BONEMEAL AND ROCK PHOSPHATE AS SOURCES OF CALCIUM AND PHOSPHORUS FOR WEANER AND GROWER PIGS.

BY

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ATHESIS

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DECLARATION:

I hereby declare that this thesis has been written by me and that it is a record of my own research work. It has not been presented in any previous application for a higher degree. All quotations are indicated and sources of information are specially acknowledged by means of references.



THESIS APPROVAL:

This thesis by KAANKUKA, FABIAN GYIZAKA meets the regulations governing the award of the degree, Master of Science of Ahmadu Bello University, Zaria and is approved for its contribution to scientific knowledge and literary presentation.

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DEDICATION:

This Thesis is dedicated to the memory of my father the late

MR. KAANKUKA NENKOP (RIP)
(1926 - 1988)

His silent presence guided my effort.

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F.G. Kaankuka
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ABSTRACT:

Three experiments involving a total of 78 Large White X Hampshire cross-bred pigs were conducted to compare bonemeal and rock phosphate as sources of calcium and phosphorus for weaner and grower pigs.

In the first two trials, 48 weaner and 24 grower pigs with average initial weights of 11.85kg and 35.64kg respectively were used in 2 x 3 factorial randomized-block design experiments with two sources of calcium and phosphorus (bonemeal and rock phosphate) and three levels of calcium and phosphorus (low, medium and high). There were no significant (P>.05) differences in performance and serum calcium concentration between pigs fed bonemeal and rock phosphate supplemented diets in both trials. increasing dietary calcium and phosphorus levels did not affect performance in the weaner trial but significantly (P<.05) depressed total weight gain and average daily gain in the grower trial. Serum calcium concentration increased significantly (P<.05) at 18 days in the weaner trial but not in the grower phase while serum inorganic phosphorus concentration increased significantly (p<.05) when dietary calcium and phosphorus increased from low to high in the weaner trial but only from low to medium in the grower trial. Metacarpal bones were significantly (P<.05) longer in pigs fed bonemeal diets while those fed rock phosphate diets had higher values for metacarpal and metatarsal bone diameter. increasing dietary calcium and phosphorus levels significantly (P<.05) reduced metacarpal and metatarsal bone lengths while the medium dietary level of calcium and phosphorus resulted in significantly (P<.05)

higher values for ash, calcium and phosphorus content of metacarpals.

The third trial was a nutrient balance trial involving six litter-mate weaner barrows averaging 10.52kg used in a randomized-block design to determine the effect of source and dietary levels of calcium and phosphorus on the digestibility and retention of feed nutrients. Source of phosphorus had no effect on nutrient digestibility and retention. Apparent digestibility of dry matter decreased with increasing dietary calcium and phosphorus levels. Pigs fed the high level of calcium and phosphorus had significantly ($P<.05$) lower dry matter digestibility and retention than those fed the low and medium levels.

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CHAPTER ONE

GENERAL INTRODUCTION:

1.0 Background to the study:

Future meat production from cattle, sheep and goats is unlikely to meet expected increases in demand for animal protein in developing countries (Kroeski, 1972, 1984). These species have strong biological restraints for a rapid rise in population so that increasing their productivity will take a very long time. Furthermore, the current nomadic husbandry practised in these regions cannot rapidly improve within a short time due to socio-cultural factors. Meanwhile, the human population in these areas has been rising steadily due to high birth rates and low death rates resulting from improvements in medical services. Agricultural production especially livestock production has however not achieved any appreciable growth. This increasing population growth has continued to create additional pressure on agricultural production with consequent effects on animal protein supply.

Any concious attempt aimed at meeting the protein needs of the teaming human population in developing countries including Nigeria, should place emphasis on species like swine and poultry which have relatively shorter generation intervals and therefore a faster rate of multiplication. They are also superior to other species (cattle, sheep and goats) in their ability to convert feeds to animal protein. Modern strains of pig breeds are particularly prolific, well adapted to tropical environments and therefore have greater potential for meeting the protein needs of Nigerians. Pigs are second only to poultry in their ability to produce more edible meat per unit of live weight (Eusebio, 1980). In spite of these advantages, several problems still militate against the

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expansion of the swine industry in Nigeria.

According to Balogun (1987), the most important problem facing the development of the swine industry in Nigeria is religious prejudice which tends to deprive potential consumers access to pork and pork products. The high cost of feeds has also continued to stiffle the swine industry in areas where the industry flourishes. It is a well known fact that the nutrition of the pig resembles that of man in more ways than any other non-primate mammalian specie due to similarities in the physiology and anatomical make-up of their digestive tracts (Pond and Houpt, 1978). Although these similarities have provided a basis for use of the pig in many human nutritional studies, it has also resulted in a competition between man and pigs for the already scarce feed resources especially cereals and tubers.

Since feed costs constitute between 60 and 80 percent of the cost of production of pigs (Cunha, 1977), it has become imperative that cheaper and more readily available feed sources be evaluated for use in swine rations. A lot of research is currently on to find alternatives for the conventional protein and energy sources which are becoming increasingly scarce or are available only at prohibitive prices. The use of industrial by-products from flour milling, fermentation by-products and products of microbial culture have been scrutinized (Babatunde et al., 1975; Tegbe, 1975 and Tegbe, 1985). However, little has been done in the area of alternative mineral supplements in swine nutrition in Nigeria.

Calcium and phosphorus are two of the most important mineral elements required in the largest amounts by all

classes of livestock. About 99 percent of calcium and 80 percent of phosphorus are found in bones and teeth playing major roles in the development and maintenance of the skeletal system. The remaining 1 and 20 percent of calcium and phosphorus respectively are widely distributed in the body fluids and soft tissues where they perform many other physiological functions. An inadequate supply of these mineral elements in the diets of swine has been reported to have an adverse effect on growth and bone mineralization (NRC, 1988), while an improper ratio between them has also proved equally detrimental (Reinhart and Mahan, 1986).

Limestone has been used as a major source of calcium for pigs the world over and it is readily available in Nigeria. However, feed grade calcium and phosphorus sources are not readily available. Potchanakorn and Potter (1978) reported that phosphorus represents the third most expensive nutrient following energy and protein. Dicalcium phosphate which is a common calcium and phosphorus source for pigs in developed countries is available but at extremely high costs. The supply of bonemeal which is generally used in Nigeria is limited. Apart from the fact that Nigeria suffered from a devastating effect of rinderpest infestation which wiped out hundreds of thousands of cattle in 1982/83, drought has also been taking its toll on cattle population in the northern parts of the country. Furthermore, with industrialization, animal bones are being diverted into other uses notably for the manufacture of a host of products such as glue, gelatin, ossein, mealsfoot, dicalcium phosphate and fertilizer (Adewoye, 1982). It should be noted also that a large number of animals are slaughtered outside government approved abattoirs with the result that bones from these animals go to waste.

The actual figures of animals slaughtered in Nigeria is not known. According to the Federal Livestock Department (1986) the number of cattle slaughtered rose from 443,731 in 1972 to 1,894,371 in 1984. Adewoye (1982) reported that 1,152,000 cattle, 602,000 sheep and 1,455,000 goats were slaughtered in 1979 alone. Considering that bones account for about 17 percent of the total live weight of an animal (Adewoye, 1982), about 77,895 metric tonnes of bones was derivable that year. Despite this, the demand for bonemeal and its price has continued to rise. While in 1979 bonemeal sold for between ₦120 and ₦200 per tonne (Adewoye, 1982) it now sells for over ₦600. Okaiyeto (1986) viewed increasing prices of meat and by-products partly as a reflection of the inflationary trends in the country which followed the introduction of the Second-tier Foreign Exchange Market (SFEM) policy of the Federal Government.

It has become desirable that alternative sources of calcium and phosphorus which are cheaper and more readily available be evaluated for use in livestock feeds. One of such alternatives that readily comes to mind is rock phosphate. Large deposits of rock phosphate are found in several West African countries, notably Togo, Senegal, Benin Republic and Nigeria (Wright et al., 1985). Although rock phosphate mining is relatively new and is still largely in its exploration stage in Nigeria, commercial quantities have been found in Sokoto, Abeokuta and Arochukwu areas of Imo State (Wright et al., 1985). These deposits have great potential not only as a raw material for the manufacture of superphosphate fertilizer but also as a mineral supplement in livestock feeds. Although Nigeria currently imports rock phosphate, it is cheap. One metric tonne sells for

₦160 (Federal Superphosphate Fertilizer Company, 1989).

Since calcium and phosphorus availability in rock phosphate may differ from that of bonemeal, it is important that an optimum dietary level of calcium and phosphorus be determined using bonemeal as a standard. It is known that high levels of rock phosphate in the diets of livestock for long periods has injurious effects (Phillips et al., 1934). It is also known that rock phosphate can be used gainfully at tolerable levels in dairy cattle without adverse effects (Snook, 1962). Information is lacking on the use of rock phosphate as a calcium and phosphorus supplement in the diets of swine.

1.1 Objectives of the study.

(a) To compare bonemeal and rock phosphate as sources of calcium and phosphorus for weaner and grower pigs.

(b) To evaluate the effect of source of calcium and phosphorus and low, medium and high levels and ratios of calcium and phosphorus on growth performance, serum calcium and phosphorus concentrations and bone parameters.

(c) To evaluate the effect of source of calcium and phosphorus and dietary calcium and phosphorus levels on the digestibility and retention of the proximate components of diets, and calcium and phosphorus balance.

CHAPTER TWO:

2.0 LITERATURE REVIEW:

2.1 Mineral requirements and animal productivity in Nigeria:

Fetuga (1977) has attributed the low productivity of Nigerian livestock to "inadequate and unbalanced nutrition, inherent restricted growth, prevalence of diseases, failure to harmonize crop and animal farming in agricultural practice and inadequate knowledge of sound herd management". Adegbola (1977) also recognized low demand for livestock products due to a poorly organized marketing system as another contributory factor. Of these problems, inadequate and unbalanced nutrition ranks one of the highest. In the developing countries of the world, animal production is limited primarily by shortages of available energy and protein. As these problems are increasingly receiving attention, mineral deficiencies and imbalances are becoming more apparent and critical (Underwood, 1981).

There is a paucity of information on the mineral composition of West African feedstuffs and animal requirements. Suttle (1968) advanced two reasons for the scarcity of information on mineral element requirements of livestock in developing countries. Firstly, while it is comparatively easy to determine the energy and protein needs of livestock with considerable accuracy, it is not the case with mineral elements. Secondly, scientific resources for mineral metabolism studies often require the use of sophisticated and costly technology.

Adegbola (1977) reported that information available indicate that calcium, phosphorus and other mineral elements are deficient in some West African soils and this deficiency

will invariably be reflected in the status of feedstuffs with respect to these mineral elements. Livestock rations in these regions are largely based on feeding standards obtained from temperate countries or on extrapolations of these values. It cannot therefore be guarranteed that livestock obtain the right amounts of these mineral elements in view of the numerous variables which influence the mineral element needs of livestock. These factors include breed, species, physiology of the animal, climate, soil and chemical form in which the mineral is offered (Underwood, 1981).

When livestock do not consume adequate diets, nutritional disorders arise. These may range from acute or severe mineral deficiency or toxicity with marked clinical signs, often accompanied by high mortality, to mild subclinical conditions. These are often confused with the effects of starvation and parasitic infections. Mineral imbalances also assume great importance in animal nutrition. The relationship between calcium and phosphorus in animal nutrition has received much attention. Loosli (1973) reported that calcium present in feeds or as inorganic supplement can only be utilized if the ratio of calcium to phosphorus in the diet is satisfactory and if specific factors do not interfere with its absorption, although this depends on species. Earlier studies (Maynard et al., 1979) showed that ideal ratios for the utilization of calcium and phosphorus should lie between 2:1 and 1:1. Recent studies (NRC, 1980) however show that this is more applicable to the non-ruminants. The most favourable ratio for swine lies between 1:1 and 1.5:1 (NRC, 1988). The exactness of the ratio of calcium to phosphorus is less emphasized today than was the case. Some of the consequences of mineral imbalances include marked

losses in productivity and other sub-clinical effects which may pass undetected (Suttle, 1968).

2.2 Importance of calcium and phosphorus in livestock nutrition.

Calcium, phosphorus and vitamin D are closely related in metabolism. They jointly play a vital role in the physiology of the animal. Calcium has been recognized as a dietary essential element in animal nutrition for a long time. Its most important quantitative function is as a structural component of the skeleton. About 99 percent of total body calcium is found in bones and teeth. The remaining 1 percent functions in a number of essential processes and is found in extracellular fluid, soft tissues and as a component of various membrane structures (Bronner, 1964).

Blood clotting or coagulation is an important phenomenon in the life of an animal. It helps prevent blood loss from ruptured blood vessels resulting from an injury. Although the process is principally the function of vitamin K which is necessary for the synthesis of prothrombin in the liver, calcium is necessary for the conversion of prothrombin to thrombin which reacts with fibrinogen to form clot (Schmidt-Neilsen, 1985).

Other functions of calcium include nerve impulse condition, maintenance of muscle contraction and relaxation. Reduced calcium ion concentration results in hyperirritability of the muscular system and hypocalcaemic tetany. The maintenance of the integrity of intracellular cement substances, various membranes and the activation of some enzymes are other functions of calcium (NRC, 1980). Calcium has also been reported to govern cell permeability thereby regulating the amount of salts present (Irving, 1957).

Phosphorus was first prepared in the free state by Brandt in 1669 but its importance in nutrition was recognized in 1769 (Van Wazer, 1961). Apart from being a major component of bone and teeth which contain about 80 percent of the total body phosphorus, it is an essential component of organic compounds involved in almost every aspect of metabolism. Irving (1964) reported that phosphorus plays a key role in muscle, energy, carbohydrate, amino acid, fat and nerve tissue metabolism; normal blood chemistry and skeletal growth. It is also a constituent of necleic acids, many co-enzymes and adenosine di-and triphosphate involved in energy transfer reactions. The buffering of blood fluid has also been reported as one of the functions of phosphorus. (White et al., 1968).

2.3 Calcium and phosphorus metabolism:

2.3.1 Intestinal absorption:

Although it is generally accepted that absorption of calcium and phosphorus takes place from all sites of the intestine, studies on the rate of disappearance from the lumen showed that the principal site of absorption is the duodenum and jejunum of most species (Patridge, 1978). There are also opinions that calcium and phosphorus absorption in the stomach is of considerable importance. Moore and Tyler (1955a) reported that in early digestion, calcium and phosphorus were absorbed from the stomach at a greater rate than dry matter and insoluble ash. This preferential removal however ceased during the third two hour period of feeding.

The major mechanism of calcium transport across the mucosa is by an active transport against concentration gradient and therefore energy requiring. The evidence of the involvement of a vitamin D-dependent calcium binding protein has been reported (Wasserman and Corradino, 1973; Borle, 1974 and Wasserman and Fuller, 1983). There is also evidence that the active transport of calcium is regulated to meet the needs of the body and is most active when dietary calcium is restricted or when the needs are greater such as during pregnancy and egg production (Wills, 1983).

Several factors influence the absorption and distribution of calcium in the body. There are differences between diets in relation to the importance of the regions where absorption occurs (Moore and Tyler, 1955b). Fox and Care (1978) reported that intestinal absorption of calcium was not affected by the presence of phosphate, but calcium enhanced the absorption of phosphate. Young animals have been reported to be more efficient in calcium absorption than older ones (Hansard et al., 1961).

Although calcium and phosphorus are closely related in metabolism, their mode of absorption differ slightly. Like calcium, phosphorus absorption occurs in the small intestine, in the duodenum. In contrast to calcium however, phosphorus absorption is by a passive mechanism (Moore and Tyler, 1955a). Its efficiency of absorption depends upon several dietary factors among which are the form in which it is ingested, the pH of the intestinal fluids, calcium to phosphorus ratio and the amount of vitamin D present (Hansard and Barth, 1962). Smith et al. (1955) reported that the absorption of phosphorus is enhanced in acid media and also

in the presence of strontium and magnesium. Lactose and fat intake have also been shown to aid phosphorus absorption (Irving, 1964).

2.3.2 Factors influencing calcium and phosphorus absorption and utilization:

2.3.2.1 pH.

The absorption of calcium and phosphorus from the intestinal tract requires an acid medium to solubilize them. Tricalcium phosphate which is insoluble in neutral pH is readily available for utilization at lower pH. The lower pH which prevails in the duodenum is responsible for the absorption of calcium and phosphorus in this region of the tract (Webbling and Holdsworth, 1965). This low pH was provided by the secretion of HCl by the gastric glands in the stomach.

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2.3.2.2 Free fatty acids:

Feeding of high-fat diets to non-ruminant animals has been recognized to affect calcium and phosphorus absorption through the formation of insoluble soaps. Atteh and Leeson (1983) studied the effect of supplementing 3-week old pig diets with 0 - 10 percent fat and dietary calcium and available phosphorus levels of 0.8 - 1.2 and 0.53 - 0.8 percent respectively. Both average daily gain and feed intake reduced with fat supplementation. There was however improvement in feed : gain ratio at the 10 percent fat supplementation. Dietary fat or calcium and phosphorus levels did not significantly affect the digestibility of calcium and phosphorus nor the pH of the duodenal contents.

In another study, Atteh and Leeson (1985) examined the effect of soapstock on performance, nutrient digestibility and bone mineralization in weaner pigs fed normal (0.8 percent) or high (1.2 percent) levels of calcium. Dietary soapstock did not influence feed intake, although a decrease in average daily gain was recorded when dietary soapstock was increased to 10 percent. The reduction in average daily gain was attributed to the inhibitory effect of fats on calcium and phosphorus absorption. Wilkinson (1976) showed that triglycerides had less inhibitory effect on calcium and phosphorus absorption than free fatty acids.

2.3.2.3 Protein level.

Reports on the effect of protein level on the absorption and retention of calcium and phosphorus are conflicting. McCance et al. (1942) reported that addition of protein to a basal diet increased calcium absorption. Wasserman et al. (1956) also showed that calcium absorption was enhanced by lysine and arginine. Mahan et al. (1980) evaluated the effect of two protein levels (18 and 20 percent) on calcium and phosphorus utilization using performance and bone mineralization as indices in swine. Average daily gain, feed intake, feed : gain ratio and bone mineralization were significantly higher when 20 percent protein was fed with a plateau at 0.8 and 0.6 percent calcium and phosphorus respectively.

In another study, Allen et al. (1979) found that dietary protein stimulates urinary excretion of calcium. Harrold et al. (1983) also studied the effect of protein source on the availability of phosphorus to chicks using diets containing caesin or isolated soybean protein. Soybean protein reduced tibia ash content. This was attributed to the phytin content of soybean meal which tied up phosphorus making it unavailable

to the chicks.

2.3.2.4 Phytic acid:

Phytic acid or inositol hexaphosphoric acid is a component of organic phosphorus of cereals and may be found partly in free state or as phytin (the calcium magnesium salt) (Irving, 1957). Its nutritional significance as far as calcium and phosphorus metabolism is concerned is that it forms an insoluble salt with calcium and therefore interferes with its absorption in the intestine. The amount or proportion present in the diet as phytin significantly affect the animal's requirement for phosphorus (Underwood, 1981).

Phytin is closely linked with calcium and vitamin D in nutrition and the interaction between them in causing rickets in young animals has been reviewed by Taylor (1979). With diets low in calcium, rickets was reported to be due to an impairment of calcium by high phytate concentration while with diets high in calcium, it was due to a deficiency of phosphorus caused by low availability of phytate phosphorus.

For phytate phosphorus to become available, an enzyme phytase is required to release it. Taylor (1979) reported that three possible sources of the enzyme are food, digestive juices and bacteria. The author found that wheat and rye contained more phytase than barley, oats and maize. Yoshida et al. (1986) reported that the availability of phytate phosphorus was also higher in wheat and barley than in maize.

2.3.2.5 Bile Secretion:

Increased bile flow has been shown to enhance calcium absorption (Lengemann and Dobbins, 1958). This was thought to be due to increased solubility of calcium and lipid solvents thereby increasing their absorption from the intestine.

2.3.2.6 Oxalates:

Oxalic acid has been of interest to nutritionists for several reasons. It is the primary toxic constituent of several plants, excessive intake of which has been shown to cause nutritional secondary hyperthyroidism in horses (Blaney et al., 1981), diarrhoea, gastrointestinal entiritis, renal damage and osteodystrophic fibrosa also in horses (Walthall and McKenzie, 1956). Oxalic acid also binds divalent cations such as calcium and magnesium, thereby rendering them unavailable (Hintz et al., 1984).

Ward et al. (1979) reported that 20 - 33 percent of the calcium in alfalfa is in the form of oxalates and therefore not available to ruminant animals. The effect of oxalates in non-ruminant nutrition is not well elucidated.

2.3.2.7 Vitamin D:

It is now generally accepted that calcium absorption and utilization is accomplished by the interaction between several factors, notably the level of circulating parathyroid hormone (Parsons and Potts, 1972) and vitamin D. Although the details of the interaction is still obscure, there is evidence that calcium absorption in a normal healthy animal depends on parathyroid hormone modulating the hydroxylation of vitamin D (Parsons and Potts, 1972).

Borle (1974) and Wasserman and Fuller (1983) reported that after vitamin D absorption in the intestine or its synthesis in the skin, it is hydroxylated in the liver to 25 - hydroxycholecalciferol by an oxygen dependent process and stimulated by pyridine nucleotide. 25-hydroxycholecalciferol which is more potent than vitamin D_3 on bone and intestine

is the metabolite circulating in blood (Wasserman and Fuller, 1983). Its subsequent conversion to 1,25-dihydroxycholecalciferol occurs in the kidney by a reaction catalyzed by an enzyme 25-hydroxycholecalciferol - hydroxylase. This reaction is also regulated by parathyroid hormone, calcium and phosphorus levels of the blood. An increase in circulating level of parathyroid hormone increases the level of 1,25-dihydroxycholecalciferol (Melanon and DeLuca, 1970) which interacts with a pre-existing carrier protein which has a calcium binding activity. The reaction which is energy requiring and mediated by ATP-ase (Parsons, 1976) plays a role in the subsequent uptake of calcium across the mucosal membrane (Wasserman and Fuller, 1983).

2.3.2.8 Calcium: phosphorus ratio.

The adequacy of calcium and phosphorus nutrition is dependent upon three factors: a sufficient supply of each element, a suitable ratio among them and the presence of vitamin D (Loosli, 1973). While an adequate supply of each element is the first essential factor, the ratio between them is also equally important. Most animals require a fairly narrow ratio (not wider than 2:1). Ruminants can however tolerate wider ratios provided the phosphorus level is adequate (NRC, 1980).

