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VARIATIONS IN PHOSPHORUS ACCUMULATION AND POLYPHOSPHATE HYDROLYSIS BY SELECTED MAIZE FAMILIES (*ZEA MAYS* L.)

by

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

To Gode and Lino

This work is dedicated

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LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

INTRODUCTION

Most attempts to overcome fixation of phosphorus by acid as well as alkaline soils have involved applications of soluble phosphorus carriers and use of recommended methods of application. The more water soluble P materials have usually been most efficient. General superiority of banded versus broadcast P may have been overemphasized, however.

Relatively, little attention has been devoted to the plant itself. Differential nutrient accumulation observed in a number of species may be a partial answer to understanding the problem of phosphorus availability to plants. Some suggest, for instance, that the atmospheric N_2 fixing nitrogenase enzyme of legumes may be transferable to cereals (CIMMYT[1/], CIMMYT Review 1975).

Extensive plant analyses conducted by many research groups have indicated significant differences in genetic materials in terms of nutrients concentrations. Consequently, a survey of maize varieties in hope of finding some which have improved ability to efficiently absorb phosphorus is in order. Such varieties could have potential value in reducing phosphorus fertilizer requirements and minimizing phosphorus fixation reactions on soils with high fixation capacity.

With increasing world-wide fertilizer industry interest in condensed phosphates (polyphosphates) from the standpoint of reduced transportation costs (high analysis), it is also timely to screen the ability of maize varieties to hydrolyze various condensed phosphates species. Work conducted at Kansas State University (Subbarao, 1975) and other locations (Gilliam, 1970) has revealed that plant root hydrolysis of condensed phosphates is an

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1/ CIMMYT: The International Maize and Wheat Improvement Center important factor in the utilization of these forms P fertilizers by various plant species. However, little information in this context exists regarding the ability of different genetic materials within a particular species to hydrolyze these long chain compounds.

Research on nitrate reductase activity in the evaluation of the nitrogen efficiency of Mex-Mix maize families in the CIMMYT program at Kansas State University has prompted investigations into the phosphorus efficiency of the same materials which may in turn influence decisions on use of different types of phosphorus fertilizers.

Based on these considerations, a study was designed with the following objectives:

1. To evaluate variations in the concentrations and uptake of phosphorus in 100 maize families.
2. To evaluate selected maize families for their responsiveness to applied phosphorus.
3. To evaluate the potential differences and abilities of selected maize families to hydrolyze polyphosphates in soil and solution culture.

LITERATURE REVIEW

Differential accumulation

Considerable variation exists in the ability of plants to absorb nutrients from soil. This ability has been extensively studied as "feeding capacity", "feeding power", "cation exchange capacity of roots" or "differential accumulation" and may be of great importance in tailoring the plant to fit soil problems.

Differential nutrient accumulation has been well demonstrated by many investigators in many species: maize (Brown and Bell, 1971); bean (Ambler and Brown, 1970); soybean (Ambler et al., 1973); tomato (Brown et al., 1973) and sorghum, (Mikesell et al., 1973). Truog (1916) classified millet, rye, wheat, oat, corn and barley as weak feeders and rape, pea, buckwheat, lupine, alfalfa, tobacco and turnip as strong feeders on rock phosphate. Koyama and Snitwongse (1952) reported rice varietal differences in absorbing phosphorus from P deficient soils.

In maize differential accumulation of P is under genetic control (Gorsline et al., 1964). Evidence for the heritability element concentration in the ear leaf for P and some other elements has also been established (Gorsline et al., 1965). Baker (1970) confirmed the existence of genetically controlled P accumulation and found that at least two genetic factors were involved. Studies of De Turk (1933) showed differences of maize hybrids on a phosphorus deficient soil treated with superphosphate. One hybrid exhibited a pronounced response to phosphate fertilizers whereas the other failed to respond appreciably. Where phosphate was not applied the responsive cross maintained a higher phosphorus concentration from the limited supply available.

Several theories have been advanced to explain greater P uptake by maize. Stuart (1934) suggested that a high ratio of secondary-primary roots may be the cause of efficiency in the inbreds lines of maize and inheritance of branched roots is a probable cause of the efficiency in maize hybrids. According to Phillips et al., (1971) higher P absorption may possibly be associated with physiological process which produced several phosphorylated metabolites. A more recent explanation by Gilliam (1970) and Clark and Brown (1973) showed that different amounts of pyrophosphatase present on the external portions of intact roots of maize may account for greater hydrolysis of longer chain phosphate species and therefore, for greater P absorption.

Factors affecting crop response to phosphatic fertilizers.

