig No. 15A (A) received 0.23 percent phosphorus in his ration. Pictures taken at the beginning of the experiment and at 8, 16, and 24 weeks are shown in 1, 2, 3, and 4, respectively. Note that this pig is better developed than pig No. 13A (fig. 13) but not quite so well developed as pig 18A (B).

Pig No. 18A (B) received 0.3 percent phosphorus in his ration. Pictures tak n at the beginning of the experiment and at 8, 16, and 24 we ks are shown in 1, 2, 3, and 4, respectively. Note the straight legs, strong pasterns, well-arched back, and thrifty appearance of the pig. This pig apparently develop d normally which indicated that 0.3 percent phosphorus in the ration was adequate for normal development.

EFFECT OF RATIONS UPON CONSUMPTION OF WATER

Since an increased thirst was again manifested in this experiment by the low-phosphorus pigs, observations were made on the consumption of water in the same manner as in the previous experiment. Because of the eagerness of the pigs for water there was more difficulty in determining the consumption and after the first two periods the attempts were discontinued. Nevertheless, it was observed that the pigs in lot 4, the low-phosphorus group, continued to consume more water than the pigs in either of the other groups. Later, in the sixth period when balance trials were attempted, an additional check was made on the water consumption. These data are presented in Table XIX and show a decided increased thirst in the low-phosphorus group, lot 4.

TABLE XIX.—WATER CONSUMED DAILY

Average for the first two and the last periods

Period (28 days).	Number of pigs.	Water consumed daily.		
		Lot 4.	Lot 5.	Lot 6.
		Lbs.	*Lbs.*	*Lbs.*
1 (*a*)	6	9.2	8.8	8.0
2 (*a*)	6	19.0	15.3	13.3
6 (*b*)	2	28.2	18.9	19.9

(*a*) Calculated from the water consumption for two days.
(b) Calculated from the water conuption for four days.

EFFECT OF RATIONS UPON COMPOSITION OF THE BLOOD

By an analysis of the blood of the pigs in Experiment I, the low-phosphorus pigs were shown to develop early a state of phosphorus deficiency which became more marked as the experiment progressed. In Experiment II the effect of the different levels of phosphorus in the rations on the composition of the blood was determined and the symptoms of aphosphorosis again were demonstrated in the low-phosphorus pigs. The data are shown in Table XX.

TABLE XX.—CALCIUM AND INORGANIC PHOSPHORUS CONTENT OF THE BLOOD

Average per pig by 28-day periods

Period (28 days).	Number of pigs.	Calcium (mg. per 100 c. c. serum).			Inorganic phosphorus (mg. per 100 c. c. whole blood).		
		Lot 4.	Lot 5.	Lot 6.	Lot 4.	Lot 5.	Lot 6.
Initial	6	9.7	10.0	10.0	5.5	5.7	5.7
1	6	12.4	11.2	11.2	4.1	5.0	5.7
2	6	12.6	12.0	12.1	3.4	4.7	5.5
3	4	11.0	10.6	10.3	2.9	4.7	5.5
4	4	11.9	12.1	11.0	2.7	4.8	5.3
5	2	11.5	12.0	11.1	3.5	5.1	5.5
6	2	13.2	13.7	11.5	2.6	5.4	6.2

An inspection of these data shows that the percentage of inorganic phosphorus in the blood reflects the amount of phosphorus received in the ration.

The amount of calcium varied little in the three lots of pigs, but again, as in Experiment I, this factor was slightly higher at the end of the experiment in the lots receiving the smaller amounts of phosphorus in their ration.

EFFECT OF RATIONS UPON INTERNAL ORGANS AND THE CARCASSES

The data, Table XXI, show the weight of the heart, liver, spleen, brain, and the two kidneys expressed as percentages of the body weight. The weights of the brains of the pigs in lot 4, receiving 0.15 percent phosphorus, were as large or larger at each 2-month interval than the brains of the pigs of the other two lots, receiving 0.23 percent and 0.3 percent phosphorus, respectively. The figures also show a large difference in the comparative size of the kidneys of the pigs in the different lots. The kidneys of the low-phosphorus group were considerably larger. There was no great difference in the kidneys of the pigs slaughtered at the end of the first two periods, but thereafter there was a marked difference.

The increase in relative kidney size was observed also in Experiment I and is interesting because the low-phosphorus pigs were possessed with an abnormal thirst and consumed larger amounts of water daily than the pigs receiving a larger percentage of phosphorus in the ration.

The data show no significant difference in the dressing percentage of the carcasses. A physical inspection of them showed that the low-phosphorus pigs at each slaughter were somewhat shorter in length, thicker and plumper, and seemed to carry a larger amount of fat. (Fig. 15.)

TABLE XXI.—DRESSING PERCENTAGE AND WEIGHT OF THE BODY ORGANS COMPARED TO THE DRESSED BODY WEIGHT

Average of two pigs at 56-day periods

Period (28 days).	Lot No.	Percentage of dressed body weight.					Dressing percentage.
		Heart.	Liver.	Spleen.	Brain.	Two kidneys.	
2	4	0.68	2.86	0.26	0.32	0.67	73.5
	5	.55	2.60	.23	.24	.60	76.3
	6	.63	2.68	.28	.30	.65	70.9
4	4	.45	2.00	.31	.19	.62	78.2
	5	.48	2.08	.22	.16	.57	73.2
	6	.49	1.82	.22	.16	.47	74.6
6	4	.41	1.86	.20	.12	.53	82.9
	5	.40	1.95	.26	.10	.41	79.7
	6	.40	1.90	.23	.10	.36	79.2

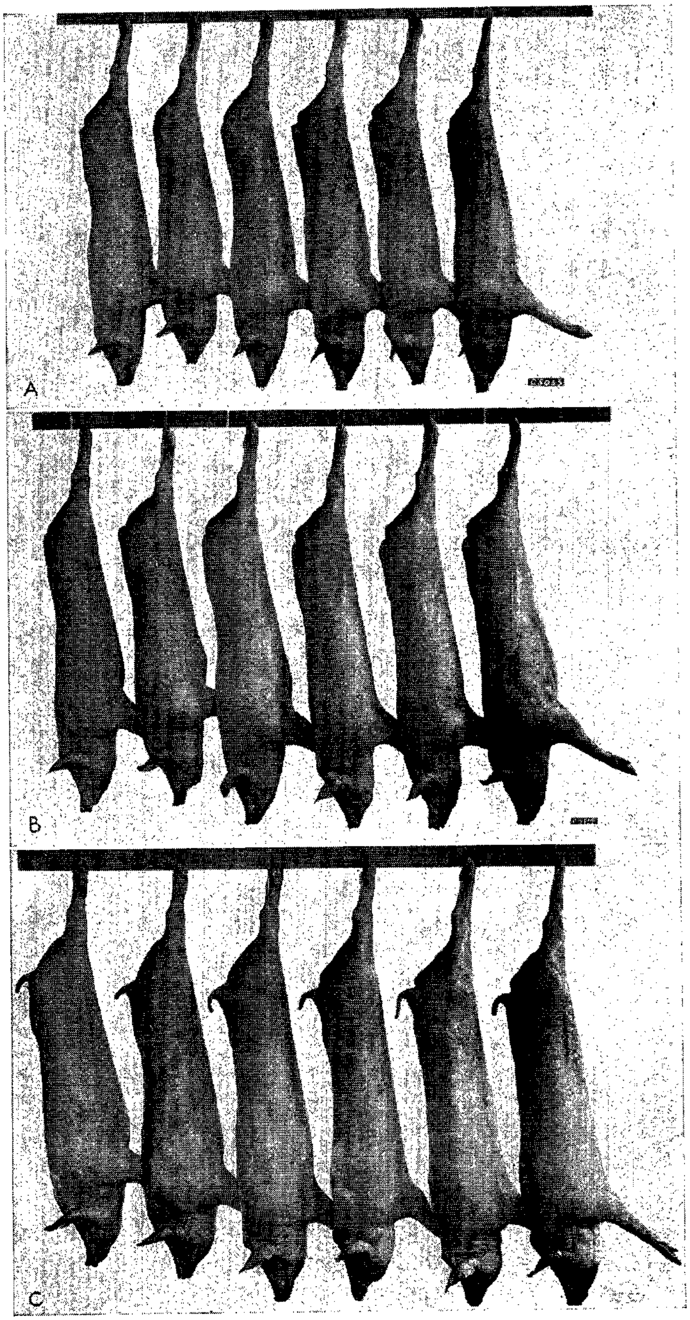

FIG. 15.—The carcasses of pigs in Experiment II. (A) At the end of 8 weeks; (B) at the end of 16 weeks; and (C) at the end of the experiment. Note the length and thickness of the carcasses. The two carcasses on the left in each group are from lot 4; the next two carcasses in each group are from lot 5; and the two on the right in each group are from lot 6.

