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

by

JAMES ALLEN ARMBRUSTER

B.S., Kansas State University, 1970

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

Approved by:

Larry Murphy

Major Professor

THIS BOOK CONTAINS NUMEROUS PAGES WITH THE ORIGINAL PRINTING BEING SKEWED DIFFERENTLY FROM THE TOP OF THE PAGE TO THE BOTTOM.

THIS IS AS RECEIVED FROM THE CUSTOMER.

TABLE OF CONTENTS

Page

ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation to Dr. Larry S. Murphy, major professor, who accepted the author as a graduate student and for his patience and guidance in planning and conducting the experiments, interpreting the data, and preparing the manuscript.

Gratitude is extended to Drs. Roscoe Ellis, Jr., and Jerry S. Weis, members of the supervisory committee, for administration of the program. Sincere appreciation is also expressed to Mr. Louis Meyer for assistance in the field studies and guidance in statistical analysis of the data, and to Mr. Pat Gallagher and Dr. David Whitney for advice on chemical analysis procedures. Thanks are also expressed to Messrs. W. Wallingford, K. Kelly, and R. Voth for their assistance with the field studies. Special thanks are due to Pennzoil United, for financial support of the investigations.

Special appreciation is extended to the author's wife, Nancy, for her interest, encouragement, and sacrifice during the course of this study, and to the author's families, Mr. and Mrs. Ernest Armbruster and Mr. and Mrs. Kenneth Denu, for their interest and financial support.

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

INTRODUCTION

Potassium polyphosphate (KPP) of general formula $(KPO_3)n$ 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 thes 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), and 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 H_3PO_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 $(KPO_3)_n$. 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 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 P_2O_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 H_3PO_4

with KCl at temperatures generally above 700C (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% Al_2O_3 or Fe_2O_3 impurities could result in a glassy or vitreous product of fairly high water solubility.

Others have produced KPP via variations of the H_3PO_4-KCl process used by TVA. Scottish Agricultural Industries Ltd. produced KPP by reacting wet process H_3PO_4 and fertilizer grade KCl in a rotary reactor below 550C (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 (Settaria 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.

<u>Residual Effectiveness of KPP as a P Source</u>

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 particles 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 performed about the same and all were equal in effectiveness to KCl and K_2SO_4 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 $>$ $KH_2PO_4 > K_2SO_4 >$ KCl. They implied that leaching losses were greater from K_2SO_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_2SO_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_2SO_4. They assumed that a portion of the added K from K_2SO_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_2PO_4, and K_2HPO_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.

<u>Effect on Germination</u>

It has been proposed that KPP might have a less depressive effect on germinating seeds than KCl or K_2SO_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 seedling injury to corn from high applications of KPP, KCP, KCl, and K_2SO_4. They noted seedling injury with high rates of KCl and K_2SO_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_2SO_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_2SO_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 KH_2PO_4 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 $ZnSO_4$, 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 ligninsulfonate.

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.

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

* 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.

Scott and Pawnee Counties 1970

Nutrient Rates P kg/ha	Nutrient Rates K kg/ha	Carrier P	Carrier K
0	0	-	-
0	50	-	KCl
20	0	APP	-
20	50	APP	KCl
40	0	APP	-
40	50	APP	KCl
20	0	AOP	-
20	50	AOP	KCl
40	0	AOP	-
40	50	AOP	KCl
20	25	KPP	KPP
20	50	KPP	KPP+KCl
40	50	KPP	KPP

Sedgwick, Geary, and Clay Counties 1971

P Rate kg/ha	P Carrier
0	-
20	AOP
40	AOP
60	AOP
20	APP
40	APP
60	APP
20	TSP
40	TSP
60	TSP
20	KPP
40	KPP
60	KPP

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 $ZnSO_4$ 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 NH_4NO_3 or ammonium-N from P materials. Plots receiving banded KPP treatments also received a banded amount of N as NH_4NO_3 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 NH_4NO_3 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.

P Rate kg/ha	Method of Application	P Carrier
0	Broadcast*	-
5	Broadcast	AOP
10	Broadcast	AOP
20	Broadcast	AOP
5	Banded	AOP
10	Banded	AOP
20	Banded	AOP
5	Broadcast	KPP
10	Broadcast	KPP
20	Broadcast	KPP
5	Banded	KPP
10	Banded	KPP
20	Banded	KPP

* Plots receiving no P were controls and received only 134 kg/ha N as NH_4NO_3 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_2O-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.

County	Crop	Variety	Row Spacing
Pawnee	Corn	Pioneer 3306	76 cm
Scott	Grain Sorghum	Pioneer 846	76 cm
Sedgwick	Grain Sorghum	NC+ 702	76 cm
Clay	Corn	Pioneer 3300	76 cm
Geary	Corn	Pioneer 3390	76 cm
Riley	Grain Sorghum	Pioneer 846	61 cm

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_2SO_4 digestion procedure of J.J. Hanway, Iowa State University. A one-half gram sample of tissue, 10 ml of 36 N H_2SO_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_2SO_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-G 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.

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

* No analysis for Zn was performed.

Table 6. Treatments used in growth chamber study to determine effectiveness of KPP as a P source.

P Concentration	P Carrier
0 ppm	-
40 ppm	MAP
80 ppm	MAP
40 ppm	APP
80 ppm	APP
40 ppm	KPP
80 ppm	KPP

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 $ZnSO_4$

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) HNO_3, and deionized water.

All treatments were replicated three times and randomly placed in a growth chamber with 30C-day and 20C-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 AOP 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.

Treatment	P Concentration	Method of Application	P Material
1[a]	0 ppm	-	-
2[b]	8 ppm	Broadcast	AOP
3[b]	16 ppm	Broadcast	AOP
4[c]	8 ppm	Banded	AOP
5[c]	16 ppm	Banded	AOP
6[a]	8 ppm	Broadcast	KPP
7[a]	16 ppm	Broadcast	KPP
8[d]	8 ppm	Banded	KPP
9[d]	16 ppm	Banded	KPP

a/ Received broadcast applications of 40 ppm N as NH_4NO_3 and 8 ppm Zn as $ZnSO_4$.

b/ Received balance of N up to 40 ppm as broadcast NH_4NO_3, broadcast KCl to equal K from KPP, and 8 ppm Zn broadcast as $ZnSO_4$.

c/ Received balance of N up to 40 ppm as broadcast NH_4NO_3, banded KCl to equal K from KPP, and 8 ppm Zn broadcast as $ZnSO_4$.

d/ Received banded N as NH_4NO_3 to equal N from banded AOP, balance of N to 40 ppm broadcast as NH_4NO_3, and 8 ppm Zn broadcast as $ZnSO_4$.

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 germination was calculated. The plants were harvested 16 days after planting, oven-dried, and total dry-matter weight for each container 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 H_2SO_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 vanado-molybdophosphoric 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.).

K Concentrations	K Materials
0 ppm	-
50 ppm	KPP
100 ppm	KPP
50 ppm	KCl
100 ppm	KCl
50 ppm	K_2SO_4
100 ppm	K_2SO_4
50 ppm	KNO_3
100 ppm	KNO_3
50 ppm	K_2CO_3
100 ppm	K_2CO_3
50 ppm	KH_2PO_4
100 ppm	KH_2PO_4

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

N - 120 ppm, majority as NH_4NO_3, balance as $(NH_4)_2SO_4$ and $NH_4H_2PO_4$.

P - 80 ppm as $NH_4H_2PO_4$.

S - 41 ppm as $(NH_4)_2SO_4$.

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) HNO_3, 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 NH_4NO_3 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; AOP 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.

P Concentration	Zn Concentration	P Source	Zn Source
0 ppm	0 ppm	-	-
0 ppm	8 ppm	-	$ZnSO_4$
80 ppm	0 ppm	KPP	-
80 ppm	8 ppm	KPP	$ZnSO_4$
80 ppm	0 ppm	AOP	-
80 ppm	8 ppm	AOP	$ZnSO_4$
80 ppm	0 ppm	APP	-
80 ppm	8 ppm	APP	$ZnSO_4$
80 ppm	0 ppm	TSP	-
80 ppm	8 ppm	TSP	$ZnSO_4$

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

N - 150 ppm, majority as NH_4NO_3, balance as $(NH_4)_2SO_4$.

K - 120 ppm as KNO_3.

S - 20 ppm, majority as $(NH_4)_2SO_4$, 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.

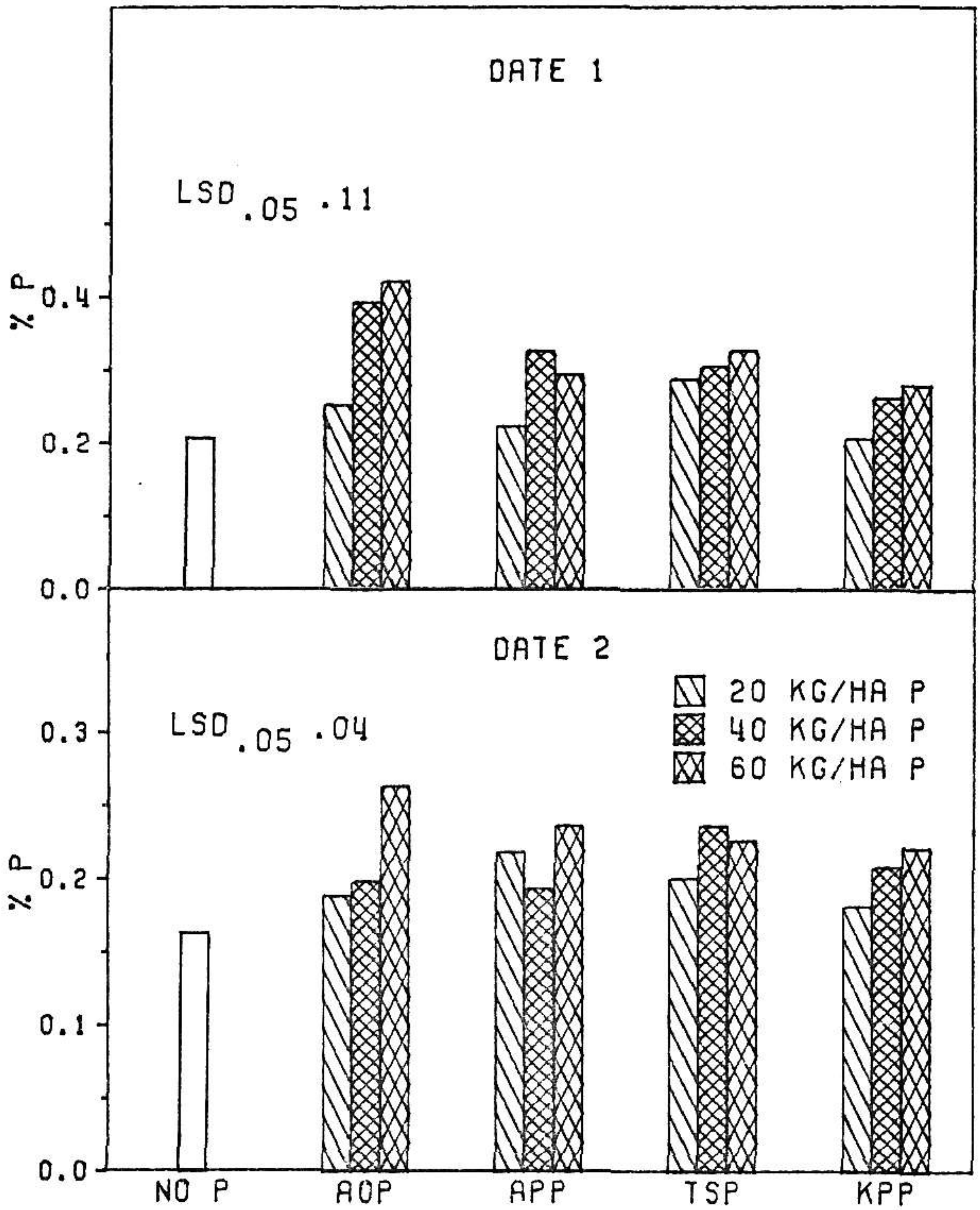


FIG. 1 - EFFECTS OF THREE RATES OF AOP, APP, TSP, AND KPP ON P CONTENT OF GRAIN SORGHUM LEAVES. (SEDGWICK COUNTY, 1971.)

