AMMONIUM POLYPHOSPHATE VERSUS DICALCIUM PHOSPHATE
AS A PHOSPHORUS SUPPLEMENT FOR GROWING-FINISHING SWINE

by

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CHAPTER I

INTRODUCTION

The importance of phosphorus (P) in swine diets has long been known. Phosphorus and its interrelationship with other nutrients, especially calcium (Ca), has been shown to be a major factor affecting gain, feed efficiency and bone development (NCR, 1979).

The P requirement in diets for growing-finishing pigs averages between 0.4 and 0.5%. In a sorghum-soybean meal diet only 56 to 65% of the total P is supplied by the sorghum and soybean meal and only 20 to 60% of the total plant P is estimated to be available for the pig (NRC, 1979). Supplemental P, therefore, is essential to insure an adequate P level for optimum performance and bone development.

The constant need for feed grade P by the swine industry, as well as other livestock industries, keeps a constant demand on P supplies. A variety of P sources with varying contents of P for use in swine diets are available but supplies are limited. Ammonium polyphosphate,¹ which is used as a non-protein nitrogen and P source by the cattle industry, could supply another P source for

¹Compen_R: Allied Chemical, Houston, Texas.

the swine industry. Ammonium polyphosphate is approximately 14.8% P, which is equal to or higher than some of the common P sources used in swine diets.

A P source must supply adequate P to insure that the pig is receiving the correct P level. Criteria generally used to evaluate the value of a P source are: (1) availability of P for bone mineralization and (2) effect on pig performance.

The objective of this research was to evaluate ammonium polyphosphate as a P source for growing-finishing swine.

CHAPTER II

LITERATURE REVIEW

Types of Phosphorus Sources

The phosphorus in swine diets generally is supplied by two sources: (1) plant materials and (2) inorganic supplements. Both of these sources of P have an important role in supplying the correct level of P in swine diets.

Grains and plant protein supply about two-thirds of the P in a swine diet (NRC, 1979). A large percentage of the P supplied by plant materials is in the form of phytate P, which has a lower P availability.

Plant protein sources, such as soybean meal and cottonseed meal, are often used in swine diets. The NRC (1979) lists soybean meal (44% protein) with an average content of .65% P, while cottonseed meal (41% protein) has an average content of .97% P.

Another source of protein occasionally used in swine diets is from animal sources. These protein sources usually contain much higher levels of P than plant sources due to the high bone content. Two of the common animal protein sources, fish meal and meat and bone meal (50% protein), have average P levels of 2.43 and 4.96% respectively (NRC, 1979). Their use in swine diets is usually limited because plant protein sources are generally more

economical.

Grains used in swine diets are corn, sorghum, barley, wheat, and oats which range from .27 to .37% P (NCR, 1979). The percent P varies very little between these grains.

Supplemental P sources such as reagent grade orthophosphate, feed grade orthophosphate, steamed bone meal, defluorinated phosphates and raw rock phosphates may be used (Gillis et al., 1954). Feed grade orthophosphates are similar to reagent grade orthophosphates but are not as purified. Feed grade orthophosphates are the most commonly used P supplements. These include tricalcium phosphate, dicalcium phosphate, monocalcium phosphate, sodium phosphate and disodium phosphate. The percent P in these sources range from 18.5 to 25.5% (Peo, 1975).

Bone as a P source is limited in the forms available for feeding. Steamed bone meal is the most common form used in swine diets and contains 12.6% P (NRC, 1979).

Raw rock phosphates as P sources found in nature are not widely used. Some of the most notable raw rock phosphates are colloidal clay with soft phosphate, Curacao Island phosphate and rock phosphate. These P sources may contain high quantities of fluorine, which may be toxic to swine. Once the fluorine is removed the classification changes to defluorinated rock phosphate which has a P level of 17.9% and is widely used as a supplemental P source (Newman et al., 1976).

Another P source not often used in the swine industry is ammonium polyphosphate. Ammonium polyphosphate does have a P level comparable to other P sources. Sullivan (1967) found ammonium polyphosphate to contain 14.5% P.

Factors Affecting the Availability of Phosphorus

Availability of Plant Phosphorus

The availability of P from plants for swine ranges from 20 to 60% (Peeler, 1972 and NRC, 1979). The main factor causing this low availability of plant P is that a large percentage of the P is tied up as phytic acid or phytate. Spitzer and Phillips (1945) and Nelson et al. (1968) found that 58% of the P in soybean meal (44% protein) was in phytate form. Lolas et al. (1976) found in the examination of fifteen varieties of soybeans that phytate P accounted for a low of 51.4% to a high of 57.1% of the total P. Cottonseed meal has a higher P content but 70% of the P is tied up as phytate P (Nelson et al., 1968). Nelson et al. (1968) found that the variation in the percentage of total P as phytate P in corn, sorghum, barley, wheat and oats was 66, 68, 56, 67 and 56% respectively. O'Dell et al. (1972) found that 80% of the total P in corn was phytate P, which was higher than the 66% found by Nelson et al. (1968).

Phytate P must first be hydrolyzed to yield inorganic P before it is available (Nelson, 1967). The enzyme needed to hydrolyze phytate P is phytase. Phytase can be found

in the plants themselves (Hill and Tyler, 1954) and in the digestive tracts of animals (Spitzer and Phillips, 1945). The availability of plant P is therefore largely dependent on the amount of P tied up as phytate and the amount of phytase present to break down phytic acid.