In Experiment I it was observed that the carcasses of the low-phosphorus pigs seemed to carry more fat than the pigs receiving higher levels of phosphorus. Accordingly an effort was made in the fourth and sixth periods of this experiment to determine the condition of the carcasses with respect to the amount of fat that each carried. This was accomplished by measuring the thickness of the back fat opposite the seventh and eleventh ribs on the right half of the carcass. In the sixth period an additional measurement was made opposite the thirteenth rib.

Table XXII shows the measurements of the thickness of the back fat, and figure 16 presents it pictorially.

TABLE XXII.—THICKNESS OF THE BACK FAT AT THE 7TH, 11TH, AND 13TH RIBS

Average of two pigs at the end of the fourth and sixth periods

Period (28 days).	Thickness at 7th vertebra.			Thickness at 11th vertebra.			Thickness at 13th vertebra.		
	Lot 4.	Lot 5.	Lot 6.	Lot 4.	Lot 5.	Lot 6.	Lot 4.	Lot 5.	Lot 6.
	Mm.	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*
4	34	27	30	30	26	27	....	....	....
6	51	43	45	46	40	41	42	39	35

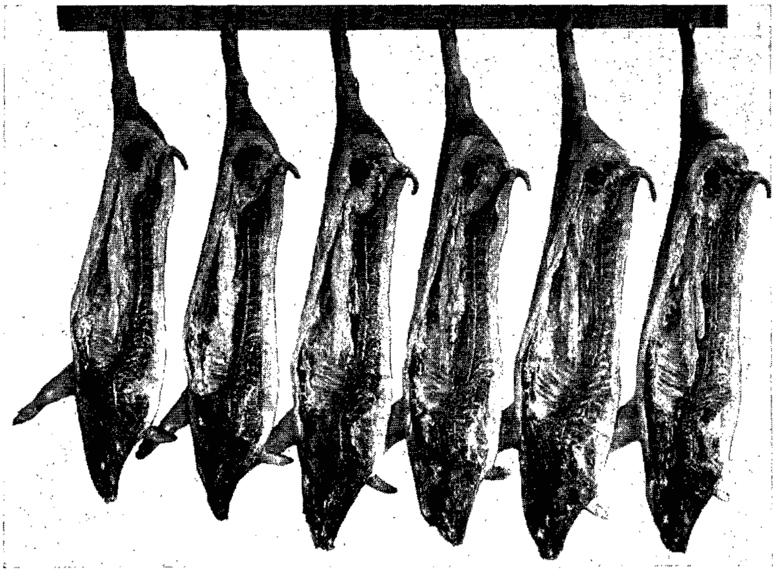

FIG. 16.—The inside of the carcasses of the six pigs slaughtered at the end of Experiment II. Note the thickness of back fat of the low-phosphorus pigs, the two on the left, compared with the four pigs on the right, representing the medium-phosphorus and the high-phosphorus levels.

PATHOLOGICAL INSPECTION OF THE CARCASSES

An examination of the carcasses of the pigs in Experiment II at the end of 8 weeks showed the low-phosphorus fed pigs to have soft vertebra, very similar to those observed in the pigs on the low-phosphorus ration in Experiment I. (Fig. 9.) The bones were more firm in the medium-phosphorus fed pigs, and were the hardest in those receiving the high level of phosphorus. This relative difference in the vertebrae was observed in the remaining two slaughters of the experiment. An additional difference in calcification was disclosed in bone sections made from the rib at the costochondral junction. These sections showed an even line of ossification in all groups, but the difference in density of calcification between the bone sections of the high-phosphorus fed pigs and the low-phosphorus fed pigs was very marked.

Microscopic examinations were made of sections of the heart, spleen, liver, pancreas, thyroid, parathyroid, pituitary, bone, brain, kidney, and spinal cord of the pigs of all groups. With the exception of the kidney and spinal cord of the pigs fed a low-phosphorus ration, all the structures presented a normal appearance when stained by the Marchi method, with osmic acid, hemotoxylin and eosin, and with Van Gieson's stain.

The condition of the kidneys was similar to that described in the low-phosphorus fed pigs in Experiment I. They were much enlarged and showed chronic diffuse nephritis of the parenchymatous type.

The sections made from the spinal cords of the lumbar region of the pigs slaughtered the third period showed the pigs on the low-phosphorus ration to have well marked fatty degeneration of the white matter. A pathological spinal cord was not observed in any of the other pigs slaughtered previously.

The carcasses of all the pigs showed a number of abscesses, mostly in the cervical glands, but only in one low-phosphorus pig were they likely to have produced any generalized reaction. It is possible that the general metabolism of this pig might have been influenced, since there was a generalized hemorrhagic lymph adenitis in most of the body and visceral lymph nodes. However, a comparison of the gains made by this pig with those made by the other low-phosphorus pig did not disclose any difference.

EFFECT OF RATIONS UPON DIGESTION

So interesting were the effects of the rations upon the utilization of feed in Experiments I and II that balance studies were planned for the sixth period of the latter experiment.

Accordingly crates were made and the six pigs remaining in the experiment at this time were subjected to a 3-day balance trial procedure. Although much difficulty was experienced in getting the low-phosphorus pigs to eat and drink normally while in the metabolism crate, considerable interesting data were collected. Unfortunately, however, the records were destroyed by fire in the burning of the chemistry building in August, 1934.

However, some duplicate records filed elsewhere give data on the passage of urine for a 3-day period in connection with these trials. While 3 days are not long enough to give an accurate balance on water, yet these data are interesting, especially in connection with the data already presented on the increased water consumption and also on the enlarged and impaired kidneys that were observed at the time of slaughter in the pigs on a low level of phosphorus. Table XXIII shows the average daily consumption of water, the amount of urine excreted daily, and the average size of the kidneys of two pigs in the sixth period. From this it is seen that not only did the pigs on the low-phosphorus ration show a greater urinary output, as would be expected from their larger water intake, but the urine excretion was nearly twice as great in proportion to the water consumed.

TABLE XXIII.—AMOUNT OF WATER INGESTED AND URINE EXCRETED DAILY AND WEIGHT OF KIDNEYS

Average of two pigs in the sixth period of Experiment II

Water ingested.			Urine excreted.			Weight of kidneys.		
Lot 4.	Lot 5.	Lot 6.	Lot 4.	Lot 5.	Lot 6.	Lot 4.	Lot 5.	Lot 6.
Gm. 11,514	*Gm.* 6,190	*Gm.* 5,903	*Gm.* 8,541	*Gm.* 2,300	*Gm.* 2,355	*Gm.* 411	*Gm.* 366	*Gm.* 335

EFFECT OF RATIONS UPON THE BONES

As in Experiment I, two leg and two rib bones were removed from the right side of each carcass of the pigs slaughtered at the end of each 2-month period. These bones were used to determine the effect of the rations upon the physical measurements and chemical composition of the skeleton.

PHYSICAL MEASUREMENTS

Table XXIV shows the data on the physical measurements of the bones. An inspection of these data shows the specific gravity of the bones to be considerably less in the lot 4 pigs on the low-phosphorus level and slightly less in the lot 5 pigs on the medium-phosphorus level than that in the lot 6 pigs receiving 0.3 percent phosphorus in their ration. In most cases the differences in specific gravity between the lots became more marked as the experiment progressed.

The differences in the breaking pressure of the bones in the lots were significant. The weakest bones were found in lot 4 and the strongest in lot 6, while the bones of the pigs in lot 5 were weaker than lot 6 but stronger than lot 4. The differences in the breaking strength between the lots became more marked as the experiment progressed.