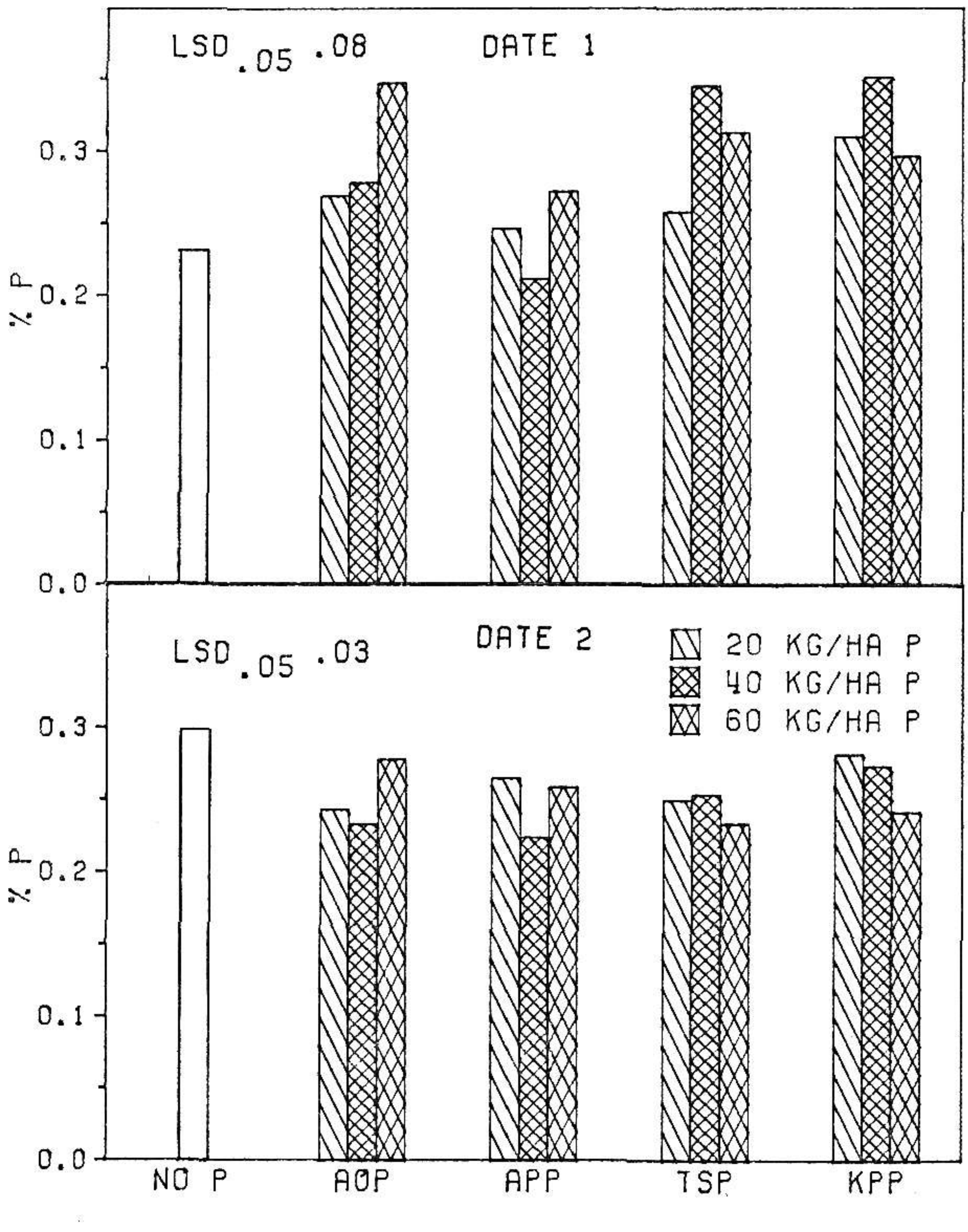


FIG. 2 - EFFECTS OF THREE RATES OF AOP, APP, TSP, AND KPP ON P CONTENT OF CORN LEAVES. (GEARY COUNTY, 1971.)

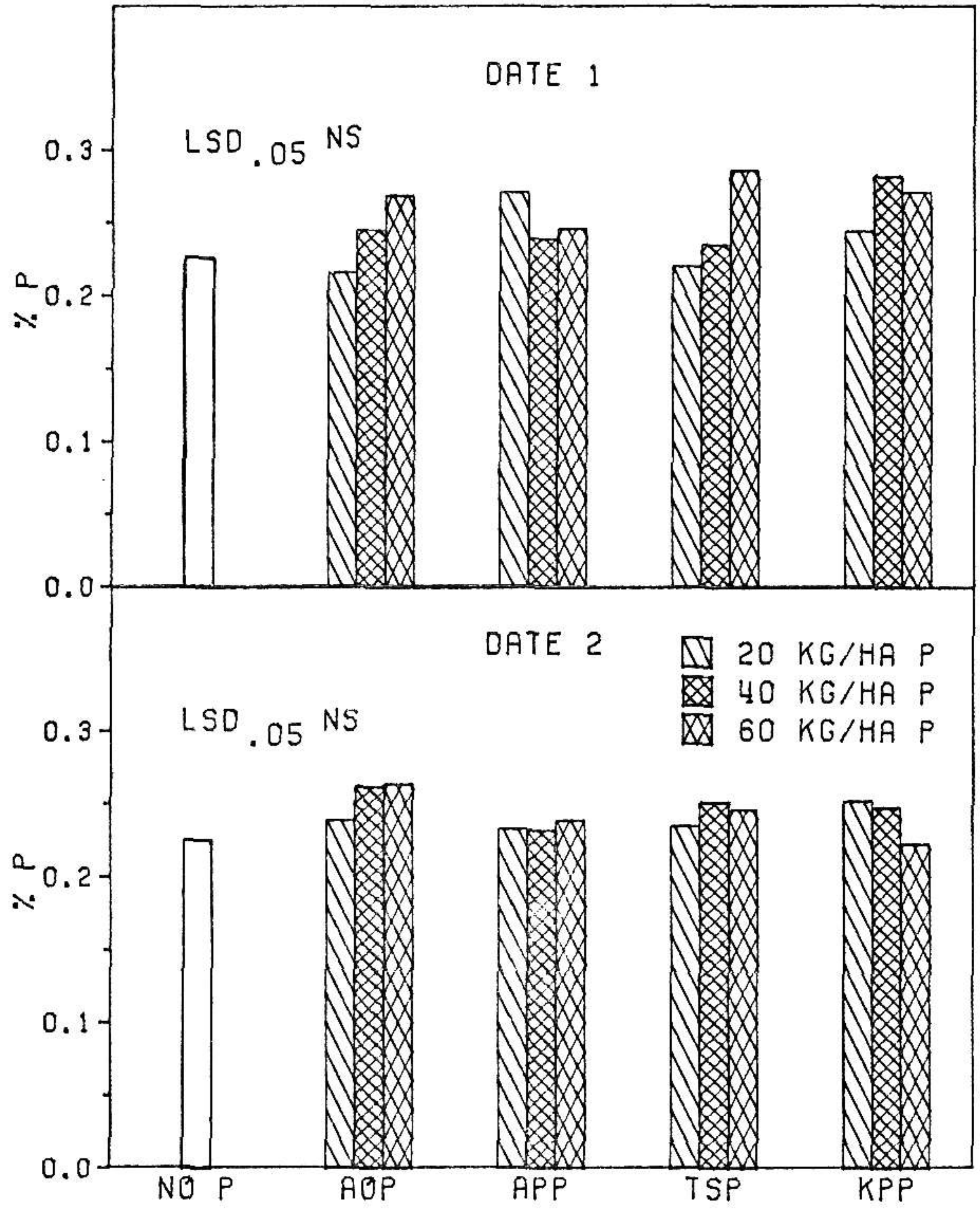


FIG. 3 - EFFECTS OF THREE RATES OF AOP, APP, TSP, AND KPP ON P CONTENT OF CORN LEAVES. (CLAY COUNTY, 1971.)

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.


KPP EVALUATION
P_2O_5
AOP 80 KPP


KPP EVALUATION
P_2O_5
LBS./ACRE
KPP 40 TSP
SPEXARTH
SEGDWICK COUNTY JULY 9, 1971


KPP EVALUATION
80 P_2O_5
AOP
KPP
SPEXARTH SITE SEDGWICK CO
KANSAS STATE UNIVERSITY
AUG. 18, 1971


KPP EVALUATION
40 P_2O_5
KPP
TSP
SPEXARTH SITE SEDGWICK CO
KANSAS STATE UNIVERSITY
AUG. 18, 1971

Table 10. Effects of two rates of AOP, APP, KPP, and two rates of K on yield of irrigated grain sorghum and corn (1970).

Nutrient Rate		Carrier		Pawnee Co.	Scott Co.
P kg/ha	K kg/ha	P	K	Corn kg/ha	Grain Sorghum kg/ha
0	0	-	-	7649	4765
0	50	-	KCl	6960	5016
20	0	APP	-	7838	5518
20	50	APP	KCl	6834	4389
40	0	APP	-	7022	5204
40	50	APP	KCl	6646	5455
20	0	AOP	-	7022	5392
20	50	AOP	KCl	8151	5204
40	0	AOP	-	7461	5204
40	50	AOP	KCl	8527	5016
20	25	KPP	KPP	6897	4201
20	50	KPP	KPP+KCl	8841	4640
40	50	KPP	KPP	7336	4703
$LSD_{.05}$ 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.

Nutrient Rate		Carrier		Pawnee Co. Corn %P		Scott Co. Grain Sorghum %P	
P kg/ha	K kg/ha	P	K	Date 1	Date 2	Date 1	Date 2
0	0	-	-	.255	.258	.397	.197
0	0	-	KCl	.228	.225	.363	.188
20	0	APP	-	.297	.271	.378	.228
20	50	APP	KCl	.289	.271	.364	.228
40	0	APP	-	.260	.244	.385	.194
40	50	APP	KCl	.270	.274	.363	.195
20	0	AOP	-	.296	.279	.381	.215
20	50	AOP	KCl	.281	.258	.375	.191
40	0	AOP	-	.274	.286	.374	.218
40	50	AOP	KCl	.289	.268	.359	.213
20	25	KPP	KPP	.272	.257	.389	.211
20	50	KPP	KPP+KCl	.276	.286	.345	.193
40	50	KPP	KPP	.253	.251	.382	.204
$LSD_{.05}$ Treatment				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.

P Rate kg/ha	P Carrier	Sedgwick Co. Grain Sorghum kg/ha	Geary Co. Corn kg/ha	Clay Co. Corn kg/ha
0	-	2759	9029	5706
20	AOP	4765	9468	7022
40	AOP	5518	9907	7524
60	AOP	6521	10408	9092
20	APP	4076	10220	7649
40	APP	4765	7649	6521
60	APP	6207	9907	5894
20	TSP	3762	8778	7336
40	TSP	4765	10722	8903
60	TSP	5455	10157	7838
20	KPP	4452	10471	7963
40	KPP	4828	11223	7900
60	KPP	5580	10032	7712
$LSD_{.05}$	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.

P Rate	P Carrier	Method of Application	% P		Yield
kg/ha			Date 1	Date 2	kg/ha
0	-	-	.500	.357	8026
5	AOP	Broadcast	.466	.361	7085
10	AOP	Broadcast	.483	.344	7649
20	AOP	Broadcast	.513	.369	7775
5	AOP	Banded	.450	.348	7963
10	AOP	Banded	.519	.364	7022
20	AOP	Banded	.523	.354	7587
5	KPP	Broadcast	.516	.400	8276
10	KPP	Broadcast	.519	.357	7461
20	KPP	Broadcast	.480	.375	8151
5	KPP	Banded	.504	.347	7649
10	KPP	Banded	.500	.368	7649
20	KPP	Banded	.459	.352	6458
$LSD_{.05}$ 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, K_2CO_3, KNO_3, KH_2PO_4, and K_2SO_4 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, KH_2PO_4, and K_2SO_4, no significant differences between carrier effects were noted (Appendix Table XI).

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

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 adjacent 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 uptake was significantly increased when 8 ppm Zn as $ZnSO_4$ was supplied with the P applications (Figure 13).

Although Fe was uniformly applied in this experiment, significant differences occurred in plant Fe content (Appendix Table XII). Applications of 80 ppm P as TSP with no Zn applied significantly 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 University, 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.

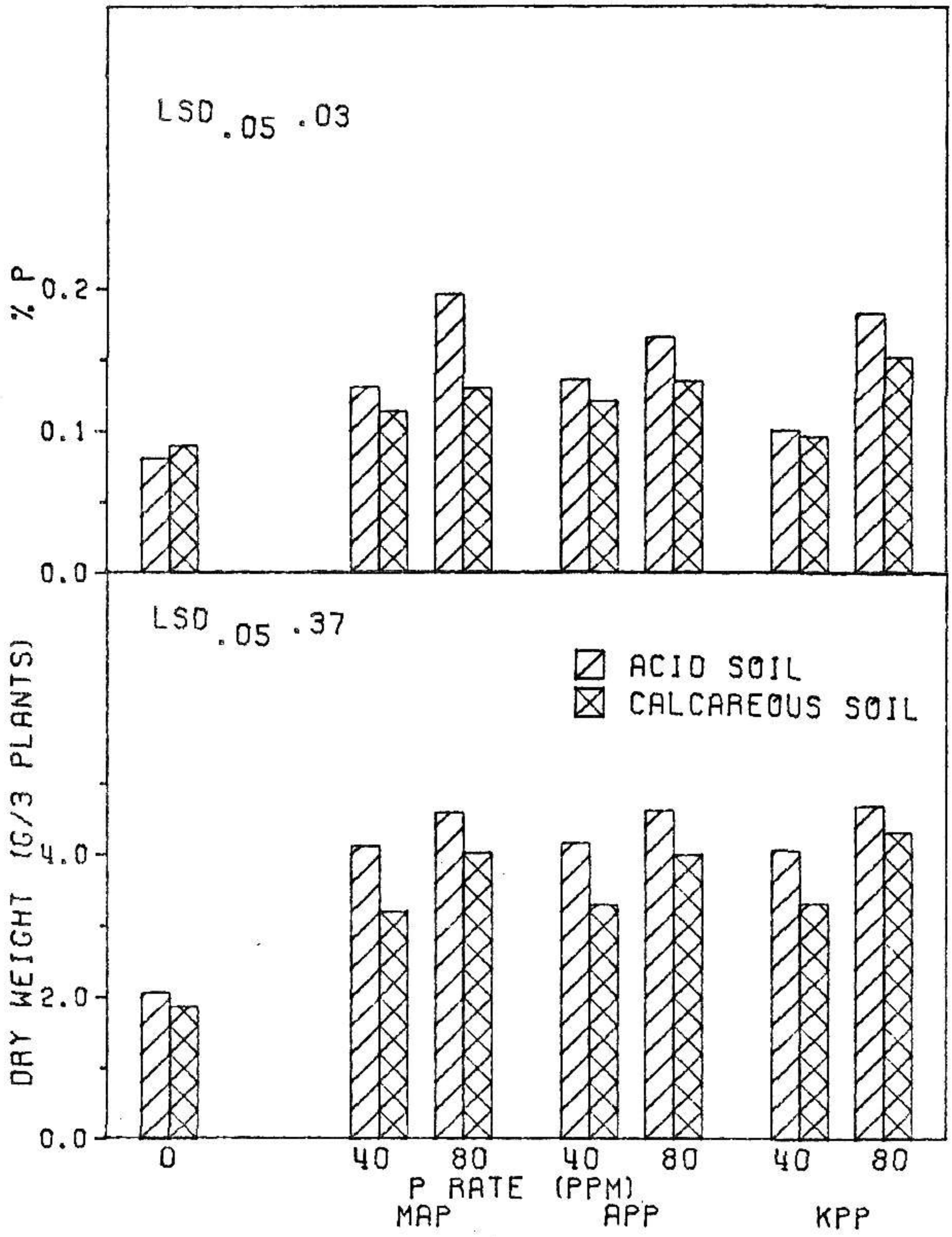


FIG. 6 - EFFECTS OF TWO RATES OF MAP, APP, AND KPP IN TWO SOILS ON P CONTENT AND DRY WEIGHT OF CORN PLANTS GROWN IN A GROWTH CHAMBER.

