EVALUATION OF POTASSIUM POLYPHOSPHATE AS A SOURCE OF PHOSPHORUS AND POTASSIUM FOR PLANTS

by

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INTRODUCTION

Potassium polyphosphate (KPP) of general formula \((\text{KPO}_3)^n\) has been produced experimentally for several years, but as yet no commercial production has been recorded. Production costs have not made it economically feasible to produce. However, KPP is still of interest to the agricultural world because its high analysis could reduce the cost of handling, bagging, and transport over long distances (Harris, 1963).

Evaluations of experimental KPP materials as phosphorus sources for various crops have been fairly numerous in the past. However, possibly more interest has been shown in the use of these materials as slowly soluble potassium sources. The more common K sources in use today are completely water soluble. In most areas water soluble sources have performed satisfactorily, but in areas with soils of low exchange capacities (sands and loamy sands, for example) and in areas of high rainfall, excessive K losses can occur via leaching with these sources.

Instead of trying to increase the cation exchange capacity of the soil, use of a slowly soluble K source would seemingly be more economical. In addition to reducing leaching losses of K, a slower dissolution rate might be advantageous in reducing luxury consumption of K and in reducing salt injury during germination (Stanford and Hignett, 1957).

As a result of variation in the production processes used to produce KPP, conclusions from comparative evaluations of these materials have not always been consistent. Chemical impurities
in the final product can affect solubility properties and thus the performance of this product in greenhouse and field tests.

Most phosphorus evaluations of KPP have used triple superphosphate as a standard for comparison. Potash-superphosphate and potassium sulfate-superphosphate mixtures have been the main standards for comparison as a K source. More extensive comparisons of KPP with other common fertilizers in use today are needed to fully assess the agricultural value of this material. In order to obtain this information, an agronomic evaluation of an experimental KPP material was designed to: 1) compare KPP, diammonium orthophosphate (AOP), triple superphosphate (TSP), ammonium polyphosphate (APP) as P sources for irrigated corn and grain sorghum in both growth chamber and field experiments; 2) compare germination effects of KPP on wheat and grain sorghum with that of AOP in the field and in the growth chamber; 3) compare KPP and several other K materials as K sources for corn in the growth chamber; and to 4) compare KPP, AOP, TSP, and APP as to the severity of the P carriers on P-Zn interactions in corn.
REVIEW OF LITERATURE

Early KPP Products and Processes

Materials produced from the reaction of $\text{H}_3\text{PO}_4$ and KCl were termed 'potassium metaphosphates' in early literature. Nomenclature of today reserves the name 'metaphosphate' for compounds having a ring structure and it is likely that most of the early 'metaphosphate' products were actually long-chain polyphosphates (Hignett, 1970).

Examination of potassium metaphosphate by Pfanstiel and Iler (1952) led them to conclude that it was a polymer with a molecular weight possibly as high as 120,000. Lehr et al. (1967) described it as a very long-chain potassium polyphosphate with a general formula of $(\text{KPO}_3)_n$. Van Wazer (1953) suggested the nomenclature confusion may have risen from the fact that when $n$ in the general polyphosphate formula, $K_{n+2}P_nO_{3n+1}$, becomes very large, the formula is analytically indistinguishable from that of metaphosphate. Although strong evidence is in favor of KPP being a more correct name for $\text{KPO}_3$, potassium metaphosphate (KMP) is still in use in the literature.

TVA was one of the first to produce KPP on a pilot-plant basis. In 1939, TVA produced a fertilizer grade material by burning elemental phosphorus in a combustion chamber with air and reacting the resulting $\text{P}_2\text{O}_5$ gas with finely ground KCl (Walthall, 1953). Products of this reaction varied in K content from 29 to 32%, in P content from 24-25%, and in Cl content from 1-4%. In a later TVA process, KPP was produced by reacting wet process $\text{H}_3\text{PO}_4$
with KCl at temperatures generally above 700°C (New Developments in Fertilizer Technology. p 23-24, TVA 5th Demonstration October 6-7, 1964).

Pure crystalline KPP contains 33% K and 26% P and is only slightly water soluble according to AOAC standards (Englestad, 1968). However, the crystallinity and solubility of this material is greatly affected by impurities and the rate of cooling. Stanford and Hignett (1957) noted that 2-3% Al₂O₃ or Fe₂O₃ impurities could result in a glassy or vitreous product of fairly high water solubility.

Others have produced KPP via variations of the H₃PO₄-KCl process used by TVA. Scottish Agricultural Industries Ltd. produced KPP by reacting wet process H₃PO₄ and fertilizer grade KCl in a rotary reactor below 550°C (Harris, 1963). Their product was low in water-soluble P (5%), very high in citrate-soluble P, and contained 31% K. Chemical and Phosphates Ltd., of Haifa, Israel, uses this same process to produce KPP of approximate analysis 0-30-30 (0-58-37) (Hagin and Scherzer, 1967).

Effectiveness as a P Source

Granule size, P solubility, and placement all seem to be related to the effectiveness of a phosphate fertilizer. Evidence of this relationship has been shown in evaluations of KPP as a phosphate source.

Dement, Terman, and Bradford (1963) compared four particle sizes of KPP and potassium calcium pyrophosphate (KCP) with minus 35 mesh TSP as phosphorus sources for corn. Phosphorus was supplied
at three rates to the corn grown in greenhouse pots on Hartsells fine sandy loam (pH 5.2). The two middle particle sizes of KPP (-14+20 and -6+9 mesh) were more than twice as effective and the large size (0.64 cm) was only slightly more effective than fine TSP. Effectiveness of KCP as a phosphorus source was considerably less than that of KPP.

Hagin (1966) found a powdered form of KPP to be superior to a granular form for Foxtail millet (Setaria italica) grown in a greenhouse on alkaline soils. The granular KPP was inferior to both potassium orthophosphate and a mixture of monocalcium phosphate plus potassium nitrate. However, in slightly acid soil, no significant differences were noted either between particle sizes or sources.

A review of research with KPP in England and Scotland by Harris (1963) again emphasizes the influence of granule size on a P fertilizer. In pot tests with Italian ryegrass, total forage from five cuttings was significantly lower with a large-granule KPP material than when a potassic super (superphosphate plus KCl) was used as a P source. Finer particle sizes of KPP equaled potassic supers in effectiveness. In field trials on red clover, KPP in all granule sizes equaled response to potassic supers. It should be noted that these trials were performed on soils low in available P and K and potassium effects seemed to be confounded with phosphorus effects.

The influence of P solubility and particle size on KPP performance was again defined in work by Munk (1963). In pot experiments with oats comparing KPP with monocalcium phosphate and
dicalcium phosphate, fine crystalline KPP was immediately more effective than a glassy (more water soluble) form. However, a large size of the glassy material was more effective than the same size in a crystalline form.

Comparisons of KPP with other phosphates without reference to particle size or solubility effects also appear in the literature. Terman and Seatz (1956) summarized results of tests in twelve states from 1940-1952 comparing a KPP material from TVA with TSP and ordinary superphosphate. Response to KPP over all crops was generally superior to TSP, but generally inferior to ordinary superphosphate.

Tests in New York by Chandler and Musgrave (1944) comparing KPP with a mixture of superphosphate and KCl gave no significant differences between carriers on dry-matter yields of a variety of crops. A high variability of yields among replicates in their studies deleted the chance for any statistical differences. They could only conclude that KPP was fully as effective as the superphosphate-KCl mixture.

In England, Mattingly and Penny (1968) found P uptake from KPP by Italian ryegrass to be significantly higher than from superphosphates, but with a crop of barley, uptake was lower from KPP. They explained the contrast in behavior of KPP on barley and ryegrass by the slow hydrolysis rate of the polyphosphate which could result in a less concentrated solution of orthophosphate in the soil than from superphosphate.
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Residual Effectiveness of KPP as a P Source

Researchers have noted that the residual response to KPP is different in acid than in calcareous soils. This differential response seems to be related to particle size of the material and rate of dissolution in the soil. Dement et al. (1963) found that residual yields of corn were greater on an acid soil when using coarse granules of KPP. Hagin (1966) also found indications of KPP in a coarse form being more effective on a second crop of Romaine lettuce grown in a slightly acid soil. However, in calcareous soil, he noted that powdered KPP was superior in effectiveness to granular KPP and superphosphate plus potassium nitrate. It is interesting to note that in an earlier pot study (Hagin, 1962) in a highly calcareous soil with barley as a second crop, powdered KPP failed to equal the residual performance of superphosphate plus KCl.

In England, dry-matter yields from the fourth and fifth cuttings of Italian ryegrass were higher in pots supplied with coarse granules of KPP than those supplied with powdered KPP or potassic supers (Harris, 1963). Yields from earlier cuttings had been higher with powdered KPP and potassic supers than with the coarse granular form of KPP. Field trials with red clover gave nearly the same results. However, in the field tests, immediate effectiveness of coarse KPP equaled that of powdered KPP and the potassic supers.

Residual response from KPP was tested in Israel during a greenhouse pot experiment with two calcareous soils and a slightly acid soil (Rosenberg and Hagin, 1966). Three successive crops
(Romaine lettuce, corn and Romaine lettuce again) were used to compare the immediate and residual response of KPP, magnesium phosphate and defluorinated rock phosphate to a standard source (monocalcium phosphate). Effectiveness of KPP on the first crop equaled that of the standard on two of the soils and exceeded it on the third, a highly calcareous soil. With the second crop, residual response to KPP was about the same as for monocalcium phosphate on all three soils. The residual effect of KPP on the third crop was equal to that of the standard on a slightly calcareous soil and less than the standard on a highly calcareous soil. None of the materials showed a residual response on the slightly acid soil. The researchers concluded that possibly the phosphorus in this soil was converted to an unavailable form.

It has been known for some time KPP undergoes hydrolysis to the orthophosphate form in the soil (Volkerding and Bradfield, 1943; MacIntire, Shaw, and Robinson, 1953). However, the exact nature of the reactions of KPP in the soil has not been well researched (Huffman, 1968). The rate of hydrolysis of KPP and whether it complexes with certain cations which could produce relatively unavailable phosphorus compounds are unsolved problems at this time. A solution to these problems might explain the varied residual performance of KPP on different soils.

**Effectiveness as a K Source**

TVA initially produced KPP on an experimental basis because this material appeared promising as a slowly soluble potassium source (Stanford and Hignett, 1957). Agronomic evaluations of
KPP, produced by TVA and via other processes, as a K source for plants have been numerous.

Chandler and Musgrave (1944) compared KPP to KCl as a K source for ladino clover in a greenhouse pot test and for sudan grass hay in the field. In the greenhouse, where leaching was eliminated, plants supplied with KCl had higher K contents than those supplied with KPP. They attributed these results to the greater solubility of KCl. Under field conditions, however, where leaching of K was possible, yields of sudan grass were consistently higher on plots fertilized with KPP.

The K availability to crops from KPP varying in water solubility was compared with that from KCl and KCP by Dement and Stanford (1959). KPP materials in this greenhouse experiment were of one particle size (minus 35 mesh) and varied in K-water solubility from less than 4 to 100%. They found no relationship between K-water solubility of KPP and K availability to corn plants in this study. In further studies with two sizes of KPP and KCP (-35 mesh and -6+9 mesh), Dement and Stanford (1959) noted that all of the fine KPP and KCP sources were equal in effectiveness to KCl in a one week period following application. However, the large size particles of low water-soluble KPP and KCP, ranging in solubilities from 7-31%, were much lower in availability during the same period.