Doige et al. (1975) demonstrated with growing pigs that dietary calcium and phosphorus could vary considerably without adversely affecting the animal's rate of gain and feed: gain ratio provided that calcium : phosphorus ratio in the diet remained near 1.3:1. Chapman et al. (1962) reported that at high levels of dietary phosphorus, detrimental effects due to excess calcium were not observed at the same calcium: phosphorus ratio. This suggests that the ratio

between these may not be critical at high levels of dietary phosphorus. Reinhart and Mahan (1986) also reported that dietary calcium: phosphorus ratios above 1.3:1 adversely affected swine performance and bone development if the dietary phosphorus was low; whereas at high dietary phosphorus levels detrimental effects were not observed until calcium: phosphorus ratio exceeded 2:1.

2.3.2.9 Other minerals:

The relationship between calcium, phosphorus and zinc and the incidence of parakeratosis in swine has attracted the attention of several researchers. Cabell and Earle (1965) and NRC (1968) reported that high levels of calcium and phosphorus in the diets of pigs induced symptoms of zinc deficiency including parakeratosis. Luecke et al. (1956) produced a 100 percent incidence of parakeratosis in pigs on a diet with 1.5 percent calcium and 0.8 percent phosphorus and 31 ppm of zinc. An additional 20 ppm of zinc to the diet eliminated the disease.

While Newland et al. (1958) associated parakeratosis with an accelarated rate of zinc metabolism, Lowry et al. (1985) reported that it was due to slow zinc absorption from the intestine due to its chelation. Stevenson and Earle (1956) however, indicated that other factors may also be involved in the etiology of parakeratosis other than high dietary levels of calcium.

Lowry et al. (1985) found that high dietary levels of calcium in the diets of post weaning swine increased selenium retention in the body. Calcium retention on the other hand was not affected by dietary selenium.

The relationship between calcium, phosphorus and magnesium has also been studied. Alcock and MacIntyre (1960) suggested that since calcium and magnesium are absorbed from the gastrointestinal tract by the same mechanism, the deficiency of one may produce an increase in the absorption of the other.

2.3.2.10 Lactose:

Wasserman et al. (1956) showed that dietary lactose increased the absorption and utilization of calcium. It was considered that lactose favours an acid medium in the intestine and therefore tends to prevent the formation of insoluble tricalcium phosphate. The authors also found that the absorption of calcium was additive when lactose and lysine were provided together in the diet.

2.3.2.11 Age of animal:

The effect of age on the absorption of calcium has been studied with different species. Experiments with cattle showed that its net absorption decreased with age. Hansard et al. (1954) found that calcium absorption decreased from 99 percent in the young calf to 23 percent in older cattle (12 years), and dropped from 95 percent at one month of age to 41 percent at 6 months of age.

In similar experiments with pigs Hansard et al. (1961) observed that calcium absorption and retention was greatest in 15 day-old pigs, decreasing rapidly to 5 months of age and then decreasing more slowly until the animal ages 30 - 72 months. The authors however, found that the actual amount of calcium absorbed remained approximately the same as the animal ages, although with an increasing intake of feed the percentage of calcium absorbed declined (Bronner, 1964).

2.3.2.12 Fibre content of feed:

Fibre represents a cheap source of dietary energy in swine feeds and has been extensively used without producing a large negative impact on the mineral utilization of pigs. Kornegay and Moore (1986) suggested that it was premature to safely state that high-fibre feeds do not affect mineral utilization especially when used extensively. Experiments with humans have shown that cellulose administration increased faecal calcium excretion (Ismail-Beigi et al., 1977). The use of partially refined flour also lowered calcium absorption (Reinhold et al., 1976).

2.3.3 Homeostatic Control of blood calcium and phosphorus:

The calcium content of blood in most species is remarkably constant under different physiological conditions. In the rabbit, plasma calcium level is subject to great variations under normal conditions (Chapin and Smith, 1967). The normal blood calcium concentration in most species ranges between 9 and 11 mg per 100 mls of blood (Underwood, 1981). Blood calcium is virtually all present in plasma (or serum) although blood cells contain variable amounts. Plasma calcium exists in two forms: ionized and diffussible, and non-diffusible forms (Irving, 1957).

Experimentally raising or lowering blood calcium level has proved detrimental to animals. Irving (1957) noted that hypocalcaemia was characterized by muscle spasm, which was attributed to increased sensitivity of the neuro-muscular junction, although involvement of the central nervous system was also implicated.

According to Borle (1974) calcium homeostasis is achieved by shifts in calcium among the extracellular fluids, the intestinal lumen and the renal tubular fluid. Several factors are involved in the regulation of blood calcium level. These include the bone, parathyroid hormone and calcitonin (Copp et al., 1969) and the active metabolite of vitamin D (DeLuca, 1979). Aubert and Bronner (1965) noted that calcium homeostasis appeared to depend primarily on the catabolism of bone which is a process influenced by parathyroid hormone and calcitonin. Carlson (1952) reported that although bone mineralization is the primary function of vitamin D, it also plays a role in the mobilization of calcium from bone to the extracellular fluid compartment. Parathyroid hormone is involved in raising the level of plasma calcium under conditions of hypocalcaemia while calcitanin lowers it under conditions of hypercalcaemia (Copp et al., 1969).

Parathyroid hormone restores normal blood calcium through its action on the kidney, liver, bone and intestine (Zull and Repke, 1972 and Blum et al., 1974). Under conditions of hypocalcaemia, parathyroid hormore is secreted by the parathyroid gland. The hormone acts on the kidney by stimulating renal reabsorption of calcium (Kleeman et al., 1961). The hydroxylation of vitamin D_3 to 25-hydroxycholecalciferol and subsequently to 1,25-dihydroxycholecalciferol in the kidney is also controlled by parathyroid hormone. The hydroxylated product reacts with a pre-existing calcium binding protein (Wasserman and Fuller, 1983), the product of which stimulates intestinal absorption of calcium thereby elevating plasma calcium level.

Under conditions of hypercalcaemia however, calcitonin is secreted from the c-cells of the thyroid. Calcitonin suppresses mobilization of calcium and phosphorus from bone and probably stimulates the secretion of calcium and phosphorus in the kidney (Maier et al., 1974). These factors are responsible for bringing down the plasma concentration of these minerals within the normal ranges. Calcitonin has a negative feed back on parathyroid hormone (Simons, 1974).

The mechanism of calcium homeostasis is complex. Details has been reviewed by Borle (1974). The first evidence that calcium was mobilized from bones to support serum calcium concentration was revealed by Carlson (1952) and Nicolaysen and Eeg-Larsen (1956). The authors discovered that animals placed on a calcium-free diet but with vitamin D had elevated plasma calcium level and infered that the source must be from the bone fluid since bone mineral was not in direct communication with extracellular fluid component. Talmage (1969) reported that there must be a membrane of cells seperating the bone fluid component from the extracellular fluid compartment and that vitamin D was necessary at the bone cell membrane to control the flux of calcium from the bone fluid compartment into the extracellular fluid. The involvement of parathyroid hormone has been reported (Garabedian et al., 1974). DeLuca (1979) has shown that both parathyroid hormone and 1,25-dihydroxycholecalciferol stimulated resorption of bone in a culture. Raiz et al. (1972) found that the majority of bone resorption appeared to be osteoclast mediated and that response was too slow to account for calcium homeostasis in vivo. Although the mechanism is still not well understood, Tanaka and DeLuca (1971) noted that parathyroid hormone responses probably

involves cyclic adenosine monophosphate and the rate of 1,25-dihydroxycholecalciferol in this system probably involves a new protein synthesis. The mobilization of calcium to support serum calcium concentration in response to 1,25-dihydroxycholecalciferol was reported to be blocked by the administration of actinomycin D and other protein inhibitors by the same authors.

Blood contains about 35 - 45 mg/100ml of phosphorus which occurs in several forms, principally in organic combination. The inorganic form which is present in blood plasma is more important from the stand point of nutrition. The normal values of plasma inorganic phosphorus are 4 - 9 mg per 100 ml in adults and 6-8 mg per 100 ml in young animals (Maynard et al., 1979 and Underwood, 1981).

The maintenance of plasma inorganic phosphate level is less closely controlled than calcium. Serum phosphorus level is more responsive to dietary intakes of the mineral than calcium. Irving (1964) reported that the mechanism of controlling blood phosphate concentration is through the control of its excretion by parathyroid hormone. The author found that parathyroidectomy resulted in abrupt hypophosphouria.

2.3.4 Excretion of Calcium and phosphorus:

Calcium is lost from the body through three major avenues: faeces, urine and sweat. The faecal fraction is made up mainly of unabsorbed and endogenous calcium resulting from intestinal mucosal secretions. Urinary calcium loss which is often considered less is influenced by other factors. High protein diet for example has been reported to stimulate urinary excretion of calcium (Allen

et al., 1979). Bronner (1964) estimated that about half of the plasma calcium in filtered in the kidney and about 99 percent of this is reabsorbed under normal conditions. The calcium lost in sweat is of minor significance in most species especially pigs which lack sweat glands.

The excretion of phosphorus through the kidney is the main regulator of blood phosphorus concentration - a process regulated by parathyroid hormone and 1,25-dihydroxycholecalciferol. Irving (1964) found that when intestinal absorption of phosphorus was low, urinary phosphorus fell to a low level with reabsorption by the kidney tubules approaching 99 percent.

2.4 Factors influencing the calcium and phosphorus needs of swine:

2.4.1. Animal factors:

Different species and breeds of livestock differ in their physiology and therefore in their requirement for calcium, phosphorus and other nutrients. Although chickens and pigs consume similar diets, chicks require higher dietary levels of calcium and phosphorus than baby pigs. NRC (1971) requirements by 0-8 weeks pullets and broilers for calcium and phosphorus are 1.0 and 0.7 percent respectively while requirements by baby pigs for the same mineral elements are 0.8 and 0.7 percent respectively (NRC, 1979). Differences in response to dietary calcium and phosphorus levels by local and exotic breeds of pigs have been noted. Ilori et al. (1976) found that rate and efficiency of gain were not significantly different among local pigs fed varying levels of calcium and phosphorus. In contrast, exotic pigs receiving similar diets had significant improvements in rate of gain with increasing levels of calcium and phosphorus.

Dietary calcium and phosphorus levels however, increased metacarpal length and weight and carcass quality of local pigs although to a lesser extent than in the exotic pigs.

Animals of the same breed, species and age may differ in their requirements for a nutrient because of differences in physiology. While the calcium and phosphorus requirements of baby pigs which are growing very fast is 0.8 and 0.7 percent respectively, that of finishers which are generally slower in growth is 0.65 and 0.5 percent respectively (NRC, 1979).

The animal body also has the ability to adjust to sub-normal intakes of calcium and phosphorus by reducing the amount of mineral excreted or in products such as milk and eggs. Young et al. (1966) have shown that sheep can adapt to variations in dietary calcium and phosphorus by withdrawing from the skeleton and also through an increased efficiency of absorption of the minerals from the intestinal tract under conditions of inadequate supply. Information is lacking on the ability of the pig to adapt to low intakes of calcium and phosphorus for long periods.

The calcium and ph sphorus requirements of young animals is higher than older ones because of the need to calcify newly laid down cartilage. Bone calcification takes place at a faster rate in young growing animals than in older ones (Irving, 1957).

2.4.2 Mineral factors:

It has been recognized that the physical and chemical form in which calcium and phosphorus exist in the ration influence the efficiency of utilization. The calcium and phosphorus present in foodstuff and of supplements vary greatly in availability. This is particularly so with

phosphorus sources. The relative physiological availability of calcium and phosphorus in different compounds has been studied in different species of livestock. Kornegay et al. (1984) evaluated the effect of defluorinated phosphate and dicalcium phosphate as phosphorus sources for swine using bone characteristics, serum mineral levels, weight gain and feed efficiency as indices. The results showed that defluorinated phosphate and dicalcium phosphate were equally effective as phosphorus sources provided sodium intake was adequate. Harmon et al., (1970) found that dicalcium phosphate supported more rapid gains than soft phosphate, although rib and turbinate bone ash values were similar for the two sources.

Ross et al. (1984) examined the effect of different sources and particle sizes on the availability of calcium in calcium supplements for growing swine. There was no significant difference between the bioavailability of calcium in calcite, oyster shell flour, gypsum, marble dust and aragonite. These sources had relative bioavailability ranging from 93 - 103 percent, calcium carbonate as a standard. Particle sizes with geometric mean diameter of 0.1 - 0.54 did not affect the availability of calcium from these sources. Pond et al., (1982) evaluated the bioavailability of calcium from limestone of different particle sizes and rates of activity in swine. Degree of fineness and rate of activity did not affect weight gain, feed: gain ratio weight of liver and kidney or femur and humerus bone ash. Serum phosphorus level was lower in pigs fed low calcium (0.5%) and phosphorus (0.4%). Variation in bioavailability can significantly influence the net requirement of the animal for a mineral element.

2.4.3 Other factors:

Climate can influence the calcium and phosphorus requirements of livestock indirectly by affecting their content in plants. Phosphorus content of crops and forages decline with advancing age while calcium content tends to increase (Underwood, 1981). The direct effect of climate on mineral requirement of swine has not been well elucidated. It is well known however that high environmental temperatures depress feed intake in most species, with a consequent depressing effect on the intake of minerals.

Holmes and Grace (1975) evaluated the effect of two environmental temperatures (25 C and 35 C) on the metabolism of calcium, phosphorus, magnesium, sodium and potasium in pigs. The pigs exposed to 33 C had more significantly increased urinary excretion of calcium and potassium than those exposed to 25 C. This may explain why in an earlier experiment, the author found that pigs fed moderate levels of diet at 33 C air temperature became lame, while those fed on the same diet at 25 C were normal. Bragg et al. (1971) have also shown that high ambient temperatures depress calcium levels in chickens.

2.5 Calcium and phosphorus requirement of swine:

ARC (1967) defined mineral requirements of swine as "the amount of the element that must be supplied in the diet to satisfy the net requirement of the animal" and net requirement as "the sum of endogenous losses of the element in faeces, urine, skin and hair: storage of the element in the body and pregnancy and the amount lost to the body in milk". Mineral requirements of swine are expressed as percentage of the air dry diet, rather than as daily requirements

The factors which influence the calcium and phosphorus requirements of swine have been discussed earlier. There is paucity of information on the calcium and phosphorus requirements of swine in Nigeria. Temperate values or extrapolations from those have been used for many years without any apparent ill effect. The practice does not however ensure that pigs obtain optimum amounts of these mineral elements in view of the differences in climate between the tropical and temperate regions. Climate is one of the factors which directly or indirectly influence the mineral needs of swine (Underwood, 1981).

A lot of work has been done on the calcium and phosphorus requirements of temperate swine. Inspite of the vast literature accummulated over the years, there is still uncertainty as to the optimum dietary levels of calcium and phosphorus for various categories of swine. Recommendations based on growth performance, feed efficiency, blood parameters and skeletal development have appeared in literature.

There are indications that some developments in livestock husbandry have combined to raise the mineral requirements of swine (ARC, 1967 and Underwood, 1981); so that levels which were considered adequate some years back are no more so. These developments include genetic improvements in the animal resulting in faster growth and higher yields, increased use of more energy dense diets, early weaning practice which emphasizes higher mineral requirements in early growth periods and the use of growth promoters such as antibiotics, hormones and other feed additives.

2.5.1 Calcium and phosphorus requirement of piglets:

Miller et al. (1962) reported that 6-8 weeks old pigs require in their diet 0.4 percent calcium and 0.4 percent phosphorus to permit normal growth and feed utilization, 0.8 and 0.5 percent calcium and phosphorus respectively to maintain normal serum calcium, phosphorus and alkaline phosphotase activity. Higher levels (1.0 and 0.6 percent) calcium and phosphorus were essential for optimum bone density and breaking strength. Dudley et al. (1961) reported that 0.2 percent calcium could support maximum gain and feed efficiency in 2-7-week old pigs. Rutledge et al. (1961) however suggested that to support maximum gains and feed efficiency, baby pigs require in their diet, at least 0.8 percent calcium. ARC (1967) recommended levels of calcium and phosphorus for 1-20 kg pigs was 0.8 and 0.7 percent respectively. Levels of 0.9 and 0.7 percent calcium and phosphorus were recommended for 1-5 kg baby pigs (NRC, 1988).

Coalson et al. (1972) reported that under pathogen free condition, young pigs require 0.95 percent calcium and 0.73 percent phosphorus to support maximum gains and feed efficiency. Optimum skeletal development as measured by bone weight, diameter, ash and phosphorus content of bones also occured at these levels of calcium and phosphorus. The authors also found that serum phosphorus concentration increased with dietary calcium and phosphorus levels while serum alkaline phosphotase was elevated in pigs fed low levels (0.27 and 0.4%) of calcium and phosphorus. Blair and Benzie (1964) evaluated the effect of feeding diets containing 1.6 percent calcium and 0.6, 0.9, 1.2 and 1.5 percent phosphorus on growth and skeletal development of pigs (25 lb).

Dietary calcium and phosphorus levels had no effect on rate of weight gain and feed conversion but dry fat-free bone weight increased with increasing levels of calcium and phosphorus in the diet.

Zimmerman et al. (1963) reported that high levels of calcium in the diet of young pigs reduced rate of gain and feed efficiency, while a calcium: phosphorus ratio of 1.6:1 or wider also adversely affected gains. The authors suggested a maximum dietary calcium level of 0.8 percent and a minimum phosphorus level of 0.6 for optimum performance and skeletal development in these category of pigs. Combs and Wallace (1962) had earlier shown that calcium can adversely affect performance when provided in amounts which exceed the requirement to sustain an adequate nutritional status. The depression in performance was attributed to a low apparent digestibility of various fractions in the diet.

2.5.2 Calcium and phosphorus requirements of growing-finishing swine:

The ARC (1967) recommended calcium and phosphorus requirements for 10 - 35 kg pigs are higher (0.8 and 0.6% respectively) than NRC (1968) levels (0.65 and 0.5%). Both requirements were based on growth rate and feed efficiency. Newman and Elliott (1976) reported that growing pigs (16-46 kg) fed diets containing 0.6 or 0.8 percent phosphorus gained faster than those fed 0.4 percent. Mahan (1982) evaluated the dietary calcium and phosphorus levels for growing pigs (7 - 20 kg) using a 20 percent crude protein diet with dicalcium phosphate and limestone as phosphorus and calcium sources respectively. Dietary calcium and phosphorus levels of 0.8 and 0.68 percent respectively were necessary for maximum

bone ash whereas 0.1 percent less phosphorus was needed to maximize performance. The requirement for available phosphorus was 0.35 percent.

Maxson and Mahan (1983) fed cross-bred pigs (18 - 57 kg liveweight) diets supplying total phosphorus levels ranging from 0.4 - 0.9 in 0.1 percent intervals with calcium : phosphorus ratio maintained at 1.3:1 in a 16 percent crude protein diet. Average daily gain was maximum at 0.65 and 0.5 percent calcium and phosphorus levels respectively, while bone ash increased quadratically as the mineral levels of 0.9 and 0.7 percent and 0.72 and 0.55 percent were fed at 40 and 57 kg body weights respectively. Combs et al. (1988) found a linear response in performance when 70, 75, 100, 115 and 130 percent NRC (1988) calcium-phosphorus suggested requirements were fed.

Finishing swine generally require lower levels of calcium and phosphorus. The NRC (1968) recommended levels for these minerals are 0.5 and 0.4 percent respectively. ARC (1967) recommended requirements for the same category of pigs are higher (0.6 and 0.5) percent respectively). Both recommendations were based on performance and not bone mineralization.

Brennan and Arherne (1986) fed growing - finishing pigs NRC (1981), ARC (1981) or 130 percent ARC (1981) recommended calcium and phosphorus levels to evaluate their effect on growth and bone parameters. There was no significant difference between these levels with respect to average daily gain, average daily feed intake and feed: gain ratio during the 20 - 100 kg growth period. Femoral ash contents however, increased in response to calcium - phosphorus increments. The incidence and severity of osteochondrosis

of the femur, humerus, radius and ulna and leg soundness scores improved with increasing calcium and phosphorus levels indicating that the NRC (1981) recommended calcium and phosphorus levels may not be adequate for bone mineralization.

2.5.3 Calcium and phosphorus requirements of breeding pigs:

There are indications that during pregnancy, the physiological requirements for calcium and phosphorus increase in proportion to the need for foetal development to a maximum later in gestation. During lactation however, the requirements are dictated by the level of milk production by the gilt or sow (NRC, 1988). Feeding of dietary levels of calcium and phosphorus sufficient to maximize bone mineralization in gilts during early growth and development has been reported to improve reproductive longevity in some trials (Nimmo, 1981a, b) but not in others (Arthur et al., 1983 and Kornegay et al., 1985).

There appears to be a considerable variation in the information on the calcium and phosphorus requirements of gilts and sows. NRC (1968) recommendations of 0.6 and 0.5 percent for pregnant and lactating sows and gilts are similar for finishing pigs. More recent recommended levels are however 0.75 and 0.6 percent respectively (NRC, 1988).

Kornegay et al. (1985) evaluated the effect of two calcium and phosphorus levels (100 and 150 percent NRC 1979 recommended levels) on the reproductive performance of sows. It was found that feeding higher than NRC (1979) recommended calcium and phosphorus levels during growth and development did not improve their subsequent reproductive performance

and longevity. In a similar study, Grandhi and Strain (1983) fed finisher, gestation and lactation diets containing NRC (1979) or 150 percent NRC (1979) dietary calcium-phosphorus requirements. Average daily gain, feed intake and feed efficiency were similar for both treatments. However, the 150 percent NRC (1979) recommendation recorded a higher total and live pigs born and weaned although with lower piglet weight gains. Grandhi et al. (1986) also found that feeding 150 percent NRC (1979) recommended calcium and phosphorus levels during finishing, gestation and lactation improved bone characteristics in gilts and second litter sows.

The relatively high incidence of leg unsoundness in boars continues to attract the attention of swine nutritionists. Smith (1965) reported that about 35 percent of boars tested exhibited some form of leg abnormality while and estimated 10 percent were eliminated from sales due to leg abnormalities (Bereskin, 1979). Although many factors may be responsible for this such as reduced exercise from confinement rearing, genetic selection for large framed boars, nutrition and disease, deficiency of calcium and phosphorus is largely responsible.

Literature on the optimum dietary calcium and phosphorus requirements of boars are variable. Liptrap et al. (1970) suggested that boars require 0.6 and 0.5 percent calcium and phosphorus respectively from weaning to 100 kg of body weight. Nimmo et al. (1981a) have however demonstrated that higher levels are required to achieve greater femoral bone breaking load without affecting boar performance. Kesel et al. (1983) also reported that feeding boars calcium and phosphorus levels higher than NRC (1979) recommended levels improved bone mineralization and breaking strength. Reiland (1975) however

reported that elevated bone mineralization and breaking strength did not eliminate the incidence of leg unsoundness in boars.