Data on the availability of plant P is varied among the common plant materials used in swine diets. Huang and Allee (1980) using the slope-ratio technique determined that the bioavailability of P in corn was 29% for crossbred pigs. The digestability of P in yellow corn was found to be only 8.5% by Calvert et al. (1978). Abrams et al. (1975) observed that high moisture corn had a higher P availability than regular corn for baby pigs. Huang and Allee (1980) found that the P bioavailability of soybean meal ranged from 17 to 36%. Tonroy et al. (1973) determined that soybean meal P was only 27% digestable. A diet of corn-soybean meal had a P digestability of approximately 30 to 60% when fed to growing pigs to a finishing weight of 90 kg (Noland et al., 1968). Huang and Allee (1980) determined that the bioavailability of sorghum P was 25% while Tonroy et al. (1970) determined that the average digestability of sorghum P was 63.72% for swine.

The level of the enzyme phytase can be the variable responsible for the wide variation of plant P availability. Spitzer and Phillips (1945) tested the phytase activity from rat intestines at varying pH levels and found

that the highest level activity was at pH 7.8 where 98% of the phytate P was liberated in six hours. Phytase activity was found in the digestive tracts of chickens and pigs at pH 7.8 (Spitzer and Phillips, 1945). Hill and Tyler (1954) found the greatest activity of phytase in wheat and bran was at pH 5.1. The greatest hydrolysis of phytate P in a nine to ten week old pig occurred in the early stages of digestion in the stomach before the pH reached 1.97 (Moore and Tyler, 1955). Pierce et al. (1977) fed calcium phytate as a supplemental P source at .26, .38 and .49% to growing pigs. The results showed that the digestability of phytate P averaged 19.1% and increased with the level of calcium phytate. Supplementing corn-soybean meal diets for chickens with phytase, increased the digestability of phytate P from 0 to 94% (Nelson et al., 1971).

✓ The availability of plant P has also been shown to be affected by Calcium (Ca), vitamin D and steam pelleting. High dietary levels of Ca form an insoluble salt with phytic acid thus decreasing the availability of the phytate P (Taylor, 1965 and Nelson, 1967). Taylor and Coleman (1979) showed in a study with golden hamsters and rats that high dietary Ca significantly decreased phytate P absorption from 23.5 to 20.3 mmol/kg and 27.7 to 13.6 mmol/kg respectively. Taylor (1965) observed that vitamin D increased the utilization of phytate P by an influence on intestinal phytase. A review by Nelson (1967) also in-

licated that vitamin D increased the utilization of phytate P. Bayley et al. (1969) determined that growing-finishing pigs fed a steam pelleted corn-soybean meal diet with no added P had significantly better performances than pigs fed a meal form diet. The improved performance was attributed to an increase in P absorption. Harmon et al. (1970) showed that finishing pigs fed a corn-soybean meal diet retained 39% of the plant P from a steam pelleting diet as compared to 32% from a meal diet. Bayley et al. (1975) observed no significant benefit of steam pelleting for growing-finishing pigs fed a corn-soybean meal diet with .32 and .48% P. These data agree with earlier work done with chickens which showed that steam pelleting significantly increased the availability of plant P (Summers et al., 1967 and Bayley et al., 1968).

Availability of Phosphorus in Phosphorus Sources

A large number of supplements are used in swine diets and some of the common ones are; monocalcium phosphate, dicalcium phosphate, tricalcium phosphate, rock phosphate, defluorinated rock phosphate, soft phosphates, colloidal clay phosphate, steamed bone meal and ammonium polyphosphate. The availability of P from these supplemental P sources has been measured by P absorption, bone development and biological value, which are similar to the methods used to determine plant P availability.

The biological value of P for male leghorn chickens

was determined using the slope ratio of percent supplement to percent of bone ash and found to be 113% for monocalcium phosphate, 98% for dicalcium phosphate, 100% for tricalcium phosphate, 94% for defluorinated rock phosphate, 70 to 100% for steamed bone meal and too low to measure for colloidal clay (Gillis et al., 1954). A similar study also with chickens by Jensen and Edwards (1980) determined that the biological value of tricalcium phosphate, dicalcium phosphate, defluorinated rock phosphate and ammonium polyphosphate to be 100, 123, 121 and 118%, respectively. Work done by Sullivan (1967) with turkeys indicated that the biological value of monocalcium phosphate, dicalcium phosphate, defluorinated rock phosphate and ammonium polyphosphate based on a slope ratio of bone ash to gain: feed ratio was 101.5, 99.5, 88.7 and 95.2% respectively.

Bohstedt et al. (1926) found that feeding dicalcium phosphate to growing-finishing pigs resulted in higher bone ash than those receiving tricalcium phosphate as a P supplement. Noland et al. (1964) observed similar results with growing pigs.

The studies comparing steamed bone meal to dicalcium phosphate indicated that steamed bone meal was equal to or better than dicalcium phosphate based on bone ash and strength (Chapman et al., 1955; Van Zante et al., 1967 and Cromwell et al., 1976). Shrewburry and Vestal (1945)

found no significant difference in percentage of bone ash between finishing pigs receiving steamed bone meal, defluorinated rock phosphate or rock phosphate as supplemental P. Work by Chapman et al. (1955) indicated that finishing pigs fed steamed bone meal had higher bone breaking strength but lower ash than pigs fed colloidal clay as the P source.

Defluorinated rock phosphate has been shown to equal dicalcium phosphate for bone development of pigs fed corn-soybean meal diets (Cornelius and Harmon, 1974 and Harmon et al., 1974). Ammerman et al. (1963) determined by radioactive labeling of defluorinated rock phosphate and dicalcium phosphate that in growing pigs defluorinated rock phosphate absorption was 41.1% and dicalcium phosphate absorption was 35.4% but net retention was not significantly different.

Peo (1975) indicated that soft phosphate was of limited value as a P source due to the variability of P level. This agrees with earlier work which indicated poor bone development and bone formation when soft phosphate was used as a supplemental P source (Plumlee et al., 1955 and Plumlee et al., 1958).