Research has shown that differences in nutrient absorption among crop varieties are genetically controlled, therefore, selection of efficient genotypes is an important step in selection for differential accumulation.

Lyness (1936) evaluated varietal differences in phosphorus feeding capacity of 21 inbred lines of Reid yellow maize and concluded that the gene for P deficiency behaved as a recessive gene in the F_1 generation.

Using different root zone temperature with two different soils, Knoll et al. (1964) found that P content and P uptake increased with increased soil temperature. Other workers, however, pointed out that increase of P uptake with high temperature may be due to greater mineralization of organic P.

Studies dealing with micro-organisms have indicated that they favorably influence P uptake (Murdoch et al., 1973). It was found that P content of maize seedlings grown with tricalcium phosphate in presence of mychorrizae, Endogone specie, was increased by 31% respectively over that of non-mycorrhizal plants. In a greenhouse, Ross and Gilliam (1972) reported, with the same strain of mychorrizae, an increase of P uptake by 79, 530, 0 and 56% when soybean was fertilized with Al, Fe, rock or monocalcium phosphate, respectively.

Numerous reports have suggested that use of herbicides such as atrazine and simazine occasionally resulted in higher N and P uptake (DeVries, 1963). Duncan and Ohlrogge (1958) attributed an increased P absorption to the synergistic effect of N which causes proliferation of roots where N and P were applied in bands.

Liming of acid soil to a near neutral pH can promote phosphorus availability (Truog, 1947). On the other hand, Hemwall (1957) reported that Al and Fe compounds, amount of Al and Fe hydroxides and clay minerals were the main factors affecting P fixation in acid soils; whereas, in alkaline soils large amounts of free calcium carbonate were responsible for P fixation.

The importance of phosphorus content of the seed has been stressed by Guttay (1957). Working with maize seed differing in weight and P content he observed that the weight of maize plants 1, 2 and 11 weeks old was dependent on increased P content of the seed and was independent of the seed weight. This may be more easily appreciated when one recognizes that about 80% of P is in the form of phytin or phytic acid and provides energy for the germinating seedlings.

Total phosphorus concentrations and movement of P in maize.

Phosphorus response studies have been conducted on a wide variety of plant species under field, greenhouse or growth chamber conditions. Comparisons of the results do not always agree because plant requirements differ greatly when grown under different environmental conditions. Cook and Millar (1946) reviewed the conditions which help to make greenhouse investigations comparable with field plot experiments.

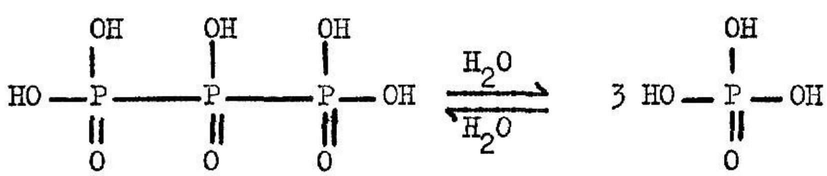
Sprague (1955) noted that one hectare of maize was able to remove approximately 34 Kgs of P from the soil and this amount was just as essential to successful growth as 161 Kgs of N and 127 Kgs of K. Hanway (1972) observed that three fourths (72-82%) of total plant P was in the grain at maturity. He also pointed out that half or more of total grain P at maturity represented phosphorus translocated from the above-ground portions of the plant. The amount of P in leaves during the major part of the growing season amounted from 15 to 20% of the total P taken up by maize. Sayre (1948) reported that the greatest rate of P accumulation in maize plants occured at the same time as that of N and was practically a straight line function with time.

Phosphorus is more mobile in the plant than in the soil. Oliver (1952) noted that radioactive phosphate in month-old maize was translocated to all parts of the plant with greatest concentration in the rapidly growing parts. It has also been established that in P deficient plants, P moves to the grain first from the husks, cob, shank, then from stalks, tassels and leaf sheaths and finally from leaves. When leaves run out of P, transformations of sugars into anthocyanin take place giving characteristic purple leaf color.

Effects of P concentrations on yield of maize.

Phosphorus plays a vital role in the structure of numerous compounds such as ADP, ATP and $NADPH_2$ which store and supply energy for plant metabolism. Seatz and Sterges (1963) studied the effect of initial and supplemental additions of P at one week interval to maize in the greenhouse. They concluded that a critical period exists in the growth of maize plants during which time P must be available if it is to be reflected in higher by plants, longer chains of phosphates may be absorbed in certain cases. Coix, et al. (1967) observed that pyrophosphates (PP) and tripolyphosphates (TPP) were absorbed by maize and tomato (Lycopersicum esculentum Mill.) in solution cultures deprived of P at the same speed as OP. Soluble metaphosphate (longer chains) were not absorbed. Gilliam (1970) observed that PP ion per se was absorbed by corn, oat (Avena sativa L.) and wheat (Triticum aestivum) plants. Phillips et al., (1971) used ion exchange chromatography to identify and separate the compounds that could account for the observed differences in P levels of maize hybrids. Their results showed that orthophosphates were more readily absorbed than adenosine diphosphate (ADP) and adenosine monophosphate.