TABLE XXIV.—SPECIFIC GRAVITY, BREAKING STRENGTH, LENGTH, DIAMETER, AND THICKNESS OF WALLS OF THE GREEN LEG AND RIB BONES

Average of two pigs for each of lots 4, 5, and 6 by 56-day periods

Period (28 days).	Bones.	Specific gravity.			Breaking pressure.			Length of bones (*a*).			Diameter of bones (*b*).			Thickness of walls (*c*).		
		Lot 4.	Lot 5.	Lot 6.	Lot 4.	Lot 5.	Lot 6.	Lot 4.	Lot 5.	Lot 6.	Lot 4.	Lot 5.	Lot 6.	Lot 4.	Lot 5.	Lot 6.
					Lbs.	*Lbs.*	*Lbs.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*
2........	Humerus...	1.135	1.177	1.182	320	479	480	5.82	5.67	5.66	0.660	0.667	0.706	0.092	0.103	0.102
	Femur.....	1.122	1.164	1.171	330	540	550	6.51	6.46	6.36	.660	.663	.712	.087	.191	.135
	6th rib.....	1.079	1.116	1.166	29	75	78	6.24	5.96	6.11	....	....	....	....	....	....
	11th rib....	1.077	1.147	1.188	29	48	47	6.01	6.12	6.12	....	....	....	....	....	....
4........	Humerus...	1.173	1.205	1.184	440	755	897	6.40	6.65	6.90	.748	.836	.883	.107	.172	.165
	Femur.....	1.166	1.191	1.242	375	747	900	6.85	7.70	7.90	.732	.789	.797	.099	.152	.175
	6th rib.....	1.128	1.177	1.252	56	114	176	6.50	7.50	7.60	....	....	....	....	....	....
	11th rib....	1.196	1.204	1.318	46	86	154	6.50	7.30	7.45	....	....	....	....	....	....
6........	Humerus...	1.181	1.221	1.300	560	840	1,220	7.17	7.38	7.68	.824	.886	.932	.136	.176	.193
	Femur.....	1.171	1.221	1.294	590	1,030	1,310	7.72	8.46	8.80	.800	.892	.911	.130	.157	.180
	6th rib.....	1.079	1.177	1.284	65	160	295	7.17	8.08	8.48	....	....	....	....	....	....
	11th rib....	1.152	1.281	1.308	62	145	295	6.92	7.79	7.89	....	....	....	....	....	....

(*a*) Length over all of legs bones. Ribs shortest distance from head to end of shaft.
(*b*) Average of smallest and greatest diameter at breaking point.
(*c*) Average of smallest and greatest thickness of wall at breaking point.

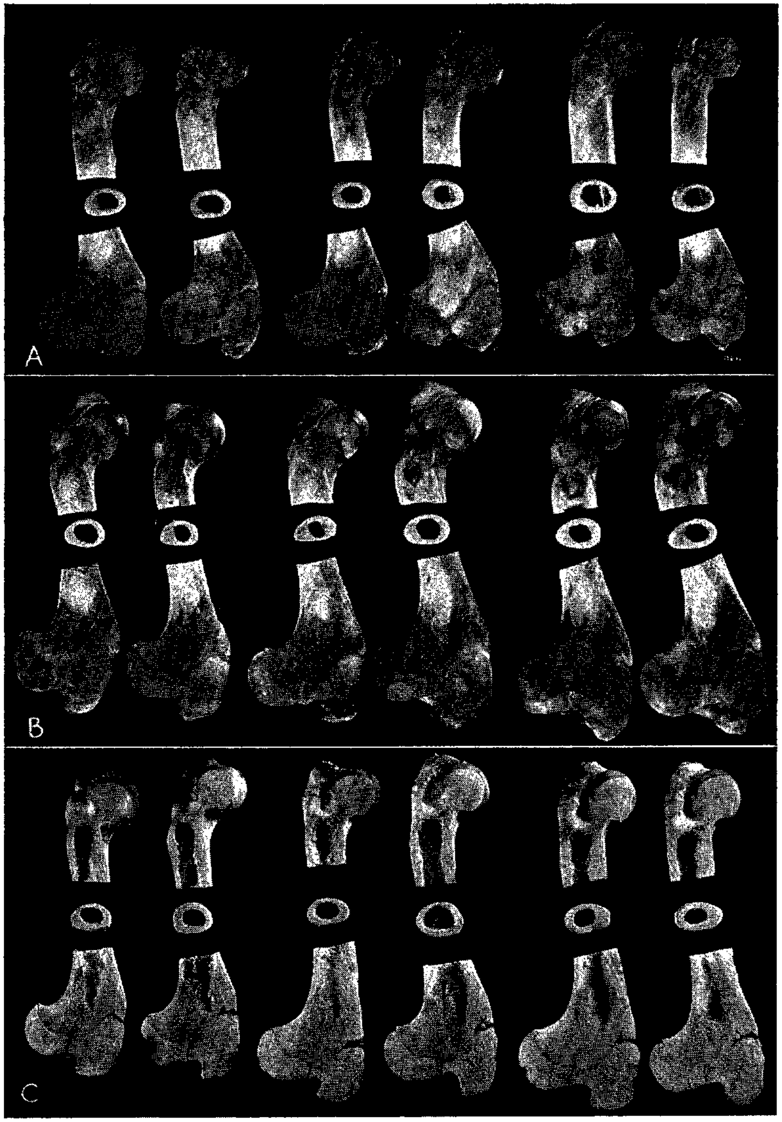

FIG. 17.—Longitudinal sections and cross-section rings of the left humeri of: (A) Pigs slaughtered at the end of 8 weeks; (B) pigs slaughtered at the end of 16 weeks; and (C) pigs slaughtered at the end of 24 weeks. The two bones on the left in each group are from the low-phosphorus pigs receiving only 0.15 percent phosphorus in their ration; the middle two bones in each group are from pigs receiving 0.23 percent phosphorus in their ration; and the two bones on the right in each group are from pigs receiving 0.3 percent phosphorus in their ration. The low-phosphorus pigs developed considerably less bone than the medium-phosphorus pigs. The medium-phosphorus pigs developed less bone than the high-phosphorus pigs. Note the short length and the thin walls of the bones of the low-phosphorus pigs.

The data indicating the thicknesses of the bone walls conform very well with the specific gravity and the breaking pressure data. They show that the thinnest bone wall was in the lot 4 pigs and that in lot 5 the bone wall was somewhat thicker. The heaviest bone wall was found in the lot 6 pigs.

The thickness of bone walls and the length and diameter of the bones of the three lots are illustrated in figure 17.

CHEMICAL COMPOSITION

After the bones had been measured and crushed to determine the physical data, they were analyzed in the same manner as in Experiment i. It is impossible to give the results of these analyses, for a short time after their completion they were destroyed by fire along with the balance-trial records already mentioned as having been destroyed in the burning of the chemistry building.

However, the data showed that the bones of the lot 6 pigs had as much ash, calcium, and phosphorus as the pigs in lots 2 and 3 in Experiment I. The amounts of these substances were slightly less in lot 5. In lot 4 the amounts were decidedly less and corresponded to the amount in the bones of the pigs in lot 1, Experiment I.

From the data relating to the physical measurements of the bones and the chemical composition, it is evident that the amount of phosphorus in the ration of lot 4, which received 0.15 percent phosphorus was not enough to develop normal bone and that since the data for the bones of the pigs comprising lot 5, which received 0.23 percent phosphorus, showed them to be less normal than those in lot 6, which received 0.3 percent, it would indicate that 0.23 percent was not enough phosphorus in the ration for optimum development of bone.

REQUIREMENTS OF PHOSPHORUS DETERMINED FROM EXPERIMENT II

Considering the results from feeding the different levels of phosphorus in this experiment, it is clear that the level of 0.15 percent fed in lot 4 was too low to produce normal development in the pigs. The level of 0.3 percent fed in lot 6 produced normal development, while the results in lot 5, which received 0.23 percent, showed that they did not do quite so well as lot 6, indicating that this level was below the minimum amount of phosphorus necessary for normal growth and development. (Fig. 18.)

Therefore under the conditions of this experiment the minimum level of phosphorus lies some place between 0.23 and 0.3 per cent.

Calculations are given in Table XXV in order to present the amount of phosphorus ingested per unit of body weight.

FIG. 18.—The six pigs at the end of Experiment II. The pig in the foreground at the extreme left of the picture is a low-phosphorus pig. Note the crooked legs and low back. The pig in the central foreground is a medium-phosphorus pig. He shows a tendency to broken pasterns and low back.