The research done with ammonium polyphosphate as a supplemental P source for poultry and swine is relatively recent. Clawson and Alsmeyer (1971) found no difference in bone development of growing pigs between ammonium poly-

phosphate and defluorinated rock phosphate as supplemental P sources. Jensen and Edwards (1980) also found no difference in the percent bone ash of chickens fed ammonium polyphosphate as a P source when compared to tricalcium phosphate, dicalcium phosphate and defluorinated rock phosphate. The breaking strength of growing-finishing pigs metatarsal bones were approximately the same for pigs receiving ammonium phosphate or dicalcium phosphate as supplemental P sources (Peo, 1975).

Phosphorus Level

The effect of P level on P availability has been widely studied. Methods used to determine the availability of P at different dietary P levels are bone ash, bone breaking strength, bone P, P retention, P absorption and serum P.

Work done with growing-finishing pigs has shown a significant increase in femur percent ash when dietary P levels were increased from as low as 0.2% to as high as 0.7% (Combs et al.; 1960, Chapman et al., 1962; Bayley et al., 1975 and Stone and McIntosh, 1977). Parker et al. (1975) found a linear increase in humerus ash and strength as dietary P level was increased from 0.4 to 0.6% for growing-finishing pigs. Newman et al. (1964) found similar results with weanling pigs when dietary P levels was increased from .35 to .65%. Cromwell et al. (1976) found an increase ($P < .01$) in metatarsal breaking

strength and percent ash as P supplementation was increased from 0.1 to .25% for 14.8 kg pigs. Newman et al. (1967) determined that above a dietary P level of .45%, percent ash and P of femurs of weanling pigs did not increase significantly. This agrees with later work by Cromwell et al. (1970) which showed a significant increase in percent metacarpal ash up to a 0.5% dietary P level. Parker et al. (1974) also found no significant increase in humerus ash content of growing-finishing pigs for dietary levels above 0.6% P.

Increasing the P level in a solution perfused through a thirty-vella loop in two weanling pigs resulted in an increase in net P absorption (Fox and Care, 1978). Vipperman et al. (1971) indicated an increase in P retention in weanling pigs up to a dietary P level of 0.5%. Earlier work by Mudd et al. (1969) showed that in weanling pigs the P retention as a percent of intake decreased from 47.3 to 19.9% as dietary P level was increased from .38 to 1.47 of the diet. Work by Miller et al. (1964) with baby pigs demonstrated that P retention significantly decreased from 88 to 59% when the dietary P level was increased from 0.5% to 0.8% of the diet.

Serum inorganic P has been used to evaluate the effect of dietary P level on the availability of P. Ullrey et al. (1967) indicated that growing-finishing pigs fed recommended levels of P maintained a constant serum P level of

7.1 mg/100 ml. An earlier study by Plumlee et al. (1955) indicated that serum P increased as the dietary P level was increased from 0.3 to 0.6%.

The effect of dietary P level on the availability of P has also been examined as an interaction between the grains in the diet and level of P fed. Cromwell et al. (1972) determined an interaction ($P < .01$) between grain sources (corn and wheat) and dietary P level based on fourth metatarsal breaking strength. The results indicated that pigs fed wheat had less variation in breaking strength as P levels changed. Cromwell et al. (1974) determined that metatarsal ash was not significantly affected by grain source as P level decreased.

Calcium and Phosphorus Interrelationship

The Ca and P interrelationship for swine is generally examined from the standpoint of how the Ca affects the P utilization by the pig. This is usually regarded as the Ca:P ratio. The affect of Ca on P is mainly examined in relationship to bone development or P absorption.

The importance of Ca to the transport of P has been thoroughly investigated. Harrison and Harrison (1961) in their study with rats stated that no P transport occurred without Ca. Chen et al. (1974) found P transport in male weanling rats to be greatest in the duodenum and was enhanced in the presense of Ca. Lee et al. (1979) further

demonstrated this with albino rats fed P depleted diets. Their results indicated that Ca absorption was also increased to obtain higher P absorption. These rat studies agree with studies by Miller et al. (1972) and Fox and Care (1978) with pigs which showed a limited increase in dietary Ca enhanced P absorption. Earlier studies with cross-bred pigs had indicated that an increase of Ca in the diet caused a decrease in P absorption (Davis, 1959 and Morgan et al., 1969). Nielsen (1972) determined for growing-finishing pigs that the Ca:P absorption ratio was 1.35:1. Stockland and Baylock (1973) found a significant decrease in plasma P as dietary Ca increased for growing pigs.

The Ca:P ratio is an important element in a swine diet because of the way Ca influences P utilization. Pond et al. (1975) determined that if the Ca:P ratio was kept at 1.2:1 for growing-finishing pigs, increasing the Ca and P levels in the diet did not significantly affect the percent bone ash. Doige et al. (1975) found no difference in metacarpal ash for growing-finishing pigs fed diets with Ca and P levels below and above NRC recommended levels if the Ca:P was maintained at 1.3:1. Modifying the Ca:P ratio beyond the ranges of 2:1 to 1:1 by changing either the Ca or P levels in the diets of growing-finishing pigs generally results in decreased bone ash or breaking force (Bethlee et al., 1933; Dunlop, 1935; Combs et al., 1963; Libal et al., 1969 and Pond et al., 1978)

Vitamin D Affect on Phosphorus

DeLuca and Schnoes (1976) determined that 1-25 dihydroxycholecalciferol ($1-25-(OH)_2-D_3$) activates the transfer of inorganic phosphates across the intestinal wall of the ileum and jejunum. Harrison and Harrison (1961) and Chen et al. (1974) demonstrated by their studies with rats that $1-25-(OH)_2-D_3$ only increased P transport across the intestinal wall in the presents of Ca. Vitamin D has also been linked with an increase in the enzyme phytase, which is needed to use phytate P (Taylor, 1965 and Nelson, 1967). Dunlop (1935) indicated that vitamin D increased average percent ash of tibias of pigs fed low Ca and P diets. Stone and McIntosh (1977) added vitamin D to growing-finishing pigs diets with varying Ca and P levels and found no significant difference in percent metacarpal bone ash due to the addition of vitamin D to the diet.