Additional evidence of the variation in response to different particle sizes of KPP was reported by Dement, Terman, and Bradford (1963). Their pot tests with four particle sizes of KPP and KCP on corn showed that the immediate effectiveness of KPP
and KCP decreased with increase in particle size. Again all
sources applied as fine material were equal in effectiveness as
was previously noted by Dement and Stanford (1959).

Pritchett and Nolan (1960) also concluded that with fine
sizes of KPP, availability of K was unrelated to water solubility.
They did observe, however, that increasing the particle
size of the material reduced the availability.

Placement of material whether on the surface or mixed with
the soil seems to affect the efficiency of different particle
sizes of KPP. Dement et al. (1963) noted that the effectiveness
of large particles was greater when applied to the surface of
their pots than when mixed in the soil. At the conclusion of
their experiments all surface-applied KPP had dissolved, evidently
as a result of frequent watering, but residues of KPP mixed with
the soil remained evident. The dissolution of even large par-
ticles of KPP on the soil surface indicated to them rate of
solution of KPP was more important than immediate solubility
in water when determining availability to plants.

Although there is considerable evidence to show that particle
size does affect K availability of KPP, some workers have shown
no relationship between particle size and availability. Caldwell
and Kline (1963) concluded that KPP materials of 99 and 45% water
solubility were equal to KCl regardless of particle size for corn
and alfalfa. Lachover and Feldhay (1966) reported nearly the
same results with potatoes. Three particle sizes of KPP per-
formed about the same and all were equal in effectiveness to
KCl and K₂SO₄ in their pot experiments.
Metson and Saunders (1962) compared KCl, KHCO$_3$, KPP, and calcined potash feldspar as K sources for white clover on a K deficient mineral soil in New Zealand. The studies were conducted with the hope of finding a slowly soluble K source that could reduce luxury uptake and leaching losses of K. Results of their pot tests indicated no significant differences between KHCO$_3$, KPP, and KCl on total K uptake and dry-matter yield of six cuttings of clover. There was also no indication of a longer duration of response from KPP than from KCl. Very little leaching of K occurred in this experiment and was equal from all carriers. It was concluded that KPP did not reduce luxury consumption of K at high application rates.

In a greenhouse lysimeter experiment Pritchett and Nolan (1960) reported more K was leached from KCl than from KPP treatments. Ayres and Hagihara (1953) found additional evidence of this fact in their lysimeter experiments with latosolic Hawaiian soils. After heavy leaching, uptake of K by sudangrass from various K treated pots decreased in the following order: KPP > KH$_2$PO$_4$ > K$_2$SO$_4$ > KCl. They implied that leaching losses were greater from K$_2$SO$_4$ and KCl than from KPP.

In contrast, MacIntire et al. (1954) reported that recovery of K from lysimeters was nearly the same from KPP and K$_2$SO$_4$ annual treatments of 186 kg K/ha. However, with a single application of 1267 kg K/ha, more K was detected in the leachate from KPP than from K$_2$SO$_4$. They assumed that a portion of the added K from K$_2$SO$_4$ was fixed in a nonreplaceable form.

Thorup and Mehlich (1961) also noted quite low K leaching
losses from KPP. They compared leaching losses of K from KPP, 
KNO$_3$, KH$_2$PO$_4$, and K$_2$HPO$_4$. Losses of K from KPP were well below 
that of the orthophosphates and KNO$_3$.

Dement and Stanford (1959) studied the effect of different 
particle sizes and water solubilities on the amount of K leached 
from treatments of KPP. They discovered an interaction between 
particle size and water solubility. More K was leached from 
minus 35 mesh than from -6+9 mesh particles of low water-soluble 
KPP (7-15%). However, with high water-soluble KPP (30-96%), 
more K was leached from large sized material than from small. 
The soil used was of low exchange capacity. They concluded that 
relatively high concentrations of K dissolved from the large 
particles of KPP might have been free to move out in the leachate. 
With smaller particles of KPP, a lower concentration of K in 
solution would have resulted in more K being retained by the 
soil colloids.

**Effect on Germination**

It has been proposed that KPP might have a less depressive 
effect on germinating seeds than KCl or K$_2$SO$_4$. This proposal 
was evidently based on lower salt effects from KPP and a lower 
rate of dissolution (Engelstad, 1968).

Dement and Stanford (1959) studied the possibility of seed-
ling injury to corn from high applications of KPP, KCP, KCl, and 
K$_2$SO$_4$. They noted seedling injury with high rates of KCl and 
K$_2$SO$_4$ (200 ppm K), but not with the same rates of KPP and KCP.

An increasing delay in the emergence of flax seedlings with
increasing application rates of KCl, KCP, and KPP was reported by Caldwell and Kline (1963). At a rate of 460 kg K/ha, KCl proved the most damaging to emergence of the seedlings grown in greenhouse pots, while KCP had very little effect on emergence. KPP of 45 and 99% water solubility was intermediate in delaying emergence. Although the KPP materials varied widely in water solubility, no evidence could be found that they had any different effect upon the final stand of flax.

Younts and Musgrave (1958b) could find no differences in germination time or rate of germination of corn resulting from high application rates of KPP, KCl, or K$_2$SO$_4$. Although KPP gave the best growth at a high rate (104 kg K/ha), this was mainly attributed to the high rate of P supplied by KPP. The high rate of KPP supplied 87 kg P/ha, while 19 kg P/ha as TSP was supplied with the high rates of K$_2$SO$_4$ and KCl. In addition to finding no differences in germination effects from these carriers, it was also concluded that they were equally effective as K suppliers to the plant (Younts and Musgrave, 1958b).

The effect of KPP on the germination of spring wheat was tested in England (Harris, 1963). Reduced plant establishment and delayed emergence were factors used to judge the amount of germination damage. KPP was compared with a KCl-superphosphate mixture, a KPP-ammonium nitrate mixture, and a 12-5-15 grade fertilizer based on monoammonium phosphate, ammonium sulfate, and KCl. Of all the materials studied, only KPP was found to be completely safe. Even at the high application rate (about 390 kg/ha of material), it neither reduced plant establishment nor
delayed emergence.

**Possible Effect on Micronutrient Absorption**

Macronutrient effects on uptake and translocation of micronutrients in plants have been frequently studied in recent years. One that has been well researched is the depressive effect of P on Zn uptake. As a result of this research it has been learned that either or both added K or high levels of soil K may modify the P-Zn interaction in plants.

Ward et al. (1963) demonstrated in greenhouse studies that the depressive action of applied P on Zn uptake decreased with increasing per cent K saturation of the soil. Just how the high K percentage influenced the P-Zn relationship could not be explained from their data.

Additions of K in the growth medium of corn were shown to reduce the detrimental action of fertilizer P on Zn uptake by Stukenholtz et al. (1966). These additions of K were also shown to enhance uptake of Mn by the corn plants. They concluded that the benefit to Zn uptake from the additions of K may have resulted from a depressive action by K on P uptake, and secondarily from the enhanced Mn uptake.

Other researchers, Wear and Patterson (1965), found that heavy applications of K (728 kg K/ha) increased plant Zn concentration, but only when no P was applied. When 196 or 392 kg P/ha were applied, K had no effect on Zn uptake.

Although Stukenholtz et al. (1966) used KH₂PO₄ as a K source in their experiments, there has been no research to examine the
possibility of potassium phosphates affecting P-induced Zn deficiencies any differently than non-K phosphorus sources. The question of whether KPP might possibly lower the severity of a P-Zn interaction remains unanswered at this time.
METHODS AND MATERIALS

Field Evaluations of KPP

Two sites were selected in 1970 to evaluate KPP as a P source for irrigated corn and grain sorghum. Both sites had been recently leveled for furrow irrigation (Table 1). The treatments involved comparisons of KPP, 0-24-32(0-55-38); AOP, 18-20-0 (18-46-0); and APP, 15-27-0(15-62-0) at rates of 20 and 40 kg P/ha (Table 2). A second variable, potassium, supplied as KCl, was also included in the treatments.

All plots at both locations received 280 kg/ha N as either or both urea or ammonium-N supplied by the P materials. Zinc as ZnSO₄₂₉ at 11 and 22 kg Zn/ha, was supplied to all plots at the Scott and Pawnee County sites, respectively. All plots at the Scott County location also received 9 kg/ha Fe as iron ligninsulphonate.

In 1971, three recently leveled locations were selected as experimental areas (Table 1). Fertilizer treatments at these sites involved KPP, AOP, APP, and 0-20-0(0-45-0) TSP at P rates of 20, 40, and 60 kg/ha (Table 2). The experimental KPP material used at the Sedgwick County site was of analysis 0-23-34(0-52-41) while at the other two locations the same material was applied as for the 1970 studies.

Potassium as KCl was supplied in 1971 to all plots to equal the amount of K supplied by the high rate of KPP. This amounted to 75 kg/ha K at the Clay and Geary County sites and 87 kg/ha K at the Sedgwick County location. All plots received a total of
Table 1. Soil analysis of experimental sites.

<table>
<thead>
<tr>
<th>County</th>
<th>Soil Series</th>
<th>pH</th>
<th>Avail. P kg/ha</th>
<th>Exch. K kg/ha</th>
<th>Avail. Zn ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1970</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pawnee</td>
<td>Hastings silt loam</td>
<td>6.7</td>
<td>30</td>
<td>403</td>
<td>1.9</td>
</tr>
<tr>
<td>Scott</td>
<td>Ulysses silt loam</td>
<td>7.8</td>
<td>3</td>
<td>1120+</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1971</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clay</td>
<td>Geary silt loam</td>
<td>6.3</td>
<td>27</td>
<td>818</td>
<td>2.7</td>
</tr>
<tr>
<td>Geary</td>
<td>Muir silty clay loam</td>
<td>7.4</td>
<td>16</td>
<td>560</td>
<td>2.6</td>
</tr>
<tr>
<td>Sedgwick</td>
<td>Vanoss silt loam</td>
<td>6.8</td>
<td>18</td>
<td>519</td>
<td>2.6</td>
</tr>
<tr>
<td>Riley</td>
<td>Wymore silty clay loam</td>
<td>7.7</td>
<td>88</td>
<td>438</td>
<td>*</td>
</tr>
</tbody>
</table>

* No analysis for Zn was performed.
Table 2. Treatments used for field evaluations of KPP as a P source for irrigated corn and grain sorghum.