These data show that the amount of phosphorus required daily for 100 pounds live weight in the first period of feeding for the pigs in lot 6, receiving the 0.3 percent, when their average weight was 54.6 pounds, was 6.72 grams. The requirement per 100 pounds live weight for these pigs in the third period of the experiment when their average weight was 113.8 pounds, was 4.18 grams, and in the sixth period when their average weight was 233.5 pounds, 3.5 grams.

TABLE XXV.—BODY WEIGHT, DAILY GAIN, PHOSPHORUS FED DAILY, AND PHOSPHORUS CONSUMED DAILY FOR 100 POUNDS LIVE WEIGHT

Average per pig for each period

Period (28 days).	Num. of pigs.	Body weight.			Daily gain.			Phosphorus fed daily.			Phosphorus consumed daily for 100 pounds live weight.		
		Lot 4.	Lot 5.	Lot 6.	Lot 4.	Lot 5.	Lot 6.	Lot 4.	Lot 5.	Lot 6.	Lot 4.	Lot 5.	Lot 6.
		Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*
1..........	6	50.8	53.3	54.6	0.65	0.83	0.91	1.83	2.81	3.67	3.60	5.27	6.72
2..........	6	71.4	79.0	82.3	.81	1.00	1.06	2.24	3.44	4.49	3.13	4.35	5.45
3..........	4	94.9	107.8	113.8	.86	1.05	1.19	2.38	3.65	4.76	2.50	3.38	4.18
4..........	4	119.2	141.3	150.2	.87	1.34	1.41	2.99	4.59	5.98	2.50	3.24	3.98
5..........	2	151.2	182.8	192.5	1.41	1.61	1.62	3.87	5.94	7.75	2.55	3.24	4.02
6..........	2	185.7	223.5	233.0	1.05	1.28	1.27	4.08	6.25	8.16	2.19	2.79	3.50

EXPERIMENT III

This experiment was begun November 27, 1934, and concluded May 14, 1935. The pigs employed were similar to those used in Experiments I and II (fig. 1), being pure-bred Hampshires and possessing the same breeding, age, weight, and general thrift, for they were purchased from the same breeder.

This experiment was conducted in precisely the same manner as Experiments I and II, except that all the pigs were fed for six periods of 28 days each. There was no slaughtering at the end of each two periods as in the previous experiments. Experiment III also had as its plan the feeding of three lots of pigs on similar rations, but each on a different level of phosphorus. Each lot contained three pigs except lot 7, which contained four pigs. The feeds constituting the rations were the same as those employed in the former experiments except that the debittered or palatable brand of yeast was replaced by a cheaper nondebittered product. The levels of phosphorus were a low, an intermediate, and a high, and were fed to lots 7, 8, and 9, respectively. It was decided to feed levels of phosphorus of 0.23 percent in lot 7, for the low group, 0.27 percent in lot 8, for the intermediate group, and 0.3 percent for the high group in lot 9.

These levels were decided upon because in Experiment II it was clearly demonstrated that the level of 0.3 percent produced normal development, and the 0.23 percent level was somewhat inadequate.

It was thought that if these two levels were used again in Experiment III that the results would tend to check the results in Experiment II, and that if in addition an intermediate level of 0.27 percent was used in this experiment it would help ascertain more closely the minimum requirements of a ration for young pigs.

The rations for Experiment III were compounded as they were in the previous experiments, and enough feed was prepared before starting the experiment to feed the pigs the entire time.

The percentages of calcium and phosphorus in the rations in Experiment III are shown in Table XXVI.

TABLE XXVI.—PERCENTAGES OF CALCIUM AND PHOSPHORUS IN THE RATIONS FED IN EXPERIMENT III

Calcium.			Phosphorus.		
Lot 7.	Lot 8.	Lot 9.	Lot 7.	Loy 8.	Lot 9.
Percent. 0.80	*Percent.* 0.80	*Percent.* 0.84	*Percent.* 0.23	*Percent.* 0.27	*Percent.* 0.30

RESULTS OF THE EXPERIMENT

The effect of the levels of phosphorus on the development of the pigs was determined in Experiment III in the same manner as in the previous experiments. Observations were made and data compiled pertaining to the same general developments in the body.

EFFECT OF RATIONS UPON CONSUMPTION AND UTILIZATION OF FEED

A review of the data, Table XXVII, pertaining to the effect on consumption of feed shows that the amount of feed consumed daily by each lot was the same after the second period. The low-phosphorus group, lot 7, receiving 0.23 percent phosphorus, consumed daily a little less feed the first period, and a little more the second period. This discrepancy was brought about through a difficulty in getting two of the pigs in lot 7 on feed due to the lack of palatability of the ration, which was probably due to the bitter taste of the brewers yeast used in this experiment. One of the pigs starting the experiment in lot 8 and one in lot 9 were dropped because they refused to eat a sufficient amount of the ration, which accounts for there being only three pigs in lots 8 and 9 instead of four as in lot 7. The pigs in lot 7 had their ration increased the second period a sufficient amount so that all lots would have the same average for the two periods.

Aside from the difficulty in starting the pigs on the ration there was no further trouble in getting the pigs to consume their feed. This is in accord with Experiments I and II in which there was no loss of appetite excepting in lots 1 and 4 receiving the low levels of phosphorus. Seemingly the 0.23 percent phosphorus prevented loss of appetite.

TABLE XXVII.—DAILY FEED CONSUMED AND FEED REQUIRED PER 100 POUNDS GAIN

Average per pig by 28-day periods

Period (28 days).	Feed consumed daily.		Feed required per 100 pounds gain.		
	Lot 7.	Lots 8 and 9.	Lot 7.	Lot 8.	Lot 9.
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
1	2.35	2.44	336.7	318.1	281.4
2	3.47	3.39	405.4	395.8	402.5
3	3.54	3.54	332.5	319.6	348.9
4	4.47	4.47	360.8	323.5	329.4
5	5.73	5.73	411.5	359.0	368.1
6	6.00	6.00	414.8	416.8	423.1
Average	4.26	4.26	376.9	355.4	358.9

Four pigs in lot 7, three pigs in each of lots 8 and 9.

A review of the data, Table XXVII, shows that lot 7, the low-phosphorus group, had the largest food consumption per 100 pounds gain throughout the experiment, which shows that the 0.23 percent phosphorus received by this lot was not adequate for normal nutrition. The fact that lot 8, receiving the 0.27 percent phosphorus, utilized their feed as well as lot 9, which received 0.3 percent phosphorus, would indicate that the 0.27 percent in the ration was as efficient as the 0.3 percent as far as feed utilization per 100 pounds gain is concerned.

EFFECT OF RATIONS UPON BODY GROWTH AND DEVELOPMENT

The effect of the rations on body growth and development was determined as in Experiments I and II. The data collected included that pertaining to the body weight and daily gains, and the body height, length, girth, and shin measurements. These data are presented in Tables XXVIII, XXIX, and XXX.

TABLE XXVIII.—BODY WEIGHT AND DAILY GAIN
Average per pig by 28-day periods

Period (28 days).	Body weight.			Daily gain.		
	Lot 7.	Lot 8.	Lot 9.	Lot 7.	Lot 8.	Lot 9.
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Initial	40.6	40.1	41.1	....	....	....
1	58.2	61.6	64.3	0.70	0.76	0.86
2	82.2	85.6	86.6	.86	.86	.84
3	112.0	116.6	115.0	1.06	1.10	1.01
4	146.7	155.3	153.0	1.23	1.38	1.35
5	185.7	200.0	196.6	1.39	1.59	1.55
6	226.2	240.3	236.3	1.44	1.44	1.41
Average	....	....	....	1.11	1.18	1.17

Four pigs in lot 7, three pigs in each of lots 8 and 9.

TABLE XXIX.—HEIGHT AT SHOULDERS, LENGTH OF BODY FROM BASE OF EARS TO ROOT OF TAIL, AND CIRCUMFERENCE OF THE LEFT FORE SHIN
Average per pig by 28-day periods

Period (28 days).	Height at shoulders.			Length of body.			Circumference of left fore shin.		
	Lot 7.	Lot 8.	Lot 9.	Lot 7.	Lot 8.	Lot 9.	Lot 7.	Lot 8.	Lot 9.
	Ins.	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*
Initial	15.3	15.1	15.4	26.0	26.1	26.2	4.0	4.1	4.1
1	18.3	18.4	18.5	29.5	30.2	30.0	4.5	4.5	4.5
2	20.5	21.0	21.0	34.5	35.1	34.7	5.0	5.0	5.0
3	22.5	22.0	22.2	36.8	37.1	36.4	5.4	5.4	5.6
4	23.1	24.2	24.0	41.5	42.8	43.1	5.9	5.9	5.8
5	25.5	25.9	25.8	44.7	44.8	44.3	6.1	6.2	6.1
6	26.9	27.3	27.5	46.7	47.6	48.1	6.5	6.6	6.6

Four pigs in lot 7, three pigs in each of lots 8 and 9.