2.6 Sources of Calcium and phosphorus for swine and their bioavailability:

Farm animals generally derive calcium and phosphorus from two main sources - the feed they consume and inorganic supplements of geological or industrial origin. Small but significant amounts of calcium can be obtained from drinking water especially 'hard' water (NRC, 1974). Livestock feeds are made up largely of materials of plant origin and consequently, the factors which influence the calcium and phosphorus contents of these plants invariably reflect in the quantity of these mineral elements taken by the animals. These factors include the genus, species or strain of plant, the nature of the soil upon which the plant grew, climate and the stage of growth of the plant (Underwood, 1981). The extent to which these factors affect the concentration of a mineral element in the plant also varies with the mineral.

Calcium is present in variable amounts in all animal feeds (NRC, 1971). The calcium content of legumes and non-legume forages lie between 0.31 and 1.7 percent while that of grains such as barley, corn, milo and wheat are generally lower (0.02 - 0.10 percent) (Underwood, 1981). The biological availability of calcium from feeds depends on the level of phosphorus and vitamine D present (Loosli, 1973).

Phosphorus is also present in variable amounts in most livestock feeds (NRC, 1971). The factors which determine the level of calcium in plants also determine the level of phosphorus.

Unlike most mineral elements however, the bioavailability of phosphorus in plants is quite variable and depends on the phosphorus compound present, the species and age of animal consuming it (Taylor, 1979; NRC, 1988 and Saha et al., 1988).

Practical swine diets are usually composed predominantly of cereals and vegetable proteins which provide a large proportion of the phosphorus in organic form, a form largely unavailable to the pig. A lot of work has been done on the biological availability of phytate phosphorus in different species and age groups. Peeler (1972) reported that the pig can utilize variable amounts of phytate phosphorus.

Apart from plants, animal products which are commonly used as protein supplements also contribute significant quantities of calcium and phosphorus. Commercial meat meals and fishmeal are rich sources of these minerals (Cunha, 1977).

The calcium and phosphorus contents of feedstuffs for swine are often lower than animal requirements or the mineral elements are present in forms which are not readily available. Consequently it has become a general practice to supplement swine diets with inorganic sources of calcium and phosphorus. According to Underwood (1981) the choice of a mineral supplement is determined by its cost per unit of the element or elements required, the chemical and physical form in which the elements are combined, the fineness of division and its freedom from harmful impurities. The bioavailability of the elements in question is also important (Peeler, 1972).

A wide range of calcium and phosphorus supplements are currently being used for livestock feeding and several others are being explored for use. The main calcium sources include ground limestone, calcium carbonate, oyster shells, calcium sulphate, calcium chloride, calcium phosphate and

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bonemeal. These range in calcium content from 16 - 38 percent (NRC 1980). Major phosphorus supplements include calcium phosphates (di-and tricalcium phosphates, ammonium phosphates, diammonium phosphate, ammonium polyphosphate), sodium phosphates (monosodium phosphate, disodium phosphate, sodium tripolyphosphate) bonemeal and phosphoric acid. Considerable variations exist in the bioavailability of phosphorus from these sources. The composition of some common calcium and phosphorus sources is shown on Table 1.

According to Peeler (1972), the total mineral content of a feed or mineral supplement is of little significance in animal nutrition unless it is qualified by a factor indicating the biclogical availability of the element to the animal intended. Bioavailability is a measure of the ability of a mineral element or ion to support some physiological processes in relative numerical terms in comparison to a reference standard (Peeler, 1972). The chemical analysis of feedstuff which is carried out in the laboratory shows only how much of a given mineral element is present but does not indicate to what degree if any, the nutrient can be utilized when it is consumed by the animal. It is a well known fact that no element is completely absorbed and utilized when fed.

Several methods have been used for the assessment of bioavailability of mineral elements in different species of livestock. Early methods include mineral balance studies (Forbes et al., 1929) and whole body analysis (Drake et al., 1949). More recent methods include the use of radioisotopy which has been used to quantitatively differentiate between exogenous and exdogenous calcium and phosphorus in the faeces, thereby making it possible to measure true absorption of

Table 1: Approximate composition of some calcium and phosphorus supplements.

Supplements.	% Calcium	% Phosphorus
Bonemeal, feed grade	37.3	13.1
Bonemeal, steamed	30.5	14.3
Bonecharcoal	30.1	14.1
Calcite	34.0	-
Calcium phosphate (dibasic)	23.1	18.6
Curacoa Island phosphate	34.0	14.0
Diammonium phosphate	-	20.0
Dolomite	22.0	-
Limestone, ground	33.8	0.02
Oyster shells	38.0	0.07
Phosphate rock, defluorinated	33.1	18.00
Phosphoric acid	-	24.00
Sodium phosphate (monosodium)	-	22.5
Sodium tripolyphosphate	-	26.0
Soft rock phosphate	18.0	9.0

Adapted from Loosli, J.K. 1973. Effect of processing on the nutritive value of feeds. National Academy Sciences. Washington D.C.

dietary calcium and phosphorus (Hansard et al., 1954). In swine, bone, blood and growth parameters are generally used in combination to determine the biological availability of these minerals from sources.

Information on the bioavailability of calcium and phosphorus from supplements is scarce. Loosli (1973) reported that the calcium present in inorganic supplements is relatively well utilized by livestock if the ratio of calcium to phosphorus in the diet is satisfactory, if vitamin D is adequate and if other specific factors do not interfere with its absorption. Forbes et al. (1921) reported that the bioavailability of calcium from pulverized limestone, calcium carbonate, steamed bone flour and precipitated bone flour ranged from 50 - 70 percent. In another study, Maynard (1932) found that the biological availability of calcium from calcium phosphate, monocalcium phosphate and bonemeal did not differ significantly. Combs and Wallace (1962) recorded no significant difference in growth rate and bone ash when pigs were fed diets supplemented with limestone, dicacium phosphate or gypsum.

Rose et al. (1984) evaluated the bioavailability of calcium in calcite, limestone, dolomitic limestone, oyster shell flour, gypsum, marble dust and aragonite for growing swine using calcium carbonate as a reference standard. The results showed that the bioavailability of calcium from all sources except dolomitic limestone were not significantly different (93-102 percent); that of dolomitic limestone was lower (5 - 78 percent) relative to calcium carbonate.

The biological availability of phosphorus from different supplements has also been studied by several researchers. Like calcium, several factors influence the bioavailability of phosphorus. Peeler (1972) stated that the order of effectiveness of various sources are the same under a similar set of conditions. The author found that soluble phosphates such as sodium phosphate, phosphoric acid and monocalcium phosphate had the highest bioavailability followed closely by defluorinated phosphate and steamed bonemeal while low fluorine rock phosphate and soft phosphate had the least bioavailability.

Work has also been done on the relative bioavailability of phosphorus from several supplements for the pig. The criteria used include growth rate, feed consumption, feed efficiency, bone ash, skeletal abnormalities, percent net retention of phosphorus, incidence of paralysis, litter size, alkaline phosphotase activity, rate of absorption, phosphorus balance and blood serum phosphorus level.

Harmon et al. (1970) studied the effect of dicalcium phosphate and soft phosphate on the structure and composition of turbinate and long bones of pigs. Dicalcium phosphate supported more rapid gains than soft phosphate, although rib and turbinate ash values were similar for both sources. The fluorine content of bones was highest in pigs receiving soft phosphate.

Newman and Elliott (1976) compared monosodium phosphate, sodium tripolyphosphate, defluorinated rock phosphate and dicalcium phosphate as sources of phosphorus for growing - finishing pigs. Monosodium phosphate and sodium tripolyphosphate were more effective utilized than dicalcium phosphate

and defluorinated rock phosphate in one trial but no significant differences were observed in other trials. In a similar study, Kornegay et al. (1984) evaluated the biological availability of phosphorus from defluorinated phosphate and dicalcium phosphate which varied in sodium content. Both sources were found to be adequate provided sodium intake was adequate. Peeler (1972) reviewed work on the bioavailability of phosphorus from different sources using different techniques. The bioavailability of phosphate, phosphoric acid, bonemeal and soft phosphate was between 41 and 145 percent using bonemeal as a standard. The differences in magnitude of values was attributed partly to indices used for the measurement.

2.7 Effects of Calcium and phosphorus deficiency/toxicity:

The deficiencies of calcium and phosphorus in domestic animals usually occur in different circumstances. According to Underwood (1981), a dual deficiency in which both minerals are equally deficient is rare. While grazing animals are more prone to phosphorus deficiency, calcium is more often a problem of hand fed animals which feed on low-calcium cereal grain-based rations.

Several disorders have been reported in different species due to calcium and phosphorus deficiency or a lack of vitamin D which interferes with the absorption and utilization of these minerals. These disorders range from changes in bone and teeth, subnormal growth, decreased milk production, depressed appetite and efficiency of feed utilization, the development of pica or deprived appetite and impairment of fertility.

Although blood serum calcium level may decline slightly during early period of dietary calcium deficiency (Church and Pond, 1974), calcium level in the blood is generally not influenced by dietary intakes. There are however species differences (Chapin and Smith, 1967). The first response to dietary phosphorus deficiency is a fall in inorganic phosphate fraction of the blood usually accompanied by an increased alkaline phosphatase activity (Boyd et al., 1983). This increased alkaline phosphatase activity was associated with bone resorption and this was used to determine phosphorus availability to swine.

The skeleton, apart from being a structural frame of the body, serves as a reservior for calcium and phosphorus. Under conditions of insufficient dietary intake, these elements are withdrawn from the bones to meet the physiological demands (Boyd et al., 1983). When livestock are exposed to long periods of deficiency, the mobilization of calcium and phosphorus may become excessive and consequently structural deformities of bone may result.

In young animals, rickets is the term used to describe a bone condition in which calcium salts fail to be deposited in newly formed bone matrix resulting in subnormal calcification of bones. A widening of the epiphyseal-diaphyseal cartilage due to excessive production of uncalcified tissue is responsible for the characteristic enlargement of joints (Church and Pond, 1974). In adult animals, this disease condition is called osteomalacia, which results due to excessive mobilization of calcium and phosphorus from bones. In both rickets and osteomalacia, there is a reduction in total calcium and phosphorus concentration of bones but

with little alteration in the proportion of these minerals (Cohen, 1975). The author also found that low dietary phosphorus alone resulted in osteomalacia, indicating that phosphorus may be essential for the rigidity of bones.

Two concepts on the etiology of atrophic rhinitis in swine are nutrition and infection. Brown et al. (1966) considered this condition to be caused by secondary parathyroidism due to low dietary calcium and or low phosphorus. Logomarsino et al. (1974a, b) experimentally produced atrophy of the nasal turbinates in growing swine by feeding diets low in calcium or an imbalance in calcium : phosphorus ratio. The authors observed that histological changes which are associated with this condition were not only present in the turbinates but also in the remainder of the skeleton. Hsu et al. (1976) however, found that atrophy of the turbinate was not induced experimentally in in-exposed pigs by under-feeding calcium or over-feeding phosphorus. The disease was only produced by nasal instillations of nasal washings from pigs naturally affected with atrophic rhinitis.

Lameness, multiple rib fractures, epiphysiolysis of the femoral head and femoral fractures, reduction in bone ash and reduction in length of metacarpal bones have been reported as some of the consequences of low dietary calcium in swine (Rousseaux et al., 1981 and Kaantee, 1983). The effects of phosphorus deficiency on growth is not well documented in swine. Poor growth and abnormal appetite are some of the defficiency symptoms observed in other stock (Church and Pond, 1974).

Sows, when fed low calcium diets, maintain their ability to reproduce at least through one gestation (NRC, 1968). This is because of their ability to draw on their own skeleton

to meet the needs of the foetus. Brown et al. (1966) reported that gilts fed diets containing 0.2 percent calcium produced litters which were not significantly different from those of gilts fed adequate calcium diets in total number of live pigs or in individual pig weights. Milk production also did not decrease significantly during the first lactation. A common problem of calcium - or phosphorus - deficiency in sows however is paralysis of the hind legs (NRC, 1988). This condition which is referred to as posterior paralysis occurs mostly in high-milk producing sows towards the end or just after termination of lactation.

Calcium compounds which are orally ingested are usually not considered toxic. The homeostatic mechanism of the animal tends to protect it against the absorption of excess quantities of the element. However, because calcium and phosphorus are closely related in metabolism, feeding of high levels or excess levels of calcium for long periods may lead to detrimental effects on performance. Optimum performance is linked with a close calcium: phosphorus ratio (Reinhart and Mahan, 1986).

Zimmerman et al. (1963) found that when 2-7 week-old pigs were fed high levels of dietary calcium, a reduction in rate of gain was recorded while a calcium: phosphorus ratio of 1.6:1 or wider adversely affected gains. Combs et al. (1965) also observed that increasing the dietary calcium level of pigs from 0.48 to 0.88 and then to 1.32 percent decreased average daily gain and feed conversion efficiency. The decrease was attributed to a decline in apparent digestibility of calcium and dry matter. Hall et al. (1985) have also reported a hemorrhagic syndrone in pigs fed diets with calcium levels as high as 2.7 percent with low vitamin K.

Whether high calcium inhibits synthesis, reduces absorption or partially destroys vitamin K in the gut is not known.

Phosphorus deficiency syndrome or symptoms such as osteodystrophic fibrosa, nutritional secondary hyperparathyroidism and osteomalacia have been reported in several species whose diets are low in phosphorus (Bartter, 1964). High dietary phosphorus levels on the other hand caused elevated serum phosphorus and a lowering of serum calcium level (NRC, 1980), a condition which leads to the stimulation of parathyroid hormone to increase serum calcium by resorption of bone and increased renal phosphate excretion. This condition was also produced in animals fed low levels of calcium.

2.8 Prospects and Limitations of Rock phosphate as mineral supplement for swine:

Rock phosphate or phosphate rock is a generic name used to describe mineral phosphates which exist in nature. Although several types exist, Sauchelli (1965) broadly grouped them into crystalline apatites and amorphous phosphorites. Rock phosphate is primarily used for phosphate fertilizer production, although its use also extends to the production of different phosphate compounds and elemental phosphorus (NRC, 1960). Geologists have attempted estimating world reserves of rock phosphate but discoveries of new deposits are frequently being made. It is however evident that world reserves are vast and capable of supporting world agriculture for a considerably long period of time.

The major world producers of rock phosphate include Algeria, Morocco, Naura, Tunisia, USSR, United States of America, Brazil, Isreal, Jordan, North Vietnam, South Africa,

Senegal and Togo. The deposits in Nigeria have not been fully explored. Sauchelli (1965) noted that from the point of view of phosphate fertilizer production, Nigerian rock phosphate is of a low quality due to its high content of aluminium and iron. Casey (1952) described Nigerian phosphate rock to be made up of three varieties - the granular, nodular and vesicular types.

The chemical composition of rock phosphate is quite variable depending on its origin and method of processing. With regard to its use as a mineral supplement in livestock feeds, its fluorine content is more critical because of its injurious effects when fed at high levels or for long periods.

Although fluorine is present in varying amounts in most livestock feeds and drinking water, rock phosphate which is becoming a popular mineral supplement in livestock feeds is a major source. Continental sources of rock phosphate have been reported to contain higher (3-4 percent) fluorine than island deposits (Underwood, 1981). Defluorinated rock phosphates usually contain lower levels of fluorine and can be safely used in livestock feeds. It was suggested that rock phosphate meant for livestock feeding should not contain more than one part fluorine to 100 parts of phosphorus in the diet (NRC, 1960).

Several phosphate supplements are used in livestock feeds in many advanced countries of the world. Notable among them are defluorinated phosphate rock, dicalcium phosphate, normal superphosphate, curacoa phosphate rock, steamed bonemeal, colloidal phosphate and or the phosphoric acid. In Nigeria, bonemeal which is commonly used is becoming scarce and expensive. Large deposits of rock phosphate have been discovered and is currently being used in superphosphate

fertilizer production. Information is lacking on the use of rock phosphate as a mineral supplement for swine in Nigeria. Some studies in other countries have shown that rock phosphate can be used economically and safely as a mineral supplement not only in feeds for other livestock but also swine. Snook (1962) in long term controlled experiments showed that Christmas Island phosphate could be fed continuously at generous levels to dairy cows over many lactations without producing any symptoms suggestive of fluorosis. The author suggested that the phosphate can be used with equal assurance in the rations of beef cattle, sheep, swine and poultry.

Harmon et al. (1970) studied the effect of feeding dicalcium phosphate and soft phosphate on turbinate and long bones of pigs; and found that although dicalcium phosphate supported more rapid gains than soft phosphate, rib and turbinate ash values were similar for the two sources. The fluorine content of bones of pigs fed soft phosphate was however higher than those given dicalcium phosphate. In a similar experiment, Newman and Elliott (1976) found no difference between monosodium phosphate, sodium tripolyphosphate, defluorinated rockphosphate and dicalcium phosphate as phosphorus sources for finishing swine. Kornegay et al. (1984) also evaluated the bone characteristics, serum mineral content, weight gain and feed utilization of growing - finishing pigs when fed dicalcium phosphate or defluorinated rock phosphate. Results showed that both sources were equally effective when sodium intake was adequate.

The main problem limiting the use of rock phosphate especially the raw product as a livestock feed supplement is its fluorine content. The question as to whether fluorine is essential in metabolism is not yet resolved. Fluorine is

however a constant constituent of bones and teeth and traces have been reported to be beneficial in the development of caries - resistance as well as preventing excessive demineralization of bones (NRC, 1980). The claim that fluorine might stimulate growth in rats (McClendon and Gershion-Cohen, 1953) has not been fully substantiated. The essentiality of fluorine therefore remains uncertain and consequently dietary requirements have not been established.

Although the toxic effects of fluorine on livestock has received some attention, there are evidences that fluorine can be consumed continuously below certain critical levels without apparent ill effects. When ingested in amounts above the critical levels, fluorine toxicity occurs. The precise dietary level at which fluorine ingestion becomes harmful has not been determined. Phillips et al. (1934) reported that high fluorine rock phosphate can be injurious to livestock when fed over long periods in amounts ordinarily required as calcium and phosphorus supplements. Several factors however influence the level at which fluorine ingestion becomes harmful. These factors include the level of intake, type of fluorine compound ingested, duration during which excessive intake occured, the species involved, the age, general nutritional status and also toxicity modifying factors (NRC, 1960 and NRC, 1980).

When fluorine is fed at low levels, tolerance depends upon the operation of any one or two factors; at high levels of intake however systemic toxic effects may result. It is difficult to assess the fluorine sensitivity of different species, unless conditions under which they are assessed are standardized. Swine have been reported to be more tolerant to fluorine than cattle and sheep (Suttle, 1977); while young animals were more

prone than older ones (NRC, 1980). The solubility of the fluorine compound and its subsequent rate of absorption also play a part in toxicity. About 50 percent of fluorine from rock phosphate has been reported to be absorbable (NRC, 1980).

Chronic signs of fluorine toxicity require a long time to show. Clarke and Clarke (1979) reported that prolonged ingestion of small amounts of fluorine produced characteristic signs of poisoning. Notable among these signs are impaired movement due to stiffness of joints, anorexia, unthriftiness, dry hair and thick non-pliable skin (NRC, 1980). The degree of severety of these depends on the amount and duration of ingestion and the age of the animal. Johnson (1965) and Shupe and Alther (1966) described the radiographic signs of fluorine toxicity on bones to include osteoporosis, osteoclerosis, osteomalacia, hyperostosis and osteophytosis or any combination of these. Affected bones appear chalky, enlarged, heavier than normal bones and with irregular surfaces. The adverse effects of fluorine on reproduction and lactogenesis are not clearly understood. Stoddard et al. (1963) recorded a reduction in milk production in cattle fed diets containing high level of fluorine. The author attributed this to dental and skeletal damage and consequent reduction in feed intake. Subnormal growth and weight loss due to high fluorine diets have also been reported (NRC, 1980).

Acute fluorine toxicosis is relatively rare although experimental poisoning have been demonstrated. The rapidity with which toxic signs appear depends on the amount ingested. Acute signs of fluorine toxicity is accompanied by an upthrust in fluorine content of blood and urine, restlessness, stiffness,

anorexia, reduced milk production, excessive salivation, nausea, vomiting, urinary and faecal incontinence, weakness, depression, cardiac failure and death (NRC, 1980).

The animal body is protected from fluorine toxicosis by excretion of fluorine in urine, its retention in bones and teeth and refusal to feed when excretion and retention ceilings are reached (NRC, 1960). The animal may also vomit when fluorine contaminated feed is ingested (Clarke and Clarke, 1979).

Several compounds have proved effective in aleviating the toxic effects of fluorine. Aluminium compounds such as alumium chloride and aluminium sulphate have been shown to reduce fluorine toxicity in rats (NRC, 1960). High level of calcium, sodium chloride and fat also exert protective effect against high intakes of fluorine by depressing fluorine absorption from the gastrointestinal tract (NRC, 1974). Some magnesium salts have also proved effective against fluorine toxicity. Vitamins C and B_{12} and pasture rearing have been reported to protect pigs against fluorine toxicity (NRC, 1960).

These facts can be applied in husbandry practice when rock phosphate is used in swine feeds as a mineral supplement. Swine are also known to tolerate higher levels of fluorine than ruminants and because of their shorter life cycle, rock phosphate can be fed at safe levels without the fear of fluorine toxicity.

CHAPTER THREE

3.0 LABORATORY AND BIOLOGICAL STUDIES

3.1 Location of Experiments:

The study involved laboratory assay of the mineral supplements and test diets and biological studies with weaner and grower swine. The weaner and grower trials were conducted at the Swine Research Station, National Animal Production Research Institute, Ahmadu Bello University, Otukpo, Benue State. The research station is located at Kilometer 2, along Otukpo - Otobi road. Otukpo which lies approximately on longitude 8^{o} East and Latitude 7^{o} North is located within the southern guinea savanna zone of Nigeria. The climate is tropical with an annual precipitation of about 1200 mm, most of which falls within the months of April and October. The weaner trial was conducted during the months of October and November while the grower trial was carried out between the months of February and April.

The nutrient balance trial and laboratory analyses were carried out at the Ahmadu Bello University Farm and the Department of Animal Science laboratory respectively in Zaria. Zaria is located with the northern guinea savanna belt and has climate which does not differ much from that obtained in Otukpo.

3.2 LABORATORY STUDIES

3.2.1 Methodology:

Samples of the rock phosphate and bonemeal used were procured and analyzed for calcium, phosphorus, fluorine and other mineral elements. Samples of the test diets were also subjected to proximate and mineral analyses.

3.2.1.1 Chemical Analysis:

Analyzed chemical composition of the rock phosphate used in this study was supplied by Federal Superphosphate Fertilizer Company Kaduna. The calcium and phosphorus contents of feeds, faeces, bonemeal and bone ash were determined by Atomic Absorption Spectrometry as outlined by De Ruig (1986) and the molybdovanadate method of Gomori (1942) respectively.