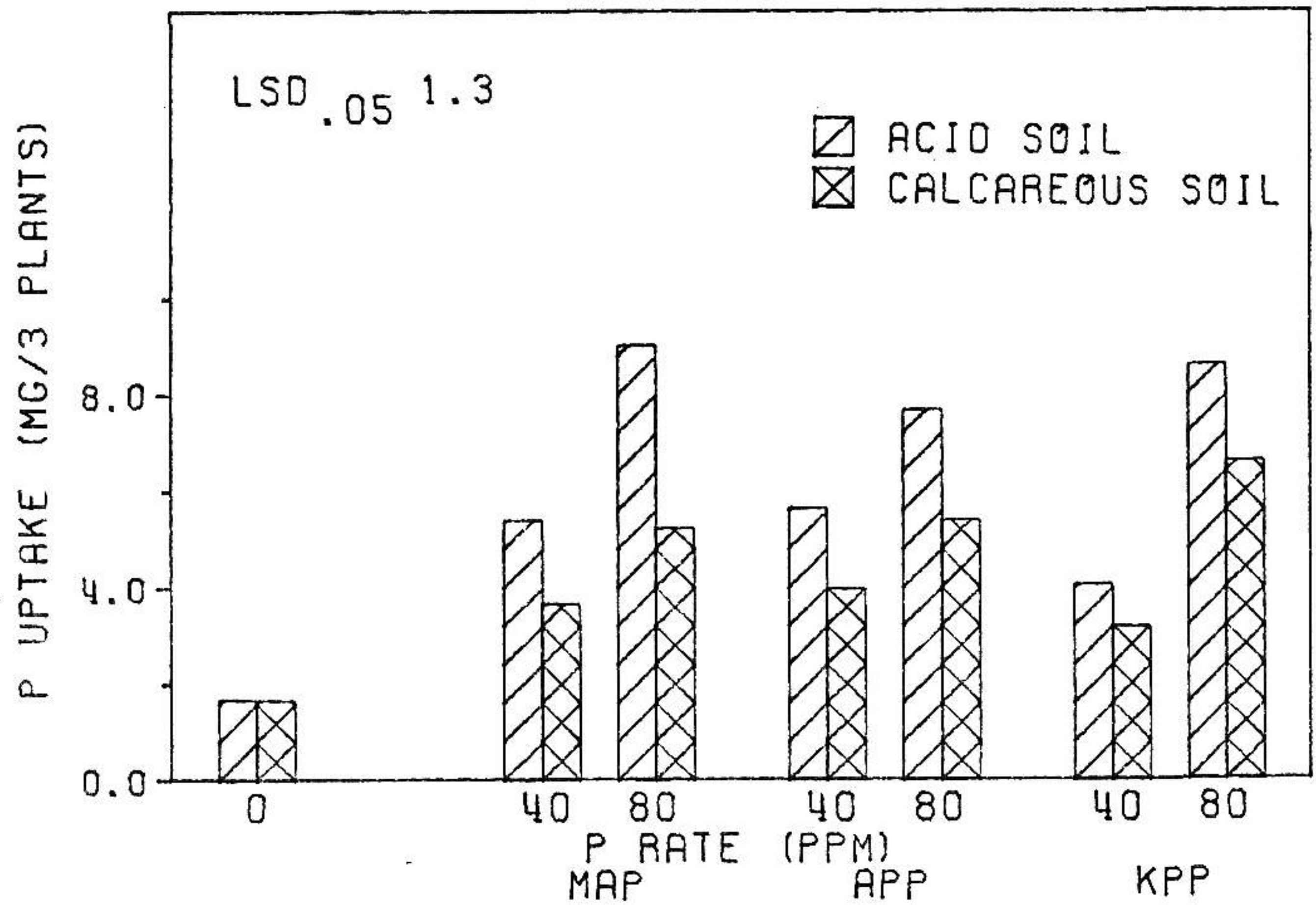


FIG. 7 - EFFECTS OF TWO RATES OF MAP, APP, AND KPP IN TWO SOILS ON P UPTAKE OF CORN PLANTS GROWN IN A GROWTH CHAMBER.

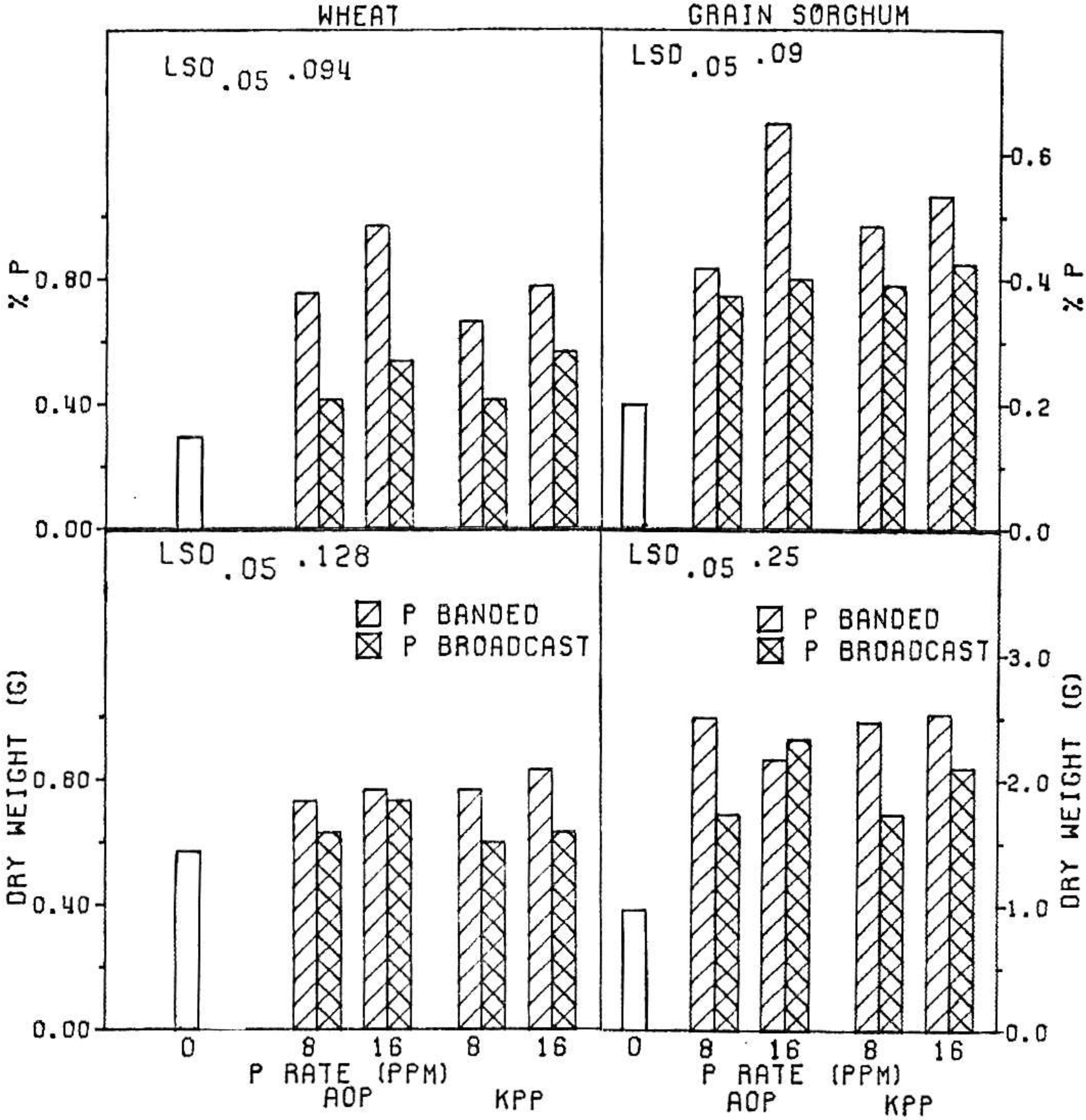


FIG. 8 - EFFECTS OF BANDED AND BROADCAST APPLICATIONS OF TWO RATES OF AOP AND KPP ON P CONTENT AND DRY WEIGHT OF WHEAT AND GRAIN SORGHUM PLANTS GROWN IN A GROWTH CHAMBER.

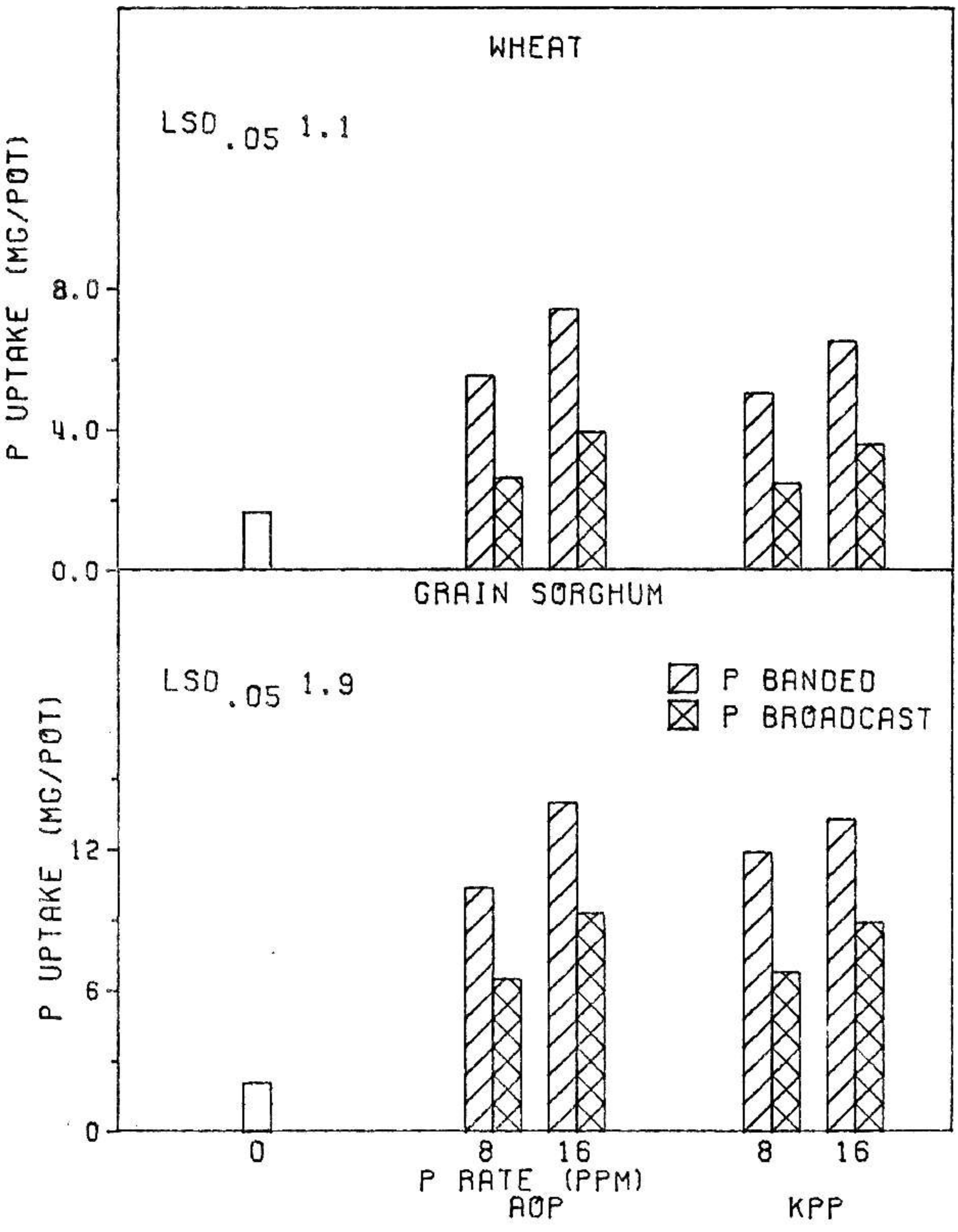


FIG. 9 - EFFECTS OF BANDED AND BROADCAST APPLICATIONS OF TWO RATES OF AOP AND KPP ON P UPTAKE OF WHEAT AND GRAIN SORGHUM PLANTS GROWN IN A GROWTH CHAMBER.