TABLE XXX.—CIRCUMFERENCE OF BODY AT HEART, PAUNCH, AND FLANK GIRTHS

Average per pig by 28-day periods

Period (28 days).	Heart circumference.			Paunch circumference.			Flank circumference.		
	Lot 7.	Lot 8.	Lot 9.	Lot 7.	Lot 8.	Lot 9.	Lot 7.	Lot 8.	Lot 9.
	Ins.	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*
Initial....	24.8	24.3	25.0	26.2	25.8	26.0	24.6	24.6	24.9
1........	28.8	29.2	29.1	31.0	31.0	31.0	28.7	28.7	29.1
2........	33.2	32.4	33.1	33.5	34.2	34.3	31.3	32.0	31.0
3........	35.9	36.4	38.2	38.3	38.4	38.1	34.7	36.0	34.8
4........	39.4	40.1	39.7	40.8	42.9	42.9	39.3	40.1	39.7
5........	43.3	42.9	42.8	45.5	44.6	44.5	42.2	42.4	42.1
6........	46.7	47.1	47.5	49.8	50.7	51.0	47.0	47.2	47.8

Four pigs in lot 7, three pigs in each of lots 8 and 9.

From an inspection of the data in Table XXVIII, lot 7 failed to gain so well as the other two lots the first five periods, but in the last period they gained as well as the other two lots. An average of the gains for the entire experiment shows that the gains of lot 7 were not so satisfactory as the gains of lots 8 and 9. This would indicate that the 0.23 percent phosphorus fed to lot 7, was inadequate for normal gains in weight. Since lot 8, receiving 0.27 percent phosphorus, made slightly greater gains than those made by lot 9 which received 0.3 percent, it would indicate that the 0.27 percent phosphorus was adequate for normal body gain.

In regard to the measurements of the bodies of the pigs as shown in Tables XXIX and XXX it is clear that the 0.23 percent phosphorus received in lot 7 was inadequate, as was the same amount of phosphorus in the ration of lot 5, Experiment II. It is also evident that lot 8, receiving the 0.27 percent phosphorus, did not make quite so good body development as lot 9, which received 0.3 percent phosphorus. This would indicate that the 0.27 level is below the amount required for normal body development.

Figures 19, 20, and 21 provide pictorial evidence of the effects of the different levels of phosphorus on body growth.

FIG. 19.—(A) Pig No. 1C; (B) Pig No. 4C, lot 7, at the end of Experiment III. These pigs received 0.23 percent phosphorus in their ration. Note the tendency to crooked legs and weak pasterns. This amount of phosphorus was inadequate to insure normal development.

FIG. 20.—(A) Pig No. 8C, a representative of lot 8; (B) Pig No. 10C, a representative of lot 9, at the end of Experiment III. Pig No. 8C received 0.27 percent phosphorus in her ration, gained as much in weight, but did not develop quite the depth and length of body as the pigs in lot 9. No. 10C apparently developed normally, which indicated that 0.3 percent in the ration was adequate for normal development.

FIG. 21.—The ten pigs at the end of Experiment III. The pig in the foreground at the left of the picture is a low-phosphorus pig. Note the crooked legs and low back.

EFFECT OF RATIONS UPON COMPOSITION OF THE BLOOD

An inspection of the data of Table XXXI shows that lot 7, receiving 0.23 percent phosphorus in the ration, had the lowest amount of inorganic phosphorus in the blood. It is significant that while the amount of inorganic phosphorus in the blood in this lot dropped slightly from the initial amount, there was sufficient amount of phosphorus in the feed apparently to prevent any further decline in the blood during the remainder of the experiment. These data also show that lot 9 had the largest amount of inorganic phosphorus in the blood, and that the content for lot 8 was somewhat lower than lot 9, and higher than lot 7.

The amount of calcium varied little in the three lots of pigs but, as in previous experiments, this substance was slightly higher at the end of the experiment in the lots receiving the smallest amounts of phosphorus in their ration.

TABLE XXXI.—CALCIUM AND INORGANIC PHOSPHORUS CONTENT OF THE BLOOD

Average per pig by 28-day periods

Period (28 days).	Calcium (mg. per 100 c. c. serum).			Inorganic phosphorus (mg. per 100 c. c. whole blood)		
	Lot 7.	Lot 8.	Lot 9.	Lot 7.	Lot 8.	Lot 9.
Initial	10.4	10.5	10.7	5.6	5.1	5.5
1	....	....	....	....	....	....
2	13.1	12.3	12.3	4.3	4.3	4.5
3	13.1	11.9	11.6	4.1	4.5	4.4
4	12.4	11.6	11.5	4.1	4.5	4.7
5	12.7	11.8	11.7	4.3	4.7	5.1
6	12.6	12.0	11.8	4.5	5.3	6.1

Four pigs in lot 7, three pigs in each of lots 8 and 9.

EFFECT OF RATIONS UPON INTERNAL ORGANS AND THE CARCASSES

The data, Table XXXII, show the weight of the heart, liver, spleen, brain, and the two kidneys expressed as percentages of the body weight. The weights of the brains of the pigs in lot 7, receiving 0.23 percent phosphorus, were larger at the time of slaughter than the brains of the pigs of the other two lots, receiving 0.27 and 0.3 percent phosphorus, respectively. The figures also show a difference in the size of the kidneys. These differences, although small, are in line with the differences found in Experiments I and II, where significant differences in the relative size of the organs were found between the low-phosphorus fed pigs and those receiving larger percentages of phosphorus. Table XXXII also shows the measurements of the thickness of the back fat and figure 22 presents it pictorially.

TABLE XXXII.—WEIGHT OF THE BODY ORGANS COMPARED TO THE DRESSED BODY WEIGHT, THE DRESSING PERCENTAGE, AND THE THICKNESS OF THE BACK FAT

Average per pig

	Percentage of dressed body weight.		
	Lot 7.	Lot 8.	Lot 9.
Heart	0.32	0.31	0.29
Liver	1.89	1.47	1.41
Spleen	.18	.17	.17
Brain	.13	.11	.12
Kidneys	.36	.34	.33
Dressing percentage	84.19	82.65	79.62
Thickness of back fat:	*mm.*	*mm.*	*mm.*
7th vertebra	42	45	42
11th vertebra	41	43	38
13th vertebra	39	41	34

PATHOLOGICAL INSPECTION OF THE CARCASSES

The pathology revealed by the pigs in this experiment was not at all striking. There was no outstanding lesions, which is in accord with the findings in Experiments I and II in the lots receiving similar levels of phosphorus. However, it was observed that the bones of the low-phosphorus pigs were softer than those of the pigs receiving higher levels of phosphorus. All of the pigs with the exception of pig No. 11 in lot 9 presented an acute catarrhal gastritis. Pig No. 1, lot 7, showed a few small areas of broncho-pneumonia.

No explanation of these lesions was found. Debittered yeast was not used in this experiment and it is possible that the bitter substance in the yeast may have some connection with the inflammation of the stomach although there is no direct evidence of such. The small area of broncho-pneumonia was probably of embolic origin.