However, Sutton and Larsen (1966) reported that PP must first be hydrolyzed into single OP units before they can be efficiently taken up by plants roots. The hydrolysis of PPP normally takes place as follows:



Tripolyphosphate Orthophosphate

TPP OP

The sequence followed is probably (Philen and Lehr, 1967):

$$\text{PPP} \longrightarrow \text{PP} \longrightarrow \text{OP}$$

Factors responsible for the hydrolysis have been reviewed by Van Wazer (1952). Temperature, pH, microbial activity, enzymes, presence of colloidal gels, complexing cations, phosphate concentrations and ionic environment in the solution are important for PP or PPP hydrolysis. Hossner and Melton (1970) reported that hydrolysis was more rapid in acid than in basic soils. Other workers, however, found increasing rates of hydrolysis with increasing pH (Philen and Lehr, 1967; Sutton and Larsen, 1966).

yields.

Phosphorus concentrations in maize have been studied extensively to determine the optimum P status of the plant and its relationship to yield and/or other nutrients at different stages of growth. Baker et al., (1967) studied the chemical composition of maize selected for high and low P accumulation. They found that the P concentrations of maize grown on 44 soils was positively associated with dry weight and P uptake. Viets et al., (1954) reported P correlations with yield varying from 0.83 to 0.91 and concluded that leaf P concentrations selected before silking gave lower correlations with yield than those selected at silking.

Critical P concentrations below which deficiency symptoms are observed have also received considerable attention. Tyner (1946) reported critical nutrient concentrations for maize as 2.90% N, 0.292% P and 1.30% K for the sixth leaf from the base at silking. In a greenhouse study, Terman (1973) found minimal concentrations of 7 to 9 week old maize plants to be in the range of 1.1 to 1.3% N and 0.13 to 0.16% P.

Several investigators have reported the antagonistic effect of high P applications on Zn availability (Adriano and Murphy, 1971). The exact mechanism by which P induces Zn deficiency is not fully understood. Some workers suggested a dilution due to higher growth response, slower translocation rates from roots to tops of P-Zn interactions in the soil. Interactions of P with other nutrients are many and complex depending upon the amounts and types of nutrients supplied or present in the soil as well as several environmental factors.

<u>Absorption, hydrolysis and reactions of condensed phosphates (PPP) with soils.</u>

If orthophosphates (OP) are preferential forms in which P is absorbed

Recent research conducted on hydrolysis of PPP have shown different ability of plant species to hydrolyze PPP. Gilliam (1970) ranked the hydrolyzing power of wheat, oat and maize as follows: wheat > maize > oat. Subbarao (Kansas State University, Ph.D. Thesis, 1975) found that 42% of PP was hydrolyzed in 12 hours by maize roots whereas 76% was hydrolized by soybeans (Glycine max.) in 67 hours. When TPP was used, 86% was hydrolyzed in 22 hours by maize and only 69% in 96 hours by soybean roots. During hydrolysis, TPP concentration decreased linearly and OP increased linearly with time.

Reactions of PPP with soils minerals contrast with OP. Philen and Lehr (1967) reported that concentrated solutions of condensed phosphates were much less reactive with various soils minerals than OP and speculated that a water soluble PPP fertilizer should diffuse farther through the soil than OP. Further work showed, however, that this supposition was incorrect, at least with ammonium pyrophosphates (Sample, Agronomy Abstracts, 1967, p 84). More recently, Subbarao (1975) found that reactions products of pyro and polyphosphates in calcium solutions and soils, resulted in precipitations of $Ca_3K_2(P_2O_7)_2.2H_2O$, $CaKHP_2O_7$, $CaK_2P_2O_7.4H_2O$ and $CaK_2P_2O_7$. Those compounds may restrict P uptake by plants from PPP fertilizers.

Reactions of PPP with irrigation water.

Despite some advantages, injection of PPP in irrigation water (fertigation) may cause precipitation problems and clog nozzles and screens of the irrigation system. Duis and Burman (1969) reported that introduction of PPP in irrigation water caused precipitation of calcium ammonium pyrophosphate in presence of Ca. However, possibility of testing irrigation water compatible with APP exists.