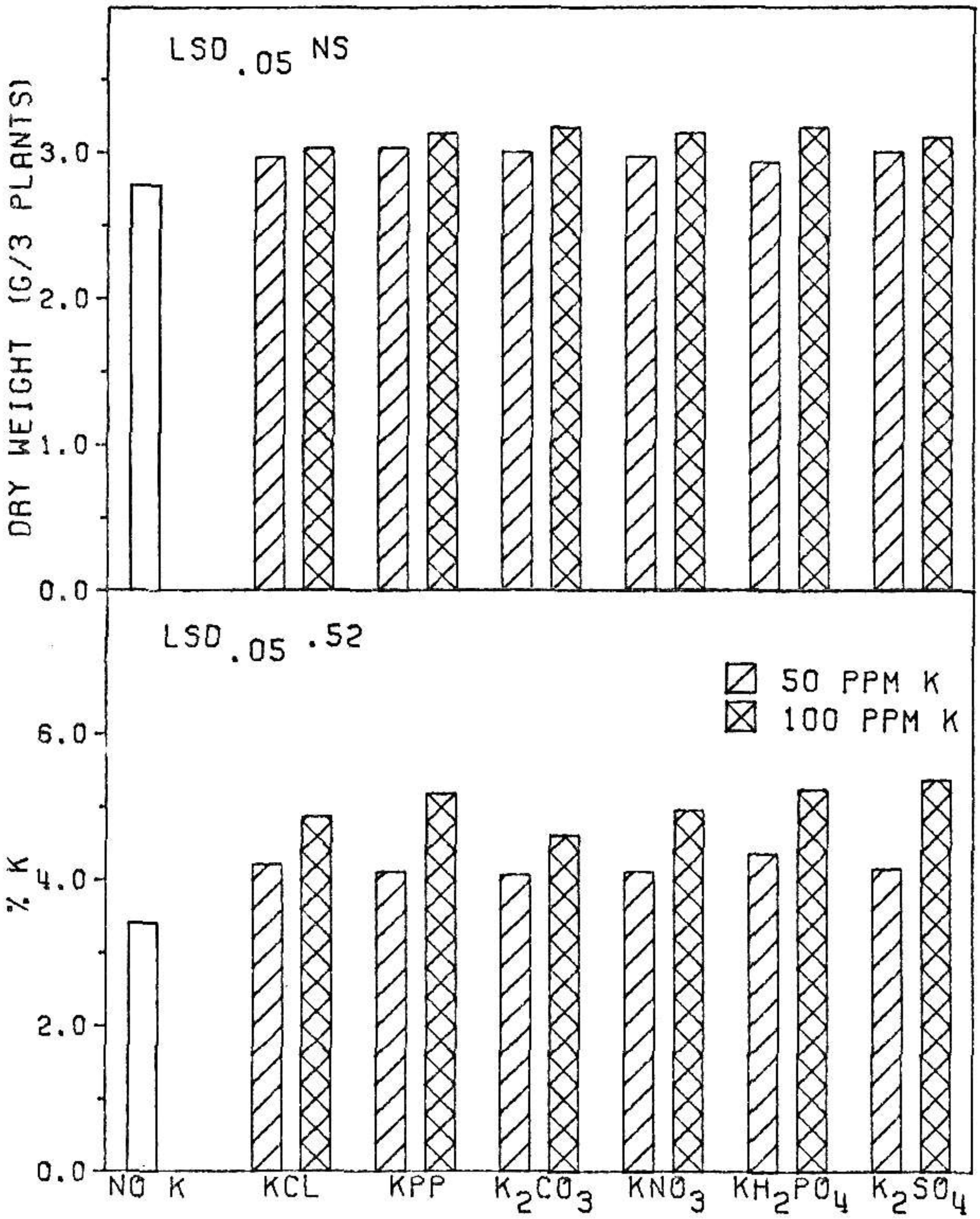


FIG. 10 - EFFECTS OF TWO RATES OF KPP AND FIVE OTHER K SOURCES ON DRY WEIGHT AND K CONTENT OF CORN PLANTS GROWN IN A GROWTH CHAMBER.

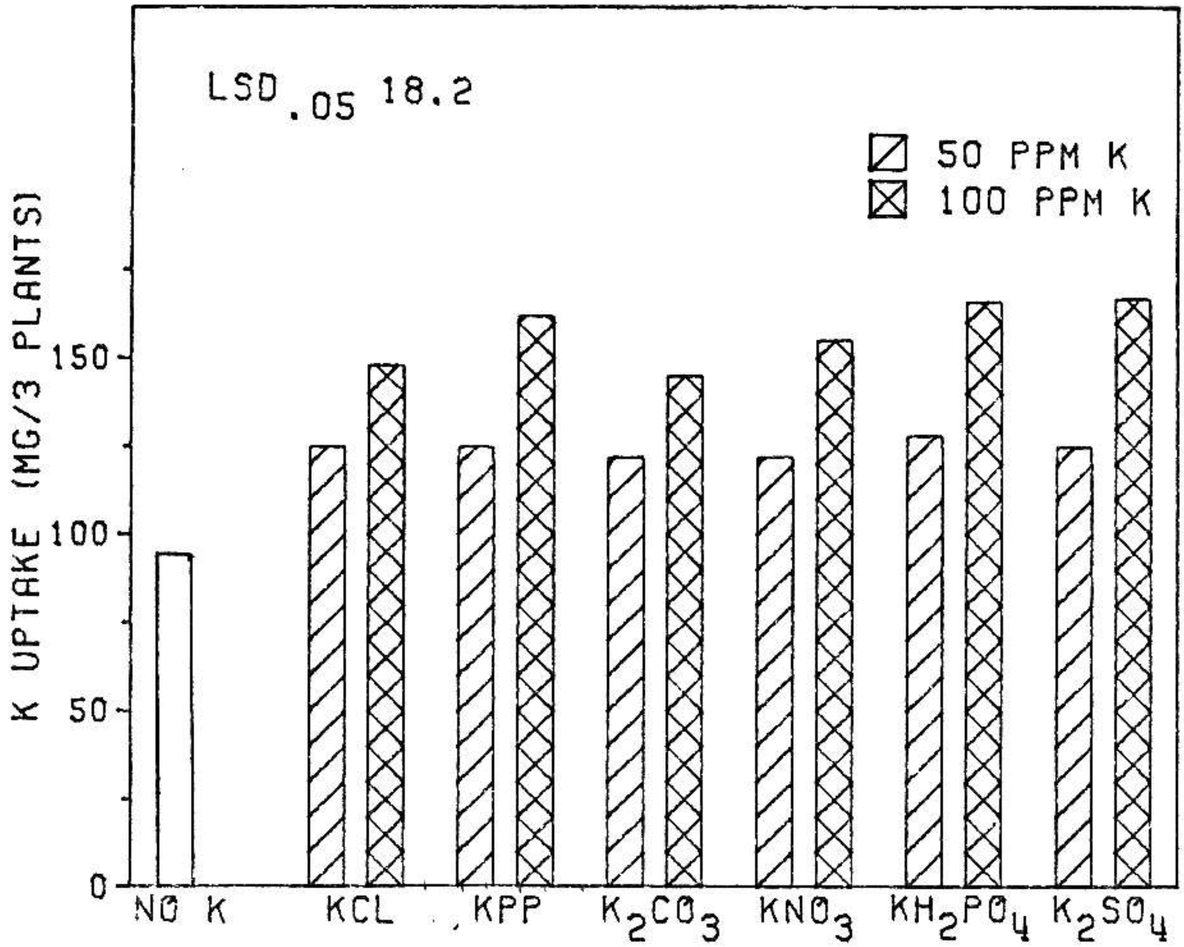


FIG. 11 - EFFECTS OF TWO RATES OF KPP AND FIVE OTHER K SOURCES ON K UPTAKE OF CORN PLANTS GROWN IN A GROWTH CHAMBER.

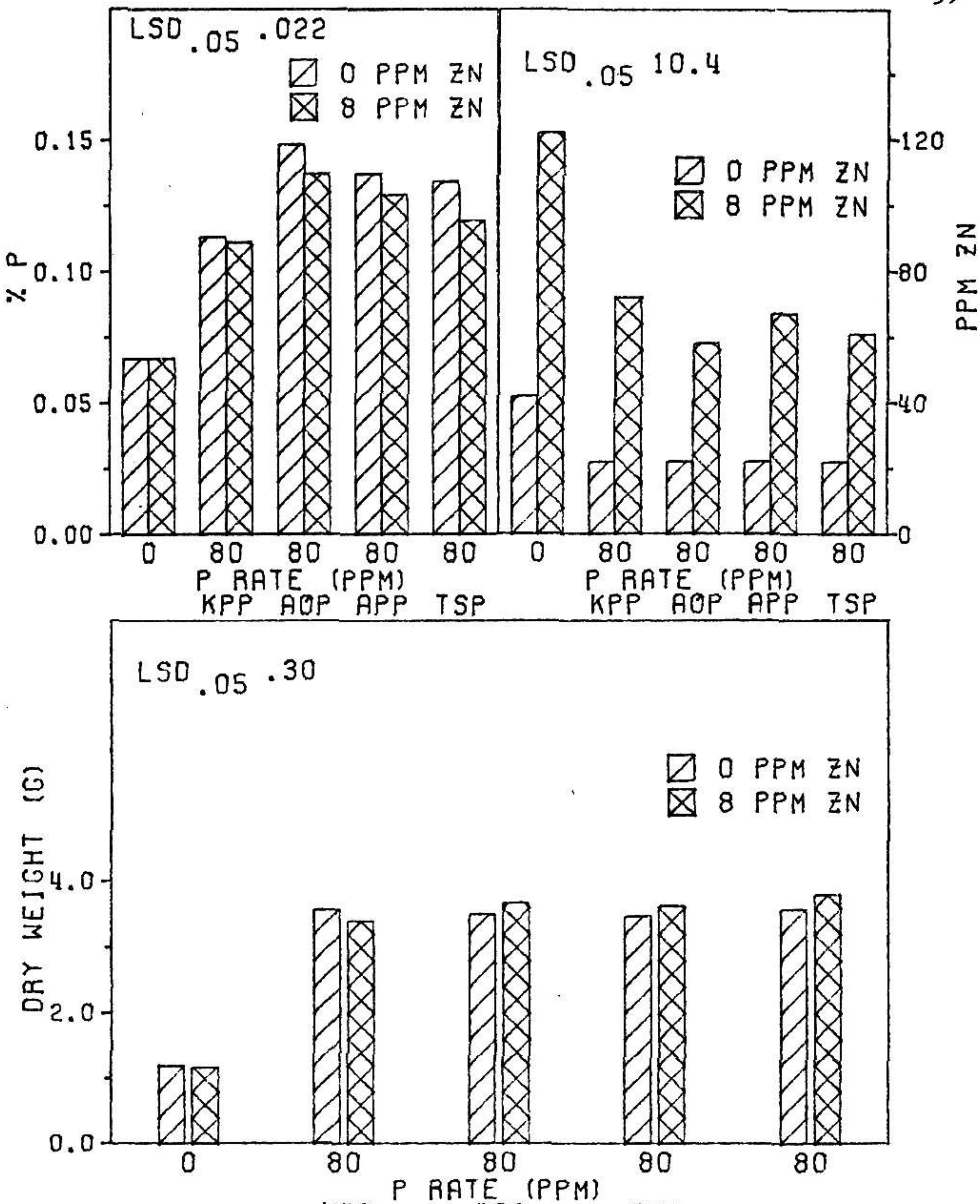


FIG. 12 - EFFECTS OF KPP, AOP, APP, TSP, AND TWO RATES OF ZN ON P CONTENT, ZN CONTENT, AND DRY WEIGHT OF CORN PLANTS GROWN IN A GROWTH CHAMBER.