3.2.2 Results and Discussion

3.2.2.1 Laboratory Analysis of mineral composition:

The analyzed chemical composition of bonemeal and rock phosphate used in this study is presented in Table 2. Rock phosphate contained 37.11 percent calcium, 16.10 percent phosphorus and 3.65 percent flourine, while bonemeal contained 34.64, 16.98 and 0.36 percent calcium, phosphorus and fluorine respectively. The analyzed chemical composition of test diets are also presented in the respective tables of diet composition (Tables 3, 8 and 15). From the chemical analyses of bonemeal and rock phosphate it was evident that rock phosphate compares favourably with bonemeal in total phosphorus content and even exceeds bonemeal in total calcium contents. Its major draw back however seemed to be its high fluorine content which was several times higher than bonemeal (3.65, 0.36 percent respectively). High levels of absorbable fluorine has been reported to be injurious to livestock (NRC, 1980 and Underwood, 1981).

Table 2: Analyzed chemical composition of rock phosphate and bonemeal

Minerals	*Rock phosphate %	Bonemeal %
Calcium	37.11	34.64
Phosphorus	16.10	16.98
Fluorine	3.65	0.36
Fe_2O_3	1.19	-
Al_2O_3	0.48	-
SiO_3	2.34	-
Zinc	-	0.44
Manganese	-	0.047
SO_3	0.64	-
Magnesium	0.25	0.50
Carbon dioxide	1.61	-

*Analysis was done at Federal Superphosphate Fertilizer Company, Kaduna.

3.3 BIOLOGICAL STUDIES

Three experiments were carried out as follows:-

Experiment 1 - Weaner trial

Experiment 2 - Grower trial

Experiment 3 - Nutrient balance trial

3.3.1 Experiment 1 - Bonemeal and rock phosphate as sources of calcium and phosphorus for weaner pigs.

3.3.1.1 Aim of the study:

To compare bonemeal and rock phosphate as sources of calcium and phosphorus for weaner pigs using growth performance and blood characteristics as indices.

3.3.1.2 Materials and methods:

(i) Experimental design:

Fourty-eight cross-bred weaner pigs averaging 11.83 kg (range 8.6 kg to 15 kg) were used in this study. The pigs were placed on an experiment which consisted of six dietary treatments consisting of 2 calcium and phosphorus sources (bonemeal and rock phosphate) and three calcium-phosphorus levels (low, medium and high).

The pigs which were raised at the Swine Research Station, National Animal Production Research Institute, Otukpo were managed intensively. There were eight pigs per treatment. The pigs were weighed and randomly alloted on the basis of sex and initial liveweight to the six dietary treatments in a randomized complete block design in a 2 x 3 factorial arrangement, with 2 sources of calcium and phosphorus and 3 levels of calcium and phosphorus. The trial lasted for 35 days.

(ii) Housing:

The pigs were housed four per pen in concrete floor houses equipped with feeders and waterers. The pens each had a dimension of 3 x 3 m with frontal runs of similar dimension. The houses were roofed with asbestos sheets with a lean-to type configuration.

(iii) Experimental diets:

The composition of the six rations used in this experiment is presented in Table 3. The diets which were formulated to be isocaloric and isonitrogenous were maize-soybean meal based with either bonemeal or rock phosphate as the source of calcium and phosphorus. The dietary calcium and phosphorus levels were 0.60, 0.45; 0.86, 0.60 and 1.12, 0.75 percent for bonemeal diets and 0.62. 0.46; 0.85, 0.61 and 1.07, 0.69 percent respectively for rock phosphate diets. Calcium : phosphorus ratios were maintained at 1.3:1, 1.4:1 and 1.5:1 respectively for both bonemeal and rock phosphate diets. Limestone was used to adjust calcium levels and to maintain the desired calcium : phosphorus ratios in the diets. One hundred kilogrammes of the experimental diets were mixed at a time and stored in labelled jute bags.

(iv) Feeding:

The pigs were fed the experimental diets at six percent of body weight twice daily - at 08.00 hours and 16.00 hours. Left-over feeds were weighed every morning and feed intake determined by difference. Water was provided ad libitum.

Table 3: Percentage composition of weaner diets fed in Experiment 1.

Diets	1	2	3	4	5	6
	Supplemented bonemeal			Supplemented rock phosphate		
Calcium in diet, %	0.60	0.86	1.12	0.62	0.85	1.07
Phosphorus in diet, %	0.45	0.60	0.71	0.46	0.61	0.69
Ingredient:						
Maize, ground	35.48	35.48	35.48	35.48	35.48	35.48
Soybean meal	30.92	30.92	30.92	30.92	30.92	30.92
Palm kernel meal	10.00	10.00	10.00	10.00	10.00	10.00
Maize offal	15.75	14.80	14.25	15.75	15.10	14.50
Molases	5.00	5.00	5.00	5.00	5.00	5.00
Palm oil	1.50	1.50	1.50	1.50	1.50	1.50
Vit/TM premix[1]	0.20	0.20	0.20	0.20	0.20	0.20
Salt	0.40	0.40	0.40	0.40	0.40	0.40
Limestone	-	0.20	-	-	-	-
Bonemeal	0.75	1.50	2.25	-	-	-
Rock phosphate	-	-	-	0.75	1.40	2.00
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated nutrient levels:						
Crude protein, %	20.12	20.16	20.10	20.12	20.16	20.10
Energy DE Mcal/kg	3.12	3.10	3.08	3.12	3.10	3.08
Fluorine, ppm	27	54	81	273.75	511.00	730.00
Analyzed nutrient levels:						
Crude protein, %	20.19	19.98	20.68	21.13	20.19	20.08
Calcium, %	0.62	0.88	1.15	0.63	0.89	1.10
Phosphorus, %	0.47	0.62	0.72	0.50	0.62	0.72
Ca:P ratio	1.3:1	1.4:1	1.5:1	1.3:1	1.4:1	1.5:1

[1]The commercical premix (Roche VM 502) contributed the following per kg Vit. A, 12,000 IU; Vit. D_3, 1200 IU; Vit. E, 3.61 IU; Vit. K, 1.8mg; Vit. B_2, 3.6mg; Nicotinate, 18mg; calcium-d-pantothanate, 9.6mg; Biotin, 3.6 mg; Vit. B_{12}, 0.012mg; choline chloride, 120mg; chlotetracycline, 48 mg; Mn, 24 mg; Iron, 48mg; Zn, 96 mg; Cu, 60mg; Iodine, 1.8mg; cobalt, 0.48 mg.

(v) Weighing of animals:

The pigs were weighed at the beginning of the experiment and thereafter at weekly intervals. All weights were taken after fasting the animals for about 16 hours.

(vi) Clinical observations:

The animals were observed daily for any clinical symptoms. The pigs were observed in standing and walking position for any signs of stiff-joints, lameness, swollen hocks and any other clinical signs suggestive of fluorine toxicity or calcium and phosphorus deficiency. The animals were also watched for symptoms of respiratory problems.

(vii) Blood sampling and preparation:

Blood samples were taken from the ear vein of each pig at the beginning, middle and end of the experiment. The samples were allowed to clot, stored ir a freezer and later transported to Zaria for the determination of serum calcium and phosphorus concentrations.

To 1ml of serum, 4 ml of 12.5 percent t ichloroa-cetic acid (TCA) was added and centrifuged for 15 minutes to precipitate serum proteins. The resulting protein-free supernatant was diluted to a ratio of 1:1 with Strontium A (61.0g $Srcl_2 .6H_2O$ + 10.0g Nacl in 1 litre). Serum calcium was determined at 422.6 nm by atomic absorption spectrophotometry as described by Ullrey et al. (1967). Inorganic phosphorus was determined by the molybdovanadate method as outlined by Gomori (1942).

(viii) Statistical analysis:

The data obtained from this experiment were subjected to Analysis of Variance using the Computer facilities at the National Animal Production Research Institute, Data Processing, Unit, Shika. Treatment means were compared using Duncan's Multiple Range Test as outlined by Steel and Torie (1960).

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3.3.1.3 Results and discussions:

3.3.1.3.1 Growth performance

The results of the weaner trial is presented in Table 4. No significant difference ($P > .05$) existed among treatments for final weight, total weight gain, average daily gain, average daily feed intake and feed to gain ratio. Close similarities were observed in pigs fed dietary treatments 1 and 4 (low calcium - phosphorus levels), 2 and 5 (medium calcium-phosphorus levels) and 3 and 6 (high calcium-phosphorus levels) in all parameters measured.

The influence of source of calcium and phosphorus and dietary calcium and phosphorus levels on growth performance is summarized in Table 5. No significant difference ($P > .05$) was observed in performance between pigs fed either rock phosphate or bonemeal supplemented diets as recorded in final weight (26.91, 26.50 kg), total weight gain (15.12, 14.65kg), average daily gain (0.43, 0.42 kg), average daily feed intake (0.87, 0.87 kg) and the amount of feed consumed per unit of live weight gain (2.03, 2.17). Pigs fed the bonemeal supplemented diets however performed slightly better than those fed rock phosphate supplemented diets in all parameters measured except feed intake.

Table 4: Growth performance of pigs fed different dietary treatments in Experiment 1:

Source of Ca and P	Bonemeal			Rock phosphate			
Level of Ca-P	Low	Medium	High	Low	Medium	High	
Treatment	1	2	3	4	5	6	SEM[1]
Performance parameter:							
Initial weight, kg	11.75	11.84	11.85	11.81	11.65	11.91	-
Final weight, kg	26.43	26.74	26.96	27.61	26.26	26.25	±0.53
Total weight, gain, kg.	15.44	14.94	14.79	15.04	14.38	14.53	±0.38
Av. daily weight gain, kg.	0.44	0.43	0.43	0.43	0.41	0.41	±0.01
Av. daily feed intake, kg.	0.87	0.87	0.87	0.87	0.87	0.87	-
Feed: gain ratio	2.04	2.09	2.10	2.09	2.21	2.22	±0.06

[1]Standard error of means.
Differences between treatment means are not statistically significant (P>.05).

Table 5: Growth performance of pigs fed different sources of calcium and phosphorus and different levels of calcium and phosphorus in Experiment 1:

	Source of calcium and Phosphorus			Calcium-Phosphorus levels			
Factor	Bonemeal	Rock phosph te	SEM[1]	Low	Medium	High	SEM[1]
Initial weight, kg	11.70	11.86	±.14	11.78	11.84	11.85	±.17
Final weight, kg	26.91	26.50	±.73	27.02	26.50	26.61	±.89
Total weight gain, kg	15.12	14.65	±.55	15.24	14.66	14.75	±.67
Av. daily weight gain, kg.	0.43	0.42	±.02	0.44	0.42	0.42	±.02
Av. daily feed intake	0.87	0.87	-	0.87	0.87	0.87	-
Feed: gain ratio	2.00	2.17	±.08	2.06	2.15	2.16	±.10

[1]Standard error of means
Differences between treatments are not statistically significant (P>.05).

This is due to the method adopted in feeding the pigs. Due to high cost of feeds and scarcity at the time of the experiment, pigs were given equal amount of daily ration on the basis of average weight of pigs.

The lack of significant difference in performance between pigs fed bonemeal and rock phosphate supplemented diets in this study was surprising. The rock phosphate supplemented diets contained between 274 and 730 ppm (average 504.92 ppm) of fluorine, levels far above the reported tolerable level for swine. A maximum fluorine tolerable level of 150 ppm has been reported for swine (NRC, 1980 and Underwood, 1981). The authors however, noted that tolerance to dietary fluorine by livestock depended on other factors such as age of the animal consuming it, the chemical form of the mineral, duration and continuity of intake, nature and amount of the diet being consumed. It has also been reported that not all the fluorine present in rock phosphate is absorbable when fed. This factor could be very important in explaining the result obtained. The result suggests that the rock phosphate used in the study had low levels of absorbable fluorine. NRC (1980) and Underwood (1981) reported that about one-third to two-thirds of fluorine in rock phosphate was absorbable when it is fed as a mineral supplement. Calcium, aluminium, sodium chloride and high fat diets have been reported to depress fluorine absorption by binding fluorine in a less soluble form (NRC, 1974). Some of these factors were also presumably at work to protect the animals from fluorine toxicity in this study.

Information on the use of raw rock phosphate as a mineral supplement in swine nutrition is scarce. This stems from the fact that early attempts were met with disappointing results because of the toxic effects of fluorine present in the basic

material (Snook, 1960). With the dicovery of the methods of defluorination however, defluorinated phosphates have been produced which vary in calcium and phosphorus levels depending on the source and method of manufacture but much lower in fluorine than the raw product.

Review of previous work on defluorinated rock phosphate (Futrell et al., 1969 and Newman and Elliott, 1976) show that these products were equal to mono- and disodium phosphate and dicalcium phosphate as sources of supplemental calcium and phosphorus for pigs fed barley-soybean meal diets as judged by rate of gain and efficiency of gain. Van Zante et al. (1967) fed early weaned pigs a corn-soybean meal diet with 0.1 percent phosphorus from steamed bonemeal or defluorinated rock phosphate or dicalcium phosphate and observed that pigs fed dicalcium phosphate and steamed bonemeal diets were more efficient in feed conversion than those fed defluorinated rock phosphate diets suggesting that availability of phosphorus from defluorinated rock phosphate was lower than the other sources. Other workers (Plumlee et al., 1958; Peeler, 1972 and Harmon et al., 1974b) have also reported poor phosphorus availability in high fluorine rock phosphate, soft phosphate and colloidal clay. The results obtained in this study also suggest that bonemeal is slightly superior to rock phosphate in bioavailability as measured by weight and feed conversion efficiency, although the differences were not statistically significant ($P>.05$).

Increasing dietary calcium and phosphorus levels from 0.60 and 0.45 (low) to 0.86 and 0.60 (medium) and to 1.12 and 0.72 percent (high) in the bonemeal diets and from 0.62 and 0.46 (low) to 0.85 and 0.61 (medium and to 1.07 and 0.69 percent (high) respectively in the rock phosphate diets

did not have any significant effect on mean final weight (27.02, 26.50, 26.61 kg), mean total weight gain (15.24, 14.66, 14.75 kg), mean average daily gain (0.44, 0.42, 0.42 kg) and mean feed conversion efficiency (2.06, 2.15, 2.16). In other words, increasing dietary calcium : phosphorus ratios from 1.3:1 to 1.4:1 and to 1.5:1 in both bonemeal and rock phosphate supplemented diets did not influence any of the growth parameters measured significantly (P>.05). Pigs fed the low dietary calcium and phosphorus levels and ratios were slightly superior to those fed the medium and high dietary calcium and phosphorus levels and ratios in all parameters measured in both bonemeal and rock phosphate treatments but the difference observed were not statistically significant (P>.05).

Results of previous work on the effect of dietary calcium and phosphorus levels on pig performance vary considerably. Libal et al. (1969) reported that dietary calcium and phosphorus levels and ratios can vary considerably without significantly affecting daily gains and feed conversion by pigs. Nimmo et al. (1980) found that feeding dietary calcium and phosphorus levels twice the levels suggested by NRC (1973) for weaner pigs did not adversely affect performance of boars. Atteh and Leeson (1983) also reported no significant differences in average daily gain, feed intake and feed : gain ratio of weaner pigs fed calcium and phosphorus levels from 0.8 to 1.2 percent and 0.53 to 0.8 percent respectively.

However, Kornegay et al. (1977) observed superior gains and feed efficiency in boars fed dietary calcium and phosphorus levels 25 percent higher than NRC (1973) recommended dietary levels of these elements. Pammatre et al. (1977) and Mahan et al. (1980) also found that weaner pigs responded to dietary

calcium and phosphorus levels when feed was adequate in protein with a maximum response at 0.9 percent calcium and 0.7 percent phosphorus. Kesel et al. (1983) reported that boars fed 150 percent NRC (1979) recommended calcium and phosphorus levels performed better than those fed 100 percent recommended levels in daily gain and feed : gain ratio.

High levels of dietary calcium and phosphorus have been reported to have detrimental effects on performance. Hall et al. (1985) and Reinhart and Mahan (1986) recorded significant reduction in performance of pigs fed high dietary levels of calcium and phosphorus. Similarly, low dietary phosphorus levels were equally detrimental to performance of pigs. Reduction in feed intake and growth rates have been reported due to low dietary phosphorus levels (Baylay et al., 1975 and Newman and Elliott, 1976).

Previous work on dietary calcium : phosphorus ratios show that high ratios adversely affect performance of pigs (Peo et al., 1969; Doige et al., 1975; Hall et al., 1985 and Reinhart and Mahan, 1986). It was found that high calcium : phosphorus ratios interfered with phosphorus absorption. NRC (1988) suggested a calcium : phosphorus ratio of 1:1 to 1.5:1 for swine when fed a grain-soybean based diet. The calcium : phosphorus ratio in the diets used in this study ranged from 1.3:1 to 1.5:1. Maximum growth response was obtained when calcium : phosphorus ratio was 1.3:1.

No source x level, source x sex or level x source x sex interactions were observed for any of the growth parameters measured.

3.3.1.3.2 Clinical observation:

There was no mortality throughout the period of the trial. The animals looked clinically healthy, without any signs of stiff-gait, lameness, arched back or dental fluorosis which are characteristic of fluorine toxicity (NRC, 1980 and Underwood, 1981). This supports earlier observation that the high fluorine content of the rock phosphate used had no significant effect on growth performance.

3.3.1.3.3 Serum mineral concentration:

Serum calcium and inorganic phosphorus concentrations were generally observed to be higher than reported normal values (Ullrey, et al., (1967) (Tables 6 and 7). These high values may be attributed to the fact that serum was not decanted and retracted immediately after blood samples were collected due to lack of facilities on the Research Farm where this study was conducted. Consequently, haemolysis of blood cells might have occured during storage and transportation leading to high values for these minerals.

Serum calcium and phosphorus concentrations of pigs as influenced by dietary treatments is summarized in Table 6. No significant difference ($P>.05$) was observed among treatment groups in serum calcium concentration at the first and third bleeding periods (at 1 and 35 days respectively). Significant differences ($P>.05$) however, existed among treatment groups during the second bleeding period (day 18). Pigs fed dietary treatment 2 recorded significantly higher ($P<.05$) serum calcium concentration than the other groups. There was no significant difference among treatment groups 1, 3, 4, 5 and 6 in serum calcium concentration.

Significant difference ($P<.05$) was observed among treatment groups in serum inorganic phosphorus concentration during the second and third bleeding periods. Pigs fed dietary treatment 3 had significantly ($P<.05$) higher inorganic phosphorus concentration during these periods. The lowest serum inorganic phosphorus concentration occured in pigs fed dietary treatments 1 and 4 (low levels of calcium and phosphorus) during the second bleeding period. Generally, serum inorganic phosphorus concentration was observed to increase in pigs from treatments 1 to 3 (bonemeal diets) and also from 4 to 6 (rock phosphate diets).

The result of the influence of source of calcium and phosphorus and dietary calcium and phosphorus levels on serum calcium and inorganic phosphorus concentrations is summarized in Table 7. No significant difference ($P>.05$) was observed in serum calcium concentration for pigs fed bonemeal and rock phosphate supplemented diets. Pigs on the bonemeal supplemented diets had a slightly higher serum calcium concentration than those fed the rock phosphate supplemented diets during the second and third periods of bleeding (days 18 and 35). Information is lacking on the effect of source of calcium and phosphorus on the serum calcium concentration of pigs. The results obtained in this study suggest that bonemeal has more absorbable calcium than rock phosphate, although differences were not statistically significant ($P>.05$).

Serum calcium concentration of pigs increased significantly ($P<0.05$) with the first dietary calcium and phosphorus increment and decreased thereafter, suggesting that the level of calcium representing the first increment (medium level) was adequate for the pigs. This finding is in agreement with Mahan (1982) who also recorded an increase in serum calcium concentration

Table 6: Effect of different dietary treatments on serum calcium and phosphorus concentrations in Experiment 1.

Source of Ca and P	Bonemeal			Rock phosphate			
Level of Ca-P	Low	medium	High	Low	Medium	High	
Treatments	1	2	3	4	5	6	SEM[1]
Serum calcium, mg/100ml.							
Initial	15.24	15.11	16.33	15.99	16.52	15.88	±0.26
18 days	14.97^{b}	16.10^{a}	15.07^{b}	15.01^{b}	15.41^{b}	15.05^{b}	±0.08
35 days	15.03	15.52	15.12	14.77	15.08	15.27	±0.09
Serum phosphorus, mg/100 ml.							
Initial	5.02	6.10	4.64	6.61	5.91	5.35	±0.27
18 days	5.23^{c}	6.31^{ab}	7.02^{a}	5.12^{c}	5.70^{bc}	5.68^{bc}	±0.13
35 days	5.47^{b}	6.83^{ab}	7.22^{b}	5.58^{ab}	6.20^{ab}	6.85^{ab}	±0.14

[1]Standard error of means.

^{a,b,c}Means in the same row with different superscripts differ significantly ($P<.05$).

Table 7: Effect of source of calcium and phosphorus and dietary calcium and phosphorus levels on serum calcium and phosphorus concentrations in Experiment 1

	Source of calcium and phosphorus			Calcium-Phosphorus levels			
Factor	Bonemeal	Rock phosphate	SEM[1]	Low	Medium	High	SEM[1]
Serum calcium mg/100ml							
Initial	15.63	16.13	±0.27	15.22	15.82	16.19	±0.25
18 days	15.38	15.16	±0.07	14.99^{b}	15.71^{a}	15.06^{b}	±0.10
35 days	15.22	15.04	±0.11	14.91	15.38	15.02	±0.10
Serum phosphorus, mg/100 ml.							
Initial	5.22	5.62	±0.22	5.32	6.01	5.00	±0.25
18 days	6.19	5.50	±0.11**	5.18^{b}	6.01^{ab}	6.35^{a}	±0.13
35 days	6.51	6.21	±0.10*	5.53	6.52	7.64	±0.17

[1]Standard error of means.

$^{a\ b}$Means in the same row with different superscripts differ significantly ($P<.05$), *Significant ($P<.05$) **Highly significant ($P<.01$)

of young pigs fed increasing dietary calcium and phosphorus levels.

Blood serum calcium concentration has been described as "one of nature's physiological constants" (Thomas and Haward, 1964). Its homeostatic control involves the parathyroid hormone, calcitonin and the active form of vitamin D_3. This mechanism has been extensively reviewed by Borle (1974) and Wasserman and Fuller (1983). The serum calcium level of pigs in this study showed an initial increase after the first dietary calcium and phosphorus increment (medium calcium - phosphorus level) but the effect disappeared thereafter. The homeostatic calcium control mechanism might have played a role in maintaining normocalcaemia irrespective of increases in dietary calcium and phosphorus levels.

Significant differences existed in serum inorganic phosphorus levels between pigs fed bonemeal and rock phosphate supplemented diets in this trial. The serum inorganic phosphorus concentration of pigs fed the bonemeal supplemented diets were significantly higher at 18 days ($P<.01$) and at 35 days ($P<.05$). This finding is in agreement with Plumlee et al. (1958) who found that soft rock phosphate which is approximately equivalent to the rock phosphate used in this study in composition, did not maintain serum inorganic phosphorus as did dicalcium phosphate and phosphoric acid.