Protein Level Affect on Phosphorus

The investigation of different protein levels for swine diets has created an interest on the effect of high protein levels on P availability. Hendricks et al. (1970) observed that baby pigs fed a 32% crude protein (CP) diet had significantly lower percent ash and breaking load of femurs than baby pigs fed at 16% CP diet. Similar results were also observed in earlier work by Hendricks et al. (1974) using the humerus of baby pigs. Studies by Reinhard

et al. (1974) and Reinhard et al. (1976) indicated that feeding high dietary levels of CP to growing pigs required higher dietary levels of P. However Fammatre et al. (1977) found no effect on bone mineralization from feeding high dietary protein levels to finishing pigs.

Other Factors Affecting Phosphorus Availability

Additional factors affecting P availability which have been investigated are floor type, water source, environmental temperature, added fat and added iron (Fe). Cromwell et al. (1972) observed higher ash content and breaking force of metatarsals from growing-finishing pigs reared on dirt floors as compared to solid concrete floors, when dietary P level varied from 0.3 to 0.5%. Work by Parker et al. (1974) showed no significant interaction between P level and floor type on humerus ash and breaking force.

Two factors, which are part of the everyday management of a swine operation, are water source and environmental temperature. Bohstedt et al. (1926) found no significant difference between well water and distilled water for growing-finishing pigs fed a recommended P level. No significant effect on bone development was observed when growing-finishing pigs on recommended dietary P levels were exposed to an ambient temperature of 25 and 33 C (Holmes and Grace, 1975).

Fat has been added to swine rations to increase the

energy content of the diet. Calverley and Kennedy (1949) found that adding fat to normal rat rations caused no significant affect on rat femur ash or in P absorption.

Newman et al. (1964) added 10% tallow to growing pig diets with varying P levels and found no significant affect on femur ash or P content due to added tallow. Similar results were obtained with growing-finishing pigs fed 0 or 10% added tallow (Newman et al., 1967).

Furugouri (1972) observed that if Fe is added at 5102 or 7102 ppm to young pig diets there was a significant decrease in bone ash and percent P of bone. Furugouri (1972) also observed P deficiency symptoms in pigs receiving supplemental Fe.

Effect of Phosphorus Sources and Levels on Growth and Feeding Performance of Swine

The P level required for the most efficient and fastest gain for swine is constantly being re-evaluated. The NRC (1953) listed the recommended dietary P level of finishing pigs at .33% while the NRC (1979) recommends the dietary P level be 0.4% for finishing pigs. Chapman et al. (1955) indicated that P level has one of the greatest influences on average daily gain. As the P levels are being evaluated for maximum performances, different sources are also being examined to fill these P requirements. The levels at which different P sources are added to meet P requirements are also examined to determine the effect, if any, on swine

growth and feeding performance.

Phosphorus Level

The younger the pig the more critical the supplemental P level becomes. Coalson et al. (1972) found that the growth rate and efficiency of baby pigs improved linearly as dietary P was increased from .14 to 1.05%. Similar studies with growing pigs, under 60 kg, also indicated that as dietary P level increased from as low as .08% to as high as 0.7% there was a significant increase in average daily gain (ADG) (Chapman et al., 1962; Zimmerman et al., 1963; Bayley and Thomson, 1969; Peo et al., 1969; Abrams et al., 1975; Bayley et al., 1975 and Fammatre et al., 1977). Mudd et al. (1969) observed no significant effect on ADG as dietary P level was increased from .38 to 1.47% for restricted fed growing pigs. Stockland and Baylock (1973) and Reinhard et al. (1976) reported similar results with growing pigs fed ad libitum when the lowest dietary P level was alone 0.4%.

The average daily feed (ADF) intake seemed to decrease and feed:gain ratio (F/G) improved only for growing pigs as the dietary P level increased from very low levels to required dietary levels (Zimmerman et al., 1963; Bayley and Thomson, 1969 and Fammatre et al., 1977). Other studies which started with the lowest dietary P level above 0.4% observed no improvement in F/G and decreased ADF as the

dietary P level was increased (Mudd et al., 1969; Stockland and Baylock, 1973 and Reinhard et al., 1976). These data indicated improved F/G and decreased ADF only when dietary P levels were increased from below the growing pig P requirement.

Examination of dietary P level for finishing pigs indicate results similar to those for growing pigs but with more erratic gains as dietary P levels were increased from 0.2 to 0.7% (Chapman et al., 1962). These studies indicate that as dietary P levels were kept close to the required level for finishing pigs, up to 92 kg, there were no significant affect on ADG, ADF and F/G (Harmon et al., 1970; Fammatre et al., 1976).