<table>
<thead>
<tr>
<th>Nutrient Rates</th>
<th>Carrier</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>K</td>
</tr>
<tr>
<td>kg/ha</td>
<td>kg/ha</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>20</td>
<td>50</td>
</tr>
<tr>
<td>40</td>
<td>0</td>
</tr>
<tr>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>20</td>
<td>50</td>
</tr>
<tr>
<td>40</td>
<td>0</td>
</tr>
<tr>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>20</td>
<td>50</td>
</tr>
<tr>
<td>40</td>
<td>50</td>
</tr>
</tbody>
</table>

Sedgwick, Geary, and Clay Counties 1971

<table>
<thead>
<tr>
<th>P Rate</th>
<th>P Carrier</th>
</tr>
</thead>
<tbody>
<tr>
<td>kg/ha</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>20</td>
<td>AOP</td>
</tr>
<tr>
<td>40</td>
<td>AOP</td>
</tr>
<tr>
<td>60</td>
<td>AOP</td>
</tr>
<tr>
<td>20</td>
<td>APP</td>
</tr>
<tr>
<td>40</td>
<td>APP</td>
</tr>
<tr>
<td>60</td>
<td>APP</td>
</tr>
<tr>
<td>20</td>
<td>TSP</td>
</tr>
<tr>
<td>40</td>
<td>TSP</td>
</tr>
<tr>
<td>60</td>
<td>TSP</td>
</tr>
<tr>
<td>20</td>
<td>KPP</td>
</tr>
<tr>
<td>40</td>
<td>KPP</td>
</tr>
<tr>
<td>60</td>
<td>KPP</td>
</tr>
</tbody>
</table>
280 kg N/ha, 56 kg N/ha as ammonium sulfate and the balance as either or both anhydrous ammonia or ammonium-N supplied by the P materials. Zinc as ZnSO₄ was supplied to all plots on the Sedgwick and Geary County sites at 11 kg/ha Zn and on the Clay County site at 9 kg/ha Zn.

A fourth site was selected in 1971 to compare the effects of KPP and AOP on the germination of grain sorghum (Table 1). Three rates (5, 10, and 20 kg P/ha) of the P materials were banded in contact with the seed or applied broadcast to the soil surface (Table 3). Potassium as KCl was mixed with each rate of AOP to correspond with the amount of potassium supplied by an equivalent rate of KPP. All plots received a total of 134 kg N/ha. Broadcast plots were supplied with this amount of N as either or both NH₄NO₃ or ammonium-N from P materials. Plots receiving banded KPP treatments also received a banded amount of N as NH₄NO₃ to equal that amount of N supplied by a similar P rate of AOP. The remainder of the N needed to equal 134 kg N/ha was broadcast as NH₄NO₃ on these plots.

All fertilizer materials were applied preplant and incorporated during tillage with the exception of the banded treatments at the Riley County location in 1971. A grain drill was used to band the fertilizer with the seed at the Riley County location. Materials were broadcast at this location with a Gandy fertilizer spreader. At the other locations KPP materials were hand applied while all remaining materials were applied with a Barber screw-feed fertilizer spreader.

The design of the experiments was randomized complete block
Table 3. Treatments used to study the effects of KPP on germination of grain sorghum (Riley County), 1971.

<table>
<thead>
<tr>
<th>P Rate kg/ha</th>
<th>Method of Application</th>
<th>P Carrier</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Broadcast*</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>Broadcast</td>
<td>AOP</td>
</tr>
<tr>
<td>10</td>
<td>Broadcast</td>
<td>AOP</td>
</tr>
<tr>
<td>20</td>
<td>Broadcast</td>
<td>AOP</td>
</tr>
<tr>
<td>5</td>
<td>Banded</td>
<td>AOP</td>
</tr>
<tr>
<td>10</td>
<td>Banded</td>
<td>AOP</td>
</tr>
<tr>
<td>20</td>
<td>Banded</td>
<td>AOP</td>
</tr>
<tr>
<td>5</td>
<td>Broadcast</td>
<td>KPP</td>
</tr>
<tr>
<td>10</td>
<td>Broadcast</td>
<td>KPP</td>
</tr>
<tr>
<td>20</td>
<td>Broadcast</td>
<td>KPP</td>
</tr>
<tr>
<td>5</td>
<td>Banded</td>
<td>KPP</td>
</tr>
<tr>
<td>10</td>
<td>Banded</td>
<td>KPP</td>
</tr>
<tr>
<td>20</td>
<td>Banded</td>
<td>KPP</td>
</tr>
</tbody>
</table>

* Plots receiving no P were controls and received only 13.4 kg/ha N as NH₄NO₃ broadcast.
with four replications. Crops were established on nine meter, four row plots (Table 4). Irrigation water was provided as needed.

At the 6- to 8-leaf stage, the first fully extended leaf from the top of the plant was collected to make up the early tissue sample of both corn and grain sorghum (Date 1). The leaf opposite and immediately below the ear of tasseling corn plants and the uppermost fully extended leaf of grain sorghum in the boot stage comprised the second tissue sample (Date 2). All leaf samples were randomly selected from the two center rows of each plot. Samples were washed in distilled water, rinsed in deionized water, and oven-dried for a minimum of 72 hours. A Wiley mill with stainless steel knives and a stainless steel 2-mm screen was used to grind the dried samples. Samples were stored in sealed plastic containers.

The leaf samples from the 1970 studies were prepared for chemical analysis following the wet oxidation procedure of Jackson (1965) as modified by Adriano (D.C. Adriano, Phosphorus-zinc interaction in Zea mays and Phaseolus vulgaris. Ph.D. thesis, Kansas State University, Manhattan, 1970). One-quarter gram samples of the tissue were digested in 200 ml tall-form beakers on a hot plate by the addition of 15 ml of a H$_2$O-HNO$_3$-HClO$_4$ mixture in a 1:1:1 ratio (v/v/v) and covered with watchglasses. After evaporation of the HNO$_3$, the hot plate was shut off, the beakers cooled for about 10 minutes, and the watchglasses and beaker walls rinsed with deionized water to flush any plant material down into the acid. Digestion was then resumed until complete dryness. The residue was allowed to cool for a few seconds and approximately
Table 4. Crop, variety, and row spacing for field studies, 1970-1971.

<table>
<thead>
<tr>
<th>County</th>
<th>Crop</th>
<th>Variety</th>
<th>Row Spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pawnee</td>
<td>Corn</td>
<td>Pioneer 3306</td>
<td>76 cm</td>
</tr>
<tr>
<td>Scott</td>
<td>Grain Sorghum</td>
<td>Pioneer 846</td>
<td>76 cm</td>
</tr>
<tr>
<td>Sedgwick</td>
<td>Grain Sorghum</td>
<td>NC+ 702</td>
<td>76 cm</td>
</tr>
<tr>
<td>Clay</td>
<td>Corn</td>
<td>Pioneer 3300</td>
<td>76 cm</td>
</tr>
<tr>
<td>Geary</td>
<td>Corn</td>
<td>Pioneer 3390</td>
<td>76 cm</td>
</tr>
<tr>
<td>Riley</td>
<td>Grain Sorghum</td>
<td>Pioneer 846</td>
<td>61 cm</td>
</tr>
</tbody>
</table>
10 ml of a 0.1 N HCl solution were added to bring the residue into solution. The mixture was then filtered through Whatman 42 filter paper and made to 25-ml volume with 0.1 N HCl.

The filtrate obtained from tissue samples at the Scott County site was assayed for P, K, Ca, Mg, Fe, Zn and Mn, while that obtained from the Pawnee County samples was assayed for P, K, Ca, and Mg. Ca, Mg, Fe, Zn, and Mn concentrations were determined by atomic absorption spectrophotometry using a Perkin-Elmer model 303 instrument. Potassium was assayed by flame photometry using a Perkin-Elmer flame photometer. Phosphorus was determined by the vanadate-molybdate yellow procedure of Chapman and Pratt (1961) as modified by Adriano (D.C. Adriano, Phosphorus-zinc interaction in Zea mays and Phaseolus vulgaris. Ph.D. Thesis. Kansas State University, Manhattan, 1970).

Leaf samples from the 1971 studies were prepared for chemical analysis following a H$_2$SO$_4$ digestion procedure of J.J. Hanway, Iowa State University. A one-half gram sample of tissue, 10 ml of 36 N H$_2$SO$_4$, a small piece of copper wire, and a glass bead were added to 100-ml Pyrex volumetric flasks and placed on a hot plate. The flasks were heated slowly until all frothing had ceased (4 to 8 hrs.). The flasks were swirled, after the solutions had cleared, to wash down the sides of the flasks. The temperature was then increased until the H$_2$SO$_4$ boiled. The solutions were allowed to boil for 24 hours and then removed from the hot plate, cooled, and diluted to volume with deionized water. Assays for N, P, and K were then performed on the solutions.

Five ml of the digested solution were used to determine N by
the micro-Kjeldahl steam distillation technique outlined by Bremner and Keeney (1965). Phosphorus was analyzed following a modification of the vanadomolybdo-phosphoric yellow color method of Jackson (1965). A 5-ml aliquot of the digest solution and 25 ml of the vando-molybdate solution\(^1\) were mixed in a test tube. After 30 minutes absorbance was read on a Beckman model DB-C spectrophotometer. Five ml of the digest solution diluted 1:10 was used to determine K with a Perkin-Elmer flame photometer.

Grain yields were obtained by harvesting the two center rows of each plot. Corn was hand harvested and shelled with a tractor-mounted sheller. Grain sorghum was either hand harvested and later threshed with a modified Massey-Harris combine or harvested directly with the combine. All yields were corrected to 12.5% moisture. Analysis of variance of the data was carried out by means of an IBM 360 computer.

**Growth Chamber Studies**

I. Effectiveness of KPP as a P source.

An investigation was initiated to compare the effectiveness of KPP, monoammonium phosphate (MAP), and APP on both an acid and a calcareous soil. The soils were collected from two recently leveled sites in Pottawatomie County (Table 5). Nutrients (Table 6) were mixed with the soil prior to planting. Six seeds of

\(^1\)Prepared by dissolving 195 g of ammonium molybdate in a liter of water. To this solution, 5.05 g of ammonium-metavanadate dissolved in a liter of boiling water, was added and cooled. This mixture was transferred to a carboy and diluted to 18 liters with deionized water.
Table 5. Analysis of soils used for growth chamber evaluations of KPP.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Soil Source</th>
<th>Soil Series</th>
<th>pH</th>
<th>Avail. P kg/ha</th>
<th>Exch. K kg/ha</th>
<th>Avail. Zn ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Pottawatomie Co.</td>
<td>Muir fine sandy loam</td>
<td>6.7</td>
<td>3</td>
<td>160</td>
<td>2.8</td>
</tr>
<tr>
<td></td>
<td>Pottawatomie Co.</td>
<td>Muir fine sandy loam</td>
<td>8.1</td>
<td>24</td>
<td>168</td>
<td>7.8</td>
</tr>
<tr>
<td>II</td>
<td>Pottawatomie Co.</td>
<td>Muir fine sandy loam</td>
<td>7.1</td>
<td>27</td>
<td>288</td>
<td>1.8</td>
</tr>
<tr>
<td>III</td>
<td>Cherokee Co.</td>
<td>Cherokee silt loam</td>
<td>6.7</td>
<td>17</td>
<td>132</td>
<td>*</td>
</tr>
<tr>
<td>IV</td>
<td>Sedgwick Co.</td>
<td>Vanoss silt loam</td>
<td>6.8</td>
<td>18</td>
<td>519</td>
<td>2.6</td>
</tr>
</tbody>
</table>

* No analysis for Zn was performed.
Table 6. Treatments used in growth chamber study to determine effectiveness of KPP as a P source.

<table>
<thead>
<tr>
<th>P Concentration</th>
<th>P Carrier</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 ppm</td>
<td>-</td>
</tr>
<tr>
<td>40 ppm</td>
<td>MAP</td>
</tr>
<tr>
<td>80 ppm</td>
<td>MAP</td>
</tr>
<tr>
<td>40 ppm</td>
<td>APP</td>
</tr>
<tr>
<td>80 ppm</td>
<td>APP</td>
</tr>
<tr>
<td>40 ppm</td>
<td>KPP</td>
</tr>
<tr>
<td>80 ppm</td>
<td>KPP</td>
</tr>
</tbody>
</table>

All pots received:

A total of 150 ppm N as either or both urea or ammonium-N from the P materials.