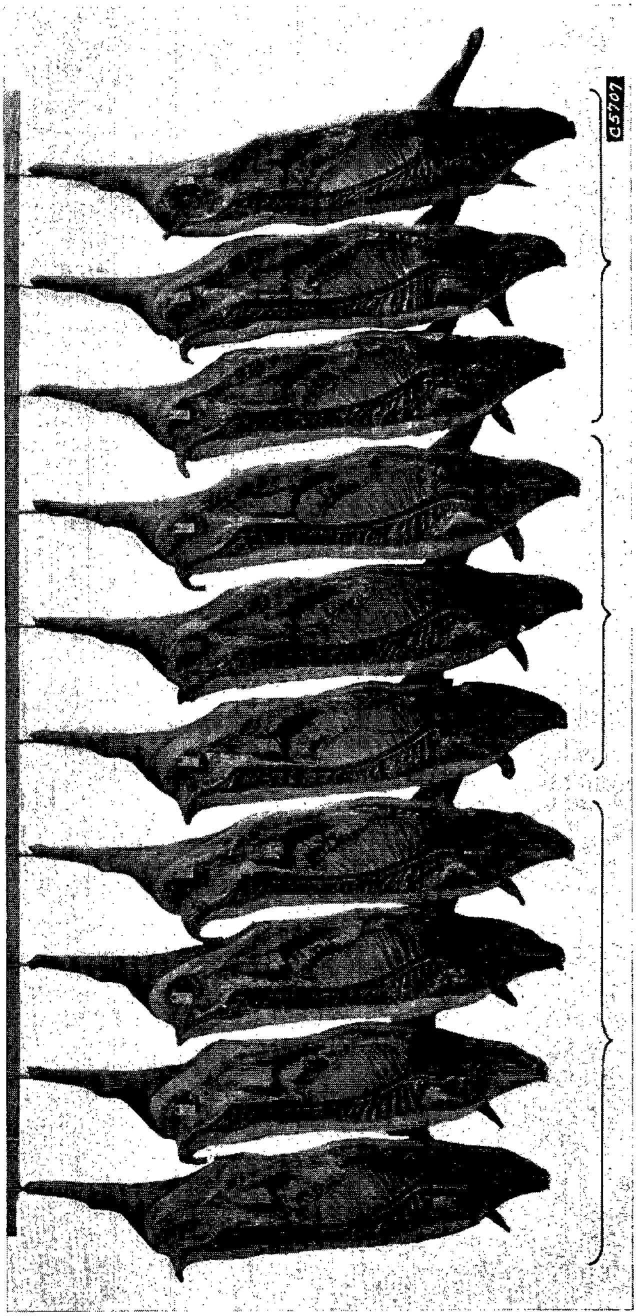

FIG. 22.—The carcasses of the pigs slaughtered at the end of Experiment III. Note the length and thickness of the carcasses. The four carcasses on the left are from lot 7; the next three carcasses are from lot 8; and the three on the right are from lot 9.

Microscopically there was no outstanding pathology found in the internal organs, except in the stomachs and lungs. The kidneys did not present the chronic diffuse nephritis of the parenchymatous type and degeneration of the epithelial cells found in the other two experiments in which the pigs received lower levels of phosphorus.

EFFECT OF RATIONS UPON THE BONES

Two leg and two rib bones were removed from the right side of each carcass of the pigs slaughtered at the end of the experiment. These bones were used to determine the effect of the rations upon physical measurements and chemical composition of the skeleton.

PHYSICAL MEASUREMENTS

Table XXXIII shows the data on the physical measurements of the bones. An inspection of these data shows the specific gravity of the bones in the lot 7 pigs on the 0.23 percent phosphorus level to be less than those in lot 8, receiving 0.27 percent. The specific gravity of the bones of the lot 8 pigs was less than those in lot 9 receiving 0.3 percent.

TABLE XXXIII.—SPECIFIC GRAVITY, BREAKING STRENGTH, LENGTH, DIAMETER, THICKNESS OF WALL, AND PERCENTAGE OF ASH OF THE GREEN LEG AND RIB BONES

Average per pig

		Lot 7.	Lot 8.	Lot 9.
Specific gravity	Humerus	1.215	1.231	1.251
	Femur	1.199	1.212	1.284
	6th rib	1.093	1.151	1.241
	11th rib	1.189	1.247	1.301
		Lbs.	*Lbs.*	*Lbs.*
Breaking pressure	Humerus	1,070	1,295	1,303
	Femur	922	1,270	1,303
	6th rib	102	172	216
	11th rib	101	172	190
		Ins.	*Ins.*	*Ins.*
Length of bones (*a*)	Humerus	7.16	7.18	7.11
	Femur	8.30	8.30	8.40
	6th rib	7.99	7.91	7.82
	11th rib	7.71	7.70	7.84
Diameter of bones (*b*)	Humerus	0.911	0.912	0.926
	Femur	.897	.899	.909
Thickness of wall (*c*)	Humerus	0.193	0.201	0.229
	Femur	.167	.168	.207
		Percent.	*Percent.*	*Percent.*
Ash (*d*)	Humerus and Femur	60.1	61.9	63.1
	6th and 11th ribs	58.5	60.4	62.4

(*a*) Leg bones, length over all. Ribs, shortest distance from head to end of shaft.
(*b*) Average of smallest and greatest diameter at breaking point.
(*c*) Average of smallest and greatest thickness of wall at breaking point.
(*d*) Ash percentage on dry fat-free bones.

The breaking pressures of the bones in the lots were significant. The weakest bones were found in lot 7, and the strongest in lot 9. The bones in lot 8 were stronger than those in lot 7, and weaker than those of lot 9.

The data indicating the thickness of the bone walls conform with the specific gravity and the breaking-pressure data. They show that the thinnest bone walls were in the lot 7 pigs and that in the lot 8 pigs the bone walls were somewhat thicker. The heaviest bone walls were found in the lot 9 pigs.

The thickness of the bone walls and the diameter of the bones of the three lots are illustrated in figure 23.

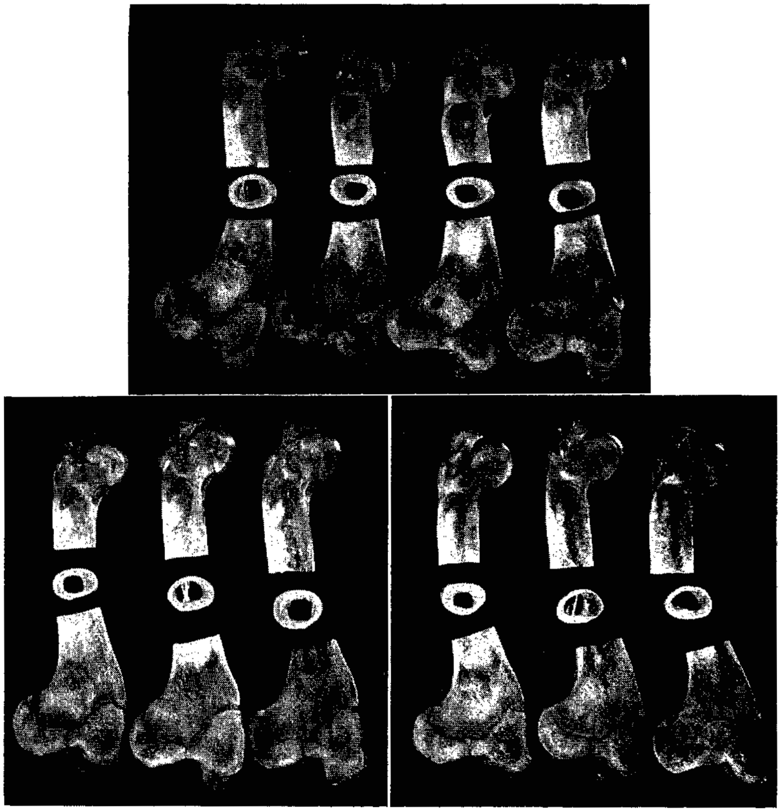

FIG. 23.—Longitudinal sections and cross-section rings of the left humeri of the pigs slaughtered at the end of Experiment III. The four bones at the top are from the low-phosphorus pigs receiving 0.23 percent phosphorus in their ration. The three bones on the left bottom are from pigs receiving 0.27 percent phosphorus in their ration, and the three bones on the right bottom of the picture are from pigs receiving 0.3 percent phosphorus.

CHEMICAL COMPOSITION

The percentage of ash in the dry fat-free bones is also shown in Table XXXIII.

The greatest percentage of ash was found in the bones of the lot 9 pigs and the smallest percentage was found in the lot 7 pigs. This also correlates with the specific gravity, breaking pressure, and thickness of the walls of the bones of the pigs in the different lots.

From these data it is observed that the 0.27 percent of phosphorus in the ration fed to lot 8 did not cause so much deposition of mineral in the bone as the 0.3 percent fed in lot 9.

REQUIREMENTS OF PHOSPHORUS DETERMINED FROM EXPERIMENT III

Considering the results from feeding the different levels of phosphorus in this experiment, it is clear that the level of 0.23 percent fed in lot 7 was too low for normal development of the pigs. The level of 0.3 percent fed in lot 9 produced a normal development, which was quite comparable to the development of the pigs in lot 2, Experiment I, and lot 6, Experiment II, which received the same level of phosphorus.