Generally the growing-finishing pigs growth performance is not separated for evaluation but is evaluated from about 18 kg to about 100 kg. A large number of studies have demonstrated that maximum gain and efficiency was reached once dietary P level had reached the 0.4 to 0.5% level (Cromwell et al., 1970; Cromwell et al., 1972; Parker et al., 1974; Allee et al., 1975; Parker et al., 1975 and Greer and Lewis, 1978). Combs et al. (1962) had observed a significant increase in ADG as dietary P level was increased from 0.4 to .48% but the best efficiency was at the 0.4% level. Most work dealing with higher than required levels of dietary P shows no significant benefit in gain, feed intake or efficiency above the 0.5% dietary

P level (Newman et al., 1967; Bunch et al., 1969; Forsyth et al., 1969; Libal et al., 1969; Hays et al., 1970; Cromwell et al., 1972; Bayley et al., 1975 and Pond et al., 1975). Earlier work by Jordan et al. (1957) had observed a 6% decrease in F/G as dietary P level was increased from .45 to 0.6% but with no effect on gains. Bethke et al. (1933) also found a significant increase in ADF from .61 to 1.24 kg as dietary P level was increased from .33 to .64% respectively.

Phosphorus Source

The effect of P source on pig performance is generally measured by adding the P source at varying levels and determining the effect on ADG, ADF, and F/G. A P source is also usually compared to a standard source which is known to have a high P availability and is widely used. Dicalcium phosphate is one of the most common sources and fills the general requirements for a P standard.

Bohstedt et al. (1926) compared dicalcium phosphate to tricalcium phosphate for growing-finishing pigs and observed a higher ADG and ADF for the pigs fed the dicalcium phosphate. Noland et al. (1964) on the other hand observed a significant improvement in ADG and F/G for growing pigs receiving tricalcium phosphate as compared to dicalcium phosphate.

Defluorinated phosphate is another widely used P

source. When defluorinated phosphate was tested against dicalcium phosphate at varying levels of supplementation from 0.3 to 0.8% for growing finishing pigs no significant differences were found in ADG, ADF, and F/G (Plumlee et al., 1955; Harmon et al., 1974 and Newman and Elliott, 1976). Similar results were found by Plumlee et al. (1958) for growing pigs and by Van Zante et al. (1967) for weanling pigs.

Soft phosphate with colloidal clay for swine showed indication of reduced growth rate (Gobble et al., 1953). Plumlee et al. (1955) observed a significant decrease in gain of weanling pigs fed diets with soft phosphate and colloidal clay as compared to pigs fed dicalcium phosphate. Studies comparing soft phosphate with colloidal clay to dicalcium phosphate for growing-finishing pigs have shown a decrease in ADG, an increase in ADF and an increase in F/G (Chapman et al., 1955; Plumlee et al., 1958; Aldinger et al., 1959 and Harmon et al., 1970).

Steamed bone meal has often been used as a P source. Shrewsbury and Vestal (1945) report that no significant difference was obtained in ADG or F/G between pigs fed rations containing either steamed bone meal or defluorinated rock phosphate. Chapman et al. (1955) and Plumlee et al. (1958) observed that growing-finishing pigs fed diets with steamed bone meal had ADG equal to pigs fed diets with dicalcium phosphate and showed a tendency to be more ef-

ficient. Van Zante et al. (1967) found that for baby pigs there was no difference between steamed bone meal and dicalcium phosphate for ADG and F/G.

Another possible P source which has been examined very little is ammonium phosphate. Peo (1975) found ammonium phosphate in diets for growing-finishing pigs had no affect on ADG, ADF and F/G when compared to dicalcium phosphate.

Other P sources such as monocalcium phosphate, monosodium phosphate and rock phosphate have been used. Monocalcium phosphate had no adverse effect on ADG or F/G when compared to dicalcium phosphate (Plumlee et al., 1955 and Plumlee et al., 1958). Newman and Elliott (1976) determined monosodium phosphate to be equal to dicalcium phosphate for growing-finishing pigs in ADG, ADF, and F/G. Rock phosphate has no adverse effects on ADG, ADF or F/G when compared to other supplemental P sources (Shrewsbury and Vestal, 1945; Plumlee et al., 1955 and Newman and Elliott, 1976).

CHAPTER III

AMMONIUM POLYPHOSPHATE VERSUS DICALCIUM PHOSPHATE AS A PHOSPHORUS SUPPLEMENT FOR GROWING-FINISHING SWINE

Summary

A total of 160 crossbred pigs were fed a sorghum-soybean meal diet with ammonium polyphosphate (APP) or dicalcium phosphate (DiCa) as supplemental phosphorus sources for growing-finishing swine. The diets contained P levels of 0.5 and 0.4% for the grower phase and 0.4 and 0.33% for the finisher phase. Ammonium polyphosphate as a P source was evaluated on the basis of pig performance and bone development and compared with DiCa as a standard. The first rib and third and fourth metacarpals were removed from eight barrows from each of the four treatments.

No effect ($P > .05$) was obtained for average daily gain, average daily feed and feed:gain ratio of growing-finishing pigs due to the replacement of DiCa with APP as the P supplement. No effect on bone variables examined on the first rib and third and fourth metacarpals was obtained between pigs fed APP or DiCa. Pigs on the lower supplemental P levels had lower ($P < .01$) dry fat-free weight and percent ash for all three bones. The

breaking force of the first ribs and third metacarpals was less ($P < .01$) for the pigs fed the lower P supplements of APP and DiCa.

A trend was observed for an apparent decreased P availability from APP than DiCa when fed at the lower level of supplementation but this was not observed when APP was added to provide a P level to meet NRC (1979) requirements. Ammonium polyphosphate as a P supplement for growing-finishing swine was satisfactory for performance and bone mineralization as compared to DiCa.

Introduction

The importance of adequate P in swine diets is constantly being reinforced by investigations. This in addition to the use of P sources by livestock and fertilizer industries, which places a constant demand on limited P supplies, makes the investigation of new P supplies for the swine industry much more important.

Ammonium polyphosphate which is approximately 14.8% P, could be an alternate P supply for the swine industry. Ammonium polyphosphate has been proven as an excellent alternate P source for the poultry industry. (Sullivan, 1967 and Jensen and Edwards, 1980).