Serum inorganic phosphorus levels increased slightly with increasing dietary calcium and phosphorus level and over time. The serum organic phosphorus level was significantly ($P<.05$) higher for the high than the low level of supplementation. This finding is in agreement with Coalson et al. (1972), Baylay et al. (1975) and Nimmo et al. (1980)

who found that serum inorganic phosphorus concentration in swine responded in a positive linear fashion with increasing dietary phosphorus levels.

A significant level x source x sex interaction ($P<.05$) existed for serum phosphorus concentration at day 18, while a level x source x sex and source x level x sex interactions ($P<.05$) also existed for serum phosphorus concentrations at day 35 of the trial.

3.3.2 Experiment 2 - Bonemeal and rock phosphate as sources of calcium and phosphorus for grower pigs.

3.3.2.1 Aim of the study:

To evaluate bonemeal and rock phosphate as sources of calcium and phosphorus for grower pigs using growth performance, blood and bone parameters as indices.

3.3.2.2 Materials and methods:

(i) Experimental design:

Twenty-four cross-bred grower pigs were used in this study. The pigs which had an initial weight of 35.64 kg (range 29.5 kg to 43.6 kg) were held from the weaner trial to the grower phase. The animals were re-alloted to six dietary treatments as described for Experiment 1. There were four pigs per treatment, and the experimental design was similar to that of Experiment 1. At the end of the trial which lasted for 49 days; six boars (one each from a treatment selected on the basis of pen average weight) weighing between 63.7 and 71.1 kg liveweight were slaughtered. Fresh liver and kidney weights were taken. The carcasses were also observed for any treatment related changes.

The third and fourth metacarpal and metatarsal bones were removed for the determination of bone physical and chemical characteristics.

(ii) Housing:

The pigs were housed in similar pens as in the weaner trial.

(iii) Experimental diets:

The composition of the six rations used in this experiment is shown in Table 8. The diets which were also formulated to be isocaloric and isonitrogenous had maize and groundnut cake as the basal ingridients, with inorganic phosphorus supplied by bonemeal or rock phosphate. The dietary calcium and phosphorus levels were 0.45, 0.35; 0.63, 0.50 and 0.84, 0.60 percent respectively for bonemeal diets and 0.41, 0.37; 0.64, 0.5 and 0.82, 0.56 percent respectively for rock phosphate diets. Limestone was used to adjust calcium levels and calcium : phosphorus ratios in the diets. One hundred kilogrammes of experimental diets were mixed at a time and stored in labelled jute bags.

(iv) Feeding and clinical observation:

The pigs were fed the experimental rations on a similar regime and were observed daily for any clinical signs as in the weaner trial.

(v) Sampling and preparation of samples:

Blood.

Blood samples were collected and prepared for the determination of serum calcium and inorganic phosphorus concentration as for the

Table 8: Percentage composition of grower diets fed in Experiment 2:

	Treatment No.					
	1	2	3	4	5	6
	Supplemented bonemeal			Supplemented rock phosphate		
Calcium in diet, %	0.40	0.63	0.84	0.41	0.64	0.82
Phosphorus in diet,%	0.35	0.50	0.60	0.37	0.50	0.56
Ingredient:						
Maize, ground	37.68	37.68	37.68	37.68	37.68	37.68
Groundnut cake	20.22	20.22	20.22	20.22	20.22	20.22
Palm kernel cake	10.00	10.00	10.00	10.00	10.00	10.00
Maize offal	25.50	24.70	24.00	25.50	24.90	24.40
Molases	5.00	5.00	5.00	5.00	5.00	5.00
Vit/TM premix[1]	0.20	0.20	0.20	0.20	0.20	0.20
Salt	0.40	0.40	0.40	0.40	0.40	0.40
Limestone	0.50	0.50	0.40	0.40	0.20	0.30
Bonemeal	0.50	1.30	2.10	-	-	-
Rock phosphate	-	-	-	0.60	1.40	1.80
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated nutrient levels:						
Crude protein, %	16.30	16.25	16.19	16.30	16.24	16.22
Energy, DE Mcal/kg	3.02	3.00	2.98	3.02	3.01	3.00
Fluorine, ppm	18	48	75	219	511	657
Analyzed nutrient levels:						
Crude protein, %	16.12	17.02	17.75	16.19	16.94	16.63
Calcium, %	0.43	0.68	0.95	0.43	0.68	0.89
Phosphorus, %	0.33	0.49	0.62	0.33	0.50	0.61
Ca : P ratio	1.3:1	1.4:1	1.5:1	1.3:1	1.4:1	1.5:1

[1]The commercial premix (Roche VM 502) contributed the following per kg Vit. A, 12,000 IU; Vit.D_3, 1200 IU; Vit. E, 3.61 IU; Vit. K, 1.8 mg; Vit. B_2, 3.6 mg; Nicotinate, 18mg; calcium-d-pantothate, 9.6 mg; Biotin, 3.6mg; Vit. B_{12}, 0.012mg; Choline chloride, 120mg; chlotetracycline, 48mg; Mn, 24mg; Iron, 48mg; Zn, 96mg; Cu, 60mg; iodine, 1.8mg; Cobalt, 0.48mg.

Bones:

The metacarpal and metatarsal bones which were removed at the end of the experiment were immersed in boiling water for 15 minutes to facilitate the removal of soft tissues as described by Reinhart and Mahan (1986). The bones were then even dried at 100 C for 24 hours. Fat was extracted from them in a soxhlet apparatus using petroleum spirit (BP 40-60 C) as the solvent. The dry fat-free bones were then subjected to some physical measurements - bone length, weight (in air and in water), volume, diameter, breaking strength, percent ash and percent calcium and phosphorus contents of the dry fat-free bone.

Specific gravity:

The third and fourth metacarpal and metatarsal bones were weighed individually in air and in water at 4 C (Palmer, 1970) for the determination of specific gravity (S.G) according to the following formula:-

$$SG = \frac{\text{weight of bone in air}}{\text{Weight of bone in air} - \text{Weight of bone in water}}.$$

Bone diameter:

External bone diameter was determined by measuring the circumference of each bone at the middle with a string and using the following equation to determine its external diameter.

$$C = 2\pi r$$

Where C is the circumference and r is the radius of the bone.

Bone strength:

The third and fourth metacarpals were used in the determination of breaking strength using Denison Universal Testing Machine (Model T 42 C.2 Saml Denison and Sons Ltd. Motor Road, Leeds 10 England). Each bone was placed on two supports about 5 mm in diameter and 32 mm apart as described by Cromwell et al. (1972). A third rod, 5 mm in diameter was placed between and parallel to the centre of the bone. Force was applied by the machine and the peak force required to break the bone was recorded in Kilo Newtons (KN).

Bone ash:

The bones were ashed at 550 C in a muffle furnace overnight. The ash content of each bone was weighed to enable the calculation of percent bone ash as follows:-

$$\text{Percent ash} = \frac{\text{weight of ashed bone}}{\text{Weight of dry, fat-free bone}} \times 100$$

Bone calcium and phosphorus contents:

The ash left was used for the determination of percent calcium and phosphorus content of dry fat-free bone. The bone ash was ground in a motar and duplicate samples from each bone digested with a mixture (5:1) of perchloric acid and nitric acid until the solution became colourless. The calcium and phosphorus content of ash were determined using the Atomic Absorption Spectrometer as described by De Riug (1986) and the molybdovanadate method of Gomori (1942) respectively. The calcium and phosphorus contents of ash were expressed as a percentage of dry, fat-free bone.

3.3.2.3 Results and discussions:

3.3.2.3.1 Performance study:

The general results of growth performance of pigs in the grower trial as influenced by different dietary treatments is presented in Table 9. No significant difference ($P>.05$) existed among treatment groups in final weight, average daily feed intake and feed : gain ratio. Significant differences ($P<.05$) however existed among pigs fed different dietary treatments for total weight gain and average daily gain. Pigs fed dietary treatments 1, 2 and 4 had significantly higher ($P<.05$) total weight gain than the other groups at the end of the trial. Pigs fed dietary treatment 5 recorded total weight gain which was not statistically different from treatments 1, 2, 3, 4 and 6, while treatments 3 and 6 had significantly lower total weight gains than the other groups. The same trend was also observed between treatment groups for average daily gain.

Final weight, total weight gain, feed intake and feed : gain ratio of pigs fed different sources of calcium and phosphorus and dietary calcium and phosphorus levels is summarized in Table 10. No significant difference was observed between pigs fed bonemeal and rock phosphate supplemented diets with respect to final weight (66.47, 66.74 kg), total weight gain (30.93, 30.99 kg), average daily gain (0.63, 0.63 kg), daily feed intake (1.88, 1.86 kg) and feed : gain ratio (3.02, 2.92). The difference between this result and that obtained in the weaner pig study may be an indication that grower pigs could utilize rock phosphate more effectively than weaner pigs. Plumlee *et al.* (1958) and Kornegay (1984)

Table 9: Influence of different dietary treatments on growth performance in Experiment 2:

Source of Calcium and phosphorus	Bonemeal			Rock phosphate			
Levels of Ca-P	Low	Medium	High	Low	Medium	High	
Treatments	1	2	3	4	5	6	SEM[1]
Growth parameter:							
Av. initial weight	35.62	35.45	35.53	35.50	35.73	35.98	-
Av. Final weight, kg	67.90	68.23	63.27	68.95	66.63	64.63	±1.20
Av. total weight gain kg.	32.28[a]	32.78[a]	27.75[b]	33.45[a]	30.93[ab]	28.60[b]	±0.72
Av. daily gain, kg	0.66[a]	0.67[a]	0.57[b]	0.68[a]	0.63[ab]	0.58[b]	±0.02
Av. daily feed intake, kg	1.96	1.91	1.78	1.93	1.74	1.82	±0.10
Feed : gain ratio	2.98	2.86	3.21	2.86	2.78	3.12	±0.07

[1]Standard error of means.

[ab]Means in the same row with different superscripts differ significantly (P<.05).

Table 10: Growth performance of pigs fed different sources of calcium and phosphorus and dietary calcium and phosphorus levels in Experiment 2.

	Source of Calcium and phosphorus			Calcium-phosphorus levels			
	Bonemeal	Rock phosphate	SEM[1]	Low	Medium	High	SEM[1]
Initial weight, kg	35.54	35.98	±0.98	35.57	35.59	35.76	±0.91
Final weight, kg	66.47	66.74	±1.58	68.43	67.43	63.75	±1.48
Total weight gain, kg	30.94	30.99	±0.44	32.87[a]	31.86[a]	28.18[b]	±0.83
Av. daily gain, kg	0.63	0.63	±0.01	0.67[a]	0.65[a]	0.58[b]	±0.02
Av. daily feed intake, kg	1.88	1.83	-	1.94	1.82	1.80	-
Feed : gain ratio	3.02	2.92	±0.11	2.92	2.82	3.26	±0.07

[1]Standard error of means.

[a,b]Means in the same row with different superscripts differ significantly ($P<.05$).

also found that rock phosphate was equal to steamed bonemeal as a calcium and phosphorus source for swine provided rock phosphate contained up to 13 percent phosphorus. The rock phosphate used in this study contained 16 percent phosphorus.

Total gain and average daily gain decreased significantly ($P<.01$) with increasing dietary calcium and phosphorus levels and ratios. A decrease in performance was also observed in final weight except for the medium level of calcium-phosphorus supplementation. Feed efficiency also decreased with increasing dietary calcium and phosphorus levels and ratio, but these were not statistically significant ($P>.05$). Other workers Combs and Wallace (1962), Zimmerman et al. (1963), Hall et al. (1985) and Reinhart and Mahan (1986) have also recorded significant decreases in performance with increasing levels of dietary calcium and phosphorus. Doige et al. (1975) reported that levels of calcium and phosphorus in the diets of swine can vary considerably with little effect on performance provided the calcium : phosphorus ratio was maintained near 1.3:1. The tendency for the pigs to perform poorly in this experiment on the high calcium - phosphorus levels might have been due to an increasing dietary calcium : phosphorus ratio in the diets; although the ratios used in this study were within the NRC (1988) suggested values for swine (1:1 to 1.5:1).

The mechanism whereby changes in levels and ratios of calcium and phosphorus in the diet alter performance is not clearly understood. Doige (1975) suggested that this may be a reflection of the changes in skeletal development or in factors such as energy production, enzyme activity or membrane permeability. There is evidence also to suggest that high level of calcium in the diet could affect the utilization of other nutrients.

Feed intake declined slightly with increasing dietary calcium and phosphorus levels and ratios. The difference in feed intake between pigs fed bonemeal and rock phosphate supplemented diets was not pronounced. This finding suggests that rather than fluorine, increasing dietary calcium and phosphorus levels and ratios might be responsible for the observed decrease in feed intake.

Significant level x source ($P<.05$) and level x source x sex ($P<.01$) interactions were observed for average daily gain. These findings are in agreement with Cromwell et al. (1970).

3.3.2.3.2 Clinical observations:

No mortality was recorded throughout the grower trial. However, mild stiffness upon rising and walking was evident in some pigs fed dietary treatment 6 (high calcium and phosphorus, rock phosphate diet) during the course of the experiment. Postmortem findings revealed that there were no treatment related changes in the lungs and liver. However, one kidney each from pigs fed dietary treatments 5 and 6 (rock phosphate

diets with medium an^ high diecary calcium and phosphorus respectively) were found to have an accummulation of fluid. The condition of the kidney samples was diagnosed in the Veterinary Pathology Department of the University to be "congenital polycystic kidney" of no serious consequence and without any bearing on the experiment* Reports of Hodge (1964) however indicated that high levels of fluorine in drinking water caused kidney damage in rats.

3.3.2.3.3 Serum mineral concentrations:

Serum calcium and phosphorus concentrations in pigs as influenced by dietary treatments is summarized in Table 11. No significant difference (P>.05) was observed in serum calcium concentration of pigs due to dietary treatments during the three periods of bleeding. Serum inorganic phosphorus levels of pigs fed the different dietary treatments showed significant differences (P<.05) during the second and third periods of bleeding. Pigs fed dietary treatments 2 and 3 (bonemeal supplemented diets) recorded significantly higher (P>.05) blood serum inorganic phosphorus levels than the other groups. Pigs on dietary treatment 5 (rock phosphate, medium supplemented diets) came next and had significantly higher (p<.05) serum phosphorus level than treatments 1, 4 and 6. Pigs on dietary treatment 4 recorded the lowest serum inorganic phosphorus level. During the third bleeding period (at 49 days) pigs on dietary treatment 2 (medium bonemeal supplemented diets) had the highest serum phosphorus level while no significant difference (P>.05) existed among pigs on the other dietary treatments.

The summary of the influence of source of calcium and phosphorus and dietary calcium and phosphorus levels on serum calcium and phosphorus concentrations is shown in Table 12. No significant difference existed between the serum calcium concentration of pigs fed bonemeal and rock phosphate diets. Pigs fed the bonemeal supplemented diets however had slightly but non-significantly higher serum calcium concentration compared to those on the rock phosphate diets. Similarly, increasing dietary calcium and phosphorus levels and ratios did not significantly influence serum calcium concentrations during the three periods bleeding. There was however a tendency for serum calcium concentration to increase when dietary calcium and phosphorus levels increased from low to medium level of supplementation, in both bonemeal and rock phosphate treatments but these were not statistically significant ($P>.05$). Coalson et al. (1972), Pammatre et al. (1977) and Nimmo et al. (1980) have reported similar findings with grower pigs. These findings suggest that the homeostatic calcium control mechanism was quite effective in maintaining serum calcium levels fairly constant irrespective of dietary levels of calcium and phosphorus fed in this study.

Blood serum inorganic phosphorus concentration of pigs fed bonemeal and rock phosphate supplemented diets did not differ significantly ($P>.05$) at the first bleeding period. Differences in serum phosphorus levels were however observed during the second and third periods of bleeding. Pigs fed the bonemeal supplemented diets had significantly higher serum phosphorus concentration than those fed the rock phosphate supplemented diets during the second ($P<.01$)

Table 11: Serum calcium and phosphorus concentration of pigs fed different dietary treatments in Experiment 2:

Source of Ca and P	Bonemeal			Rock phosphate			
Levels of Ca-P	Low	Medium	High	Low	Medium	High	
Treatments	1	2	3	4	5	6	SEM[1]
Serum calcium, mg/100ml							
Initial	14.08	14.07	14.08	13.77	13.65	14.03	±0.08
25 days	14.21	14.70	14.68	14.07	14.43	14.31	±0.08
49 days	14.10	14.27	14.07	14.03	14.46	14.33	±0.11
Serum phosphorus, mg/100ml							
Initial	5.03	4.99	5.08	5.05	5.21	5.03	±0.06
25 days	4.92^{c}	6.13^{a}	6.28^{a}	4.57^{c}	5.29^{b}	4.95^{c}	±0.10
49 days	5.23^{b}	6.71^{a}	5.82^{b}	5.25^{b}	5.83^{b}	5.50^{b}	±0.10

[1]Standard error of means.

^{a,b,c}Means in the same row with different superscripts differ significantly (P<.05).

Table 12: Effect of source of calcium and phosphorus and dietary calcium and phosphorus levels on serum calcium and phosphorus concentration in Experiment 2:

	Source of calcium and phosphorus			Calcium-phosphorus Level			
Factor	Bonemeal	Rock phosphate	SEM[1]	Low	Medium	High	SEM[1]
Serum calcium, mg/100ml							
Initial	14.08	13.82	±0.07	13.93	13.86	14.06	±0.07
25 days	14.53	14.31	±0.05	14.14	14.57	14.56	±0.07
49 days	14.15	14.27	±0.11	14.07	14.37	14.20	±0.11
Serum phosphorus mg/100ml							
Initial	5.03	5.10	±0.07	5.04	5.10	5.06	±0.04
25 days	5.78	4.94	±0.16*	4.75^{b}	5.71^{a}	5.62^{a}	±0.14
49 days	5.92	5.53	±0.12*	5.24^{b}	6.27^{a}	5.66^{ab}	±0.14

[1]Standard error of means

^{a,b}Means in the same row with different superscripts differ significantly (P<.05).

*Significantly different (P<.05)

and third ($P<.05$) periods of bleeding. This finding further suggests that the bioavailability of phosphorus in bonemeal was higher than rock phosphate and that the medium level of supplementation was optimum. Poor availability of calcium and phosphorus in high fluorine rock phosphate, soft phosphate and colloidal clay has been reported (NRC, 1988). Similar results were obtained in Experiment 1 of this study.

Significant level x source, source x sex and level x source x sex ($P<.05$) interactions were observed during the second bleeding period for serum phosphorus concentration. These effects however disappeared during the third bleeding period.

Underwood (1981) reported that serum phosphorus level was the most sensitive index for determining the dietary phosphorus level for all livestock. Ullrey et al. (1967) gave normal serum inorganic phosphorus level for 2 - 85 kg pigs to be between 3.0 and 4.2 mg/100 ml. The serum inorganic phosphorus levels obtained in this study were higher for reasons earlier advanced. It has been reported that apart from nutritional factors, age, stress and sampling site also affect both serum calcium and phosphorus concentrations (Fajemisin and Umunna, 1990). These factors probably contributed in influencing the results obtained in this trial to some extent.

3.3.2.3.4 Physico-chemical characteristics of bones:

Most of the physico-chemical properties of bones measured were influenced by dietary treatments. This is an indication that bone parameters may be a more sensitive index in the determination of optimum levels of calcium and phosphorus in the diets than growth parameters in swine. The general

response trend of physico-chemical properties to dietary treatments is presented in Table 13.

The summary of the influence of source of calcium and phosphorus and dietary calcium and phosphorus levels is shown in Table 14. Significant differences existed between the bones of pigs fed bonemeal and rock phosphate supplemented diets as demonstrated by the external diameter and breaking strength of third and fourth metacarpal and metatarsal bones.

Bones of pigs fed the bonemeal supplemented diets were significantly thicker and stronger ($P<.01$) than those of pigs fed the rock phosphate supplemented diets. No significant differences were however observed between metacarpal and metatarsal bones of pigs fed the bonemeal and rock phosphate supplemented diets as judged by weight of dry fat-free bone, bone volume and bone density as measured by specific gravity. The metacarpals of pigs fed the bonemeal supplemented diets were significantly longer ($P<.01$) than those of pigs on the rock phosphate supplemented diets, but source of calcium and phosphorus did not influence metatarsal bone lengths of pigs. The pigs fed the bonemeal supplemented diets had significantly higher ($P<.01$) metacarpal a and metatarsal bone ash than those fed the rock phosphate supplemented diets. Calcium and phosphorus content of metacarpal bones responded similarly to source of calcium and phosphorus as bone ash.

Information is lacking on the effect of bonemeal and rock phosphate on the physico-chemical properties of bones. In related studies, Futrell et al. (1969) evaluated the effect of sodium phosphate, dicalcium phosphate and defluorinated rock phosphate on some properties of bones and found that bone ash and calcium and phosphorus contents were similar for all dietary treatments.

Table 13: The effect of different dietary treatments on physico-chemical properties of bones of grower pigs in Experiment 2.

Source of Ca and P	Bonemeal			Rock phosphate			
Levels of Ca-P	Low	Medium	High	Low	Medium	High	
Treatments	1	2	3	4	5	6	SEM[1]
Physical measurements, Metacarpals:							
Bone length, cm	7.65[a]	6.93[b]	7.15[b]	7.13[b]	6.80[b]	7.08[b]	±0.06
Bone weight, gm	9.63	9.98	10.78	9.66	9.73	9.35	±0.18
Bone volume, cm^3	9.88	9.38	10.50	9.63	8.38	9.00	±0.27
Bone ext. diameter, cm	1.43[b]	1.42[b]	1.42[b]	1.52[b]	1.55[b]	1.74[a]	±0.02
Bone breaking strength, KN	0.82	1.02	1.05	1.64	0.66	0.55	±0.05
Bone specific gravity	1.14[c]	1.17[bc]	1.32[a]	1.21[b]	1.14[c]	1.12[c]	±0.02
Physical measurements, Metatarsals:							
Bone length, cm	8.35[a]	7.85[b]	8.10[ab]	7.95[b]	7.75[b]	8.15[a]	±0.06
Bone weights, gm	10.19	10.17	10.76	10.49	10.12	9.38	±0.16
Bone volume, cm^2	10.50	10.13	11.50	11.75	11.63	11.00	±0.23
Bone external diameter, cm	1.29[d]	1.39[c]	1.41[c]	1.46[b]	1.66[a]	1.66[a]	±0.03
Bone breaking strength, KN	0.77	0.79	1.02	0.50	0.45	0.31	±0.05
Bone specific gravity	1.21	1.28	1.43	1.28	2.00	1.91	±0.03
Chemical measurements, Metacarpals:							
Ash in fat-free dry bone, %	57.22[abc]	58.71[ab]	60.13[a]	53.66[c]	55.88[bc]	45.85[d]	±1.06
Calcium in dry fat-free bone, %	18.68[c]	21.49[a]	19.93[b]	18.72[c]	18.95[c]	18.56[c]	±0.22
Phosphorus in dry fat-free bone, %	9.54[c]	11.48[a]	10.64[b]	8.98[d]	8.99[d]	8.92[d]	±0.20
Chemical measurements, Metatarsals:							
Ash in dry fat-free bone, %	60.85	61.33	63.09	59.79	55.59	57.91	±0.63

[1] Standard error of mean

[a,b,c] Means in the same row with different superscripts differ significantly ($P<0.05$). KN = Kilo Newton.