A total of 150 ppm K as either or both KCl or K from the KPP material.

8 ppm Zn as ZnSO₄

10 ppm Fe as Fe DTPA
Pioneer 3306 corn were planted in each pot and fine, white sand was placed on the soil surface to reduce evaporation. The containers used in this experiment were 15-cm-diameter plastic pots. These containers were washed in 0.1 M EDTA, distilled water, 10% (v/v) HNO₃, and deionized water.

All treatments were replicated three times and randomly placed in a growth chamber with 30°C-day and 20°C-night temperatures. Day length was 16 hours and lighting was provided by sixteen 160-watt fluorescent lamps and six 300-watt incandescent lamps (a total of 1500 foot-candles). Pots were watered to approximately field capacity as determined by weighing.

Plants were thinned to three plants per pot after attaining a height of approximately 10 cm. All plants were harvested 21 days after planting, oven-dried, and dry weights per three plants determined. Plant material was then ground using a small Wiley mill with stainless steel knives and a stainless steel 40-mesh screen. The samples were prepared for chemical analysis by the modified wet oxidation procedure as described earlier. Digest solutions were analyzed for P by the vanadate-molybdate yellow method and Zn by atomic absorption spectrophotometry. Both methods were discussed previously.

II. Effect of KPP on germination of plants.

A growth chamber study was designed to compare the effects of KPP and ACP on germination of grain sorghum and wheat. Nutrients (Table 7) were broadcast by mixing with the soil prior to planting. Banding of nutrients was accomplished by removing a
Table 7. Treatments and methods of application used in growth chamber study of the effects of KPP on germination of grain sorghum and wheat.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>P Concentration</th>
<th>Method of Application</th>
<th>P Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>1&lt;sup&gt;a/&lt;/sup&gt;</td>
<td>0 ppm</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2&lt;sup&gt;b/&lt;/sup&gt;</td>
<td>8 ppm</td>
<td>Broadcast</td>
<td>AOP</td>
</tr>
<tr>
<td>3&lt;sup&gt;b/&lt;/sup&gt;</td>
<td>16 ppm</td>
<td>Broadcast</td>
<td>AOP</td>
</tr>
<tr>
<td>4&lt;sup&gt;b/&lt;/sup&gt;</td>
<td>8 ppm</td>
<td>Banded</td>
<td>AOP</td>
</tr>
<tr>
<td>5&lt;sup&gt;b/&lt;/sup&gt;</td>
<td>16 ppm</td>
<td>Banded</td>
<td>AOP</td>
</tr>
<tr>
<td>6&lt;sup&gt;a/&lt;/sup&gt;</td>
<td>8 ppm</td>
<td>Broadcast</td>
<td>KPP</td>
</tr>
<tr>
<td>7&lt;sup&gt;a/&lt;/sup&gt;</td>
<td>16 ppm</td>
<td>Broadcast</td>
<td>KPP</td>
</tr>
<tr>
<td>8&lt;sup&gt;d/&lt;/sup&gt;</td>
<td>8 ppm</td>
<td>Banded</td>
<td>KPP</td>
</tr>
<tr>
<td>9&lt;sup&gt;d/&lt;/sup&gt;</td>
<td>16 ppm</td>
<td>Banded</td>
<td>KPP</td>
</tr>
</tbody>
</table>

<sup>a/</sup> Received broadcast applications of 40 ppm N as NH₄NO₃ and 8 ppm Zn as ZnSO₄.

<sup>b/</sup> Received balance of N up to 40 ppm as broadcast NH₄NO₃, broadcast KCl to equal K from KPP, and 8 ppm Zn broadcast as ZnSO₄.

<sup>c/</sup> Received balance of N up to 40 ppm as broadcast NH₄NO₃, banded KCl to equal K from KPP, and 8 ppm Zn broadcast as ZnSO₄.

<sup>d/</sup> Received banded N as NH₄NO₃ to equal N from banded AOP, balance of N to 40 ppm broadcast as NH₄NO₃, and 8 ppm Zn broadcast as ZnSO₄.
portion of soil from the containers in the form of a v-shaped
trench approximately 2.5-cm deep and uniformly spreading the
material and seed in this trench. The soil was then replaced
over the fertilizer and seeds. The soil used in this experiment
was calcareous and obtained from a recently leveled site in
Pottawatomie County (Table 5).

Containers used were plywood boxes, 14-cm wide, 25-cm long,
and 17-cm deep. Four holes approximately 1 cm in diameter were
bored in the bottom of the containers to facilitate drainage.
Twenty seeds of Shawnee wheat and 10 seeds of Pioneer 846 grain
sorghum were evenly spaced in their respective containers. Per
cent germination of each variety was determined before planting
and only healthy appearing seeds were planted. Fine, white sand
was then placed on the soil surface to reduce evaporation.

All treatments were replicated three times for both crops
and randomly distributed in a growth chamber. Growing conditions
were the same as for the previous experiment. Plant population
counts were taken five days after emergence and per cent germi-
nation was calculated. The plants were harvested 16 days after
planting, oven-dried, and total dry-matter weight for each con-
tainer was determined. Plant material was then ground as in the
previous experiment. The samples were prepared for chemical
analysis following the H_2SO_4 digestion procedure described
earlier. The digest solutions were analyzed for N by the micro-
Kjeldahl steam distillation technique, P by the modified vanado-
molybdophosphoric yellow color method, and K by flame photometry.
All procedures were described earlier.
III. Effectiveness of KPP as a K source.

In order to investigate the ability of KPP to supply potassium to plants, a growth chamber comparison of KPP and five other K materials was conducted. Soil from a site low in available K in Cherokee County was used in this experiment (Table 5).

Nutrients (Table 8) and soil were mixed together in a mechanical mixer. Six seeds of DeKalb variety XL-390 (white grain) corn were planted in each pot and fine, white sand was placed on the soil surface to reduce evaporation. The pots used in this experiment were the same as described in growth chamber study I. They were cleaned by washing in 0.1 N HCl and deionized water.

All treatments were replicated three times and randomly distributed in a growth chamber. Growing conditions were as described before. Plants were thinned to three plants per pot at an approximate height of 10 cm. All plants were harvested 17 days after planting, oven-dried, and dry weights per three plants determined. The dried plant material was prepared for analysis by the $\text{H}_2\text{SO}_4$ digestion procedure. The digest solution was assayed for N, P, and K. Nitrogen was determined by the micro-Kjeldahl steam distillation technique, P by the modified vanadomolybdophosphoric yellow color method, and K by flame photometry.

IV. Effect of KPP on P-Zn interaction.

Additions of K to plants have been known to lessen the severity of phosphorus depression on zinc uptake (Stukenholtz et al., 1966). With this fact in mind a growth chamber experiment was initiated to investigate the possibility of KPP having
Table 8. Treatments used for growth chamber evaluation of KPP as a K source for corn (*Zea mays* L.).

<table>
<thead>
<tr>
<th>K Concentrations</th>
<th>K Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 ppm</td>
<td>-</td>
</tr>
<tr>
<td>50 ppm</td>
<td>KPP</td>
</tr>
<tr>
<td>100 ppm</td>
<td>KPP</td>
</tr>
<tr>
<td>50 ppm</td>
<td>KCl</td>
</tr>
<tr>
<td>100 ppm</td>
<td>KCl</td>
</tr>
<tr>
<td>50 ppm</td>
<td>K$_2$SO$_4$</td>
</tr>
<tr>
<td>100 ppm</td>
<td>K$_2$SO$_4$</td>
</tr>
<tr>
<td>50 ppm</td>
<td>KNO$_3$</td>
</tr>
<tr>
<td>100 ppm</td>
<td>KNO$_3$</td>
</tr>
<tr>
<td>50 ppm</td>
<td>K$_2$CO$_3$</td>
</tr>
<tr>
<td>100 ppm</td>
<td>K$_2$CO$_3$</td>
</tr>
<tr>
<td>50 ppm</td>
<td>KH$_2$PO$_4$</td>
</tr>
<tr>
<td>100 ppm</td>
<td>KH$_2$PO$_4$</td>
</tr>
</tbody>
</table>

All other elements involved in the experiment were held constant with additions of the following materials:

- **N** - 120 ppm, majority as NH$_4$NO$_3$, balance as (NH$_4$)$_2$SO$_4$ and NH$_4$H$_2$PO$_4$.
- **P** - 80 ppm as NH$_4$H$_2$PO$_4$.
- **S** - 41 ppm as (NH$_4$)$_2$SO$_4$.
- **Cl** - 91 ppm as CaCl$_2$.
- **Ca** - 51 ppm as CaCO$_3$.
- **Zn** - 8 ppm as Zn EDTA.
- **Fe** - 5 ppm as Fe EDTA.
a different effect on a P-Zn interaction than other P sources.

Soil for this experiment was obtained from a P and Zn deficient site in Sedgwick County (Table 5). Nutrient treatments (Table 9) and soil were mixed together in a mechanical mixer and then transferred to plastic pots. These containers (same type as discussed previously) had been washed in 0.1 M EDTA, distilled water, 10% (v/v) HNO₃, and deionized water. Six seeds of DeKalb variety XL-390 corn were planted in the pots.

Treatments were replicated three times and randomly placed in a growth chamber. Growing conditions were the same as for the previous experiments. Plants were thinned to three plants per pot at an approximate height of 10 cm. Soil moisture was maintained at field capacity as determined by weighing.

Additional applications of 10 ppm N as NH₄NO₃ and 5 ppm Fe as Fe EDTA, both in a solution form, were required by the plants 10 days after planting to relieve deficiency symptoms. All plants were harvested 17 days after planting, oven-dried, and dry weights per three plants were determined. Plant samples were prepared for chemical analysis by the modified wet oxidation procedure. Digest solutions were analyzed for Mg, Ca, Fe, Mn, and Cu by atomic absorption spectrophotometry, P by the vanadate-molybdate yellow method, and K by flame photometry.

Source and Description of Materials

APP and MAP was obtained from the Tennessee Valley Authority (TVA), Muscle Shoals, Alabama; ACP from Gulf Oil Corporation, Kansas City, Missouri; and TSP from the J. R. Simplot Company.
Table 9. Treatments used in growth chamber investigation of the effects of KPP on P-Zn interaction.