Although poultry research indicates a high P availability for APP, research showing availability for swine is severely lacking. The objective of this study was to de-

termine the P availability of APP for growing-finishing swine.

Experimental Procedure

Feeding Trial

One hundred-sixty crossbred pigs involving the Yorkshire, Landrace, Duroc and Hampshire breeds were allotted to four dietary treatments with two replicates per treatment with a light and heavy block per replicate. Ten pigs were allotted to each treatment within each weight block according to weight, sex and ancestry. The average initial weights of the light and heavy blocks were 18.1 and 22.9 kg respectively. The pigs were reared in a completely enclosed confinement building. Pens were 2.13m x 3.76m with concrete or aluminum slatted floors and an automatic water and a three-hole self-feeder in each pen.

The Ca and P content of the feed ingredients are given in table 1. The ingredients were prepared for Ca and P analysis by methods of Chapman and Pratt (1961) and analysis of Ca and P were conducted by atomic absorption on a Perkin-Elmer (Model 290B) spectrophotometer by methods recommended by the Perkin-Elmer Corporation (1971).

The dietary treatments were divided into grower and finisher phases and diets for each phase contained approximately 16 and 14% crude protein respectively (Table 2). When an average weight of 60 kg was reached by a pen of

Table 1. Ca and P Composition of Feed Ingredients^a

Ingredient ^b	Ca%	P%
Sorghum (IFN 4-04-444)	.034	.200
Soybean meal (IFN 5-04-604)	.465	.623
Dicalcium phosphate (IFN 6-01-080)	25.000	18.461
Ammonium polyphosphate	.002	15.520
Calcium Carbonate (IFN 6-01-64)	38.00	0.

^aAs fed basis.

^bValues based on analysis with the exception of calcium carbonate (NRC, 1979).

pigs the diet was changed from the grower diet to the finisher diet. The treatments consisted of the addition of APP and dicalcium phosphate (DiCa) as P supplements at two levels to a sorghum-soybean meal diet (Table 2). Ammonium polyphosphate and DiCa were added to bring P levels to approximate NRC (1979) recommendations or 0.5 and 0.4% for the grower phase and finisher phase respectively. The two remaining diets were supplemented with half of the amounts of supplemental P from APP and DiCa to provide dietary levels of 0.4 and 0.33% for the grower phase and finisher phase respectively. Calcium carbonate was added to all diets to maintain a constant Ca:P ratio of 1.2:1 and 1.25:1 in the grower and finisher phases respectively.

Table 2. Composition of Diets^a

Ingredient ^a	Grower ^b	Finisher ^c	Grower	Finisher	Grower	Finisher	Grower	Finisher
Sorghum	74.82	81.68	76.07	82.50	76.12	82.55	75.74	82.95
Soybean meal	21.23	15.31	20.98	15.13	20.97	15.12	20.845	15.04
Salt	.30	.30	.30	.30	.30	.30	.30	.30
Ammonium polyphosphate	1.40	.90	--	--	.696	.45	--	--
Dicalcium phosphate	--	--	1.17	.76	--	--	.585	.38
Calcium carbonate	1.25	1.06	.48	.56	.914	.83	.53	.58
Vitamin-trace mineral mix ^d	1.00	.75	1.00	.75	1.00	.75	1.00	.75
Calculated Ca and P: ^e								
Ca, %	.599	.501	.599	.501	.470	.413	.470	.413
P, %	.499	.398	.499	.399	.391	.329	.391	.329
Ca:P	1.2:1	1.26:1	1.2:1	1.25:1	1.2:1	1.25:1	1.2:1	1.25:1

^aGiven as percent of diet.^b16% crude protein diets fed to an approximate weight of 60 kg.^c14% crude protein diets fed from an approximate weight of 60 to 100 kg.

^dContains the following mineral and vitamin per kg of premix: Vitamin A, 440,000 I.U.; Vitamin D 44,000 I.U.; Vitamin E, 1,100 I.U.; Vitamin K, 145 mg; riboflavin, 440 mg; niacin, 2,200 mg; d-calcium pantothenate, 1,980 mg; choline chloride, 44,000 mg; Vitamin B₁₂, 2.2 mg; iron, 5 g; manganese, 2.75g; copper, .55 g; zinc, 10g; iodine, .075g.

^eBased on values in Table 1.

Pigs were fed ad libitum with feeding records maintained throughout the trial. Pigs were weighed bi-weekly from the beginning of the trial until the pigs reached approximately 90 kg, then they were weighed weekly until they were removed from test at an average weight of 100 kg.

Bone Analysis

Two barrows from each pen were preselected on the basis of weight and ancestry midway through the trial for slaughter and collection of bone samples. At an average weight of 100 kg the selected barrows were fasted for 24 hr with water available prior to slaughter. The first rib and third and fourth metacarpal from one side of each carcass were removed at the time of slaughter. The selection of right or left side for bone sampling was based on the ability to obtain a complete first rib due to the carcass splitting technique. Bones were prepared for analysis based on procedures outlined by Nimmo et al. (1979) with minor alterations. Once the bones were removed from the carcasses and thoroughly cleaned they were wrapped in freezer paper and frozen at -10 C until all bones were collected. Bones were then thawed for 5 hr at 20 C and autoclaved for 45 minutes at 100 C to remove remaining tissue. Bones were air dried for 24 hr following the cleaning procedures. The fourth metacarpals were cut in half at the longitudinal midpoint and third metacarpals were drilled with a 4.76 mm steel bit at the tro-

chanteric and intercondyloid fussa to aid in complete fat removal. All bones were extracted for 24 hr with petroleum ether in a soxhlet apparatus, then air dried at 20 C for 24 hr and oven dried at 100 C for 12 hr. This was used to standardize all bones to a dry fat-free basis.