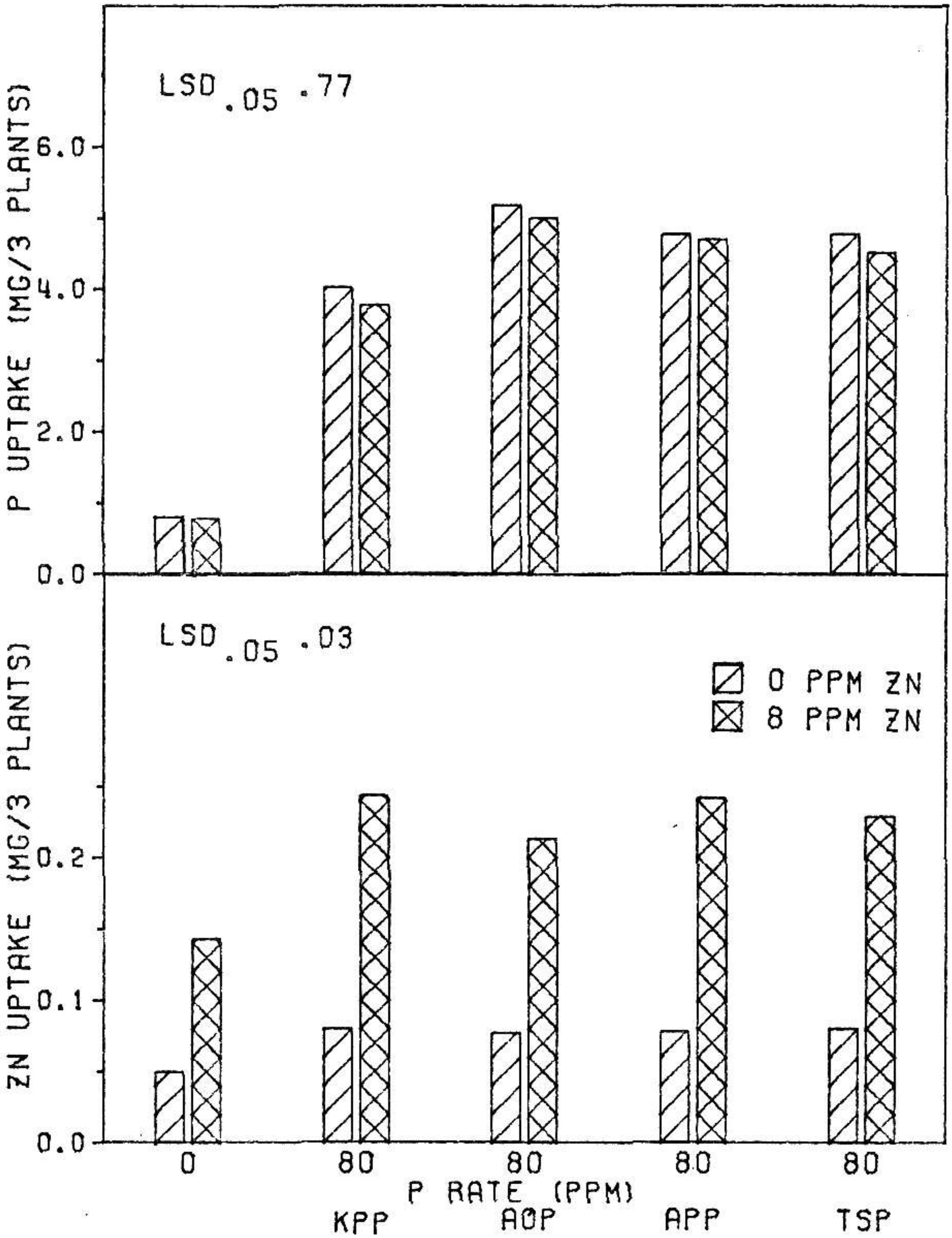
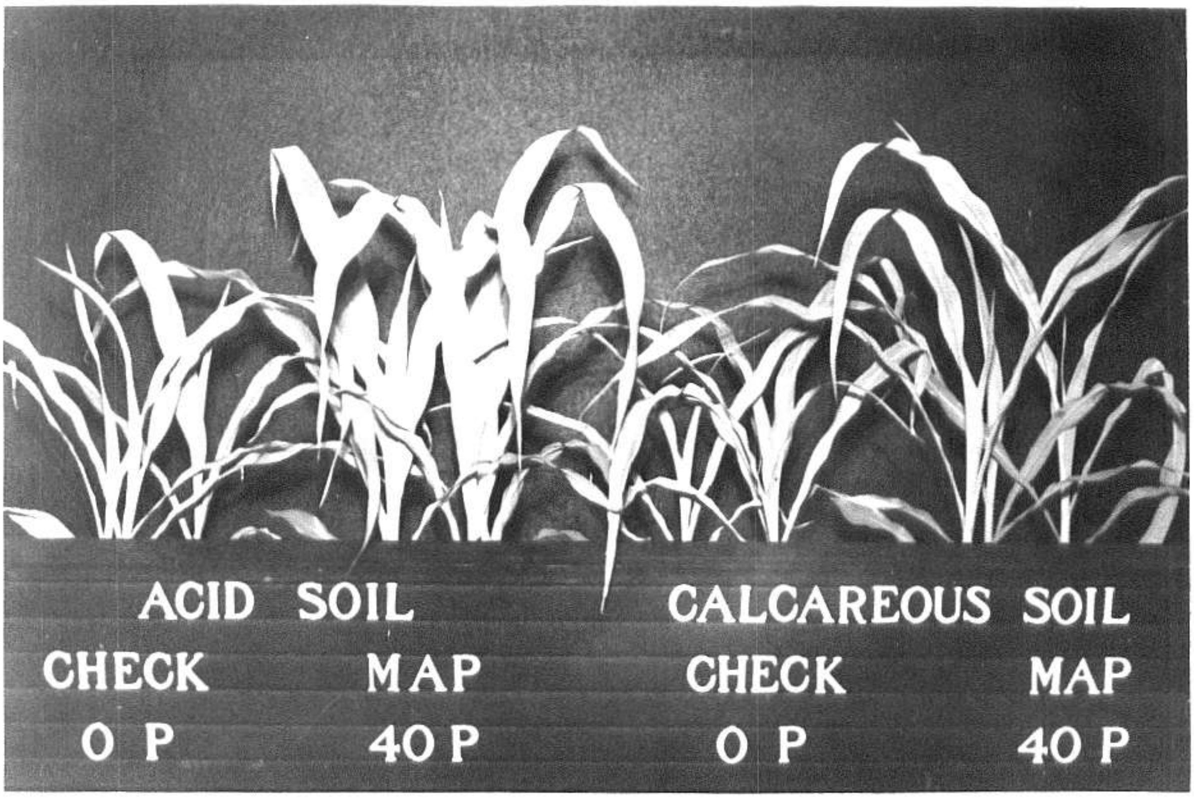


FIG. 13 - EFFECTS OF KPP, AOP, APP, TSP, AND TWO RATES OF ZN ON P AND ZN UPTAKE OF CORN PLANTS GROWN IN A GROWTH CHAMBER.

Fig. 14 - Corn plant response to two rates of P from MAP on acid and calcareous soils in a growth chamber.


ACID SOIL
CALCAREOUS SOIL
CHECK
MAP
CHECK
MAP
0 P
40 P
0 P
40 P

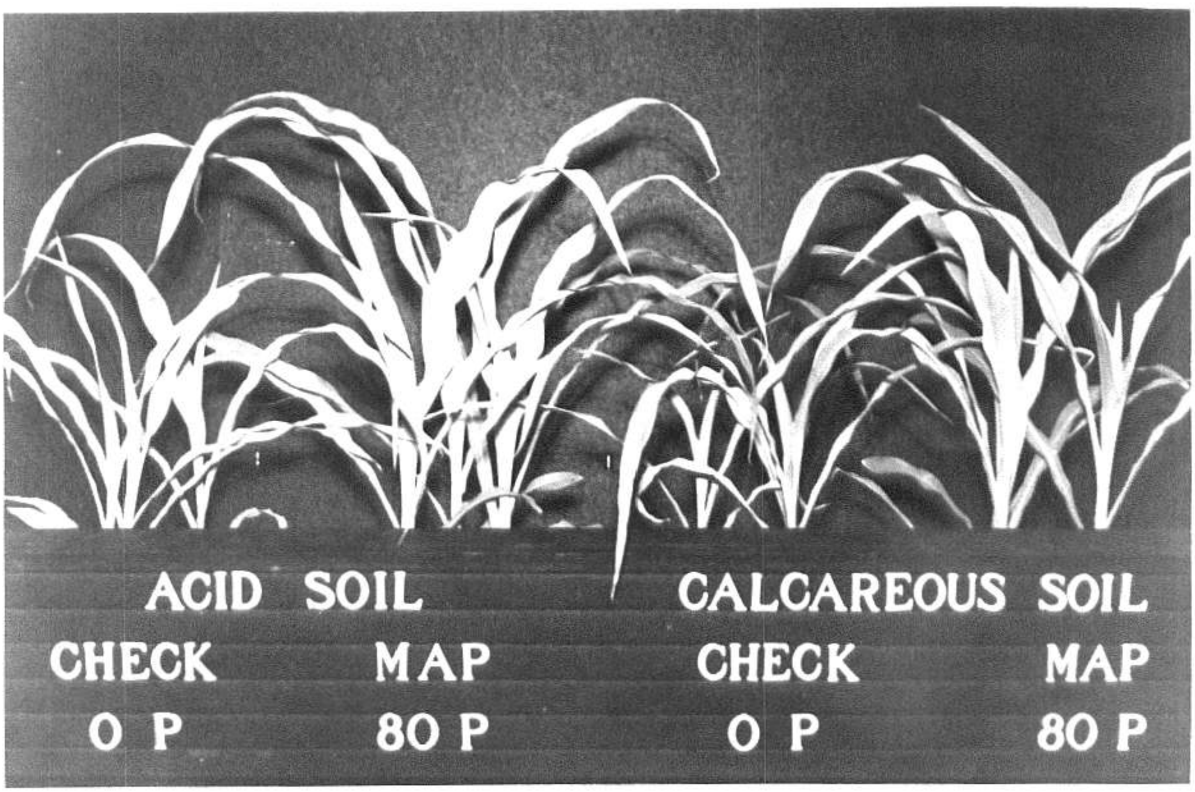
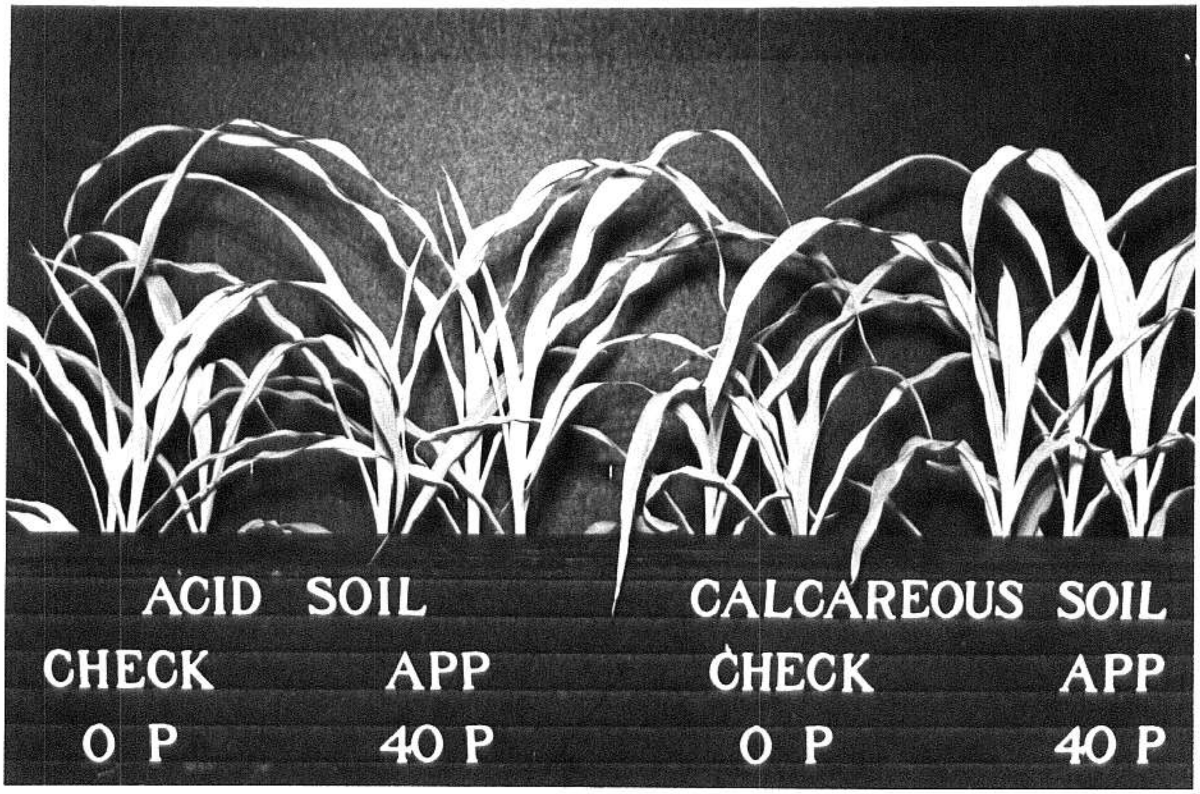

ACID SOIL
CALCAREOUS SOIL
CHECK
MAP
CHECK
MAP
0 P
80 P
0 P
80 P

Fig. 15 - Corn plant response to two rates of P from APP in acid and calcareous soils in a growth chamber.