<table>
<thead>
<tr>
<th>P Concentration</th>
<th>Zn Concentration</th>
<th>P Source</th>
<th>Zn Source</th>
</tr>
</thead>
<tbody>
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<td>0 ppm</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>0 ppm</td>
<td>8 ppm</td>
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<td>0 ppm</td>
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<td>-</td>
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<td>8 ppm</td>
<td>KPP</td>
<td>ZnSO$_4$</td>
</tr>
<tr>
<td>80 ppm</td>
<td>8 ppm</td>
<td>AOP</td>
<td>-</td>
</tr>
<tr>
<td>80 ppm</td>
<td>8 ppm</td>
<td>AOP</td>
<td>ZnSO$_4$</td>
</tr>
<tr>
<td>80 ppm</td>
<td>0 ppm</td>
<td>APP</td>
<td>-</td>
</tr>
<tr>
<td>80 ppm</td>
<td>8 ppm</td>
<td>APP</td>
<td>ZnSO$_4$</td>
</tr>
<tr>
<td>80 ppm</td>
<td>0 ppm</td>
<td>TSP</td>
<td>-</td>
</tr>
<tr>
<td>80 ppm</td>
<td>8 ppm</td>
<td>TSP</td>
<td>ZnSO$_4$</td>
</tr>
</tbody>
</table>

All other elements involved in this experiment were held constant with additions of the following materials:

- **N** - 150 ppm, majority as NH$_4$NO$_3$, balance as (NH$_4$)$_2$SO$_4$.
- **K** - 120 ppm as KNO$_3$.
- **S** - 20 ppm, majority as (NH$_4$)$_2$SO$_4$, balance as ZnSO$_4$.
- **Fe** - 5 ppm as Fe EDTA.
Pocatello, Idaho. All materials were fertilizer grade.

Fertilizer grade KPP was obtained from Pennzoil United, Shreveport, Louisiana. Crystallographic analysis of this material by TVA revealed a phosphorus constituency of 3.9% orthophosphate, 6.0% pyrophosphate, 24.3% tripolyphosphate, and 65.8% higher molecular weight phosphates. There was no evidence of ring compounds.
RESULTS AND DISCUSSION

Field Experiments

Treatment means for leaf P concentrations are presented in Figures 1 through 3 and Tables 11 and 13. Yield data are presented in Tables 10, 12, and 13. Other detailed leaf analysis data are listed in Appendix Tables I through VII. Location and soil analysis of the research sites are stated in Table 1.

Control values, referred to as 'No P' in the figures, received no phosphorus applications. Leaf sampling dates are referred to as 'Date 1' or 'Date 2' and were explained in the preceding section.

Comparisons of KPP, AOP, and APP as P Sources (1970)

Yield differences (Table 10) and leaf P concentration differences for corn and grain sorghum (Table 11) were not statistically significant at either experimental location in 1970 due to soil variations within the sites. No consistent trends in yield were noted at either of the locations. Phosphorus responses were observed early in the growing season and continued until mid-August. However, no differences in plant response to the three forms of P were indicated through visual observations. Additional plant-tissue analysis (Appendix Tables I through III) offered few additional trends at these sites.

Comparisons of KPP, AOP, APP, and TSP as P Sources (1971)

Definite phosphorus responses were noted early in the season at the Sedgwick (grain sorghum) and Geary County (corn) sites.
but only a slight response was observed at the Clay County site (corn). From early observations AOP and TSP appeared to be superior to APP and KPP at the Sedgwick and Geary County locations (Figure 4). However, at a later date (Figure 5), no visual differences between carriers could be detected.

Phosphorus applications significantly increased the P content of plants over the controls at the Sedgwick and Geary County sites (Figures 1 and 2), but not at the Clay County location (Figure 3). At the Sedgwick County site, the high P rate of AOP significantly increased leaf P contents at the early sampling date when compared with either APP or KPP. TSP was approximately equal to AOP in supplying P to the plants at this same rate. Plants supplied with 40 kg/ha P as KPP were significantly lower in P content at sampling date 1 than those fertilized with the same rate of AOP. However, at the second sampling date no statistical differences were evident from the carrier effect on leaf P content (Appendix Table IV). Possibly, as was noted by Mattingly and Penny (1968), a gradual hydrolysis of KPP with time provided the plants with an available form of P later in the growing season. This would help to explain the nearly equal performance of these four materials in supplying P to the plants at the second sampling date.

Grain sorghum yields at the Sedgwick County site (Table 12) increased with increasing P application rates. All rates of each carrier with the exception of TSP significantly increased yields over the control. Further statistical analysis of the yield data (Appendix Table IV) showed the effect of P carrier to be
significant. AOP was significantly superior to the other carriers at the 5% level.

Although AOP and TSP seemed to be superior as P sources to both of the polyphosphates in early visual comparisons at the Geary County site, this was not confirmed in the P analysis of leaf tissue (Figure 2). Only APP was statistically inferior to the orthophosphates at the first sampling date. With additional statistical analysis, P carrier influence on leaf P content at the early sampling was found to be significant (Appendix Table V). KPP, AOP, and TSP were statistically equal and all significantly superior to APP.

At the second sampling date, applications of P did not increase leaf P contents when compared to the control. There also were no significant differences in the effect of P carriers on leaf P levels. However, additional statistical analysis revealed that the P carrier by P rate interaction was significant (Appendix Table V).

Yields at the Geary County location were generally increased by P applications when compared with the control (Table 12). A P carrier by P rate interaction existed at this site. This interaction resulted in higher yields with 40 kg/ha P applications of KPP, TSP, and AOP than when the same P rate was applied as APP.

At the Clay County site phosphorus applications tended to increase P levels (Figure 3) in the leaf tissue at both sample dates, but none of these increases were significant at the 5% level. Soil variations within the site were partly responsible for the nonsignificant treatment effects. There was also no
consistent trend in yields at this site. Applications of P significantly increased yields, but no significant differences in carrier effects on these increases were evident (Table 12).

Although APP failed to equal AOP in supplying P to the plants early in the season at the Sedgwick and Geary County sites, the results of both years at all locations tend to indicate that APP is equal to AOP as a P source. These results are also in agreement with earlier work by Webb (B.B. Webb, Field and growth chamber comparisons of ortho- and polyphosphates. Ph.D. Thesis. Kansas State University, Manhattan, 1970).

Comparison of Banded and Broadcast Applications of AOP and KPP

Early plant observations at this experimental site in Riley County detected very little germination damage from the banded applications of either P carrier in direct contact with grain sorghum seed. No significant treatment differences were registered for yields at this site (Table 13). Likewise, banded or broadcast rates of either carrier had little effect on leaf P levels.
THIS BOOK CONTAINS NUMEROUS PAGES WITH DIAGRAMS THAT ARE CROOKED COMPARED TO THE REST OF THE INFORMATION ON THE PAGE. THIS IS AS RECEIVED FROM CUSTOMER.
FIG. 1 - EFFECTS OF THREE RATES OF AOP, APP, TSP, AND KPP ON P CONTENT OF GRAIN SORGHUM LEAVES. (SEDGWICK COUNTY, 1971.)
FIG. 2 - EFFECTS OF THREE RATES OF A0P, APP, TSP, AND KPP ON P CONTENT OF CORN LEAVES. (GEARY COUNTY, 1971.)
FIG. 3 - EFFECTS OF THREE RATES OF AOP, APP, TSP, AND KPP ON P CONTENT OF CORN LEAVES. (CLAY COUNTY, 1971.)
Fig. 4 - Early season grain sorghum P response, Sedgwick County, 1971.

(Above: 40 kg/ha P as AOP on left versus 40 kg/ha P as KPP on right.)
(Below: 20 kg/ha P as KPP on left versus 20 kg/ha P as TSP on right.)
THIS BOOK CONTAINS NUMEROUS PICTURES THAT ARE ATTACHED TO DOCUMENTS CROOKED.

THIS IS AS RECEIVED FROM CUSTOMER.
Table 10. Effects of two rates of AOP, APP, KPP, and two rates of K on yield of irrigated grain sorghum and corn (1970).

<table>
<thead>
<tr>
<th>Nutrient Rate P kg/ha</th>
<th>Carrier K</th>
<th>Pawnee Co. Corn kg/ha</th>
<th>Scott Co. Grain Sorghum kg/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>-</td>
<td>7649</td>
</tr>
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<td>KCl</td>
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</tr>
<tr>
<td>20</td>
<td>0</td>
<td>APP</td>
<td>7838</td>
</tr>
<tr>
<td>20</td>
<td>50</td>
<td>APP KCl</td>
<td>6834</td>
</tr>
<tr>
<td>40</td>
<td>0</td>
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<td>7022</td>
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<tr>
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<td>50</td>
<td>KPP</td>
<td>7336</td>
</tr>
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</table>

LSD.05 Treatment ns ns
Table 11. Phosphorus content of corn and grain sorghum leaves on two experimental sites (1970). Comparison of two rates of APP, AOP, KPP, and two rates of K.

<table>
<thead>
<tr>
<th>Nutrient Rate</th>
<th>Carrier</th>
<th>Pawnee Co.</th>
<th>Scott Co.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Corn %P</td>
<td>Grain Sorghum %P</td>
</tr>
<tr>
<td>P</td>
<td>K</td>
<td>Date 1</td>
<td>Date 2</td>
</tr>
<tr>
<td>-----------------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0.255</td>
<td>0.258</td>
</tr>
<tr>
<td>0</td>
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<td>0.271</td>
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<td>20</td>
<td>50</td>
<td>0.289</td>
<td>0.271</td>
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<td>0</td>
<td>0.260</td>
<td>0.244</td>
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<td>0.289</td>
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LSD .05 Treatment: ns ns ns ns ns
Table 12. Yield of corn and grain sorghum on three experimental sites (1971). Comparisons of three rates of AOP, APP, TSP, and KPP.

<table>
<thead>
<tr>
<th>P Rate kg/ha</th>
<th>P Carrier</th>
<th>Sedgwick Co. Grain Sorghum kg/ha</th>
<th>Geary Co. Corn kg/ha</th>
<th>Clay Co. Corn kg/ha</th>
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</thead>
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<td>0</td>
<td>-</td>
<td>2759</td>
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</tr>
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LSD,05 Treatment 1066 1693 1881
P Carrier 502 ns ns
P Rate 439 ns ns
Carrier x Rate ns 1693 ns
Table 13. Effects of banded and broadcast applications of three rates of AOP and KPP on yield and P content of grain sorghum, Riley County, 1971.

<table>
<thead>
<tr>
<th>P Rate kg/ha</th>
<th>P Carrier</th>
<th>Method of Application</th>
<th>% P Date 1</th>
<th>% P Date 2</th>
<th>Yield kg/ha</th>
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<td>-</td>
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<td>Banded</td>
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<td>KPP</td>
<td>Broadcast</td>
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<td>Banded</td>
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<td>.347</td>
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<tr>
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<td>.352</td>
<td>6458</td>
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</table>

LSD .05 Treatment ns ns ns
Growth Chamber Experiments

Comparisons of KPP, MAP, and APP as P Sources

KPP, MAP, and APP were compared as P sources at two rates for corn grown on calcareous and acid soils in a growth chamber. Dry weight and plant P concentration data are presented in Figure 6. Plant P uptake data are depicted in Figure 7.

Plant dry weights conformed to visual comparisons (Figures 14, 15, and 16) and were significantly greater on the acid soil than on the calcareous soil. P rate also had a significant effect in increasing dry weight of plants on both soils (Appendix Table VIII). P carrier effect was not significant, however, in increasing dry weights of the corn plants.

Phosphorus concentration in the plant tissue was significantly increased by all P applications with the exception of the 40 ppm P rate of KPP. Soil effects also exerted a significant effect on P concentration in the plant tissue. Although P carrier effect was not significant, additional statistical analysis indicated both significant carrier by rate and rate by soil interaction effects (Appendix Table VIII). Applications of 40 ppm P as APP or MAP resulted in higher P levels than an equal rate of KPP in the acid, but not in the calcareous soil. However, at a rate of 80 ppm P, MAP and KPP were equal and MAP was superior to APP in supplying P to the plants grown on the acid soil. This would suggest possibly that P availability from KPP was limiting at the lower rate.