Table 14: Effect of source of calcium and phosphorus and dietary calcium and phosphorus levels on physico-chemical properties of bones of grower pigs in Experiment 2.

Factor	Source of calcium and phosphorus: Bonemeal	Source of calcium and phosphorus: Rock phosphate	SEM[1]	Calcium-phosphorus levels: Low	Medium	High	SEM[1]
Physical measurements, Metacarpals:							
Bone length, cm	7.24	7.00	±0.05*	7.38[a]	6.86[b]	7.12[b]	±0.06
Bone weight, gm	10.13	9.58	±0.19	9.65	9.86	10.07	±0.15
Bone volume, cm^3	9.92	9.00	±0.32	9.76	8.88	9.75	±0.25
Bone ext. diameter, cm	1.42	1.60	±0.03*	1.48	1.49	1.58	±0.01
Bone breaking strength, KN	0.96	0.62	±0.07*	0.73	0.84	0.80	±0.02
Bone specific gravity	1.21	1.16	±0.01	1.18	1.16	1.22	±0.01
Physical measurements, Metatarsals:							
Bone length, cm	8.10	7.95	±0.03	8.15[a]	7.80[b]	8.13[a]	±0.07
Bone weight, gm	10.39	10.00	±0.13	10.34	10.15	10.07	±0.13
Bone volume, cm^3	10.71	11.46	±0.24	11.12	10.88	11.25	±0.15
Bone ext. diameter, cm	1.36	1.59	±0.04*	1.38[b]	1.53[a]	1.54[a]	±0.02
Bone breaking strength, KN	0.86	0.42	±0.08*	0.64	0.62	0.67	±0.02
Bone specific gravity.	1.31	1.73	±0.03	1.25	1.64	1.61	±0.02
Chemical measurements, Metacarpals:							
Ash in dry fat-free bone, %	58.69	51.80	±1.34*	55.44[a]	57.30[ab]	52.99[b]	±0.68
Calcium in dry fat-free bone, %	20.03	18.74	±0.23*	18.70[c]	20.22[a]	19.25[b]	±0.19
Chemical measurements, Metatarsal							
Ash in dry fat-free bone, %	61.76	57.76	±0.80	60.32	58.46	60.50	±0.42

[1]Standard error of means

[a,b,c]Means in the same row with different superscripts differ significantly ($P<.05$) *Significantly different ($P<.05$)
KN = Kilo Newton.

Third and fourth metacarpal and metatarsal bone lengths increased significantly ($P<.01$) with increasing dietary calcium and phosphorus levels with maximum response being achieved at the first incremental level of calcium and phosphorus. Weights of dry fat-free metacarpal and metatarsal bones, bone volume, bone breaking strength and specific gravity were not significantly influenced by dietary calcium and phosphorus levels. These parameters however showed a tendency to increase with increasing dietary calcium and phosphorus levels with bone breaking strength and specific gravity approaching significance ($P<.05$).

The metacarpal and metatarsal bones (third and fourth) responded differently to increasing dietary calcium and phosphorus levels (Table 14). While external diameter of metacarpal bones did not respond significantly to increasing dietary calcium and phosphorus levels, metatarsal bone diameter increased as dietary calcium and phosphorus levels increased in the diet.

Metacarpal bone ash responded significantly ($P<.05$) to the first incremental level of dietary calcium and phosphorus and declined thereafter. Metatarsal bone ash showed a tendency to increase with dietary calcium and phosphorus levels but this was not statistically significant ($P>.05$). The calcium and phosphorus content of metacarpals increased significantly ($P<.05$) with the first incremental level of dietary calcium and phosphorus and declined thereafter.

A lot of work has been done on the influence of dietary calcium and phosphorus levels on various physico-chemical properties of bones in swine. The results of such work are varied depending on dietary treatments and the parameters measured. The physico-chemical properties of bones

commonly determined include bone length, external and internal diameters of bone shaft, breaking strength, weight, specific gravity and cortical index. Other parameters include bone ash and calcium and phosphorus contents of various bones. More recently mechanical properties of bones are being employed (Crenshaw et al., 1981a and Crenshaw et al., 1981b). Most of the parameters measured in this study responded positively to increasing dietary calcium and phosphorus levels (Tables 13 and 14). Similar findings have been reported by Coalson et al. (1972); Kesel et al. (1983) and Arthur et al. (1983). The medium dietary calcium and phosphorus levels and ratios seemed to favour most of the parameters measured.

A significant source x level interaction ($P<.05$) existed for bone strength, specific gravity of metacarpals, strength of metatarsals, length and external diameter of metacarpal bones.

3.3.3 Experiment 3 - The effect of source of calcium and phosphorus and dietary calcium and phosphorus levels on nutrient digestibility and retention:

3.3.3.1 Aim of the study:

To evaluate the effect of source of calcium and phosphorus and different calcium and phosphorus levels on the apparent percentage absorption of calcium, phosphorus and apparent digestibility and retention of other proximate components of the diets.

3.3.3.2 Materials and methods:

(i) Experimental design:

Six Large White x Hampshire cross-bred litter - mate barrows weighing approximately 10.52 kg (range 8.7 kg to 13.15kg) were procured from a commercial farm around Zaria. The pigs were guarantined for about one week during which time they were dewormed with piperazine wormer. The pigs were subsequently alloted to the six dietary treatments in a randomized block design with period as the blocking factor. The trial had four collection periods of five days each and an adjustment period of 5 days between each collection period.

(ii) Housing:

The pigs were housed individually in locally constructed metal metabolism crates with provision for separate collection of faeces and urine.

(iii) Experimental diets:

The composition of the six rations used in this study is presented in Table 15. The diets which were formulated to be isocaloric and isonitrogenous were maize and groundnut cake based with inorganic phosphorus provided by either bonemeal or rock phosphate. The calcium and phosphorus levels were adjusted to 0.52, 0.39 ; 0.75 , 0.53 and 1.02 , 0.69 percent respectively for the bonemeal supplemented diets and 0.51, 0.40; 0.77 , 0.54 and 1.01 , 0.67 percent respectively for the rock phosphate supplemented diets.

Table 15: Percentage composition of diets fed in the nutrient balance trial - Experiment 3:

	TREATMENT No.					
	1	2	3	4	5	6
	supplemented bonemeal			Supplemented rock phosphate		
Calcium in diet %	0.52	0.75	1.02	0.51	0.77	1.01
Phosphorus in diet,%	0.39	0.53	0.69	0.40	0.54	0.67
Ingredient						
Maize, ground	67.00	65.70	64.50	67.00	65.70	64.75
Groundnut cake	31.20	31.60	31.80	31.20	31.60	31.70
Salt	0.50	0.50	0.50	0.50	0.50	0.50
Premix[1]	0.20	0.20	0.20	0.20	0.20	0.20
Limestone	1.05	1.50	2.00	1.05	1.55	2.05
Bonemeal	0.05	0.50	1.00	-	-	-
Rock phosphate	-	-	-	0.05	0.45	0.80
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated nutrient levels:						
Crude protein, %	20.00	20.07	20.05	20.00	20.07	20.03
Energy, DE, Mcal/kg	3.35	3.31	3.28	3.35	3.31	3.28
Fluorine ppm	1.8	18	36	18.25	164.25	292.00
Analyzed nutrient level:						
Crude protein, %	20.13	19.44	20.00	21.88	21.56	19.38
Calcium, %	0.50	0.70	1.11	0.52	0.75	1.07
Phosphorus, %	0.37	0.49	0.70	0.42	0.53	0.71
Ca : P ratio	1.3:1	1.4:1	1.5:1	1.3:1	1.4:1	1.5:1

[1]UNI-VIT 15 A commercial vitamin and trace mineral premix, which supplied per Kg: Vit. A, 8,000,000 IU; D_3, 1,500,000 IU; Vit. E, 3.00 mg; Vit. K, 3mg; Vit. B_2, 0.3mg; Vit. B_{12}, 8mg; Manganese, 10mg; Iron, 5mg; Zn, 45mg; Cu, 0.2mg; Iodine, 0.15mg; Cobalt, 0.02; and Selenium, 0.01mg.

Dietary calcium : phosphorus ratios and levels (low, medium and high) were similar to those used in the weaner trial. Limestone was used to adjust calcium levels and calcium : phosphorus ratios in the diets. Thirty kilogrammes of each diet were mixed and stored in labelled jute bags.

(iv) Feeding and data collection:

The pigs were fed ad libitum during the first pretest period which lasted five days to determined feed intake. Subsequently, they were fed 0.5 kg per day at approximately 08.00 hours. A five-day faecal and urinary collection then followed. Urine was collected daily in plastic buckets to which 10ml of concentrated HCl was previously added. Each daily urine collection was measured and a 10ml aliquot taken and stored in a refridgerator and the rest discarded. At the end of the five-day collection, a sample of the composite was used for chemical analysis. Faeces were collected daily for each period in plastic bags and stored in a deep freezer. Total collection for a period was dried in an oven, cooled and then weighed. It was then ground, mixed and samples taken for analysis. This was repeated for the other experimental periods, with the pigs re-alloted to the dietary treatments on a random basis. Ferric oxide powder was used as an inert marker to identify the beginning and end of each faecal collection period (Schneider and Flatt, 1975). Water was offered to the pigs ad libitum.

Unconsummed feeds were collected daily and stored. The total collection for a particular period was weighed to determine feed intake. Representative feed, faecal and urine samples were analyzed in duplicate for calcium and phosphorus. In the case of the feed and faeces, proximate analyses were also carried out.

(vi) Statistical analysis:

The data generated in this study were subjected to Analysis of Variance as outlined by Snedecor and Cochran (1967) and treatment means compared using Duncan's Multiple Range Test (Steel and Torie, 1960).

3.3.3.3 Results and discussion:

3.3.3.3.1 Dry matter digestibility and retention:

The result of apparent dry matter digestibility and retention by pigs fed different dietary treatments is presented in Table 16. No significant difference ($P>.05$) was observed among treatment groups with respect to intake, faecal and retention of dry matter. Daily dry matter retained decreased slightly as the level of calcium and phosphorus increased in the diet irrespective of source of phosphorus. Significant differences were however observed between treatment groups in apparent dry matter digestibility. Treatment groups 1, 2 and 4 had the highest apparent dry matter digestibility. These were followed closely by pigs fed treatment 5. Pigs fed dietary treatments 3 and 6 (high levels of bonemeal and rock phosphate supplementation) had the least apparent dry matter digestibility; their values being significantly lower than those of pigs fed dietary treatments 1, 2 and 4 but not 5.

Table 17 shows the influence of source of calcium and phosphorus and dietary calcium and phosphorus levels and ratios on the apparent dry matter digestibility and retention by pigs. No significant difference ($P>.05$) was observed in dry matter intake, faecal, apparent digestibility and retention between pigs fed bonemeal or rock phosphate supplemented diets. The slightly higher faecal dry matter and dry matter retention observed in the group fed rock phosphate supplemented diets may be a reflection of the slightly higher dry matter intake recorded. Apparent dry matter digestibility was slightly higher in the pigs fed bonemeal supplemented diets.

Increasing dietary calcium and phosphorus levels and ratios did not influence other parameters except apparent dry matter digestibility. Apparent dry matter digestibility decreased significantly ($P<.05$) with increasing dietary calcium and phosphorus levels and ratios. Faecal dry matter increased slightly while dry matter retention declined with increasing dietary calcium and phosphorus levels and ratios.

Literature on the influence of source of calcium and phosphorus and dietary calcium and phosphorus levels and ratios on dry matter digestibility is scarce. There is evidence (Colovos et al., 1958 and Ammerman et al., 1961) that excess calcium in the diet of cattle adversely depressed the digestibility of certain nutrient components including dry matter. Combs and Wallace (1962) however reported that dry matter digestibility by pigs fed either 0.4 or 0.88 percent dietary calcium were similar and concluded that the growth reduction recorded in that study was not due to a reduction in dry matter digestibility.

Table 16: Apparent dry matter digestibility and re'ention by pigs in Experiment 3:

Source of calcium and phosphorus	Bonemeal			Rock phosphate			
Calcium-phosphorus levels	Low	Medium	High	Low	Medium	High	
Treatments	1	2	3	4	5	6	SEM[1]
Dry matter intake, g/d	362	352	335	380	388	347	±14.42
Faecal dry matter, g/d	59	61	75	64	77	77	±2.91
Dry matter retained, g/d	303	291	260	316	311	270	+14.02
Apparent dry matter digestibility, %	83.70[a]	82.67[a]	77.61[b]	83.16[a]	80.15[ab]	77.81[b]	±0.70

[1]Standard error of means.

[a,b]Means in the same row with different superscripts differ significantly (P<.05).

Table 17: Apparent dry matter digestibility and retention as influenced by source of calcium and phosphorus and dietary calcium and phosphorus levels in Experiment 3:

	Source of calcium and phosphorus			Calcium-phosphorus levels			
Factor	Bonemeal	Rock phosphate	SEM[1]	Low	Medium	High	SEM[1]
Dry matter intake, g/d	349	369	±15.11	371	370	341	±17.16
Faecal dry matter, g/d	65	73	±2.60	62	69	76	±3.49
Dry matter retained, g/d	284	296	±14.64	309	301	265	±16.51
Apparent dry matter digestibility, %	81.38	80.22	±0.83	83.29[a]	81.35[ab]	77.71[b]	±0.[illegible]

[1]Standard error of means.

[a,b]Means in the same row with different superscripts differ significantly (P<.05).

In a series of experiments, Evans (1929) found that pigs suffering from prolonged phosphorus deficiency were equally effective in dry matter digestibility as controls. In this study, increasing dietary calcium and phosphorus levels and ratios adversely affected dry matter digestibility. This could be a reflection of the differences in the calcium and phosphorus requirements of pigs used in this experiment. Under temperate conditions and here in the tropical regions, the mechanism of reduced digestibility with increasing levels of calcium and phosphorus is not clear. This result however shows that high levels of calcium and phosphorus in the diet interfered with dry matter digestibility and could have been responsible in part for the depressed performance recorded in Experiments 1 and 2 at high levels of calcium and phosphorus. Low to medium levels of supplementation appear to be optimum. It is known that optimum dietary calcium : phosphorus ratio is critical for the utilization of each element (Reinhart and Mahan, 1986) but information on its effect on digestibility is lacking.

3.3.3.3.2 Ether extract digestibility and retention:

Ether extract (EE) intake, faecal output, apparent digestibility and retention as influenced by different dietary treatments is summarized in table 18. Treatment groups did not differ significantly ($P>.05$) in intake, faecal output and apparent ether extract digestibility. Pigs fed dietary treatments 4, 5 and 6 had slightly higher faecal ether extract, while those fed dietary treatments 2 and 4 had non-significantly higher apparent ether extract digestibility than the other treatment groups. The lowest apparent ether extract digestibility was observed in pigs

fed dietary treatment 6. Pigs fed dietary treatments 2 and 5 (medium level of supplementation) had the highest ether extract retention compared with other groups, although these values were not significantly different from those fed dietary treatments 1, 3 and 4. Pigs fed dietary treatment 6 had the least ether extract retention which was significantly lower ($P<.05$) than all other treatment groups.

The effect of source of calcium and phosphorus and dietary calcium and phosphorus levels and ratios on apparent ether extract digestibility and retention is presented in Table 19. Pigs fed bonemeal and rock phosphate supplemented diets did not differ significantly in intake, faecal and apparent ether extract digestibility. However, apparent ether extract digestibility was slightly higher in the group fed bonemeal supplemented diets.

Increasing dietary calcium and phosphorus levels and ratios did not have any significant effect on the other parameters except ether extract retention. This increased significantly ($P<.05$) with the first incremental level (medium level) of dietary calcium and phosphorus but not with the second (high level). In other words, the highest ether extract retention was observed in pigs fed the medium dietary calcium and phosphorus levels and ratios. The highest values for apparent ether extract digestibility was also observed in this group of pigs, but differences were not statistically significant.

The results obtained in this study suggests that neither bonemeal nor rock phosphate (as supplementary source of calcium and phosphorus) influenced ether extract digestibility and retention in swine. This finding further suggests that the medium dietary calcium and phosphorus levels and ratios were

Table 18: Apparent ether extract (EE) digestibility and retention by pigs in Experiment 3:

Source of calcium and phosphorus	Bonemeal			Rock phosphate			
Calcium-phosphorus levels	Low	Medium	High	Low	Medium	High	
Treatments	1	2	3	4	5	6	SEM[1]
Ether extract intake, g/d	13.75	17.25	13.95	15.21	19.41	13.73	±0.82
Faecal ether extract, g/d	2.50	2.42	2.53	5.54	3.66	3.97	±0.29
Ether extract retained, g/d	11.25[ab]	14.83[a]	11.42[ab]	12.67[ab]	15.75[a]	9.76[b]	±0.77
Apparent digestibility, %	81.82	85.97	81.86	83.30	81.14	71.09	±1.68

[1]Standard error of means.

[a,b]Means in the same row with different superscripts differ significantly (P<.05).

Table 19: Apparent digestibility and retention of ether extract as influenced by source of calcium and phosphorus and dietary calcium and phosphorus levels in Experiment 3.

Factor	Source of calcium and phosphorus			Calcium-phosphorus levels			
	Bonemeal	Rock-phosphate	SEM[1]	Low	Medium	High	SEM[1]
Ether extract intake, g/d	15.00	16.12	±0.75	14.50	18.38	13.84	±0.97
Faecal ether extract, g/d	2.39	3.35	±0.38	2.52	2.90	3.20	±0.24
Ether extract retained, g/d	12.61	12.77	±0.75	11.98[ab]	15.43[a]	10.64[b]	±1.01
Apparent ether extract digestibility, %	84.07	79.23	±2.27	82.62	84.18	76.88	±1.78

[1]Standard error of means

[a,b]Means in the same row with different superscripts differ significantly (P<.05).

optimum for maximum ether extract digestibility and retention in swine. No information was found in literature to support or disprove this finding. The significance of lipid fraction of ether extract on growth performance of pigs is evident (Atteh and Leeson, 1983) and could help to support some of the findings in the weaner and grower studies.

3.3.3.3.3 Nitrogen digestibility and retention:

The effect of various dietary treatments on the digestibility and retention of nitrogen by pigs in Experiment 3 is presented in Table 20. No significant difference ($P>.05$) existed between treatment groups in nitrogen intake, faecal nitrogen, urinary nitrogen, apparent nitrogen digestibility and retention by pigs. Pigs fed the low calcium-phosphorus diets (treatments 1 and 4) were observed to have slightly higher urinary nitrogen than the other groups. Apparent nitrogen digestibility was also slightly higher for pigs fed the low and medium Ca-P diets than the diets containing high calcium and phosphorus (diets 3 and 6), although the differences were not statistically significant ($P>.05$). Pigs fed dietary treatments 3, 4 and 5 retained more nitrogen per day than those fed treatments 1, 2 and 6. Apparent nitrogen digestibility was therefore highest at the medium level of bonemeal supplementation, while for rock phosphate, the highest was recorded for the low level.

Table 21 summarizes the influence of source of calcium and phosphorus and dietary calcium and phosphorus levels and ratios on the digestibility and retention of nitrogen by pigs in the metabolism trial. No significant difference ($P>.05$) was observed between pigs fed bonemeal and rock phosphate supplemented diets with respect to nitrogen intake, faecal nitrogen, apparent digestibility and retention. A slightly higher nitrogen intake by this group of pigs. Haydon et al. (1984) reported

Table 20: Apparent digestibility and retention of nitrogen by pigs in Experiment 3:

Source of calcium and phosphorus	Bohemeal			Rock phosphate			
Calcium-phosphorus levels	Low	Medium	High	Low	Medium	High	SEM[1]
Treatments	1	2	3	4	5	6	
Nitrogen intake, g/d	11.66	10.95	11.82	13.31	13.40	11.96	±0.56
Faecal Nitrogen, g/d	2.35	2.17	2.61	2.25	2.67	2.53	±0.11
Urinary nitrogen, g/d	3.27	2.83	2.05	3.76	2.17	2.24	±0.30
Nitrogen retained, g/d	6.04	5.95	7.16	7.30	8.56	6.76	±0.47
Nitrogen retained, % intake	51.80	54.33	60.57	55.59	63.88	56.52	±2.51
Apparent in nitrogen digestibility, %	79.84	80.18	77.92	83.10	80.07	78.85	+0.76

[1]Standard error of means.

Differences between treatment means are not statistically significant (P>.05).

Table 21: Apparent digestibility and retention of nitrogen by pigs as influenced by source of calcium and phosphorus and dietary calcium and phosphorus levels (Experiment 3).

Factor	Source of calcium and phosphorus			Calcium-phosphorus levels			
	Bonemeal	Rock-phosphate	SEM[1]	Low	Medium	High	SEM[1]
Nitrogen intake, g/d	11.48	12.89	±0.61	12.49	12.18	11.62	±0.61
Faecal Nitrogen, g/d	2.38	2.48	±0.10	2.30	2.42	2.57	±0.10
Urinary nitrogen, g/d	2.72	2.73	±0.14	3.39	2.52	2.15	±0.31
Nitrogen retained, g/d	6.38	7.68	±0.52	6.80	7.24	6.90	±0.51
Nitrogen, retained, % intake	55.57	59.58	±1.35	54.44	59.44	59.38	±2.57
Apparent digestibility %	79.27	80.76	±0.79	81.58	80.13	77.88	±0.86

[1]Standard error of means.

Differences between treatment means are not statistically significant (P>.05).

an increase in nitrogen retention with an increase in feed consumed.

Increasing the dietary calcium and phosphorus levels and ratios did not influence any of the parameters measured. Faecal nitrogen tended to increase while urinary nitrogen decreased with increasing dietary calcium and phosphorus levels and ratios. Apparent nitrogen digestibility decreased with increasing dietary calcium and phosphorus levels and ratios while nitrogen retention increased only with the first incremental level (medium level and ratio of dietary calcium and phosphorus). The maximum daily nitrogen retention of 7.24g/day was obtained at the medium dietary calcium and phosphorus level and ratio. Kornegay and Kite (1983) found that feeding pigs a daily allowance of either 10g or 15g/day did not influence nitrogen absorption and retention. In another metabolism trial in which growing pigs were fed three levels of calcium and three levels of phosphorus, Vipperman et al. (1974) found that nitrogen retention was affected more by dietary phosphorus than by calcium, and increasing dietary calcium level without increasing dietary phosphorus resulted in a decrease in nitrogen retention. In this study, dietary calcium and phosphorus levels and ratios were increased simultaneously and these had no significant effect on nitrogen retention. The result agreed with those of Vipperman et al. (1974).