Prior to extracting, the circumference at the mid-point and the length of the third and fourth metacarpals were measured. The average wall thickness of the fourth metacarpals were taken, based on four perpendicular measurements with the initial measurement taken at the posterior edge proximal to the third metacarpal.

The fourth metacarpals, following extraction, were ashed overnight at 550-600 C in Coor porcelain crucibles for ash, Ca and P determinations. The samples were prepared for analysis according to procedures by Gliksman et al. (1980). The P determinations were made according to procedures outlined by Sumner (1944). The P measurements were read on Beckman 35 spectrophotometer at 650 nm. The Ca was determined by atomic absorption on a Perkin-Elmer (Model 2380) spectrophotometer using air-acetylene flame (lean mixture) read at 422.7 nm.

The breaking force of the third metacarpals and first ribs were determined after standardization to a dry fat-free basis. The bones were suspended on a fulcrum with a distance of 3.81 cm from the centers of the .635 cm diameter supports pins (Figures 1 and 2). The fulcrum was

Figure 1. Method of determining breaking force on the third metacarpals.

Figure 2. Method of determining breaking force of the first ribs.

placed in a universal stressing frame so that the Dillon load cell would be centered on the fulcrum. The load force was applied to the midpoint on the posterior side of the third metacarpal (Figure 1) and to the approximate midpoint on the medial side of the first ribs (Figure 2). The breaking force of each bone was recorded from a Dillon meter attached to the load cell. After breaking force was determined the third metacarpals and first ribs were ashed by the procedures used for the fourth metacarpals.

Analyses of variance were determined by standard ANOVA and GLM procedures outlined by Barr et al. (1976). When significant differences were found by analyses of variances, the Duncan's New Multiple Range Test was used to separate means (Steele and Torrie, 1960).

Results and Discussion

Feeding Trial

No differences were obtained in the performance ($P > .05$) of growing-finishing pigs fed DiCa or APP as supplemental P sources to sorghum-soybean meal diets (Table 3). These data agree with those obtained by Clawson and Armstrong (1981) who reported no differences in the performance of pigs fed APP or defluorinated rock phosphate (DRP). These data indicate that APP is a satisfactory source of P for the performance of growing-finishing swine.

Reducing the supplemental P by 50% from either APP

Table 3. Effect of Phosphorus Source and Level on Performance

of Growing-Finishing Swine

Item	Phosphorus Source			Ammonium Polyphosphate			Dicalcium Phosphate		
	Phosphorus Level	.5-.4 ^a	SD ^b	.4-.33	SD	.5-.4	SD	.4-.33	SD
No. of Pigs	40			38 ^c	38 ^c			38 ^c	
Avg. initial weight, kg	20.5	3.21		20.4	3.27	20.6	3.18	20.5	3.33
Avg. final weight, kg	100.8	1.69		100.6	1.70	100.3	.78	102.7	.73
Avg. daily gain, kg	.66	.03		.66	.02	.67	.04	.67	.03
Avg. daily feed, kg	2.15	.15		2.16	.14	2.19	.15	2.17	.09
Feed:gain	3.24	.14		3.25	.10	3.27	.08	3.20	.15

^aPhosphorus levels were reduced at the start of finishing phase (approximately 60 kg).

^bStandard deviation.

^cTwo animals removed from each treatment not due to treatment.

or DiCa had no effect on pig performance (Table 3). The reduction in supplemental P resulted in diets that contained P levels of 0.4 and .33% for the grower and finisher phases which is below NRC (1979) requirements. Cromwell et al. (1972), Parker et al. (1974) and Allee et al. (1975) reported that maximum gain and efficiency were attained when dietary P level reached 0.4 to 0.5%. However Doige et al. (1975) observed that pig performance was not affected at P levels as low as 0.2% with a Ca:P ratio of 1.3:1. Data from this study would indicate that dietary P levels below NRC (1979) requirements will support satisfactory performance when the Ca:P ratio is approximately 1.2:1.

Bone Analysis

No differences ($P > .05$) in the variables examined on the fourth metacarpals were obtained from pigs fed APP or DiCa (Table 4). Metacarpal data by Clawson and Armstrong (1981) support these data when DRP was replaced by APP in pig diets. Although a difference ($P < .05$) was found in the circumference of the fourth metacarpals from pigs fed APP or DiCa at 50% supplemental P level, no explanation is apparent and the difference was attributed to individual animal variation. The dry fat-free weights of the fourth metacarpals were lower ($P < .01$) for the pigs receiving the 50% supplemental P level from either APP or DiCa which indicates that the lower level provided

Table 4. Effect of Phosphorus Source and Level on Fourth Metacarpal

Characteristics of Growing-Finishing Swine									
Phosphorus Source		Ammonium Polyphosphate				Dicalcium Phosphate			
Item	Phosphorus Level	.5-.4 ^a	SD ^b	.4-.33	SD	.5-.4	SD	.4-.33	SD
No. of Pigs		8	8		8		8		8
Length, mm		78.87	2.88	78.19	2.15	77.50	2.68	78.25	2.36
Circumference, mm		55.50 ^{xY}	2.44	55.81 ^x	2.53	54.81 ^{xY}	.80	53.50 ^Y	1.22
Avg. wall thickness, mm		1.93	.35	1.88	.33	1.95	.32	1.92	.20
Dry fat-free weight, g ^c		12.88	1.25	12.06	.96	12.84	.72	12.26	.90
Ash, % ^{d,e}		61.09 ^x	2.05	59.46 ^Y	.42	60.54 ^{xY}	.59	59.78 ^Y	.73
Ca, % ^f		37.70	1.50	38.30	.70	37.70	1.47	37.67	1.13
P, % ^f		18.37	.94	18.52	1.62	17.99	1.17	17.75	.82

^aPhosphorus levels were reduced at the start of finishing phase (approximately 60 kg).