Plant uptake of P was increased by all P applications
(Figure 7). P rate and soil effects were also significant in their influence on P uptake. P carrier effects were again non-significant, but carrier by rate interaction significantly influenced P uptake (Appendix Table VIII).

**Comparisons of Banded and Broadcast Rates of AOP and KPP**

Banded applications of two rates of AOP and KPP were compared when applied in direct contact with wheat and grain sorghum seed. Broadcast applications of these same rates were mixed with the soil in other treatments. Both crops were grown in a growth chamber for 16 days. Plant dry weight and P concentration data are presented in Figure 8. P uptake data are displayed in Figure 9. Per cent germination of the seeds is listed in Appendix Table IX.

Dry-weight production of both wheat and grain sorghum tended to increase with P applications (Figure 8). Both P rate and application method significantly affected grain sorghum dry weights, but not those of wheat (Appendix Table IX). Banded P applications as KPP significantly increased grain sorghum dry weights over those obtained when these same rates were broadcast. Only the lower rate of AOP banded increased grain sorghum dry weights. Banded applications of KPP on wheat were also superior to broadcast applications of this material.

The only apparent damage which could be noted from the banded applications of these materials was the reduction in grain sorghum dry weight with 16 ppm P banded as AOP when compared with that obtained from an application of 8 ppm P banded as AOP. This
reduction was significant at the 5% level. The high rate of AOP banded also significantly reduced grain sorghum yields below those produced by a similar rate of KPP banded.

AOP and MAP have been shown to be toxic to germinating corn plants by Allred and Ohlrogge (1964), and Harris (1963) noted germination damage in spring wheat from a MAP based, mixed fertilizer. However, in the present study there was no significant reduction (5% level) in per cent germination of either wheat or grain sorghum plants resulting from applications of AOP or KPP.

Applications of P significantly increased P levels of both wheat and grain sorghum plants (Figure 8). P rate and application method also significantly increased P concentrations. There was also a significant interaction between carrier and method of application. Grain sorghum fertilized with 16 ppm P banded as AOP had higher P concentrations than plants receiving the same rate of KPP banded.

Uptake of P by both wheat and grain sorghum was generally increased with P applications (Figure 9). P uptake from banded P applications was significantly higher than with broadcast applications for both crops. There was no significant effect of P carrier on P uptake with either wheat or grain sorghum.

Comparisons of KPP and Five Other K Materials as K Sources

Two K rates of KPP, KCl, K₂CO₃, KNO₃, KH₂PO₄, and K₂SO₄ were compared as K sources for corn grown in a growth chamber. Data for dry weights and K contents of the corn plants are presented in Figure 10. Uptake data are presented in Figure 11.
Yields of plant dry matter were not significantly affected by K applications. However, plant K content and uptake were significantly increased by increasing application rates of K (Figures 10 and 11). Although uptake and concentration of K tended to be higher with applications of KPP, KH₂PO₄, and K₂SO₄, no significant differences between carrier effects were noted (Appendix Table XI).

Comparisons of the Effects of KPP, AOP, APP, and TSP on Response of Corn Plants to Zn

The effect of each of four P carriers applied at high P rates on Zn concentrations in, and uptake by corn plants, was compared in a growth chamber study. Plant dry weight, P content, and Zn content data are presented in Figure 12. P uptake and Zn uptake data are shown in Figure 13.

Although plant dry weights were significantly increased by P applications, no differences were evident as to carrier effects (Appendix Table XII). However, carrier effects had a significant influence on P content and P uptake of the corn plants. Plant P concentrations (Figure 12) were significantly lower with P applied as KPP than with applications of AOP or APP. Plant uptake of P was also significantly lower with P applied as KPP than when it was applied as AOP (Figure 13).

Although there was a significant plant dry weight response to P in this experiment, applications of Zn did not significantly affect dry-matter yields. It should be noted that this soil was obtained from the site of the earlier field investigation in Sedgwick County. An excellent yield response to P was noted at
this site (Figure 1). However, a Zn rate study immediately adja-
cent to the P investigation at this site failed to produce
significant yield responses despite very low soil test Zn
(unpublished data).

As has been reported by other researchers, a significant
depression of plant Zn content occurred with high P applications.
However, no significant P carrier effect on this Zn depression
was noted (Appendix Table XII). Zinc uptake was not depressed
by P applications because of the offsetting increase in plant dry
weight that occurred with these applications. In fact, Zn up-
take was significantly increased when 8 ppm Zn as ZnSO$_4$ was sup-
plied with the P applications (Figure 13).

Although Fe was uniformly applied in this experiment, sig-
nificant differences occurred in plant Fe content (Appendix Table
XII). Applications of 80 ppm P as TSP with no Zn applied sig-
nificantly reduced Fe content in the plants. However, with
applications of 8 ppm Zn as ZnSO$_4$, all P carriers significantly
reduced plant Fe levels. Similar depressions in the Fe content
of corn in the presence of high plant Zn concentrations have been
reported by Adriano (D.C. Adriano, Phosphorus-zinc interaction in
Zea mays and Phaseolus vulgaris, Ph.D. Thesis, Kansas State Uni-
versity, Manhattan, 1970). There is a possibility that some of
the Fe was rendered unavailable by formation of insoluble Fe
phosphates. Another possibility is that Zn competition with Fe
reduced Fe uptake to the plants as is shown slightly in Appendix
Table XIII.
FIG. 6 - EFFECTS OF TWO RATES OF MAP, APP, AND KPP IN TWO SOILS ON P CONTENT AND DRY WEIGHT OF CORN PLANTS GROWN IN A GROWTH CHAMBER.
FIG. 7 - EFFECTS OF TWO RATES OF MAP, APP, AND KPP IN TWO SOILS ON P UPTAKE OF CORN PLANTS GROWN IN A GROWTH CHAMBER.
FIG. 8 - EFFECTS OF BANDED AND BROADCAST APPLICATIONS OF TWO RATES OF AOP AND KPP ON P CONTENT AND DRY WEIGHT OF WHEAT AND GRAIN SORGHUM PLANTS GROWN IN A GROWTH CHAMBER.
FIG. 9 - EFFECTS OF BANDED AND BROADCAST APPLICATIONS OF TWO RATES OF AOP AND KPP ON P UPTAKE OF WHEAT AND GRAIN SORGHUM PLANTS GROWN IN A GROWTH CHAMBER.
FIG. 10 - EFFECTS OF TWO RATES OF KPP AND FIVE OTHER K SOURCES ON DRY WEIGHT AND K CONTENT OF CORN PLANTS GROWN IN A GROWTH CHAMBER.
FIG. 11 - EFFECTS OF TWO RATES OF KPP AND FIVE OTHER K SOURCES ON K UPTAKE OF CORN PLANTS GROWN IN A GROWTH CHAMBER.
FIG. 12 - EFFECTS OF KPP, AOP, APP, TSP, AND TWO RATES OF ZN ON P CONTENT, ZN CONTENT, AND DRY WEIGHT OF CORN PLANTS GROWN IN A GROWTH CHAMBER.
FIG. 13 - EFFECTS OF KPP, AOP, APP, TSP, AND TWO RATES OF ZN ON P AND ZN UPTAKE OF CORN PLANTS GROWN IN A GROWTH CHAMBER.
Fig. 14 - Corn plant response to two rates of P from MAP on acid and calcareous soils in a growth chamber.
Fig. 15 - Corn plant response to two rates of P from APP in acid and calcareous soils in a growth chamber.
Fig. 16 - Corn plant response to two rates of P from KPP in acid and calcareous soils in a growth chamber.
CONCLUSIONS

Field Studies

In general, these studies indicate that KPP is equal to AOP, APP, and TSP in supplying P to the plants. However, at one location P concentrations in grain sorghum leaves early in the season were significantly higher with applications of AOP than when P was supplied in equal quantities as KPP or APP. In contrast, late season plant P levels at that location were statistically equal which indicates a gradual hydrolysis of the polyphosphates over the length of the growing season or relative equality in the amounts of P fixed in the soil.

Grain sorghum yields at this location in Sedgwick County were significantly higher with applications of AOP than when any of the other carriers were applied. Apparently the increased early P benefit to the plants from AOP at this site caused these higher yields. Only one other location showed significant yield differences. At this site in Geary County, on a slightly more basic soil, 40 kg/ha P as APP reduced yields in comparison to the other carriers. Yields with KPP tended to be slightly higher than with AOP or TSP. These differences were not significant, however.

An investigation of the effects of banded and broadcast applications of AOP and KPP on grain sorghum showed no consistent trend in yields favoring a certain carrier or application method. Plant P levels were also not affected as was expected since this site was not P deficient. Seed germination was apparently not damaged by banding either material in contact
with the seeds.

**Growth Chamber Experiments**

A growth chamber comparison of two rates of MAP, APP, and KPP as P sources for corn in acid and calcareous soils showed a consistently greater plant response to P in the acid soil. Several interactions of treatment variables also occurred. At the low P rate, plant P levels in the acid soil were significantly lower with KPP than when MAP or APP was applied. However, at the high P rate KPP was equal to MAP in supplying P to the plants. Evidently P availability from KPP was the limiting factor at the low P rate on the acid soil.

Effects of banded and broadcast rates of AOP and KPP were investigated on both wheat and grain sorghum in a growth chamber. Although no damage to germination resulted from banding the materials in contact with seed, a significant reduction in dry weight of grain sorghum did occur when 16 ppm P as AOP was applied in this manner. KPP did not appear to damage the plants as both 8 and 16 ppm P applied as banded KPP produced significantly greater dry weights with both crops than the same rates broadcast.

Banded applications of both materials significantly increased P content and P uptake of the plants over broadcast applications. AOP banded at 16 ppm P to wheat was superior to the same rate of KPP banded in terms of plant P content. Uptake data also favored AOP, but differences were not significant at the 5% level.

Application of two K rates of KPP, KCl, KNO₃, K₂CO₃, KH₂PO₄, and K₂SO₄ to corn grown in a growth chamber produced few
conclusive results. Plant K content and uptake of K were significantly increased by increasing K rates, but no consistent trends were established as to effect of the K carriers. Plant uptake and concentration of K tended to be slightly higher with applications of KPP, KH$_2$PO$_4$, and K$_2$SO$_4$, but these differences were not significant.

High P application rates of KPP, AOP, APP, and TSP with and without applied Zn were compared on corn plants grown in soil deficient in both P and Zn in a growth chamber. Although plant dry weights were increased by the P applications, there were no significant differences between carrier effects. Plant P levels were significantly lower with P applied as KPP than with applications of AOP or APP. Uptake of P by the plants was also lower when P was applied as KPP than when it was applied as AOP.

Plant Zn content was depressed by high P applications, but there was no difference in P carrier influence on this depression. Application of 8 ppm Zn as ZnSO$_4$ alone, with no applied P, significantly increased Zn uptake over the control which received no Zn or P. Addition of 80 ppm P alone, with no applied Zn, tended to increase Zn uptake over the control, but this difference was not significant at the 5% level. However, applications of both Zn and P did produce significantly higher Zn uptake than when only Zn was applied. The source of P had no effect on these differences.