The results produced in the pigs of lot 8, which received 0.27 percent, show that they did not do quite so well as the pigs of lot 9 in bone development and the content of phosphorus in the blood. This indicates that the 0.27 percent was below the minimum amount of phosphorus necessary for normal bone development. However, lot 8 made as satisfactory daily gain and as satisfactory utilization of feed as did lot 9. Therefore, under the conditions of this experiment it appears that 0.27 percent phosphorus is sufficient for normal gains and utilization of feed, but it is not sufficient to produce the maximum mineralization of the bones which is obtained by the use of 0.3 percent.

Calculations are given in Table XXXIV in order to present the amount of phosphorus ingested per unit of body weight.

These data show that the amount of phosphorus required per 100 pounds live weight in the first period of feeding for the pigs in lot 9, receiving 0.3 percent when their average weight was 64.3 pounds, was 5.14 grams. The requirement per 100 pounds live weight for these pigs in the third period of the experiment when their average weight was 115 pounds, was 3.87 grams, and in the sixth period when their average weight was 236.3 pounds, 3.45 grams.

TABLE XXXIV.—BODY WEIGHT, DAILY GAIN, PHOSPHORUS FED DAILY, AND PHOSPHORUS CONSUMED DAILY FOR 100 POUNDS LIVE WEIGHT

Average per pig by 28-day periods

Period (28 days).	Body weight.			Daily gain.			Phosphorus fed daily.			Phosphorus consumed daily for 100 pounds live weight.		
	Lot 7.	Lot 8.	Lot 9.	Lot 7.	Lot 8.	Lot 9.	Lot 7.	Lot 8.	Lot 9.	Lot 7.	Lot 8.	Lot 9.
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*
1	58.2	61.6	64.3	0.70	0.76	0.86	2.44	2.98	3.31	4.19	4.83	5.14
2	82.2	85.6	86.6	.86	.86	.84	3.61	4.14	4.61	4.39	4.83	5.32
3	112.0	116.6	115.0	1.06	1.10	1.01	3.69	4.33	4.81	3.29	3.71	3.87
4	146.7	155.3	153.0	1.23	1.38	1.35	4.66	5.47	6.08	3.17	3.52	3.97
5	185.7	200.0	196.6	1.39	1.59	1.55	5.97	7.01	7.79	3.21	3.50	3.96
6	226.2	240.3	236.3	1.44	1.44	1.41	6.25	7.34	8.16	2.76	3.05	3.45

Four pigs in lot 7, three pigs in each of lots 8 and 9.

GENERAL DISCUSSION OF RESULTS

In bringing together the results of the three experiments it is desirable to discuss them under the two phases originally planned for the study. Phase I, which considers the effects of deficient amounts of phosphorus in the ration on the development of young pigs, and Phase II, which has to do with the least amount of phosphorus in the daily diet that is necessary to support efficient feed utilization, normal growth of the body, and normal development of the blood and bone.

PHASE I—EFFECT OF LOW-PHOSPHORUS RATIONS ON DEVELOPMENT OF PIGS

In general the effects of feeding low-phosphorus rations to pigs in these experiments have been quite similar to those observed in other animals. As these experiments were conducted there were five very decided effects. There were probably other unmeasured ones not brought out by the methods employed, but five obvious effects stand out in importance. These were observed in the blood, the growth of the body and the development of bone and muscle, the utilization of feed and storage of energy, the appetite, and in the thirst and urination of the pigs.

BLOOD

Palmer and Eckles *(56)* and Riddell, Hughes, and Fltch *(58)* in this country, and Malan, Green and DuToit *(48)* in South Africa, have demonstrated that the outstanding characteristic of the blood of animals in a state of phosphorus deficiency is its low inorganic phosphorus content. In their experiments, as well as in the present investigation, it was observed that this fraction of the blood may drop well below the normal value, even before the disease can be diagnosed clinically.

In the case of dairy cows, it is possible to decrease the inorganic phosphorus content of the blood to approximately 1½ milligrams per 100 c.c. during heavy lactation. In the pigs in these experiments, the inorganic phosphorus content was observed to go below 3 milligrams per 100 c.c. only four times. The lowest point reached at any time was 2.6 milligrams.

This may be accounted for by the fact that the dairy cow requires more phosphorus because of the production of milk and therefore reduces the blood phosphorus to a very low level.

The fact that the inorganic phosphorus content of the blood of these pigs was seldom below 3 milligrams may account for the fact that there was not so much variation in the feed utilization between the pigs receiving a high level of phosphorus in their ration and those receiving a low level, as there was in the case of the dairy cattle.

GROWTH

One of the more marked effects of the lack of phosphorus in the ration was a failure of the body to grow, and especially to develop bones and muscle to a normal extent.

In experiments with cattle, Eckles, Becker, and Palmer *(20)* had observed that cattle grown in western Minnesota were decidedly stunted in growth of body. Theiler and co-workers *(65)* also reported stunted cattle on phosphorus-deficient rations. Henderson and Weakley *(36)* found a retarded growth in the dairy cattle to which they fed low-phosphorus rations. Their cattle, however, continued to gain in weight and in height at withers in the early stages of their experiment almost as well as the animals fed a normal ration; but over a period of 2 years the cattle did not make the gains either in weight or height at withers that were made by the cattle fed a normal ration.

In experiments with pigs, Hart, McCollum, and Fuller *(34)* found that on rations extremely low in phosphorus the percentage of ash in the skeleton was reduced to nearly one half that of the pigs receiving normal rations. Henderson and Weakley *(36)* found that in feeding rations that were low in phosphorus to dairy calves there were very significant reductions in the bones in ash, breaking strength, and size.

In this study with pigs, the bones failed to develop fully because of the inadequate supply of phosphorus; the failure manifested itself in the appearance, breaking strength, and in the mineral composition.

A comparison of the figures at the end of Experiment I shows that the leg bones of the pigs on the high levels of phosphorus, receiving 0.33 and 0.59 percent of phosphorus in their rations, were 6 percent greater in length, had 96.9 percent thicker shaft walls, 15.8 percent greater specific gravity, 165.6 percent more breaking strength, and in mineral composition had 15.4 percent more ash than the corresponding bones of the pigs receiving only 0.18 percent phosphorus. Quite similar differences were observed in Experiment II between the lots receiving 0.3 percent phosphorus and 0.15 percent.

This smaller size of bone reflected itself in the size of the pigs, for the high-phosphorus pigs at the end of Experiment I were 8.6 percent longer in body and 4.6 percent higher at shoulder than the low-phosphorus pigs. In Experiment II the differences were 15.6 percent and 13.1 percent, respectively, between lots 6 and 4.

This smaller size of bone also was correlated with the lighter body weight found in the low-phosphorus pigs. The difference was 17 percent in favor of the high-phosphorus pigs in Experiment I and 25.1 percent in Experiment II between lots 6 and 4.

It is rather to be expected that the growth of bone, which contains a high percentage of calcium and phosphorus, would be materially influenced if the phosphorus were not provided in the feed. It is not generally thought, however, that this mineral plays such an important part in the development of the muscle, because the percentage of ash in muscle is comparatively low. When it is considered that phosphoric acid is an integral part of the nuclei of the cells, which have much to do with the cell development, and that the phospholipins play an essential part in the function of the muscle fibre, it does not seem impossible that a deficiency in phosphorus would be reflected in decreased muscle development.

There is another possibility which might account for the failure of a pig to grow on a low-phosphorus ration. It is well recognized that the impulse to grow is directly controlled by a hormone elaborated in the anterior pituitary gland. It is not an impossibility that phosphorus deficiency might in some way interfere with the hormone balance, thus resulting in a decreased rate of growth.

No attempts were made in these studies to investigate either the phosphorus fraction of the muscle, or the effect of the growth hormone. It is planned in future experiments to make such studies, for it may be possible in this way to determine whether this growth is a direct or indirect result of the inadequate amount of phosphorus furnishing the necessary building material.

UTILIZATION OF FEED AND STORAGE OF ENERGY

While no direct measurements of the storage of energy were made in this experiment, the results clearly show that the pigs receiving the low-phosphorus ration stored less energy than those receiving higher amounts. The difference, however, is not so great as might be indicated by the difference in the body weights, because the low-phosphorus fed pigs carried a higher percentage of fat and showed better finished carcasses.