^bStandard deviation.

^cEffect of P level was significant ($P < .01$).

^dPercent of dry fat-free bone.

^eEffect of P level was significant ($P < .01$).

^fPercent of Bone ash.

^{xY}Means in same row having different superscripts are different ($P < .05$).

marginal P for maximum bone development. A difference ($P < .05$) was observed between the fourth metacarpals from pigs fed APP at the high supplemental level and those fed the lower supplemental P levels from APP and DiCa for percent ash (61.09, 59.46 and 59.78 respectively). This is a further indication that the lower level of P supplementation was inadequate for maximum bone mineralization. Cromwell et al. (1970) obtained similar results between dietary P levels of .36 and .44% for the second and fifth metacarpals.

Length and circumference of the third metacarpal was not affected by source of supplemental P (Table 5). A difference ($P < .05$) between pigs fed high supplemental P levels and those fed APP at the lower supplemental level for dry fat-free weight and percent ash of the third metacarpal was found (Table 5). These data agree with the data from the fourth metacarpal. Pigs fed the lower level of supplemental APP had lower ($P < .05$) percent ash of the third metacarpal than those pigs fed the other three diets. This would suggest a lower availability of P from APP for mineralization. The breaking force was not significantly different due to P source or level (Table 5). Hays et al. (1970) indicated that breaking force for swine metacarpals varied little if P level was approximately 0.4% or higher.

Data from the first ribs are shown in table 6. The first ribs from pigs fed the lower level of supplemental

Table 5. Effect of Phosphorus Source and Level on Third Metacarpal

Characteristics of Growing-Finishing Swine									
Phosphorus Source		Ammonium Polyphosphate				Dicalcium Phosphate			
Item	Phosphorus Level	.5-.4 ^a	SD ^b	.4-.33 ^c	SD	.5-.4	SD	.4-.33	SD
No. of Pigs		8		8		8		8	
Length, mm		77.62	2.82	77.19	1.94	76.44	2.30	77.37	2.63
Circumference, mm		55.31	3.22	55.62	3.17	54.75	.92	54.12	1.30
Dry fat-free weight, g ^d		13.19 ^x	.90	12.01 ^y	.97	13.11 ^x	.69	12.64 ^{x,y}	.97
Ash, % ^{e,f}		59.54 ^x	.61	58.31 ^y	.54	59.63 ^x	.61	59.32 ^x	.69
Breaking force, kg		125.17	28.62	116.70	26.19	136.19	29.67	123.92	18.19

^aPhosphorus levels were reduced at the start of finishing phase (approximately 60 kg).

^bStandard deviation.

^cOne observation for ash and dry fat-free weight was classified outlier (Dixon and Massey, 1957).

^dEffect of P level was significant ($P < .01$).

^ePercent of dry fat-free bone.

^fEffect of P level and source was significant ($P < .05$).

^{x,y}Means in the same row having different superscripts are different ($P < .05$).

Table 6. Effect of Phosphorus Source and Level on First Rib

Characteristics of Growing-Finishing Swine									
Phosphorus Source		Ammonium Polyphosphate				Dicalcium Phosphate			
Item	Phosphorus Level	.5-.4 ^a	SD ^b	.4-.33	SD	.5-.4	SD	.4-.33	SD
No. of Pigs		8		8		8		8	
Dry fat-free weight, g ^c		11.38 ^x	1.31	9.69 ^y	1.01	11.40 ^x	.82	10.40 ^{xy}	1.27
Ash, % ^{d,e}		55.15 ^x	1.07	53.89 ^y	1.76	55.63 ^x	.82	54.17 ^y	1.25
Breaking force, kg ^f		69.72 ^{xy}	19.49	61.89 ^y	17.00	82.15 ^x	12.74	63.64 ^y	19.62

^aPhosphorus levels were reduced at start of finishing phase (approximately 60 kg).

^bStandard deviation.

^cEffect of P level was significant (P < .01).

^dPercent of dry fat-free bone.

^eEffect of P level was significant (P < .01).

^fEffect of P level was significant (P < .01).

^{x,y}Means in the same row having different superscripts are different (P < .05).

P had lower ($P < .01$) dry fat-free weight with the exception of those fed DiCa, percent ash and breaking force than those from pigs fed the higher level of supplemental P. No differences were found between sources of supplemental P which agrees with data from Clawson and Armstrong (1981).

In evaluating all of the data, APP was equal to DiCa as a supplemental P source for growth performance of growing-finishing swine. A level of supplemental P below NRC (1979) recommendations appeared adequate for performance when the Ca:P ratio was maintained at about 1.2:1. However the lower level of supplemental P did not support maximum bone mineralization as indicated by the lower ($P < .01$) values for dry fat-free weight, percent ash of the metacarpals and first ribs and breaking force of the first ribs and third metacarpals from pigs fed the lower P level.

A trend was observed for a lower availability of P from APP than DiCa when fed at the lower level of supplementation. Pigs fed APP at the lower level had consistently lower bone mean values for dry fat-free weight, percent ash and breaking force as compared to pigs fed DiCa at the lower level. The percent ash from the third metacarpals was lower ($P < .05$) from pigs fed APP at the lower level as compared to values from pigs fed DiCa at the same level. However when APP is supplied at a level which provides a dietary P level to meet NRC (1979) requirements,

no difference in performance or bone mineralization of pigs were obtained as compared to those fed DiCa. These data indicate that APP was a satisfactory P supplement for growing-finishing swine.

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