Although Fe was uniformly applied in the treatments, differences did occur in plant Fe contents. With the exception of TSP, applications of P alone did not significantly reduce plant Fe
levels. However, Fe contents of the plants were consistently lower when both P and Zn were supplied to the plants than when Zn only was applied. This difference occurred regardless of the P carrier used. Evidently Zn competition with Fe influenced this Fe imbalance.
LITERATURE CITED


VITA

The author was born on November 10, 1944, son of Ernest and Nora Armbruster, at Hays, Kansas. He completed high school at WaKeeney, Kansas in 1962. He then entered Kansas State University in September of 1962 and graduated with a Bachelor of Science in Agricultural Mechanization in 1970. In September of 1970, he began work on a Master of Science program with the Agronomy Department of Kansas State University. He is married to the former Nancy V. Denu of New York, New York.

The author is presently a graduate student member of the American Society of Agronomy and the Soil Science Society of America.
Table I. Effects of P carriers, P rates and K rates on yield and composition of irrigated corn, Pawnee County, 1970.

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<td>K</td>
</tr>
<tr>
<td>kg/ha</td>
<td>kg/ha</td>
<td>P</td>
<td>K</td>
</tr>
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<td>KCl</td>
</tr>
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</tr>
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<td>KCl</td>
</tr>
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LSD .05 Treatment ns - - - - - ns - - - - ns
Table II. Effects of P carriers, P rates and K rates on the leaf composition at the first sampling date and yield of irrigated grain sorghum, Scott County, 1970.

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LSD .05 Treatment ns - - - - - - ns
Table III. Effects of P carriers, P rates, and K rates on the leaf composition of irrigated grain sorghum at the second sampling date, Scott County, 1970.

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LSD .05 Treatment  ns  -  -  -  -  -  -  -
Table IV. Comparisons of the effects of P carriers and P rates on yield and leaf composition of irrigated grain sorghum, Sedgwick County, 1971.

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76
Table V. Comparisons of the effects of P carriers and P rates on yield and leaf composition of irrigated corn, Geary County, 1971.

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<td>3.02</td>
<td>0.282</td>
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</tr>
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<td>2.73</td>
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<td>2.82</td>
<td>0.242</td>
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Carrier Means:
- AOP 9907 3.67 0.298 - 2.68 0.251 1.71
- APP 9280 3.49 0.243 - 2.83 0.249 1.86
- TSP 9844 3.75 0.305 - 2.68 0.246 1.76
- KPP 10471 3.79 0.319 - 2.86 0.266 1.62

Rate Means:
- 20 9719 3.73 0.271 - 2.86 0.260 1.76
- 40 9907 3.66 0.296 - 2.72 0.246 1.78
- 60 10157 3.64 0.307 - 2.70 0.253 1.67

LSD .05 Treatment 1693 0.25 0.081 ns 0.24 0.026 0.27
P Carrier ns 0.15 0.048 ns 0.14 ns 0.16
P Rate ns ns ns ns ns ns
P Carrier x Rate 1693 ns ns ns 0.25 0.027 ns
Table VI. Comparisons of the effects of P carriers and P rates on yield and leaf composition of irrigated corn, Clay County, 1971.

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<th>P Rate kg/ha</th>
<th>P Carrier</th>
<th>Yield kg/ha</th>
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<th>Leaf Composition Date 2</th>
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<td></td>
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<td>.216</td>
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<td>ACP</td>
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<td>3.73</td>
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<td>APP</td>
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LSD .05 Treatment 1881 ns ns ns ns ns ns ns ns
LSD .05 P Carrier ns - - - - - - -
LSD .05 P Rate ns - - - - - - -
LSD .05 P Carrier x Rate ns - - - - - - -
Table VII. Effects of banded and broadcast applications of three rates of AOP and KPP on yield and leaf composition of irrigated grain sorghum, Riley County, 1971.

| P Rate kg/ha | P Carrier | Method of Application | Yield kg/ha | Date 1 | Leaf Composition
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<td>N %</td>
<td>P %</td>
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LSD .05 Treatment ns ns ns ns ns ns ns ns


Table VIII. Effects of two rates of MAP, APP, and KPP on dry weight, nutrient content, and nutrient uptake of corn plants grown in acid and calcareous soils (growth chamber).

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<thead>
<tr>
<th>P Rate</th>
<th>P Carrier</th>
<th>Soil Type</th>
<th>Dry Weight (g)</th>
<th>Nutrient Content P %</th>
<th>Zn ppm</th>
<th>Nutrient Uptake P mg/3 plants</th>
<th>Zn ug/3 plants</th>
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</thead>
<tbody>
<tr>
<td>0</td>
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<td>78.1</td>
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<tr>
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<td>MAP</td>
<td>Acid</td>
<td>4.1</td>
<td>.131</td>
<td>62.9</td>
<td>5.4</td>
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<td>Acid</td>
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<td>55.1</td>
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<td>.136</td>
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LSD .05: Treatment 0.4, P Carrier ns, P Rate 0.2, Soil 0.2, P Carrier x P Rate ns, P Carrier x Soil ns, P Rate x Soil ns, Three Way Interaction ns.
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<thead>
<tr>
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<th>Dry Weight</th>
<th>Nutrient Content</th>
<th>Nutrient Uptake</th>
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<td>(g)</td>
<td>P %</td>
<td>Zn ppm</td>
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<td>-</td>
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<td>APP</td>
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<td>.129</td>
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<td>.163</td>
<td>-</td>
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<tr>
<td>APP-80</td>
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<td>.151</td>
<td>-</td>
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<tr>
<td>KPP-80</td>
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<td>Carrier x Soil Means:</td>
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</tr>
<tr>
<td>MAP-Acid</td>
<td>4.4</td>
<td>.164</td>
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<td>APP-Acid</td>
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<td>KPP-Acid</td>
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<td>P Rate x Soil Means:</td>
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Table IX. Effects of banded and broadcast applications of two rates of AOP and KPP on per cent germination and dry weight of wheat and grain sorghum plants (growth chamber).

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<th>P Carrier</th>
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<th>% Germination</th>
<th>Dry Weight</th>
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<td>97</td>
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LSD .05 Treatment
- P Carrier ns ns 0.25 128
- P Rate ns ns 0.14 ns
- Appl. Method ns 0.14 68
- P Carrier x P Rate ns ns ns
- P Carrier x Appl. Method ns ns 0.19 ns
- P Rate x Appl. Method ns 0.19 ns
- Three Way Interaction ns 0.27 ns

Carrier Means:
- AOP 2.18 717
- KPP 2.21 708

P Rate Means:
- 8 2.11 683
- 16 2.28 742
Table IX. (Continued)

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<td><strong>P Rate x Appl. Method Means:</strong></td>
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Table X. Effects of banded and broadcast applications of two rates of AOP and KPP on nutrient composition and nutrient uptake of wheat and grain sorghum plants (growth chamber).

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<th>P Rate</th>
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<th>Nutrient Uptake</th>
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LSD .05 Treatment ns .095 0.41 0.57 0.089 0.44 7.1 1.1 7.5 15.9 1.9 12.5
P Carrier - .049 ns 0.28 ns ns ns ns ns ns ns ns ns ns ns
P Rate - ns 0.18 ns 0.047 0.22 ns ns 6.6 1.0 6.8
Appl. Method ns .049 ns ns ns ns ns ns ns
P Carrier x P Rate ns ns ns ns ns ns ns ns ns
P Carrier x Method ns ns ns ns ns ns ns ns
P Rate x Method ns ns ns ns .066 ns ns ns
Three Way Interaction ns ns ns ns .094 ns ns ns

Carrier Means:
AOP - .669 5.62 3.83 .460 4.37 34.9 4.9 40.3 83.5 10.1 95.4
KPP - .606 5.51 4.13 .459 4.38 34.5 4.4 39.0 91.5 10.3 96.8

P Rate Means:
8 - .562 5.46 3.94 .446 4.22 33.2 3.9 37.3 83.1 8.9 88.9
16 - .713 5.67 4.02 .502 4.54 36.2 5.4 42.0 91.9 11.4 103.3
Table X. (Continued)

<table>
<thead>
<tr>
<th></th>
<th>Plant Composition</th>
<th>Nutrient Uptake</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wheat N</td>
<td>P</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td><strong>Appl. Method Means:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Banded</td>
<td>.792</td>
<td>5.61</td>
</tr>
<tr>
<td>Broadcast</td>
<td>.483</td>
<td>5.51</td>
</tr>
<tr>
<td><strong>Carrier x P Rate Means:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AOP-8</td>
<td>.585</td>
<td>5.52</td>
</tr>
<tr>
<td>KPP-8</td>
<td>.539</td>
<td>5.40</td>
</tr>
<tr>
<td>AOP-16</td>
<td>.753</td>
<td>5.72</td>
</tr>
<tr>
<td>KPP-16</td>
<td>.673</td>
<td>5.61</td>
</tr>
<tr>
<td><strong>Carrier x Method Means:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AOP-Banded</td>
<td>.863</td>
<td>5.73</td>
</tr>
<tr>
<td>KPP-Banded</td>
<td>.721</td>
<td>5.49</td>
</tr>
<tr>
<td>AOP-Broadcast</td>
<td>.476</td>
<td>5.51</td>
</tr>
<tr>
<td>KPP-Broadcast</td>
<td>.491</td>
<td>5.52</td>
</tr>
<tr>
<td><strong>P Rate x Method Means:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8-Banded</td>
<td>.710</td>
<td>5.48</td>
</tr>
<tr>
<td>16-Banded</td>
<td>.874</td>
<td>5.74</td>
</tr>
<tr>
<td>8-Broadcast</td>
<td>.414</td>
<td>5.43</td>
</tr>
<tr>
<td>16-Broadcast</td>
<td>.553</td>
<td>5.59</td>
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</tbody>
</table>
Table XI. Comparisons of the effects of K carriers and K rates on the dry weight, nutrient content, and nutrient uptake of corn plants (growth chamber).