The measurements of the thickness of the back fat opposite the seventh dorsal vertebra indicate by use of the factors suggested by Hankins and Ellis *(33)* that the low-phosphorus pigs had an average of approximately 96 pounds of fat on their carcasses compared with 108 pounds for the high-phosphorus pigs.

In the case of dairy animals on a low-phosphorus ration, it is impossible to keep the animal fat because the feed is not only poorly utilized but it is impossible to induce the animal to eat sufficient amounts of the ration in the later stages of aphosphorosis. It was possible with the pigs in this study to take advantage of their increased thirst and force them to eat their feed in the form of a slop, and thus provide excess energy to be deposited in the form of fat, even though they were not utilizing their feed so adequately as the normal pigs.

It is planned to feed other pigs in a similar manner and determine the storage of energy from the chemical composition of the carcasses. This should make it possible to determine to what extent aphosphorosis decreases food utilization in the pig.

APPETITE

Loss of appetite in the low-phosphorus pigs began to appear as early as 5 or 6 weeks after the pigs were placed on feed, making it necessary to feed very carefully in order to have them consume the same amounts of food as the other pigs. By the end of the fifth period it was no longer possible to get the pigs to eat the ration in a dry form. It was, however, possible to induce them to eat by mixing it with their drinking water. Toward the end of the experiment it was necessary to withhold all drinking water except that mixed with the feed. By mixing small portions of the feed in the water five or six times each day it was possible to get them to eat nearly 6 pounds daily at the end of the experiment. They soon learned to wait for the feed to settle out of the water. It was necessary, therefore, for an attendant to keep stirring the mixture in order to have the feed consumed.

No difficulty was experienced in loss of appetite with the pigs in lots 2, 3, 5, 6, 7, 8, and 9, which were on higher levels of phosphorus.

By forcing the pigs on the low-phosphorus ration to consume their daily allowance of feed, they were able to deposit relatively more fat in proportion to their body weight but less total fat than the pigs on higher levels.

THIRST

The literature, so far as the authors have observed, does not mention an increased thirst as one of the symptoms of aphosphorosis. In the experiment conducted by Riddell, Hughes, and Fitch *(58)*, although the authors do not specially mention it, the data for the digestion trial with dairy cows in which the consumption of water was accurately measured, showed that the average amount of water consumed by the two low-phosphorus cows was about 4 percent more than for the cows receiving the same ration supplemented with phosphorus. The low-phosphorus cows excreted 27.2 percent more urine.

In the case of the pigs in this experiment the increased thirst was outstanding. (Tables VIII and XIX.) Not only did the pigs on the low-phosphorus ration drink two times more water than the pigs on the higher levels of phosphorus, but their urine excretion was nearly twice as great in proportion to the water consumed. This points to some derangement of the water balance in the animals, which might be associated with changes in the permeability of the cells, resulting from changes in the phosphorus compounds or injury to the kidney tissue. No doubt the enlarged kidney and the chronic diffuse nephritis observed microscopically in sections of the kidneys from the pigs on the low-phosphorus ration were contributing to the excess urination and thirst observed throughout the experiments.

This increased urine output might be accompanied with abnormal losses of partially oxidized materials, which would account in part for the poor utilization of feed. This explanation for the poor utilization of the feed is eliminated in the case of the dairy cow, since Riddell, Hughes, and Fitch *(58)* showed by the gross energy determinations of the urine that there was "no abnormal loss of energy in the urine of the low-phosphorus cows resulting from the elimination of partially oxidized materials." This would suggest that such losses do not occur in the urine of pigs. However, this fact can be determined only by actual analysis.

PHASE II—THE REQUIREMENTS OF PHOSPHORUS

In Experiment I the levels of phosphorus in the rations fed the pigs were 0.18 percent for lot 1, 0.33 percent for lot 2, and 0.59 percent for lot 3.

From a consideration of the results of feeding these levels to young growing pigs for 24 weeks, it is apparent that the 0.18 percent of phosphorus fed in lot 1 did not provide enough phosphorus because the pigs failed to grow and develop normally. They failed to utilize their feed as efficiently and did not maintain their blood composition in phosphorus nor develop so strong and heavy bones as the pigs in lot 2, receiving 0.33 percent of phosphorus, or those in lot 3, receiving 0.59 percent.

From a comparison of the results from feeding the 0.33 percent phosphorus in lot 2 with those from feeding the 0.59 percent in lot 3, it is apparent that the pigs receiving the higher percentage did no better than those receiving 0.33 percent, for the pigs of both lots gained in body weight and developed at the same rate. They also were similar in the amount of feed consumed per 100 pounds gain and in the mineral composition and strength of the bones.

Therefore, from the results of Experiment I in which vitamin D was provided, it may be concluded that the minimum requirements of phosphorus in the ration for growing pigs should be definitely above 0.18 percent and probably below 0.33 percent.

Accordingly the highest level fed in Experiment II was 0.3 percent in lot 6. The middle level was 0.23 percent, and a level of 0.15 percent was fed in lot 4 to demonstrate again the effect of an amount definitely below the minimum for normal development.

From a consideration of the results from feeding these levels it is clearly evident that the 0.15 percent in lot 4 was too low because the gains in body weight, the growth, the utilization of feed, and the composition of the blood and bone of the pigs were similar to those obtained from feeding 0.18 percent phosphorus to the pigs in lot 1, Experiment I.

The satisfactory performance of lot 6, receiving 0.3 percent, showed that this level was adequate.

The results of lot 5, receiving 0.23 percent, showed that they did not do quite so well as lot 6, indicating that this level is below the minimum amount of phosphorus necessary for normal growth and development in growing pigs.

From this it is reasonable to conclude that under the conditions of this experiment the minimum level of phosphorus lies between 0.23 percent and 0.3 percent.

Accordingly the highest level fed in Experiment III was 0.3 percent in lot 9. The low level was 0.23 percent in lot 7, and a middle level of 0.27 percent was fed to lot 8.

From a consideration of the results from feeding these levels it is evident that the 0.23 percent fed in lot 7 was too low because the gain in body weight, the growth, the utilization of feed, and the composition of the blood and bone of the pigs were similar to those obtained from feeding the 0.23 percent phosphorus to the pigs in lot 4, Experiment II, in which it was indicated that this level was below the minimum amount of phosphorus necessary for normal growth and development. It is significant to point out, however, that while the amount of inorganic phosphorus in the blood in this lot dropped slightly from the initial amount, there was sufficient amount in the feed apparently to prevent any further decline during the remainder of the experiment.

The results obtained from lot 8, receiving 0.27 percent, showed that this amount of phosphorus was sufficient for normal gain and utilization of feed during the 24 weeks of the experiment, but it was not sufficient to produce the maximum mineralization of the bones which was obtained by the use of the 0.3 percent in lot 9.

The level 0.3 fed to lot 9 produced normal development, which was quite comparable to the development of the pigs in lot 2, Experiment I, and lot 6, Experiment II, which received the same level of phosphorus.

From this it is reasonable to conclude that under the conditions of this experiment the minimum level of phosphorus lies between 0.27 percent and 0.3 percent.

This represents a daily intake of about 6.5 grams of phosphorus per 100 pounds of live weight where a pig weighs about 50 pounds, and about 4 grams per 100 pounds live weight where the pig weighs about 200 pounds. While it would be desirable to separate the requirements into those for maintenance and those for growth, it cannot be done with the data available.

SUMMARY AND CONCLUSIONS

The results are reported of an investigation of the effects of the feeding of different levels of phosphorus in the rations of 46 young pigs.

Three experiments, each involving three lots of pigs, were carried on for 24 weeks.

Data are presented, first to show the effect of deficient amounts of phosphorus in the ration on the growth and development of pigs, and second to determine the minimum amount of phosphorus necessary in a ration for the normal growth and development of pigs.

The results obtained indicate that the abnormalities resulting from feeding low-phosphorus rations were: (1) A lowering of the inorganic phosphorus in the blood; (2) a failure of normal growth and development of bone and muscle; (3) a utilization of feed and storage of energy; (4) a loss of appetite; (5) a marked increase in thirst and a corresponding excretion of urine.

Under the conditions of this investigation the minimum requirements of phosphorus in the ration of growing pigs were found to be between 0.27 percent and 0.3 percent. This represents a daily intake of about 6.5 grams of phosphorus per 100 pounds live weight, when a pig weighs about 50 pounds; and about 4 grams per 100 pounds live weight when a pig weighs about 200 pounds.

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