Efficiency of phosphorus carriers and methods of applications on phosphorus availability to crops.

Agronomic effectiveness of P carriers has been investigated in comparison with phosphate rock with concentrated superphosphate as a control. Results have shown that water soluble phosphates are superior to citrate soluble and insoluble phosphate fertilizers. Bennett (1954) investigated the efficiency of eighteen sources of phosphate fertilizers on Houston black clay soil and found little difference between sources. On the average, sodium pyrophosphate and monoammonium phosphate (MAP) produced higher yields than 9% or 19% superphosphate but the difference was not significant at 5% of probability.

Superiority of PPP over OP has been claimed since their first appearance on the fertilizer market but generally yield response as well as chemical analyses of plant tissue have shown little differences (Murphy, 1968). However, agronomic capabilities of PPP were quite good in increasing yields and crop growth in most studies. Any possible PPP superiority is attributed to their higher P analysis, ability to sequester micronutrients and/or compatibilities with pesticides. In maize, for example, superiority of a liquid program of PPP (liquid broadcast and liquid starter) application was reported compared to a program of OP (dry broadcast and dry starter) the results not only show increased yield but also earlier maturing and drier corn (23).

Superiority of banded over broadcast applications has been well documented. However, great care should be taken when higher amounts of P are applied on zinc deficient or borderline zinc deficiency areas. In such a situation, it is suggested that banded applications should be conducted in the presence of adequate amounts of zinc.

Based on these considerations, it is probable that combination of selection of highly phosphorus efficient genotypes with adequate methods of applications and use of high P fertilizers might be an open area of practical importance in improving phosphorus utilization by maize.

MATERIALS AND METHODS

Field Experiments

Phosphorus accumulation of 100 Mex-Mix maize families under a high nitrogen fertilization regime. (Experiment 1)

One hundred Mex-Mix maize families were grown on plots that received 200 kg N/ha as NH_4NO_3 and 15 kg P as superphosphate, at St. John, Kansas in 1974. The families were a mixture of 1000 world collections of both temperate and tropical germplasm and were provided by CIMMYT. Soil characteristics of the experimental site are given in Table 1.

Plots were 5 m long with 0.75 m interow spacing, plants were 25 cm apart within row. The field design was a randomized complete block design with 2 replications. At silking time, four whole plants were sacrificed for determination of dry matter accumulation, phosphorus uptake and phosphorus concentrations. Plants were hand harvested, weighed and chopped with a power shredder. A composite sample was drawn, weighed and dried in an oven at 21°C for five days. Total plant weight was calculated using the dry weight to fresh weight ratio.

Phosphorus concentrations were determined by the vanadomolybdate yellow procedure devised by Chapman and Pratt (1961). The absorbance was read at 390 mu with a Spectronic 88 Bausch and Lomb spectrophotometer. Based on these analyses and amount of seed available, nine families were selected for further field, greenhouse and growth chamber investigation on the basis of their phosphorus concentrations at silking.

Total phosphorus uptake at silking was calculated by multiplying total dry weight at silking by the corresponding phosphorus concentrations for each family. Phosphorus relative efficiencies (PRE) were estimated as percentage of the highest phosphorus uptake to provide a base of comparisons.

Table 1. Initial characteristics of soil used in field and greenhouse studies.

* Soil characteristics	Field		Greenhouse	
	Exp. 1	Exp. 2	Exp. 1	Exp. 2
pH	5.3	6.3	6.2	5.9
** Avail P, ppm	12.5	14.0	14.0	17.0
+ Exch. K, ppm	134.0	183.0	159.0	117.0
++ Avail. Zn, ppm	1.7	2.7	0.6	0.7

* All chemical analyses, KSU Soil Testing Laboratory

** Available P was determined by extraction with 0.025 N HCl in 0.03 N NH_4F (Bray's P extraction procedure)

+ Soils were extracted with 1N NH_4OAc

++ DTPA

Grain yield per plant was determined by hand harvesting 10 guarded plants of each plot. Phosphorus concentrations in grain were evaluated by the same procedure described for plant tissue. Total phosphorus translocated into grain (TPTG) was determined in grams per plant by multiplying phosphorus concentrations in the grain by weight of shelled grain (dry weight basis). Simple linear correlations were performed to study the association between plant parameters.