3.3.3.3.4 Calcium absorption and retention:

The influence of various dietary treatments on apparent percentage absorption and retention of calcium is presented in Table 22. No significant difference ($P>.05$) was observed between treatments with respect to faecal, urinary and apparent percentage absorption of calcium. Pigs fed dietary treatments 3, 5 and 6 excreted slightly more calcium in their faeces than those fed dietary treatments 1, 2 and 4, while those fed

Table 22: Apparent absorption and retention of calcium by pigs in Experiment 3.

Source of calcium and phosphorus	Bonemeal			Rock phosphate			
Calcium-phosphorus levels	Low	Medium	High	Low	Medium	High	
Treatments	1	2	3	4	45	6	SEM[1]
Calcium intake, g/d	1.81[b]	2.65[b]	3.90[a]	1.98[b]	2.92[ab]	3.71[a]	±0.21
Faecal calcium, g/d	0.39	0.37	0.44	0.32	0.58	0.78	±0.05
Urinary calcium, g/d	0.11	0.13	0.08	0.10	0.10	0.13	±0.01
Calcium retained, g/d	1.31[c]	2.14[bc]	3.37[a]	1.56[c]	2.24[bc]	2.81[ab]	±0.19
Calcium retained, % intake	72.37	81.00	86.60	78.65	76.82	75.56	±2.02
Apparent percentage absorption (%)	78.27	85.91	88.73	88.85	80.18	79.11	±1.70

[1]Standard error of means.

[a,b,c]Means in the same row with different superscripts differ significantly ($P<.05$).

treatment 6 showed a non-significantly higher urinary calcium level than the other groups. Apparent percentage absorption of calcium was slightly higher in pigs fed dietary treatments 2, 3, 4 and 5. Significant differences were observed between treatment groups. Dietary treatments 3, 5 and 6 had significantly higher ($P<.01$) calcium intake than the other treatment groups. Pigs fed dietary treatments 3 and 6 (High levels of calcium and phosphorus) also had significantly higher ($P<.05$) calcium retention, while those on treatment 2 and 5 (medium levels) came next. The least calcium retention value was observed in pigs fed dietary treatments 1 and 4 (low levels).

A summary of the influence of dietary source of calcium and phosphorus and calcium and phosphorus levels and ratios on apparent percentage absorption and retention of calcium by pigs is presented in Table 23. No significant differences ($P>.05$) were observed in intake, faecal, urinary, apparent percentage absorption and retention of calcium between pigs fed bonemeal and rock phosphate supplemented diets. Apparent percentage absorption and retention of calcium were slightly higher in pigs fed bonemeal diets than those fed the rock phosphate diets. Other parameters were similar for both groups.

Faecal, urinary and apparent percentage absorption were not influenced significantly ($P>.05$) by increasing dietary calcium and phosphorus levels and ratios. However, faecal calcium tended to increase with increasing levels and ratios of dietary calcium and phosphorus. Urinary calcium increased only with the first incremental level of dietary calcium and phosphorus and declined thereafter. Apparent percentage calcium absorption increased slightly from the low dietary calcium and phosphorus levels and ratios to the highest. A significant increase ($P<.01$) was observed in calcium intake with increasing dietary calcium and phosphorus levels and ratios. This was expected because calcium levels of these diets were

Table 23: Apparent absorption and retention of calcium by pigs as influenced by source of calcium and phosphorus and dietary calcium and phosphorus levels (Experiment 3).

Factor	Source of calcium and phosphorus			Calcium-phosphorus levels			
	Bonemeal	Rock-phosphate	SEM[1]	Low	Medium	High	SEM[1]
Calcium intake, g/d	2.79	2.87	±0.14	1.90[b]	2.78[ab]	3.81[a]	±0.26
Faecal calcium, g/d	0.41	0.55	±0.47	0.36	0.48	0.61	±0.04
Urinary calcium, g/d	0.11	0.11	±0.01	0.11	0.12	0.11	±0.01
Calcium retained, g/d	2.27	2.21	±0.13	1.44[b]	2.19[ab]	3.09[ab]	±0.25
Calcium retained, % intake	81.51	77.00	±1.75	75.57	78.76	81.23	±1.93
Apparent percentage absorption (%)	85.35	80.80	±1.66	81.19	82.89	84.02	±1.48

[1] Standard error of means.

[a,b] Means in the same row with different superscripts differ significantly ($P<.05$).

increased from low to high. Calcium retention also increased significantly ($P<.01$) with increasing dietary calcium and phosphorus levels. This finding is in agreement with Nimmo *et al.* (1981a) who fed two dietary calcium and phosphorus levels (low and high) to gilts and observed that more calcium was retained by the group of pigs fed the high dietary calcium and phosphorus levels. Faecal calcium tended to increase with increasing dietary calcium and phosphorus levels, while urinary calcium increased only with the first incremental level of dietary calcium and phosphorus.

In related balance studies involving calcium, Kornegay and Kite (1983) found that dietary calcium and phosphorus did not influence absorption and retention of calcium. Dietary calcium and phosphorus levels (Vepperman *et al.*, 1974 and Atteh and Leeson, 1983) and ratios (Vipperman et al., 1974) have also been reported to have no effect on the apparent percentage calcium absorption and retention in pigs.

3.3.3.3.5 Phosphorus absorption and retention:

Percentage absorption and retention of phosphorus by pigs fed different dietary treatments is presented in Table 24. No significant difference ($P>.05$) was observed between treatment groups in faecal, urinary, apparent percentage absorption and retention of phosphorus. Pigs fed dietary treatments 5 and 6 excreted slightly higher phosphorus in their faeces than those fed treatments 1, 3 and 4. Those fed treatment 2 had the least faecal phosphorus of all other groups. Apparent percentage absorption of phosphorus was slightly higher in pigs fed dietary treatments 2, 3 and 6 than the others, while more phosphorus was retained when pigs were fed dietary treatments 3 and 6 (high calcium-phosphorus

levels) compared to other groups. Treatment groups differed significantly ($P<.01$) in phosphorus intake. Phosphorus intake increased from treatments 1 to 3 and from 4 to 6.

Table 25 summarizes the influence of source of calcium and phosphorus and dietary calcium and phosphorus levels and ratios on the apparent absorption and retention of phosphorus by pigs. No significant difference was observed in faecal, urinary, apparent percentage absorption and retention of phosphorus between pigs fed bonemeal and rock phosphate supplemented diets. Apparent percentage absorption was slightly higher for pigs fed bonemeal supplemented diets.

Increasing the dietary calcium and phosphorus levels and ratios had no significant effect on any of the parameters measured except phosphorus intake which increased significantly ($P<.01$) with increasing dietary calcium and phosphorus levels. This is not surprising because the diets contained increasing levels of phosphorus. Faecal and urinary phosphorus tended to decrease, while retention increased with increasing dietary calcium and phosphorus levels. Apparent percentage absorption of phosphorus was not influenced much by increasing dietary calcium and phosphorus levels.

Literature on the percentage absorption and retention of phosphorus are contrasting. Nimmo (1981a) reported significant increases in urinary phosphorus with increasing dietary phosphorus in the diet and also more was retained at high dietary calcium and phosphorus levels. The result in this study did not find any significant increase in urinary or faecal phosphorus with increasing levels of calcium and phosphorus. However, phosphorus retention increased but non-significantly with increasing dietary calcium and phosphorus levels. Vipperman et al. (1974) and Atteh and Leeson (1983)

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Table 24: Apparent absorption and retention of phosphorus by pigs in Experiment 3.

Source of calcium and phosphorus	Bonemeal			Rock phosphate			
Calcium-phosphorus levels	Low	Medium	High	Low	Medium	High	
Treatments	1	2	3	4	5	6	SEM[1]
Phosphorus intake, g/d	1.42[c]	1.71[bc]	2.48[ab]	1.60[c]	2.05[abc]	2.47[a]	±0.12
Faecal phosphorus, g/d	0.33	0.30	0.32	0.36	0.47	0.42	±0.03
Urinary phosphorus, g/d	0.07	0.03	0.06	0.05	0.05	0.03	±0.01
Phosphorus retained, g/d	1.02	1.38	2.10	1.20	1.53	2.01	±0.12
Phosphorus retained, % intake	72.10	80.71	84.62	74.45	74.68	81.17	±1.80
Apparent percentage absorption, %	77.05	82.71	86.96	77.85	77.02	83.00	±1.68

[1] Standard error of means.

[a,b,c] Means in the same row with different superscripts differ significantly (P<.05).

Table 25: Apparent phosphorus absorption and retention by pigs as influenced by source of calcium and phosphorus and dietary calcium and phosphorus levels in Experiment 3.

	Source of calcium and phosphorus			Calcium-phosphorus levels			
Factor	Bonemeal	Rock-phosphate	SEM[1]	Low	Medium	High	SEM[1]
Phosphorus intake, g/d	1.87	2.04	±0.10	1.51[b]	1.88[ab]	2.47[a]	±0.14
Faecal phosphorus, g/d	0.31	0.42	±0.03	0.42	0.34	0.38	±0.37
Urinary phosphorus, g/d	0.05	0.04	±0.01	0.06	0.04	0.05	±0.01
Phosphorus retained, % g/d	1.49	1.58	±0.09	1.11	1.46	2.05	±0.14
Phosphorus retained, % intake	78.04	76.27	±1.72	73.08	75.26	83.10	±2.13
Apparent percentage absorption, %	81.50	76.83	±1.58	76.83	76.01	77.79	±1.84

[1] Standard error of means.

[a,b] Means on the same row with different superscripts differ significantly (P<.05).

reported that dietary calcium and phosphorus levels had no effect on phosphorus absorption and retention. In a review, Irving (1964) found that some reports show that phosphorus retention was enhanced by dietary fluorine while others reported the contrary. This study did not establish any significant difference in phosphorus retention between bonemeal and rock phosphate supplemented diets.

CHAPTER FOUR:

4.0 GENERAL SUMMARY AND CONCLUSION:

In the weaner trial (Experiment 1) there was no significant differences between pigs fed bonemeal and rock phosphate supplemented diets. However, bonemeal supplemented diets tended to support better performance. In the grower trial (Experiment 2) source of calcium and phosphorus had no significant effect on performance. This finding clearly indicates that the rock phosphate used in this study compares favourably with bonemeal as a source of calcium and phosphorus for swine. It appears from the finding also that grower pigs can utilize rock phosphate more efficiently than weaner pigs.

There was no significant difference between pigs fed increasing dietary calcium and phosphorus levels and ratios in the weaner trial. The pigs fed the low dietary calcium and phosphorus levels and ratios tended to result in better performance than the medium and high levels. This same trend was also observed in the grower trial with the pigs fed high dietary calcium and phosphorus levels performing significantly lower in total weight gain and average daily gain than those fed the low and medium levels. This suggests that dietary calcium and phosphorus levels of 0.62 and 0.48 and 0.43 and 0.33 percent (analyzed values) respectively are adequate for optimum growth performance for weaner and grower pigs when dietary calcium : phosphorus ratio is maintained at 1.3:1. These values are lower than NRC (1988) suggested calcium and phosphorus levels for these category of pigs

Source of calcium and phosphorus had no effect on serum calcium levels in the weaner trial, but the medium calcium and phosphorus level resulted in higher serum calcium. In the grower trial, source of calcium and phosphorus also had no

effect on serum calcium. Dietary calcium and phosphorus level in the diet did not affect serum calcium level. This finding supports the fact that serum calcium level is homeostatically maintained at a fairly constant level. It also suggests that grower pigs are better able to maintain serum calcium level constant than weaner pigs.

In the weaner trial, source of calcium and phosphorus significantly affected serum phosphorus and favoured the use of bonemeal. In the grower trial source of calcium and phosphorus also significantly affected serum phosphorus and also favoured the use of bonemeal. Maximum serum phosphorus level was obtained at the medium dietary calcium and phosphorus level of supplementation. This suggests that higher dietary calcium and phosphorus levels are needed to maintain serum phosphorus than for optimum growth performance.

The results of the effect of source of calcium and phosphorus on bone parameters indicated that physical bone parameters were not influenced significantly by source of calcium and phosphorus except metacarpal bones which were significantly longer in pigs fed bonemeal supplemented diets. Pigs fed rock phosphate supplemented diets had significantly higher matacarpal and metatarsal diameters. Metacarpal and metatarsal bone lengths increased with dietary calcium and phosphorus levels while ash, calcium and phosphorus contents of bones increased only with the first dietary calcium and phosphorus levels. Metacarpal bone diameter also increased with dietary calcium and phosphorus levels and ratios. These findings suggest that higher dietary calcium and phosphorus levels than for growth are necessary for skeletal development. The finding also suggests that the medium dietary calcium and phosphorus levels are optimum for bone development in both weaner and grower pigs.

The result of the nutrient balance trial (Experiment 3) showed that source of calcium and phosphorus had no significant effect on the apparent digestibility of dry matter, ether extract, nitrogen, and apparent absorption of calcium and phosphorus. Only apparent digestibility of dry matter decreased significantly with increasing dietary calcium and phosphorus levels and ratios. Apparent retention of ether extract decreased significantly with increasing dietary calcium and phosphorus levels. From this findings, since source of calcium and phosphorus has no effect on apparent digestibility of nutrients and increasing calcium and phosphorus levels increased calcium and phosphorus retention, it would imply that the tendency of growth to decrease with increasing dietary calcium and phosphorus levels in the growth and finishing trials may infact be due to a widening dietary calcium : phosphorus ratio.

Generally speaking, the responses were not consistent. It is however clear that bonemeal tended to result in overall better performance than rock phosphate, although in many cases the differences were non-significant. That the results between bonemeal and rock phosphate were non-significant shows that rock phosphate of the quality used in this study has good potential as a source of calcium and phosphorus for pigs especially when the conventional sources of calcium and phosphorus are non available or available at high costs. The low dietary calcium and phosphorus level and ratio favoured better growth performance but the medium level and calcium : phosphorus ratio in this study favoured better blood serum mineral contents, skeletal development and nutrient digestibility suggesting that although the low dietary calcium and phosphorus level and ratio is adequate

for growth performance it is not enough to support blood mineral concentrations skeletal development and nutrient digestibility. The medium dietary calcium and phosphorus level (0.89, 0.68 and 0.62, 0.50 percent respectively for weaners and growers and ratio (1.4:1 for both categories) are therefore suggested for weaner and grower swine in Nigeria.

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APPENDIX TABLES:

ANALYSIS OF VARIANCE TABLES:

Appendix 1: Final weights in Experiment 1.

Source of Variation	Degrees of freedom	Sum of Squares	Mean Square	F. value
Replicate	3	214,905	71,635	5,596**
Ca-P levels	2	2.402	1.201	0.093
Source	1	2	2	0.156
Levels x Source	2	0.12	0.06	4E - 03
Sex	1	0	0	0
Levels x Sex	1	8.573	4.266	0.334
Source x Sex	1	0.040	0.040	3E - 03
Level x Sex x Source	2	2.737	1.368	0.106
Residual	33	422,415	12.8	
Total	47	653,196		

Appendix 2: Total weight gains in Experiment 1.

Source of Variation	DF	SS	MS	F
Replicates	3	50.251	26.76	3.723*
Ca-P levels	2	3.09	1.545	0.215
Source	1	2.707	2.707	0.376
Level x Source	2	0.053	0.026	3E - 03
Sex	1	5.74	5.74	0.798
Level x Sex	2	7.755	3.877	0.539
Source x Sex	1	3E - 03	3E - 03	0
Level x Source x Sex	2	3.14	1.57	0.218
Residual	33	237,153	7.185	
Total	47	339,926		

*Significant ($P<0.05$)

**Highly significant ($P<0.01$)

Appendix 3: Average daily gains in Experiment 1.

Source of Variation	DF	SS	MS	F
Replicate	3	0.064	0.021	3.349*
Ca-P levels	2	2E-03	1E-03	0.251
Source	1	2E-03	2E-03	0.363
Levels x Source	2	0	0	0.01
Sex	1	4E-03	4E-03	0.75
Level x Sex	2	6E-03	3E-03	0.517
Sources x Sex	1	0	0	5E-03
Level x Source x Sex	2	2E-03	1E-03	0.204
Residual	33	0.193	5E-03	
Total	47	0.276		

Appendix 4: Feed : gain ratio in Experiment 1:

Source of Variation	DF	SS	MS	F
Replicate	3	2.155	0.718	4.192*
Ca-P level	2	0.08	0.045	0.284
Source	1	0.112	0.112	0.854
Level x Source	2	0.018	8E-03	0.046
Sex	1	0.232	0.232	1.356
Level x Sex	2	0.217	0.106	0.833
Source x Sex	1	7E-03	7E-03	0.04
Level x Source x Sex	2	0.112	0.056	0.829
Residual	33	5.654	0.171	
Total	47	8.598		

* Significant (P<0.05).

Appendix 5: Final weights in Experiment 2.

Source of Variation	DF	SS	MS	F
Replicate	1	423.82	423.82	35.660**
Source of P	1	0.427	0.427	0.036
Ca-P levels	2	88.27	44.135	3.714*
Level x Source	2	10.033	5.017	0.422
Sex	1	10.667	5.334	0.449
Level x Sex	2	6.493	3.247	0.273
Source x Sex	1	9.626	9.626	0.810
Level x Sex x Source	2	60.006	30.003	2.524
Residual	11	218.738	11.885	
Total	23	828.08		

Appendix 6: Total weight gain (Kg) in Experiment 2.

Source of Variation	DF	SS	MS	F
Replicates	1	13,881	13.881	2.622
Source of P	1	0.020	0.020	0.004
Ca-P level	2	97.342	48.671	9.194**
Level x Source	2	11.032	5.516	1.042
Sex	1	0.770	0.770	0.145
Level x Sex	2	32.902	16.451	3.107
Source x Sex	1	12.761	12.761	2.410
Level x Source x Sex	2	87.249	42.625	8.052
Residual	11	58.239	5.294	
Total	23	145.989		

*Significant ($P<.05$)

**Highly significant ($P<.01$)

Appendix 7: Average daily gains in Experiment 2:

Source of Variation	DF	SS	MS	F
Replicates	1	0.005	0.005	2.500
Source of P	1	0.000	0.000	0.000
Ca-P levels	2	0.040	0.020	10.000
Level x Source	2	0.005	0.003	1.500
Sex	1	0.000	0.000	0.000
Level x Sex	2	0.019	0.010	5.000
Source x Sex	1	0.005	0.005	2.500
Level x Source x Sex	2	0.030	0.015	7.500
Residual	11	0.027	0.002	
Total	23	0.131		

Appendix 8: Feed : gain ratio in Experiment 2:

Source of Variation	DF	SS	MS	F
Replicates	1	0.477	0.477	4.631*
Source of P	1	0.057	0.057	0.553
Ca-P levels	2	0.492	0.246	2.388
Level x Source	2	0.003	0.002	0.019
Sex	1	0.280	0.280	2.718
Level x Sex	2	0.006	0.003	0.028
Source x Sex	1	0.000	0.000	0.000
Level x Source x Sex	2	0.350	0.175	1.699
Residual	11	1.131	0.103	
Total	23	2.791		

* Significant ($P<.05$)

Appendix 9: Metacarpal bone length in Experiment 2:

Source of Variation	DF	SS	MS	F
Ca-P levels	2	1.10	0.55	61.11**
Source of P	1	0.35	0.35	38.89**
Level x Source	2	0.24	0.15	16.67**
Residual	18	0.17	0.009	
Total	23	1.86		

Appendix 10: Metatarsal bone length in Experiment 2:

Source of Variation	DF	SS	MS	F
Ca-P levels	2	0.61	0.305	6.630
Source of P	1	0.135	0.135	2.935
Level x Source	2	0.21	0.105	2.283
Residual	18	0.83	0.046	
Total	23	1.785		

Appendix 11: Metacarpal bone diameter (cm) in Experiment 2:

Source of Variation	DF	SS	MS	F
Ca-P levels	2	0.050	0.025	27.778**
Source of P	1	0.185	0.185	205.556**
Level x Source	2	0.064	0.032	35.556**
Residual	18	0.017	0.0009	
Total	23	0.316		

* Significant ($P<.05$)

** Highly Significant ($P<.01$).

Appendix 12: Metatarsal bone diameter in Experiment 2:

Source of Variation	DF	SS	MS	F
Ca-P levels	2	0.122	0.061	87.143**
Source of P	1	0.322	0.322	460.000**
Level x Source	2	0.0104	0.005	7.143
Residual	18	0.013	0.0007	
Total	23	0.467		

Appendix 13: Metacarpal bone weights - dry fat-free in Experiment 2:

Source of Variation	DF	SS	MS	F
Ca-P levels	2	0.710	0.355	0.455
Source of P	1	1.804	1.804	2.310
Level x Source	2	2.411	1.206	1.544
Residual	18	14.064	0.781	
Total	23	18,989		

Appendix 14: Metatarsal bone weights dry fat-free in Experiment 2:

Source of Variation	DF	SS	MS	F
Ca-P levels	2	0.317	0.159	0.280
Source of P	1	0.832	0.832	1.465
Level x Source	2	3.561	1.781	3.136
Residual	18	10.224	0.568	
Total	23	14.934		

** Highly Significant ($P<.01$)

Appendix 15: Metacarpal bone volume in Experiment 2:

Source of Variation	DF	SS	MS	F
Ca-P levels	2	4.083	2.042	1.235
Source of P	1	5.041	5.041	3.050
Level x Source	2	1.585	0.783	0.474
Residual	18	29.749	1.653	
Total	23	40.458		

Appendix 16: Metatarsal bone volume in Experiment 2:

Source of Variation	DF	SS	MS	F
Ca-P levels	2	0.583	0.292	0.255
Source of P	1	3.375	3.373	2.943
Level x Source	2	4.750	2.373	2.071
Residual	18	20.625	1.146	
Total	23	29.339		

Appendix 17: Metacarpal specific gravity in Experiment 2:

Source of Variation	DF	SS	MS	F
Ca-P levels	2	0.020	0.010	2.00
Source of P	1	0.016	0.016	3.20
Level x Source	2	0.075	0.038	7.00**
Residual	18	0.090	0.005	
Total	23	0.137		

**Highly Significant (P<.01).

Appendix 18: Metatarsal specific gravity in Experiment 2:

Source of Variation	DF	SS	MS	F
Ca-P levels	2	0.015	0.008	0.41
Source of P	1	0.027	0.027	1.800
Level x Source	2	0.104	0.052	2.64
Residual	18	0.270	0.0197	
Total	23	0.416		

Appendix 19: Metacarpal bone ash in Experiment 2:

Source of Variation	DF	SS	MS	F
Ca-P levels	2	74.601	37.301	5.346*
Source of P	1	285.246	285.246	40.884**
Level x Source	2	164.469	82.235	11.787
Residual	18	125.589	6.977	
Total	23	649.905		

Appendix 20: Metatarsal bone ash in Experiment 2.