<table>
<thead>
<tr>
<th>K Rate</th>
<th>K Carrier</th>
<th>Dry Weight (g)</th>
<th>Nutrient Composition N %</th>
<th>P %</th>
<th>K % (Mean)</th>
<th>Nutrient Uptake N (mg/3 plants)</th>
<th>P (Mean)</th>
<th>K (Mean)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-</td>
<td>2.8</td>
<td>3.57</td>
<td>.291</td>
<td>3.43</td>
<td>100.0</td>
<td>8.0</td>
<td>94.5</td>
</tr>
<tr>
<td>50</td>
<td>KCl</td>
<td>3.0</td>
<td>3.67</td>
<td>.289</td>
<td>4.22</td>
<td>110.1</td>
<td>8.5</td>
<td>125.0</td>
</tr>
<tr>
<td>100</td>
<td>KCl</td>
<td>3.0</td>
<td>3.33</td>
<td>.271</td>
<td>4.87</td>
<td>99.9</td>
<td>8.2</td>
<td>148.3</td>
</tr>
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<td>50</td>
<td>KPP</td>
<td>3.0</td>
<td>3.40</td>
<td>.259</td>
<td>4.12</td>
<td>102.0</td>
<td>7.8</td>
<td>125.0</td>
</tr>
<tr>
<td>100</td>
<td>KPP</td>
<td>3.1</td>
<td>3.24</td>
<td>.233</td>
<td>5.19</td>
<td>100.4</td>
<td>7.3</td>
<td>162.4</td>
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<tr>
<td>50</td>
<td>K₂CO₃</td>
<td>3.0</td>
<td>3.32</td>
<td>.272</td>
<td>4.08</td>
<td>99.6</td>
<td>8.1</td>
<td>122.4</td>
</tr>
<tr>
<td>100</td>
<td>K₂CO₃</td>
<td>3.2</td>
<td>3.37</td>
<td>.274</td>
<td>4.62</td>
<td>107.8</td>
<td>8.7</td>
<td>145.4</td>
</tr>
<tr>
<td>50</td>
<td>KNO₃</td>
<td>3.0</td>
<td>3.50</td>
<td>.274</td>
<td>4.12</td>
<td>105.0</td>
<td>8.1</td>
<td>122.1</td>
</tr>
<tr>
<td>100</td>
<td>KNO₃</td>
<td>3.1</td>
<td>3.37</td>
<td>.265</td>
<td>4.96</td>
<td>104.5</td>
<td>8.3</td>
<td>155.3</td>
</tr>
<tr>
<td>50</td>
<td>KH₂PO₄</td>
<td>2.9</td>
<td>3.64</td>
<td>.297</td>
<td>4.37</td>
<td>105.6</td>
<td>8.7</td>
<td>128.2</td>
</tr>
<tr>
<td>100</td>
<td>KH₂PO₄</td>
<td>3.2</td>
<td>3.21</td>
<td>.264</td>
<td>5.25</td>
<td>102.7</td>
<td>8.4</td>
<td>165.6</td>
</tr>
<tr>
<td>50</td>
<td>K₂SO₄</td>
<td>3.0</td>
<td>3.57</td>
<td>.264</td>
<td>4.16</td>
<td>107.1</td>
<td>7.9</td>
<td>124.8</td>
</tr>
<tr>
<td>100</td>
<td>K₂SO₄</td>
<td>3.1</td>
<td>3.64</td>
<td>.263</td>
<td>5.38</td>
<td>112.8</td>
<td>8.1</td>
<td>166.7</td>
</tr>
</tbody>
</table>

LSD .05 Treatment ns ns 0.52 ns ns 18.2
K Carrier - - - ns - ns -
K Rate - - - - - ns 7.7
K Carrier x K Rate - - - ns - ns -

K Rate Means:
- 50 ppm K - - - 4.18 - - 124.6
- 100 ppm K - - - 5.04 - - 157.3
Table XII. Effects of P carriers and two rates of Zn on dry weight and nutrient content of corn plants (growth chamber).

<table>
<thead>
<tr>
<th>P Rate</th>
<th>Zn Rate</th>
<th>P Carrier</th>
<th>Zn Carrier</th>
<th>Dry Weight (g)</th>
<th>Nutrient Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ppm</td>
<td>ppm</td>
<td></td>
<td></td>
<td></td>
<td>P %     K %     Ca %   Mg %   Zn ppm  Fe ppm  Mn ppm  Cu ppm</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>1.2</td>
<td>0.067   5.32    0.729  0.295  41.6    103.0   99.4    10.0</td>
</tr>
<tr>
<td>0</td>
<td>8</td>
<td>-</td>
<td>ZnSO₄</td>
<td>1.2</td>
<td>0.067   5.32    0.729  0.295  122.0   113.8   88.2    10.2</td>
</tr>
<tr>
<td>80</td>
<td>0</td>
<td>KPP</td>
<td>-</td>
<td>3.6</td>
<td>0.113   4.06    0.382  0.236  22.5    87.3    71.5    8.0</td>
</tr>
<tr>
<td>80</td>
<td>8</td>
<td>KPP</td>
<td>ZnSO₄</td>
<td>3.4</td>
<td>0.111   4.38    0.468  0.252  71.8    92.2    76.0    6.3</td>
</tr>
<tr>
<td>80</td>
<td>0</td>
<td>AOP</td>
<td>-</td>
<td>3.5</td>
<td>0.148   3.89    0.379  0.272  21.9    90.6    69.3    8.2</td>
</tr>
<tr>
<td>80</td>
<td>8</td>
<td>AOP</td>
<td>ZnSO₄</td>
<td>3.7</td>
<td>0.137   3.92    0.355  0.286  57.9    85.6    61.6    7.3</td>
</tr>
<tr>
<td>80</td>
<td>0</td>
<td>APP</td>
<td>-</td>
<td>3.5</td>
<td>0.137   4.03    0.387  0.272  22.3    93.1    76.4    7.9</td>
</tr>
<tr>
<td>80</td>
<td>8</td>
<td>APP</td>
<td>ZnSO₄</td>
<td>3.6</td>
<td>0.129   3.99    0.406  0.273  66.6    83.3    69.6    7.7</td>
</tr>
<tr>
<td>80</td>
<td>0</td>
<td>TSP</td>
<td>-</td>
<td>3.6</td>
<td>0.134   4.03    0.373  0.296  22.4    69.4    65.7    7.2</td>
</tr>
<tr>
<td>80</td>
<td>0</td>
<td>TSP</td>
<td>ZnSO₄</td>
<td>3.8</td>
<td>0.119   3.71    0.422  0.288  60.7    74.2    63.9    6.7</td>
</tr>
</tbody>
</table>

P Carrier Means:
- KPP: 3.5, 0.112, - , - , - , 47.1, 89.7, 73.7, 8.1
- AOP: 3.6, 0.143, - , - , - , 39.9, 88.6, 65.4, 7.7
- APP: 3.6, 0.133, - , - , - , 44.5, 88.2, 73.0, 7.8
- TSP: 3.7, 0.127, - , - , - , 41.6, 71.8, 64.8, 6.9

Zn Rate Means:
- 0 ppm Zn: 3.5, 0.133, - , - , - , 22.3, 85.1, 70.7, 7.8
- 8 ppm Zn: 3.6, 0.124, - , - , - , 64.2, 84.1, 67.8, 7.5

LSD .05 Treatment
- P Carrier: 0.3, 0.022, - , - , - , 10.4, 18.8, 12.5, 1.5
- Zn Rate: ns, 0.017, - , - , - , ns, 6.6, ns, ns
- P Carrier x Zn Rate: ns, 0.017, - , - , - , 5.6, ns, ns, ns

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Table XIII. Effects of P carriers and two rates of Zn on nutrient uptake of corn plants (growth chamber).

<table>
<thead>
<tr>
<th>P Rate</th>
<th>Zn Rate</th>
<th>P Carrier</th>
<th>Zn Carrier</th>
<th>Nutrient Uptake</th>
</tr>
</thead>
<tbody>
<tr>
<td>ppm</td>
<td>ppm</td>
<td></td>
<td></td>
<td>P (mg/3 plants)</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>0.8</td>
</tr>
<tr>
<td>0</td>
<td>8</td>
<td>-</td>
<td>ZnSO₄</td>
<td>0.8</td>
</tr>
<tr>
<td>80</td>
<td>0</td>
<td>KPP</td>
<td>-</td>
<td>4.0</td>
</tr>
<tr>
<td>80</td>
<td>8</td>
<td>KPP</td>
<td>ZnSO₄</td>
<td>3.8</td>
</tr>
<tr>
<td>80</td>
<td>0</td>
<td>AOP</td>
<td>-</td>
<td>5.2</td>
</tr>
<tr>
<td>80</td>
<td>8</td>
<td>AOP</td>
<td>ZnSO₄</td>
<td>5.0</td>
</tr>
<tr>
<td>80</td>
<td>0</td>
<td>APP</td>
<td>-</td>
<td>4.8</td>
</tr>
<tr>
<td>80</td>
<td>8</td>
<td>APP</td>
<td>ZnSO₄</td>
<td>4.7</td>
</tr>
<tr>
<td>80</td>
<td>0</td>
<td>TSP</td>
<td>-</td>
<td>4.8</td>
</tr>
<tr>
<td>80</td>
<td>8</td>
<td>TSP</td>
<td>ZnSO₄</td>
<td>4.5</td>
</tr>
</tbody>
</table>

P Carrier Means:
- KPP
- AOP
- APP
- TSP

Zn Rate Means:
- 0 Zn
- 8 ppm Zn

LSD .05 Treatment
- P Carrier
- Zn Rate
- P Carrier x Zn Rate
EVALUATION OF POTASSIUM POLYPHOSPHATE AS A SOURCE OF PHOSPHORUS AND POTASSIUM FOR PLANTS

by

JAMES ALLEN ARMBRUSTER
B.S., Kansas State University, 1970

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1972
Comparisons of field applications of two rates of diammonium orthophosphate (AOP), ammonium polyphosphate (APP), and potassium polyphosphate (KPP) resulted in no consistent differences in yields or leaf P contents of irrigated corn (Zea mays L.) and grain sorghum (Sorghum bicolor) in 1970. In 1971 studies, however, significant yield and leaf P content differences did occur at two of three field locations with comparisons of AOP, APP, triple superphosphate (TSP), and KPP at two P rates.

Results at a southern Kansas site in 1971 indicated significantly higher grain sorghum leaf P concentrations at the first sampling date (6- to 8-leaf stage) with applications of AOP as compared to KPP or APP. However, at the second sampling date (boot stage), P carriers were essentially equal in their abilities to supply P to the plants. Yields at this location were significantly higher when P was applied as AOP.

At a northeastern Kansas location in 1971, P concentrations in corn leaves at the first sampling date were significantly lower with applications of APP as compared to KPP, AOP, or TSP. Yields were significantly lower with 40 kg/ha P applied as APP as compared to this rate of AOP, KPP, or TSP.

No damage to grain sorghum germination was evident from banding either KPP or AOP in direct contact with grain sorghum seed in an irrigated study in northeastern Kansas.

A growth chamber investigation comparing two rates of monoammonium orthophosphate (MAP), APP, and KPP for corn grown in both acid and calcareous soils showed a greater response to P in the acid soil. KPP applied at 40 ppm P in the acid soil
produced significantly lower plant P contents than 40 ppm P of MAP or APP. However, at 80 ppm P, KPP was equal to MAP and slightly (but not statistically superior) to APP in supplying P to the corn plants in the acid soil.

Banded (direct seed contact) and broadcast applications of AOP and KPP were studied with wheat (*Triticum aestivum* L.) and grain sorghum as test plants in a growth chamber. No reduction in germination of either crop occurred as a result of banding these materials in contact with the seeds. However, 16 ppm P banded as AOP significantly reduced grain sorghum dry weights as compared to KPP banded at this rate. Plant P uptake and P content were significantly higher when materials were banded than when broadcast. Differences as to carrier effects on plant P concentrations were significant only with banded rates of 16 ppm P. AOP was superior to KPP at this rate for both crops.

Applications of two rates of K as KPP, KCl, K₂CO₃, KNO₃, K₂SO₄, and KH₂PO₄ to corn grown on a low K soil in a growth chamber produced no significant yield differences due to carrier effect. Although uptake and plant tissue concentration of K tended to be higher with additions of KPP, KH₂PO₄, and K₂SO₄, these differences were not significant.

High rates of P as KPP, AOP, APP, and TSP with and without Zn were applied to corn grown in P and Zn deficient soil in a growth chamber. KPP was equal to TSP, but inferior to AOP and APP in supplying P to the plants. Although depression of plant Zn concentrations occurred, differences in Zn depression due to P carrier effect were not significant.