ACID SOIL
CALCAREOUS SOIL
CHECK
APP
CHECK
APP
0 P
40 P
0 P
40 P

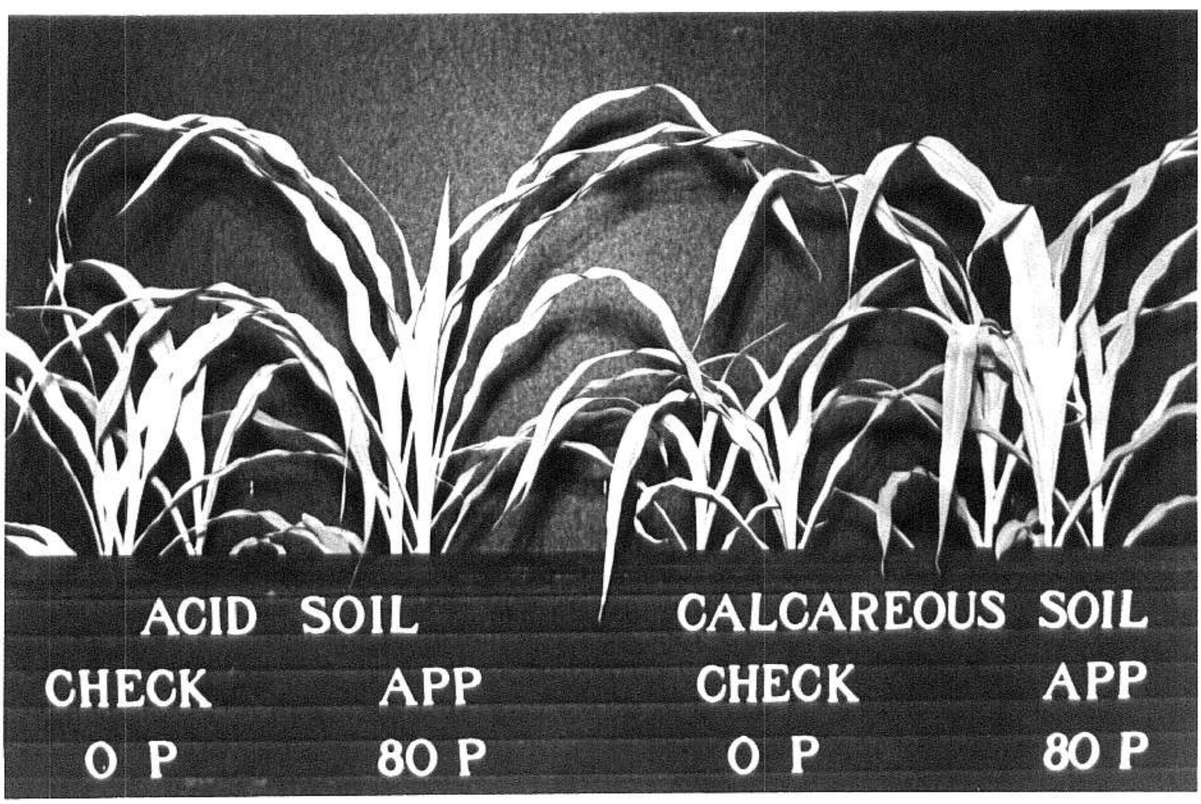
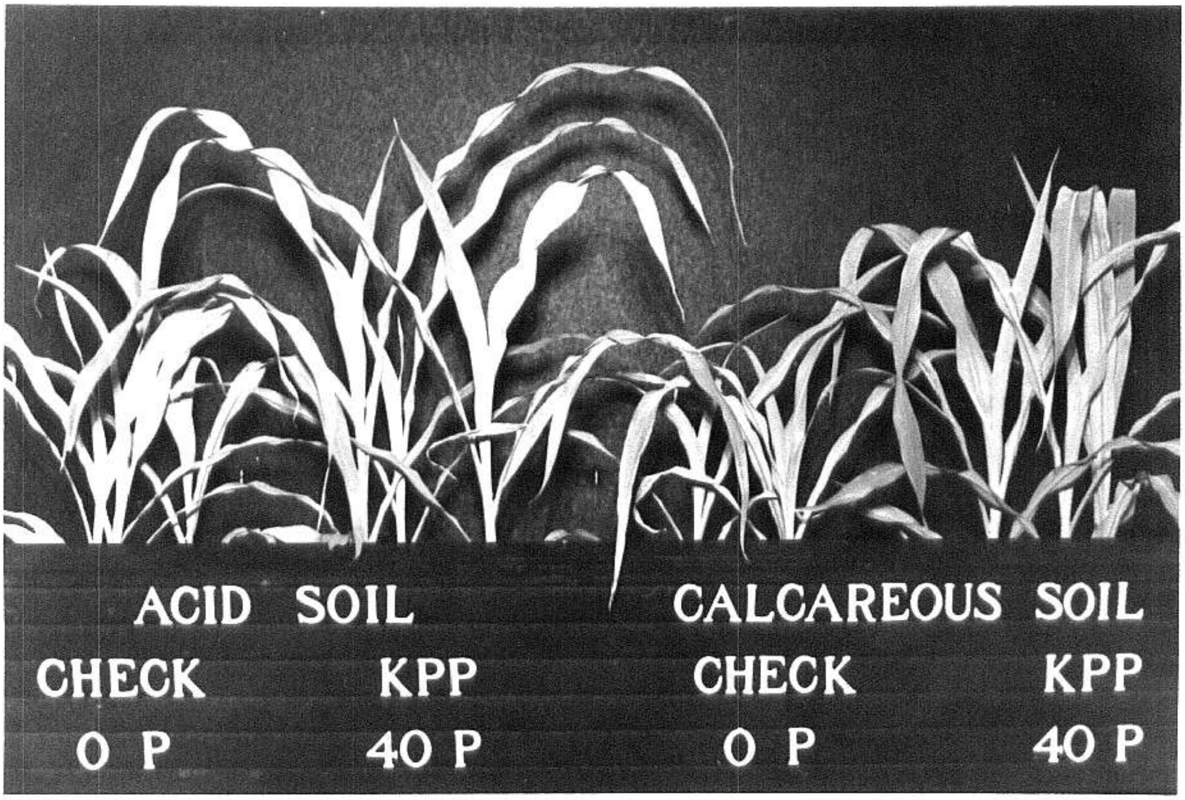
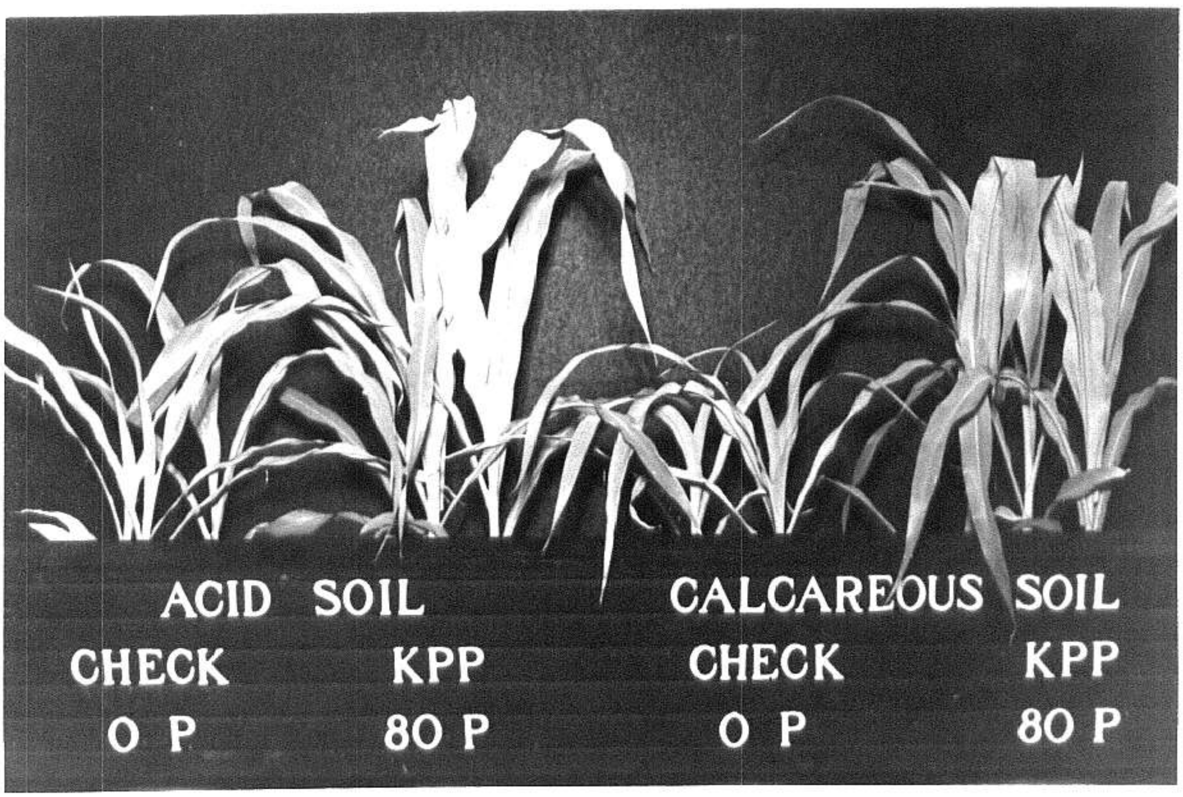

ACID SOIL
CALCAREOUS SOIL
CHECK
APP
CHECK
APP
0 P
80 P
0 P
80 P

Fig. 16 - Corn plant response to two rates of P from KPP in acid and calcareous soils in a growth chamber.


ACID SOIL
CALCAREOUS SOIL
CHECK
KPP
CHECK
KPP
O P
40 P
O P
40 P


ACID SOIL
CALCAREOUS SOIL
CHECK
KPP
CHECK
KPP
O P
80 P
O P
80 P

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, KNO_3, K_2CO_3, KH_2PO_4, and K_2SO_4 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_2PO_4, and K_2SO_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

Adriano, D.C. 1970. Phosphorus-Zinc interaction in *Zea mays* and *Phaseolus vulgaris*. Ph.D. Thesis. Kansas State University, Manhattan.

Allred, S.E. and A.J. Ohlrogge. 1964. Principles of nutrient uptake from fertilizer bands. VI. Germination and emergence of corn as affected by ammonia and ammonium phosphate. Agron. J. 56:309-313.

Ayers, A.S. and H.H. Hagihara. 1953. Effect of the anion on the absorption of potassium by some humic and hydrol humic latosols. Soil Sci. 75:1-17.

Bremner, J.M. and D.R. Keeney. 1965. Steam distillation methods for determination of ammonium, nitrate and nitrite. Anal. Chem. Acta. 32:485-495.

Caldwell, A.C. and J.R. Kline. 1963. Effect of variously soluble potassium fertilizers on yield and composition of some crop plants. Agron. J. 55:542-545.

Chandler, R.F. and R.B. Musgrave. 1944. A comparison of potassium chloride and potassium metaphosphate as sources of potassium for plants. Soil Sci. Soc. Amer. Proc. 9:151-153.

Chapman, H.D. and P.F. Pratt. 1961. Methods of analysis for soils, plants, and waters. Div. of Agr. Sci., Univ. of Calif.

DeMent, J.D. and G. Stanford. 1959. Potassium availability of fused potassium phosphates. Agron. J. 51:282-285.

DeMent, J.D., G.L. Terman, and B. N. Bradford. 1963. Crop response to phosphorus and potassium phosphates varying widely in particle size. J. Agr. Food Chem. 11:207-212.

Engelstad, O.P. 1968. Agronomic evaluation of potassium polyphosphate and potassium calcium pyrophosphates as sources of potassium. p. 63-77. In V.J. Kilmer, S.E. Younts, and N.C. Brady(ed.) The role of potassium in agriculture. Amer. Soc. Agron., Crop Sci. Soc. Amer., and Soil Sci. Soc. Amer. Madison, Wisconsin.

Hagin, J. 1962. Comparison of the efficiency of some phosphatic fertilizers on various soil types of Israel. Israel J. Agr. Res. 12(1):1-12.

Hagin, J. 1966. Evaluation of potassium metaphosphate as fertilizer. Soil Sci. 102:373-379.

Hagin, J. and S. Sherzer. 1967. Potassium metaphosphate as a fertilizer. p. 175-185. In G.V. Jacks(ed.) Soil chemistry and fertility. Trans. of Comm. II, IV, Int. Soc. Soil Sci. (Aberdeen, Scotland) 1966.

Harris, F.J. 1963. Potassium metaphosphate: a novel method of manufacture and a summary of its behavior as a fertilizer. Proc. no. 76, The Fertilizer Soc., London.

Hignett, T.P. 1970. New forms of phosphorus for fertilizer use technology. Phos. in Agr. (55):1-11.

Huffman, E.O. 1968. The reactions of fertilizer phosphates with soils. Outlook on Agr. 5(5):202-207.

Jackson, M.L. 1965. Soil chemical analysis. p. 151-153, 331-334. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Lachover, D. and H. Feldhay. 1966. Evaluation of potassium metaphosphate as a source of potassium for potatoes with special reference to foliar diagnosis, yield, and quality of tubers. J. Agr. Sci. 67:281-285.

Lehr, J.R., E.H. Brown, A.W. Frazier, J.P. Smith, and R.D. Thrasher. 1967. Crystallographic properties of fertilizer compounds. Chem. Eng. Bull. 6, TVA, Muscle Shoals, Ala.

MacIntire, W.H., W.M. Shaw, and B. Robinson. 1953. Differential behavior of potassium metaphosphate and sulfate incorporation in soils. Soil Sci. 75(1):69-80.

MacIntire, W.H., W.M. Shaw, B. Robinson, and C. Veal. 1954. Potassium fixation: differential fixation of potassium from incorporations of metaphosphate and sulfate in two soils. J. Agr. Food Chem. 2:85-91.

Mattingly, G.E.G. and A. Penny. 1968. Evaluation of phosphate fertilizers I. Immediate value of dicalcium phosphate, nitrophosphates, Gafsa rock phosphate, basic slag, and potassium metaphosphate for barley and ryegrass. J. Agr. Sci. 70:131-138.

Metson, A.J. and W.M.H. Saunders. 1962. Comparison of potassium chloride, bicarbonate, and metaphosphate, and calcined orthoclase as sources of potassium for white clover. New Zeal. J. Agr. Res. 5:145-157.

Munk, H. 1963. Potassium poly-metaphosphate as fertilizer. Zeitschrift fur Pflanzenernabrung, Dungung. 101:34-42.

Pfanstiel, R. and R.K. Iler. 1952. Potassium metaphosphate: Molecular weight, viscosity behavior and rate of hydrolysis of non cross-linked polymer. J. Amer. Chem. Soc. 74:6059-6064.

Pritchett, W.L. and C.N. Nolan. 1960. The effects of particle size and rate of solution on the availability of potassium materials. Soil Crop Sci. Soc. Florida, Proc. 20:146-153.

Rosenberg, G.M. and J. Hagin. 1964. Comparison of several phosphatic fertilizers. Israel J. Agr. Res. 14(2):37-44.

Stanford, G. and T.P. Hignett. 1957. Fertilizer development in the TVA: new processes and agronomic implications. Soil Crop Sci. Soc. Florida, Proc. 17:161-185.

Stukenholtz, D.D., R.J. Olsen, G. Gogan, and R.A. Olson. 1966. On the mechanism of phosphorus-zinc interaction in corn nutrition. Soil Sci. Soc. Amer. Proc. 30(6):759-763.

Terman, G.L. and L.F. Seatz. 1956. Crop response to metaphosphate fertilizers. Soil Sci. Soc. Amer. Proc. 20(3):375-378.

Thorup, R.M. and A. Mehlick. 1961. Retention of potassium meta and orthophosphates by soils and minerals. Soil Sci. 91:38-43.

Van Wazer, J.R. 1953. Phosphoric acids and phosphates. In Kirk-Othmer Encyclopedia of Chemical Technology, vol. 10.

Volkerding, C.C. and R. Bradfield. 1943. The solubility and reversion of calcium and potassium metaphosphates. Soil Sci. Soc. Amer. Proc. 8:159-166.

Walthall, J.H. 1953. Chemistry and technology of new phosphate materials. p. 205-255. In K.D. Jacob (ed.) Fertilizer technology and resources in the United States. Academic Press, Inc., New York.