Source of Variation	DF	SS	MS	F
Ca-P levels	2	20.432	10.216	2.081
Sources of P	1	95.520	95.520	19.458**
Level x Source	2	26.069	13.035	2.655
Residual	18	88.366	4.909	
Total	23	280.387		

* Significant ($P<0.05$)

** Highly Significant ($P<.01$)

Appendix 21: Metacarpal bone breaking load in Experiment 2:

Source of Variation	DF	SS	MS	F
Ca-P levels	2	0.045	0.023	1.731
Source of P	1	0.767	0.767	29.500**
Level x Source	2	0.134	0.067	2.577
Residual	18	0.475	0.026	
Total	23	1.421		

Appendix 22: Metatarsal bone breaking load in Experiment 2:

Source of Variation	DF	SS	MS	F
Ca-P levels	2	0.007	0.004	0.267
Source of P	1	1.175	1.175	78.333**
Level x Source	2	0.225	0.113	7.533*
Residual	18	0.261	0.015	
Total	23	1.668		

Appendix 23: Calcium in dry fat-free dry metacarpal bones in Experiment 2:

Source of Variation	DF	SS	MS	F
Ca-P levels	2	7.94	3.97	30.54**
Source of P	1	8.40	8.40	64.62**
Level x Source	2	8.25	4.13	31.77**
Residual	18	2.38	0.13	
Total	23	26.97		

* Significant ($P<.05$)

** Highly Significant ($P<.01$)

Appendix 24: Phosphorus in dry fat-free metacarpal bone in Experiment 2:

Source of Variation	DF	SS	MS	F
Level of Ca-P	2	2.88	1.44	72.00*
Source of P	1	16.75	16.75	837.50**
Level x Source	2	2.84	1.42	71.00**
Residual	18	0.32	0.02	
Total	23	22.79		

Appendix 25: Initial serum calcium concentration of pigs in Experiment 2:

Source of Variation	DF	SS	MS	F
Replicate	3	40.77	13.59	8.60**
Source of P	1	3.09	3.09	1.96
Level of Ca-P	2	2.82	1.41	0.89
Level x Source	2	8.80	2.20	0.39
Sex	1	10.64	10.64	6.73*
Level x Sex	2	1.55	0.78	0.49
Source x Sex	1	2.57	2.57	1.63
Level x Source x Sex	2	30.72	15.36	9.72
Residual	33	52.18	1.58	
Total	47	153.14		

*Significant ($P<.05$)

**Highly Significant ($P<.01$)

Appendix 26: Serum calcium concentration of pigs in Experiment at day 18:

Source of Variation	DF	SS	MS	F
Replicate	3	2.38	0.79	7.18**
Source of P	1	0.36	0.36	3.27
Level of Ca-P	2	5.59	2.80	25.45**
Level x Source	2	1.61	1.81	7.36**
Sex	1	0.04	0.04	0.363
Level x Sex	2	0.01	0.005	0.045
Source x Sex	1	0.26	0.26	2.363
Level x Source x Sex	2	1.62	0.81	7.364**
Residual	33	3.78	0.11	
Total	47	15.65		

Appendix 27: Serum calcium concentration of Pigs in Experiment 2, at day 35:

Source of Variation	DF	SS	MS	F
Replicate	3	1.83	0.61	1.396
Source of P	1	0.39	0.39	0.896
Level of Ca-P	2	1.38	0.69	1.886
Level x Source	2	0.73	0.37	0.841
Sex	1	0.32	0.32	0.727
Source x Sex	2	0.01	0.005	0.011
Level x Sex	1	0.38	0.38	0.86
Level x Source x Sex	2	0.13	0.065	0.147
Residual	33	14.53	0.44	
Total	47	19.70		

* Significant ($P<.05$)

** Highly Significant ($P<.01$)

Appendix 28: Initial serum phosphorus concentration of pigs in Experiment 1:

Source of Variations	DF	SS	MS	F
Replicate	3	21.38	7.13	0.85
Source of P	1	1.92	1.91	0.22
Level of Ca-P	2	7.72	3.86	0.45
Level x Source	2	1.53	0.77	0.09
Sex	1	0.27	0.27	0.03
Source x Sex	2	0.23	0.12	0.01
Level x Sex	1	10.41	10.41	1.20
Level x Source x Sex	2	20.19	10.10	1.17
Residual	33	285.64	8.66	
Total	47	349.29		

Appendix 29: Serum phosphorus concentration in pigs in Experiment 1 at day 18:

Source of Variation	DF	SS	MS	F
Replicate	3	1.25	0.42	1.148
Source of P	1	5.68	5.68	15.519**
Level of Ca-P	2	11.81	5.91	16.148**
Level x Source	2	2.85	1.43	3.907
Sex	1	0.096	0.096	0.262
Source x Sex	2	0.160	0.08	0.219
Level x Sex	1	1.167	1.167	3.189
Level x Source x Sex	2	4.59	2.295	6.270
Residual	33	12.087	0.366	
Total	47	39.69		

** Highly Significant ($P<.01$)

Appendix 30: Serum phosphorus concentration in pigs in Experiment 1 at day 35.

Source of Variation	DF	SS	MS	F
Replicate	3	2.91	0.97	0.856
Source of P	1	0.052	0.052	0.054
Level of Ca-P	2	12.91	6.455	5.638*
Level x Source	2	8.158	4.079	3.562*
Sex	1	0.042	0.042	0.037
Level x Sex	2	1.232	0.617	0.539
Source x Sex	1	6.276	6.276	5.481
Level x Source x Sex	2	9.858	4.929	4.305*
Residual	33	37.789	1.145	
Total	47	79.228		

Appendix 31: Initial Serum calcium concentration of pigs in Experiment 2:

Source of Variation	DF	SS	MS	F
Replicate	1	0.320	0.320	0.471
Source of P	1	0.217	0.217	1.437
Level of Ca-P	2	0.117	0.059	0.391
Level x Source	2	0.011	0.006	0.040
Sex	1	0	0	0
Level x Sex	2	0.228	0.114	0.755
Source x Sex	1	0.004	0.004	0.026
Level x Source x Sex	2	0.473	0.237	1.570
Residual	11	1.657	0.151	
Total	23	3.029		

* Significant ($P<0.05$)

Appendix 32: Serum calcium concentration of pigs in Experiment 2, at day 25:

Source of Variation	DF	SS	MS	F
Replicate	1	0.098	0.098	0.467
Source of P	1	0.286	0.286	1.362
Level of Ca-P	2	0.939	0.470	2.238
Level x Source	2	0.015	0.0075	0.036
Sex	1	0	0	0
Level x Sex	1	0.212	0.106	0.505
Source x Sex	1	0.289	0.289	1.376
Level x Source x Sex	2	0.469	0.234	1.114
Residual	11	2.307	0.210	
Total	23	4.615		

Appendix 33: Serum calcium concentration of pigs in Experiment 2, at day 49:

Source of Variation	DF	SS	MS	F
Replicate	1	1.668	1.668	5.894*
Source of P	1	0.095	0.095	0.336
Level of Ca-P	2	0.355	0.178	0.629
Level x Source	2	0.115	0.058	0.205
Sex	1	0.034	0.034	0.120
Level x Sex	2	0.486	0.243	0.859
Source x Sex	1	0.131	0.131	0.463
Level x Source x Sex	2	1.265	0.633	2.237
Residual	11	3.019	0.283	
Total	23	7.168		

* Significant ($P<0.05$)

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Appendix 34: Initial serum phosphorus concentration of pigs in Experiment 2:

Source of Variation	DF	SS	MS	F
Replicate	1	0.313	0.313	2.371
Source of P	1	0.023	0.023	0.174
Level of Ca-P	2	0.019	0.009	0.068
Level x Source	2	0.074	0.037	0.280
Sex	1	0.021	0.021	0.159
Level x Sex	2	0.033	0.017	0.129
Source x Sex	1	0.048	0.048	0.364
Level x Source x Sex	2	0.177	0.089	0.221
Residual	11	1.456	0.132	
Total	23	2.164		

Appendix 35: Serum phosphorus concentration of pigs in Experiment 2, at day 25:

Source of Variation	DF	SS	MS	F
Replicate	1	0.045	0.045	2.813
Source of P	1	4.217	4.217	263.56**
Level of Ca-P	2	4.526	2.263	141.44
Level x Source	2	0.960	0.48	30.00
Sex	1	0.001	0.001	0.063
Level x Sex	2	0.073	0.0365	2.281
Source x Sex	1	0.082	0.082	5.125
Level x Source x Sex	2	1.162	0.581	36.125
Residual	11	0.181	0.581	
Total	23	11.247		

** Highly Significant ($P<.01$).

Appendix 36: Serum phosphorus concentration of pigs in Experiment 2, at day 49:

Source of Variation	DF	SS	MS	F
Replicate	1	0.407	0.407	2.452
Source of P	1	0.893	0.893	5.379*
Level of Ca-P	2	4.467	2.234	13.358**
Level x Source	2	0.761	0.381	2.295
Sex	1	0.105	0.105	0.633
Level x Sex	2	0.065	0.033	0.199
Source x Sex	1	0.631	0.631	3.802
Level x Source x Sex	2	1.656	0.288	4.988
Residual	11	1.828	0.166	
Total	23	10.813		

Appendix 37: Daily dry matter intake in grams per pig in Experiment 3:

Source of Variation	DF	SS	MS	F
Block	3	22920.17	7640.06	1.304
Source of P	1	7280.17	7280.17	1.243
Level of Ca-P	2	1256.33	628.17	0.107
Source x Level	2	380.37	190.19	0.032
Residual	15	37898.30	5859.89	
Total	23	119735.33		

* Significant (P<.05)

** Highly Significant (P<.01)

Appendix 38: Daily faecal dry matter in grams per pig in Experiment 3:

Source of Variation	DF	SS	MS	F
Block	3	587.33	195.78	1.058
Source of P	1	352.66	352.66	1.905
Level of Ca-P	2	945.58	472.75	2.554
Source x Level	2	201.09	100.55	0.543
Residual	15	2776.67	185.11	
Total	23	4863.33		

Appendix 39: Daily dry matter retention in grams per pig in Experiment 3:

Source of Variation	DF	SS	MS	F
Block	3	88930.5	29643.5	17.54**
Source of P	1	2.5	2.5	0.0036
Level of Ca-P	2	3628	1814	1.073
Source x Level	2	1215	607.5	0.359
Residual	15	25348.5	1689.9	
Total	23	119124.5		

** Highly Significant ($P<.01$)

Appendix 40: Apparent digestibility of dry matter in Experiment 3:

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Source of Variation	DF	SS	MS	F
Block	3	106.007	35.336	5.37*
Source of P	1	5.920	5.92	0.899
Level of Ca-P	2	91.168	45.584	6.928**
Source x Level	2	3.196	1.598	0.243
Residual	15	96.706	6.58	
Total	23	284.996		

Appendix 41: Daily crude protein intake in grams per pig in Experiment 3:

Source of Variation	DF	SS	MS	F
Block	3	1398.26	466.09	1.488
Source of P	1	339.08	339.08	1.082
Level of Ca-P	2	370.83	185.42	0.592
Source x Level	2	378.11	189.06	0.603
Residual	15	4700.37	313.33	
Total	23	7186.65		

Appendix 42: Daily faecal crude protein in gram per pig in Experiment 3:

Source of Variation	DF	SS	MS	F
Block	3	83.05	27.68	2.28
Source of P	1	1.50	1.50	1.50
Level of Ca-P	2	4.78	2.39	0.197
Source x Level	2	32.40	16.20	1.336
Residual	15	181.90	12.13	
Total	23	303.63		

* Significant ($P<.05$)

** Highly Significant ($P<.01$)

Appendix 43: Daily crude protein retention in grams per pig in Experiment 3:

Source of Variation	DF	SS	MS	F
Block	3	963.38	321.13	1.432
Source of P	1	295.47	295.47	1.318
Level of Ca-P	2	457.68	228.84	1.021
Source x Level	2	291.42	145.71	0.650
Residual	15	3363.02	224.20	
Total	23	5370.97		

Appendix 44: Apparent digestibility of crude protein in Experiment 3:

Block Source of Variation	DF	SS	MS	F
Block	3	66.23	22.08	2.158
Source of P	1	9.24	9.24	0.903
Level of Ca-P	2	57.03	28.52	2.788
Source x Level	2	54.17	17.09	1.671
Residual	15	153.44	10.23	
Total	23	320.11		

Appendix 45: Daily ether extract intake in grams per pig in Experiment 3:

Source of Variation	DF	SS	MS	F
Block	3	64.39	21.46	1.511
Source of P	1	7.54	7.54	0.531
Level of Ca-P	2	94.03	47.02	3.311
Source x Level	2	5.94	2.97	0.209
Residual	15	213.05	14.20	
Total	23	384.95		

Appendix 46: Daily faecal ether extract in grams per pig in Experiment 3:

Source of Variation	DF	SS	MS	F
Block	3	6.39	2.13	0.968
Source of P	1	5.53	5.53	2.51
Level of Ca-P	2	1.82	0.91	0.414
Source x Level	2	2.58	0.078	0.035
Residual	15	32.98	2.20	
Total	23	49.30		

Appendix 47: Daily ether extract retention in grams per pig in Experiment 3:

Source of Variation	DF	SS	MS	F
Block	3	106.86	35.62	4.190*
Source of P	1	0.16	0.16	0.019
Level of Ca-P	2	97.40	48.70	5.503*
Source x Level	2	9.31	4.66	0.548
Residual	15	127.49	8.50	
Total	23	341.22		

Appendix 48: Apparent digestibility of ether extract in Experiment 3:

Source of Variation	DF	SS	MS	F
Block	3	539.05	179.68	3.73*
Source of P	1	122.45	122.45	2.55
Level of Ca-P	2	152.63	76.32	1.50
Source x Level	2	84.44	42.22	0.879
Residual	15	720.04	48.00	
Total	23	1618.61		

* Significant ($P<.05$)

Appendix 49: Daily nitrogen intake in grams per pig in Experiment 3:

Source of Variation	DF	SS	MS	F
Block	3	34.70	11.57	1.364
Source of P	1	15.25	15.25	1.798
Level of Ca-P	2	3.05	1.525	0.180
Source x Level	2	3.11	1.555	0.183
Residual	15	127.24	8.48	
Total	23	183.35		

Appendix 50: Daily faecal nitrogen in grams per pig in Experiment 3:

Source of Variation	DF	SS	MS	F
Block	3	1.46	0.487	1.715
Source of P	1	0.08	0.08	0.282
Level of Ca-P	2	0.31	0.155	0.546
Source x Level	2	0.47	0.235	0.827
Residual	15	4.26	0.284	
Total	23	6.58		

Appendix 51: Daily urinary nitrogen in grams per pig in Experiment 3:

Source of Variation	DF	SS	MS	F
Block	3	1.53	0.51	0.190
Source of P	1	0	0	0
Level of Ca-P	2	8.13	4.06	1.509
Source x Level	2	1.40	0.70	0.260
Residual	15	40.41	2.69	
Total	23	51.45		

Appendix 52: Daily nitrogen retention in grams per pig in Experiment 3:

Source of Variation	DF	SS	MS	F
Block	3	26.31	8.77	1.552
Source of P	1	12.99	12.99	2.299
Level of Ca-P	2	1.28	0.64	0.113
Source x Level	2	4.18	2.08	0.370
Residual	15	84.69	5.65	
Total	23	129.45		

Appendix 53: Daily nitrogen retention as percentage of intake, Experiment 3:

Source of Variation	DF	SS	MS	F
Block	3	729.51	243.17	1.487
Source	1	150.75	150.75	0.922
Level	2	169.35	84.68	0.518
Source x Level	2	128.06	64.03	0.392
Residual	15	2452.93	163.53	
Total	23	3630.55		

Appendix 54: Apparent digestibility of nitrogen as percentage of intake (Experiment 3).

Source of Variation	DF	SS	MS	F
Block	3	89.41	29.80	3.586*
Source	1	1.94	1.94	0.233
Level	2	49.66	24.84	2.988
Source x Level	2	66.21	33.105	3.984*
Residual	15	124.65	8.31	
Total	23	331.89		

* Significant ($P<.05$)

Appendix 55: Daily calcium intake in grams per pig in Experiment 3:

Source of Variation	DF	SS	MS	F
Block	3	1.736	0.579	1.135
Source	1	0.043	0.043	0.084
Level	2	14.574	7.287	14.288**
Source x Level	2	0.225	0.113	0.221
Residual	15	0.647	0.510	
Total	23	24.226		

Appendix 56: Daily faecal calcium excretion in grams per pig in Experiment 3:

Source of Variation	DF	SS	MS	F
Block	3	0.053	0.018	0.327
Source	1	0.134	0.134	2.436
Level	2	0.254	0.127	2.309
Source x Level	2	0.119	0.060	1.091
Residual	15	0.825	0.055	
Total	23	1.383		

Appendix 57: Daily urinary calcium excretion in grams per pig in Experiment 3:

Source of Variation	DF	SS	MS	F
Block	3	0.006	0.002	0.488
Source of P	1	0	0	0
Level of Ca-P	2	0.001	0.0005	0.122
Source x Level	2	0.006	0.003	0.732
Residual	15	0.061	0.0041	
Total	23	0.074		

* Significant ($P<.05$)

** Highly Significant ($P<.01$)

Appendix 58: Daily calcium retention in grams per pig in Experiment 3:

Source of Variation	DF	SS	MS	F
Block	3	1.617	0.539	1.093
Source of P	1	0.042	0.042	0.085
Level of Ca-P	2	11.006	5.503	11.162**
Source x Level	2	0.723	0.362	0.734
Residual	15	7.402	0.493	
Total	23	20.790		

Appendix 59: Daily calcium retention as percentage of intake in Experiment 3:

Source of Variation	DF	SS	MS	F
Block	3	136.60	45.53	0.404
Source of P	1	82.32	82.32	0.730
Level of Ca-P	2	173.93	86.97	0.771
Source x Level	2	273.00	136.55	1.211
Residual	15	1691.16	112.74	
Total	23	2357.11		

Appendix 60: Apparent calcium digestibility as percentage of intake (Experiment 3):

Source of Variation	DF	SS	MS	F
Block	3	96.69	32.23	0.406
Source of P	1	91.65	91.65	1.156
Level of Ca-P	2	57.44	28.72	0.362
Source x Level	2	226.96	113.48	1.432
Residual	15	1188.96	79.26	
Total	23	1661.70		

** Highly Significant ($P<.01$)

Appendix 61: Daily phosphorus intake in grams per pig in Experiment 3:

Source of Variation	DF	SS	MS	F
Block	3	0.72	0.24	1.026
Source of P	1	0.18	0.18	0.769
Level of Ca-P	2	3.77	1.885	8.056**
Source x Level	2	0.13	0.065	0.278
Residual	15	3.51	0.234	
Total	23	8.31		

Appendix 62: Daily faecal phosphorus excretion in grams per pig in Experiment 3:

Source of Variation	DF	SS	MS	F
Block	3	0.030	0.010	0.476
Source of P	1	0.063	0.063	3.00
Level of Ca-P	2	0.010	0.005	0.238
Source x Level	2	0.021	0.021	0.976
Residual	15	0.316	0.021	
Total	23	0.440		

Appendix 63: Daily urinary excretion of phosphorus in grams per pig in Experiment 3:

Source of Variation	DF	SS	MS	F
Block	3	0.001	0.0003	0.375
Source of P	1	0	0	0
Levels of Ca-P	2	0.002	0.001	1.25
Source x Level	2	0.002	0.001	1.25
Residual	15	0.012	0.0008	
Total	23	0.017		

** Highly Significant ($P<.01$)

Appendix 67: Atomic Absorption Spectrometric determination of calcium (De Ruig, 1986).

(i) Reagents:

1. HCl, 12 mol/l, 3 mol/l, 0.3 mol/l.
2. Lanthanium nitrate solution - 10% (w/v/)
3. Lanthanium blank-dilute 5 ml lanthanium nitrate solution and 5 ml HCl (3mol/l) to 100 ml with water.
4. Stock solution: prepared fresh by diluting stock solution to contain 20 mg/l of calcium.

(ii) Apparatus:

1. Incineration dish - platinum, quartz or procelain
2. Glass ware-hard borosilicate glass
3. Muffle furnace - Electric, capable of being controlled at 550 C $\pm$ 10 C.
4. Atomic Absorption Spectrometer (AAS)

(iii) Procedure

1. Weigh, depending on expected calcium content, 1-5g of the sample into an incineration dish.
2. Carbonize on a hot plate or over a gas burner.
3. Ash for 3 hours in a muffle furnace at 550 C.
4. Add 10 ml HCl (30 mol/1) to ash and heat until dry.
5. Dissolve residue with heating in 5 ml of HCl (3 mol/1) and transfer to a 50 ml volumetric flask.

(iv) Calibration:

From standard calcium solutions, prepare calibration solution as follows:-

1. Dilute standard solution and add per 100 ml, 5 ml lanthanium nitrate solution (w/v) and 5 ml HCl (3mol/l)
2. Choose dilutions so that when measured vs lanthanium blank solution, a linear relationship is obtained between abrorbance and concentration.

(v) Adjustment of Atomic Absorption Spectrometer:

1. Optimize response of instrument for measurement with air/acetylene flame.
2. Set wavelength at 422.6nm to obtain maximum absorbance for calcium.

(vi) Determination:

1. Dilute known quantity of standard solution, test solution and reagent blank solution and add, per 100 ml solution 5 ml lanthanium nitrate solution and 5 ml HCl (3 mol/l)
2. Measure absorbance of test solution against reagent blank solution and calculate calcium content from the absorbance measured.
3. Content of element is given by the formula

$$\text{mg/kg Ca} = \frac{C}{M} \times 100$$

Where C = The concentration in mg/ml of element in final solution.

M = mass of sample represented in 100 ml of final test solution.

Appendix 68: Spectrophotometric determination of phosphorus: (Molybdovanadate method)

The procedure for digestion of sample is the same as in (iii) above. The phosphorus content of the sample is then determined spectrophotometrically as follows:-

(i) Apparatus

1. Spectrophotometer
2. Volumetric flasks - 50 ml and 200 ml
3. Pipettes - 5 ml and 10 ml
4. Timer.

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(ii) Procedure:/

1. Pipette 10ml of each working standard solution of sample solution into a 50ml volametric flask
2. Add 5 ml of 5M HCl
3. Add 5 ml ammonium molybdate - metavanadate reagent
4. Make up to 5 ml with distilled deionized water
5. Stand for 30 minutes
6. Measure the absorbance at 400 nm
7. Plot a graph relating the absorbance to mg of phosphorus in the phosphorus standard solutions.
8. Read from the standard curve the concentration of phosphorus equivalent to the absorbance of the sample and blank solution.