Ward, R.C., E.J. Langin, R.A. Olson, and D.D. Stukenholtz. 1963. Factors responsible for poor response of corn and grain sorghum to phosphorus fertilization: III. Effects of soil compaction, moisture level, and other properties on P-Zn relations. Soil Sci. Soc. Amer. Proc. 27(3):326-330.

Wear, J.I. and R.M. Patterson. 1965. Zinc deficiency. (A symposium): Potassium and phosphorus-zinc relationships. Crops Soils. 18:10-13.

Webb, B.B. 1970. Field and growth chamber comparisons of ortho- and polyphosphates. Ph.D. Thesis, Kansas State University, Manhattan.

Younts, S.E. and R.B. Musgrave. 1958a. Chemical composition, nutrient absorption, and stalk rot incidence as affected by chloride in potassium fertilizer. Agron. J. 50:426-429.

Younts, S.E. and R.B. Musgrave. 1958b. Growth, maturity, and yield of corn as affected by chloride in potassium fertilizer. Agron. J. 50:423-426.

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.

APPENDIX

Table I. Effects of P carriers, P rates and K rates on yield and composition of irrigated corn, Pawnee County, 1970.

Nutrient Rate		Carrier		Leaf Composition								Yield
				Date 1				Date 2				
P kg/ha	K kg/ha	P	K	P %	K %	Ca %	Mg ppm	P %	K %	Ca %	Mg ppm	kg/ha
0	0	-	-	.255	2.39	.256	885	.258	1.64	.232	735	7649
0	50	-	KCl	.228	2.38	.229	856	.225	1.79	.221	796	6960
20	0	APP	-	.297	2.55	.244	910	.271	1.64	.230	781	7838
20	50	APP	KCl	.289	2.56	.264	848	.271	1.71	.228	781	6834
40	0	APP	-	.260	2.48	.241	893	.244	1.54	.242	737	7022
40	50	APP	KCl	.270	2.48	.227	808	.274	1.68	.217	764	6646
20	0	AOP	-	.296	2.60	.191	843	.279	1.53	.220	739	7022
20	50	AOP	KCl	.281	2.59	.277	877	.258	1.65	.253	803	8151
40	0	AOP	-	.274	2.41	.237	840	.286	1.61	.221	807	7461
40	50	AOP	KCl	.289	2.58	.251	845	.268	1.70	.232	750	8527
20	25	KPP	KPP	.272	2.59	.218	878	.257	1.60	.228	753	6897
20	50	KPP	KPP+KCl	.276	2.59	.290	911	.286	1.60	.241	826	8841
40	50	KPP	KPP	.253	2.42	.242	821	.251	1.69	.235	736	7336
$LSD_{.05}$	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.

Nutrient Rate		Carrier		Leaf Composition							Yield
P kg/ha	K kg/ha	P	K	P %	K %	Ca %	Mg ppm	Fe ppm	Zn ppm	Mn ppm	kg/ha
0	0	-	-	.397	3.84	.445	2880	596	73.7	168	4765
0	50	-	KCl	.363	3.54	.427	2685	499	67.0	158	5016
20	0	APP	-	.378	3.60	.453	2745	551	61.3	167	5518
20	50	APP	KCl	.364	3.60	.454	2868	566	69.8	161	4389
40	0	APP	-	.385	3.60	.416	2830	514	65.8	168	5204
40	50	APP	KCl	.363	3.62	.425	2790	538	67.2	167	5455
20	0	AOP	-	.381	3.93	.414	2870	474	63.8	160	5392
20	50	AOP	KCl	.357	3.54	.428	2793	617	60.7	165	5204
40	0	AOP	-	.375	3.79	.428	2833	585	67.8	165	5204
40	50	AOP	KCl	.359	3.42	.408	2775	561	64.5	170	5016
20	25	KPP	KPP	.389	3.70	.424	2873	625	64.1	167	4201
20	50	KPP	KPP+KCl	.345	3.64	.481	2807	598	68.6	167	4640
40	50	KPP	KPP	.382	3.70	.444	2810	583	69.4	170	4703
$LSD_{.05}$	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.

Nutrient Rate		Carrier		Leaf Composition						
kg/ha	kg/ha	P	K	P %	K %	Ca %	Mg ppm	Fe ppm	Zn ppm	Mn ppm
0	0	-	-	.197	1.60	.241	1598	143	28.5	56.7
0	50	-	KCl	.188	1.66	.297	1620	137	30.5	58.0
20	0	APP	-	.228	1.71	.233	1585	116	31.8	64.0
20	50	APP	KCl	.228	1.62	.276	1655	123	30.5	63.1
40	0	APP	-	.194	1.70	.266	1695	122	28.4	59.7
40	50	APP	KCl	.195	1.42	.282	1455	128	30.4	61.7
20	0	AOP	-	.215	1.57	.243	1500	129	31.4	61.1
20	50	AOP	KCl	.191	1.58	.253	1560	115	29.7	58.7
40	0	AOP	-	.218	1.56	.269	1628	150	31.9	62.7
40	50	AOP	KCl	.212	1.63	.264	1540	143	33.8	61.1
20	25	KPP	KPP	.210	1.62	.240	1553	128	31.3	58.9
20	50	KPP	KPP+KCl	.193	1.68	.269	1588	126	30.0	60.2
40	50	KPP	KPP	.204	1.51	.236	1495	167	28.0	58.1
$LSD_{.05}$ 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.

P Rate	P Carrier	Yield	Leaf Composition					
			Date 1			Date 2		
			N	P	K	N	P	K
kg/ha		kg/ha	%	%	%	%	%	%
0	-	2759	3.97	.209	2.91	2.46	.162	2.34
20	AOP	4765	4.34	.254	3.22	2.36	.189	2.35
40	AOP	5518	4.62	.394	3.25	2.33	.199	2.13
60	AOP	6521	4.83	.422	3.01	2.54	.264	2.05
20	APP	4076	4.32	.224	2.85	2.49	.219	2.34
40	APP	4765	4.47	.327	2.88	2.31	.194	2.16
60	APP	6207	4.57	.295	3.20	2.47	.237	2.47
20	TSP	3762	4.20	.289	3.04	2.22	.201	2.23
40	TSP	4765	4.42	.307	3.12	2.23	.237	2.21
60	TSP	5455	4.48	.329	3.35	2.36	.227	2.10
20	KPP	4452	4.25	.207	3.04	2.27	.182	2.39
40	KPP	4828	4.64	.263	3.17	2.32	.209	2.32
60	KPP	5580	4.39	.280	3.21	2.32	.222	2.25
Carrier Means:								
	AOP	5643	4.60	.356	-	2.41	.217	-
	APP	5016	4.45	.282	-	2.42	.216	-
	TSP	4703	4.37	.308	-	2.27	.222	-
	KPP	4953	4.43	.250	-	2.30	.204	-
Rate Means:								
	20	4264	4.28	.243	-	2.33	.198	-
	40	5016	4.54	.323	-	2.30	.210	-
	60	5957	4.56	.331	-	2.42	.237	-
$LSD_{.05}$	Treatment	1066	0.30	.113	ns	0.20	.043	ns
	P Carrier	502	0.16	.068	-	0.11	ns	-
	P Rate	439	0.14	.059	-	0.10	.022	-
	P Carrier x Rate	ns	ns	ns	-	ns	ns	-

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

P Rate	P Carrier	Yield	Leaf Composition					
			Date 1			Date 2		
			N	P	K	N	P	K
kg/ha		kg/ha	%	%	%	%	%	%
0	-	9029	3.73	.231	3.13	3.09	.298	2.25
20	AOP	9468	3.68	.269	2.73	2.60	.243	1.74
40	AOP	9907	3.75	.278	2.79	2.70	.233	1.83
60	AOP	10408	3.59	.347	2.68	2.73	.278	1.57
20	APP	10220	3.48	.246	2.71	2.83	.265	1.85
40	APP	7649	3.44	.211	2.71	2.90	.224	1.96
60	APP	9907	3.54	.272	2.92	2.75	.259	1.79
20	TSP	8778	3.94	.258	2.88	2.97	.250	1.89
40	TSP	10722	3.55	.345	2.90	2.55	.254	1.67
60	TSP	10157	3.77	.313	2.90	2.52	.234	1.72
20	KPP	10471	3.81	.310	2.93	3.02	.282	1.58
40	KPP	11223	3.91	.351	2.78	2.73	.274	1.67
60	KPP	10032	3.67	.297	2.81	2.82	.242	1.61
Carrier Means:								
	AOP	9907	3.67	.298	-	2.68	.251	1.71
	APP	9280	3.49	.243	-	2.83	.249	1.86
	TSP	9844	3.75	.305	-	2.68	.246	1.76
	KPP	10471	3.79	.319	-	2.86	.266	1.62
Rate Means:								
	20	9719	3.73	.271	-	2.86	.260	1.76
	40	9907	3.66	.296	-	2.72	.246	1.78
	60	10157	3.64	.307	-	2.70	.253	1.67
$LSD_{.05}$	Treatment	1693	0.25	.081	ns	0.24	.026	0.27
	P Carrier	ns	0.15	.048	-	0.14	ns	0.16
	P Rate	ns	ns	ns	-	0.12	ns	ns
	P Carrier x Rate	1693	ns	ns	-	0.25	.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.

P Rate	P Carrier	Yield	Leaf Composition					
			Date 1			Date 2		
			N	P	K	N	P	K
kg/ha		kg/ha	%	%	%	%	%	%
0	-	5706	3.96	.227	3.47	3.14	.226	1.94
20	AOP	7022	3.72	.216	3.28	3.22	.239	1.83
40	AOP	7524	3.84	.245	3.61	3.15	.262	1.88
60	AOP	9092	3.73	.269	3.76	3.14	.264	1.80
20	APP	7649	4.01	.271	3.77	3.04	.233	1.91
40	APP	6521	3.89	.239	3.58	2.97	.232	1.92
60	APP	5894	3.91	.246	3.53	3.22	.239	1.92
20	TSP	7336	3.83	.220	3.56	3.29	.235	1.92
40	TSP	8903	3.80	.235	3.47	3.02	.251	1.95
60	TSP	7838	3.83	.286	3.59	3.12	.246	1.86
20	KPP	7963	3.86	.244	3.61	2.92	.252	1.97
40	KPP	7900	3.85	.282	3.59	3.19	.248	1.84
60	KPP	7712	3.91	.271	3.61	3.18	.223	1.94
$LSD_{.05}$	Treatment	1881	ns	ns	ns	ns	ns	ns
	P Carrier	ns	-	-	-	-	-	-
	P Rate	ns	-	-	-	-	-	-
	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	P Carrier	Method of Application	Yield	Leaf Composition					
				Date 1			Date 2		
kg/ha			kg/ha	N %	P %	K %	N %	P %	K %
0	-	-	8026	3.96	.500	2.61	2.65	.357	1.68
5	AOP	Broadcast	7085	3.89	.466	2.62	2.74	.361	1.77
10	AOP	Broadcast	7649	3.91	.483	2.51	2.64	.344	1.76
20	AOP	Broadcast	7775	3.91	.513	2.67	2.74	.369	1.67
5	AOP	Banded	7963	3.93	.450	2.65	2.76	.348	1.64
10	AOP	Banded	7022	4.04	.519	2.67	2.78	.364	1.73
20	AOP	Banded	7587	4.06	.523	2.64	2.67	.354	1.71
5	KPP	Broadcast	8276	4.02	.516	2.64	2.89	.400	1.74
10	KPP	Broadcast	7461	4.01	.519	2.73	2.76	.357	1.76
20	KPP	Broadcast	8151	3.80	.480	2.73	2.79	.375	1.86
5	KPP	Banded	7649	4.04	.504	2.64	2.71	.347	1.74
10	KPP	Banded	7649	3.98	.500	2.64	2.48	.368	1.74
20	KPP	Banded	6458	3.96	.459	2.81	2.58	.352	1.83
$LSD_{.05}$	Treatment		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).

P Rate	P Carrier	Soil Type	Dry Weight	Nutrient Content		Nutrient Uptake	
				P	Zn	P	Zn
ppm			(g)	%	ppm	mg/3 plants	ug/3 plants
0	-	Acid	2.1	.081	78.1	1.7	164.0
40	MAP	Acid	4.1	.131	62.9	5.4	257.9
80	MAP	Acid	4.6	.196	55.1	9.0	253.5
40	APP	Acid	4.2	.136	61.9	5.7	260.0
80	APP	Acid	4.6	.166	48.6	7.7	223.6
40	KPP	Acid	4.1	.100	60.1	4.1	264.4
80	KPP	Acid	4.7	.183	49.6	8.6	233.1
0	-	Calcareous	1.9	.090	53.9	1.7	102.4
40	MAP	Calcareous	3.2	.114	45.9	3.7	146.9
80	MAP	Calcareous	4.0	.130	40.9	5.2	163.6
40	APP	Calcareous	3.3	.121	52.7	4.0	173.9
80	APP	Calcareous	4.0	.135	51.7	5.4	206.8
40	KPP	Calcareous	3.3	.096	45.7	3.2	150.8
80	KPP	Calcareous	4.3	.152	42.9	6.6	184.5
$LSD_{.05}$	Treatment		0.4	.026	-	1.3	-
	P Carrier		ns	ns	-	ns	-
	P Rate		0.2	.011	-	0.6	-
	Soil		0.2	.012	-	0.6	-
	P Carrier x P Rate		ns	.020	-	1.1	-
	P Carrier x Soil		ns	ns	-	ns	-
	P Rate x Soil		ns	.016	-	ns	-
	Three Way Interaction		ns	ns	-	ns	-

Table VIII. (Continued)

	Dry Weight	Nutrient Content		Nutrient Uptake	
		P	Zn	P	Zn
	(g)	%	ppm	mg/3 plants	ug/3 plants
Carrier Means:					
MAP	4.0	.143	-	5.8	-
APP	4.0	.140	-	5.5	-
KPP	4.1	.133	-	5.6	-
P Rate Means:					
40	3.7	.116	-	4.3	-
80	4.4	.160	-	7.0	-
Soil Means:					
Acid	4.4	.152	-	6.7	-
Calcareous	3.7	.125	-	4.7	-
Carrier x Rate Means:					
MAP-40	3.6	.123	-	4.5	-
APP-40	3.7	.129	-	4.8	-
KPP-40	3.7	.098	-	3.6	-
MAP-80	4.3	.163	-	7.1	-
APP-80	4.3	.151	-	6.3	-
KPP-80	4.5	.168	-	7.6	-
Carrier x Soil Means:					
MAP-Acid	4.4	.164	-	7.2	-
APP-Acid	4.4	.151	-	6.4	-
KPP-Acid	4.4	.141	-	6.3	-
MAP-Calcareous	3.6	.122	-	4.5	-
APP-Calcareous	3.7	.128	-	4.7	-
KPP-Calcareous	3.8	.124	-	4.9	-
P Rate x Soil Means:					
40-Acid	4.1	.122	-	5.0	-
40-Calcareous	3.3	.110	-	3.6	-
80-Acid	4.6	.182	-	8.3	-
80-Calcareous	4.1	.139	-	5.6	-

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).

P Rate	P Carrier	Method of Application	% Germination		Dry Weight	
ppm			Grain Sorghum	Wheat	Grain Sorghum (g)	Wheat (mg)
0	-	-	97	98	1.00	567
8	AOP	Banded	93	97	2.50	733
16	AOP	Banded	90	95	2.17	767
8	AOP	Broadcast	97	93	1.73	633
16	AOP	Broadcast	97	95	2.33	733
8	KPP	Banded	97	95	2.47	767
16	KPP	Banded	83	95	2.53	833
8	KPP	Broadcast	93	93	1.73	600
16	KPP	Broadcast	97	93	2.10	633
$LSD_{.05}$	Treatment		ns	ns	0.25	128
	P Carrier		-	-	ns	ns
	P Rate		-	-	0.14	ns
	Appl. Method		-	-	0.14	68
	P Carrier x P Rate		-	-	ns	ns
	P Carrier x Appl. Method		-	-	0.19	ns
	P Rate x Appl. Method		-	-	0.19	ns
	Three Way Interaction		-	-	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)

	% Germination		Dry Weight	
	Grain Sorghum	Wheat	Grain Sorghum (g)	Wheat (mg)
Appl. Method Means:				
Banded	-	-	2.42	775
Broadcast	-	-	2.00	650
Carrier x P Rate Means:				
AOP-8	-	-	2.12	683
KPP-8	-	-	2.10	683
AOP-16	-	-	2.25	750
KPP-16	-	-	2.32	733
Carrier x Appl. Method Means:				
AOP-Banded	-	-	2.33	750
KPP-Banded	-	-	2.50	800
AOP-Broadcast	-	-	2.03	683
KPP-Broadcast	-	-	1.92	617
P Rate x Appl. Method Means:				
8-Banded	-	-	2.48	750
16-Banded	-	-	2.35	800
8-Broadcast	-	-	1.73	617
16-Broadcast	-	-	2.22	683

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).

P Rate	P Carrier	Method of Application	Plant Composition						Nutrient Uptake					
			Wheat			Grain Sorghum			Wheat			Grain Sorghum		
			N	P	K	N	P	K	N	P	K	N	P	K
ppm			%	%	%	%	%	%	(mg/pot)			(mg/pot)		
0	-	-	4.37	.298	5.05	2.75	.208	3.36	24.8	1.7	28.6	27.5	2.1	33.6
8	AOP	Banded	4.93	.755	5.53	3.82	.417	4.14	36.2	5.6	40.5	95.6	10.4	103.5
16	AOP	Banded	4.81	.970	5.94	3.61	.649	4.90	37.1	7.4	45.5	78.3	14.0	106.2
8	AOP	Broadcast	4.81	.415	5.51	4.02	.373	4.23	30.5	2.6	34.8	69.6	6.5	73.3
16	AOP	Broadcast	4.87	.537	5.50	3.88	.400	4.23	35.7	3.9	40.3	90.5	9.3	98.5
8	KPP	Banded	4.88	.664	5.44	4.01	.485	4.25	37.5	5.0	41.8	98.5	11.9	104.6
16	KPP	Banded	4.80	.778	5.55	4.43	.533	4.51	40.0	6.5	46.3	111.9	13.3	114.0
8	KPP	Broadcast	4.78	.414	5.35	3.92	.390	4.27	28.7	2.5	32.1	68.5	6.8	74.0
16	KPP	Broadcast	5.04	.568	5.68	4.16	.425	4.51	31.9	3.6	35.9	87.0	8.9	94.6
LSD $_{.05}$	Treatment		ns	.095	0.41	0.57	.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
	P Rate		-	.049	0.18	ns	.047	0.22	ns	0.6	3.9	8.6	1.0	6.8
	Appl. Method		-	.049	ns	ns	.047	ns	3.7	0.6	3.9	8.6	1.0	6.8
	P Carrier x P Rate		-	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
	P Carrier x Method		-	.069	ns	ns	ns	ns	ns	ns	ns	12.1	ns	ns
	P Rate x Method		-	ns	ns	ns	.066	ns	ns	ns	ns	12.1	ns	9.6
	Three Way Interaction		-	ns	ns	ns	.094	ns	ns	ns	ns	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)

	Plant Composition						Nutrient Uptake					
	Wheat			Grain Sorghum			Wheat			Grain Sorghum		
	N %	P %	K %	N %	P %	K %	N	P (mg/pot)	K	N	P (mg/pot)	K
Appl. Method Means:												
Banded	-	.792	5.61	3.97	.521	4.45	37.7	6.1	43.5	96.1	12.4	107.1
Broadcast	-	.483	5.51	3.99	.397	4.31	31.7	3.2	35.8	78.9	7.9	85.1
Carrier x P Rate Means:												
AOP-8	-	.585	5.52	3.92	.395	4.18	33.3	4.1	37.7	82.6	8.4	88.4
KPP-8	-	.539	5.40	3.97	.438	4.26	33.1	3.8	37.0	83.5	9.4	89.3
AOP-16	-	.753	5.72	3.75	.524	4.56	36.4	5.7	43.0	84.4	11.7	102.3
KPP-16	-	.673	5.61	4.30	.479	4.51	36.0	5.1	41.1	99.5	11.1	104.3
Carrier x Method Means:												
AOP-Banded	-	.863	5.73	3.72	.533	4.52	36.6	6.5	43.0	86.9	12.2	104.8
KPP-Banded	-	.721	5.49	4.22	.509	4.38	38.8	5.8	44.0	105.2	12.6	109.3
AOP-Broadcast	-	.476	5.51	3.95	.387	4.23	33.1	3.3	37.6	80.1	7.9	85.9
KPP-Broadcast	-	.491	5.52	4.04	.408	4.39	30.3	3.0	34.0	77.7	7.9	84.3
P Rate x Method Means:												
8-Banded	-	.710	5.48	3.92	.451	4.20	36.9	5.3	41.2	97.1	11.1	104.1
16-Banded	-	.874	5.74	4.02	.591	4.70	38.7	7.0	45.9	95.1	13.7	110.1
8-Broadcast	-	.414	5.43	3.97	.382	4.25	29.6	2.6	33.5	69.0	6.7	73.7
16-Broadcast	-	.553	5.59	4.02	.413	4.37	33.8	3.8	38.1	88.8	9.1	96.5

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).

K Rate	K Carrier	Dry Weight	Nutrient Composition				Nutrient Uptake			
			N	P	K		N	P	K	
ppm		(g)	%	%	%	(Mean)	(mg/3 plants)			(Mean)
0	-	2.8	3.57	.291	3.43		100.0	8.0	94.5	
50	KCl	3.0	3.67	.289	4.22	4.55	110.1	8.5	125.0	136.6
100	KCl	3.0	3.33	.271	4.87		99.9	8.2	148.3	
50	KPP	3.0	3.40	.259	4.12	4.65	102.0	7.8	125.0	143.7
100	KPP	3.1	3.24	.233	5.19		100.4	7.3	162.4	
50	K_2CO_3	3.0	3.32	.272	4.08	4.35	99.6	8.1	122.4	133.9
100	K_2CO_3	3.2	3.37	.274	4.62		107.8	8.7	145.4	
50	KNO_3	3.0	3.50	.274	4.12	4.54	105.0	8.1	122.1	138.7
100	KNO_3	3.1	3.37	.265	4.96		104.5	8.3	155.3	
50	KH_2PO_4	2.9	3.64	.297	4.37	4.81	105.6	8.7	128.2	146.9
100	KH_2PO_4	3.2	3.21	.264	5.25		102.7	8.4	165.6	
50	K_2SO_4	3.0	3.57	.264	4.16	4.77	107.1	7.9	124.8	145.7
100	K_2SO_4	3.1	3.64	.263	5.38		112.8	8.1	166.7	
$LSD_{.05}$	Treatment	ns	-	ns	0.52		-	ns	18.2	
	K Carrier	-	-	-	ns		-	-	ns	
	K Rate	-	-	-	0.22		-	-	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).

P Rate	Zn Rate	P Carrier	Zn Carrier	Dry Weight	Nutrient Composition							
					P	K	Ca	Mg	Zn	Fe	Mn	Cu
ppm	ppm			(g)	%	%	%	%	ppm	ppm	ppm	ppm
0	0	-	-	1.2	.067	5.60	.723	.320	41.6	103.0	99.4	10.0
0	8	-	$ZnSO_4$	1.2	.067	5.32	.729	.295	122.0	113.8	88.2	10.2
80	0	KPP	-	3.6	.113	4.06	.382	.236	22.5	87.3	71.5	8.0
80	8	KPP	$ZnSO_4$	3.4	.111	4.38	.468	.252	71.8	92.2	76.0	8.3
80	0	AOP	-	3.5	.148	3.89	.379	.272	21.9	90.6	69.3	8.2
80	8	AOP	$ZnSO_4$	3.7	.137	3.92	.355	.286	57.9	85.6	61.6	7.3
80	0	APP	-	3.5	.137	4.03	.387	.272	22.3	93.1	76.4	7.9
80	8	APP	$ZnSO_4$	3.6	.129	3.99	.406	.273	66.6	83.3	69.6	7.7
80	0	TSP	-	3.6	.134	4.03	.373	.296	22.4	69.4	65.7	7.2
80	0	TSP	$ZnSO_4$	3.8	.119	3.71	.422	.288	60.7	74.2	63.9	6.7
P Carrier Means:												
			KPP	3.5	.112	-	-	-	47.1	89.7	73.7	8.1
			AOP	3.6	.143				39.9	88.6	65.4	7.7
			APP	3.6	.133				44.5	88.2	73.0	7.8
			TSP	3.7	.127				41.6	71.8	64.8	6.9
Zn Rate Means:												
			0 Zn	3.5	.133	-	-	-	22.3	85.1	70.7	7.8
			8 ppm Zn	3.6	.124	-	-	-	64.2	84.1	67.8	7.5
$LSD_{.05}$	Treatment			0.3	.022	-	-	-	10.4	18.8	12.5	1.5
	P Carrier			ns	.017	-	-	-	ns	6.6	ns	ns
	Zn Rate			ns	ns	-	-	-	5.6	ns	ns	ns
	P Carrier x Zn Rate			ns	ns	-	-	-	ns	ns	ns	ns

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

P Rate ppm	Zn Rate ppm	P Carrier	Zn Carrier	P	K	Ca	Mg	Zn	Fe	Mn	Cu
				Nutrient Uptake (mg/3 plants)				(ug/3 plants)			
0	0	-	-	0.8	67.4	8.7	3.8	50.0	124.3	119.3	11.7
0	8	-	$ZnSO_4$	0.8	61.9	8.7	3.4	142.7	129.7	102.3	11.7
80	0	KPP	-	4.0	144.1	13.6	8.4	80.0	311.0	265.7	28.3
80	8	KPP	$ZnSO_4$	3.8	148.7	15.9	8.6	243.7	314.0	258.3	28.3
80	0	AOP	-	5.2	135.9	13.2	9.5	76.7	317.0	242.3	28.3
80	8	AOP	$ZnSO_4$	5.0	144.1	13.0	10.5	213.0	316.7	225.3	26.3
80	0	APP	-	4.8	139.7	13.4	9.4	77.7	323.0	264.7	27.7
80	8	APP	$ZnSO_4$	4.7	145.1	14.7	9.9	242.0	302.0	252.3	28.0
80	0	TSP	-	4.8	143.7	13.3	10.6	80.0	247.3	235.0	25.7
80	8	TSP	$ZnSO_4$	4.5	140.5	16.1	10.9	229.3	280.7	242.0	25.3
P Carrier Means:											
		KPP		3.9	-	-	-	161.8	312.5	262.0	28.3
		AOP		5.1	-	-	-	144.8	317.0	233.8	27.3
		APP		4.7	-	-	-	159.8	312.5	258.5	27.8
		TSP		4.6	-	-	-	154.7	264.0	238.5	25.5
Zn Rate Means:											
		0 Zn		4.7	-	-	-	78.6	299.7	251.9	27.5
		8 ppm Zn		4.5	-	-	-	232.0	303.3	244.5	27.0
$LSD_{.05}$	Treatment			0.8	-	-	-	34.9	35.9	38.6	4.7
	P Carrier			0.6	-	-	-	ns	28.3	ns	ns
	Zn Rate			ns	-	-	-	19.5	ns	ns	ns
	P Carrier x Zn Rate			ns	-	-	-	ns	ns	ns	ns

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, K_2CO_3, KNO_3, K_2SO_4, and KH_2PO_4 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, KH_2PO_4, and K_2SO_4, 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.