Response of selected P families to applied phosphorus. (Experiment 2)

The second field experiment was carried out at the same location and involved families selected for different P concentrations at silking during the preceeding season. The families used were numbers 8, 61, 70, 72 and 98, (low P accumulators) and 1, 41, 20 and 73 (high P accumulators). The initial characteristics of the soil used in the field and greenhouse studies are presented in Table 1. The experimental design was a randomized complete block design with 2 replications. Plots were 3 m long with 0.75 m between rows and 0.25 m between plants. Phosphorus variables were 0, 20, and 40 kg P/ha as triple superphosphate, applied preplant and disced into the soil. Nitrogen was held constant at 180 kg N/ha as NH_4NO_3.

The first tissue sampling (date 1) was taken at the eight leaf stage by collecting fully mature leaves from the center rows of each plot. At silking (date 2), 2 plants were harvested for dry matter, phosphorus concentrations and phosphorus uptake determinations using the procedures described earlier.

Nitrogen, phosphorus and potassium were determined on a sulfuric acid digest using microkjeldahl, vanadomolybdate yellow and the flame photometry procedures, respectively. Zinc was determined on a perchloric acid digest with a Perkin Elmer Model 303 atomic absorption spectrophotometer. Five plants were hand harvested per plot and grain yield was reported on a dry weight basis per plant.

Greenhouse Experiments

Response of selected maize families to soil applied phosphorus.

Low P Muir silt loam soil was used as the growth medium. However, available soil P was adequate for successful plant growth. Phosphorus variables were supplied as $Ca(H_2PO_4)_2.H_2O$ and thoroughly mixed with 2 kgs of soil. All treatments were replicated three times and randomly placed in the greenhouse.

Each plastic pot received 100 ppm N as NH_4NO_3, 20 ppm S as K_2SO_4 and $ZnSO_4.7H_2O$, 80 ppm K as K_2SO_4 and KCl and 8 ppm Zn as $ZnSO_4.7H_2O$. The pots were rotated daily to provide equal light, to reduce border effect and variability. All fertilizers were mixed mechanically with soil at the time of potting. Six seeds were planted per pot and were thinned to three per container.

Visual responses were noted, dry matter yield was determined and chemical analyses were carried out on the plant material in the same manner described for the field studies.

Comparative response of selected families to potassium ortho (KOP) and potassium pyrophosphate (KPP).

In this study, families 20 and 73 (high P accumulators) and families 61 and 98 (low P accumulators) were grown for 20 days with KH_2PO_4 (KOP) and $K_4P_2O_7$ (KPP) at rates of 0, 20, 40 and 60 ppm P. All nutrients were maintained constant as outlined for experiment 1 and mixed with 2 kgs of soil. Additional K other than that in the K phosphates was supplied as

KCl at the lower P rates. Visual responses were noted and maize seedlings were harvested 20 days after emergence. Chemical analyses were performed as described earlier.

Growth Chamber Experiments

Potassium pyrophophosphate hydrolysis rates of selected families, in solution culture.

Families 20 and 73 (high P accumulators) and families 8 and 61 (low P accumulators) were germinated in moist vermiculite for 10 days. The seedlings were then washed free of vermiculite rinsed in dionized water and transferred into clean styrene pots containing phosphorus-deficient Hoagland's nutrient solution (Hoagland and Arnon, 1950). Plants were grown for 5 days in growth chamber at 30-20^{o}C day night temperature and a 16-hour photoperiod. Lighting was provided by sixteen 160 watt fluorescent lamps and six 300 watt-incandescent lamps (1500 foot candles). Solutions were adjusted to pH 6.0 initially, Fe was supplied as drops of 10 mm $FeSO_4$ every 2 days in all treatments.

Seventeen days after planting, uniform seedlings were removed from the nutrient solutions, thoroughly rinsed with dionized water and transferred to special containers with 800 ml of 60 ppm P as KPP. These special containers consisted of 58 cm X 8 cm X 5 cm plastic containers joined together with adhesive tape. Each container received 500 mls of 60 ppm P solution as $K_4P_2O_7$ in one side and phosphorus deficient Hoagland's solution in the other.

The same lighting conditions described earlier were maintained constant (no dark) during the hydrolysis period. Five plants of each family were transferred 6 cm apart in each special container, using a split root technique with half of the roots in P deficient Hoagland's solution and half in the pyrophosphate solution. Treatments were replicated twice. Ten mls of PP solution were sampled at 5 hours intervals from each special container. Solutions from the same families were mixed together to avoid excessive withdraw of substrate. Phosphorus solutions were concentrated by freeze drying to remove water. Two mls of deuterium oxide and two mls of EDTA were added to each flask to prevent interference of undesirable cations during determinations of phosphate species. Phosphate species were determined in the samples using a X-L 100 nuclear magnetic resonance (NMR) spectrometer of the Department of Chemistry. Peak areas of OP and PP spectra were measured and amounts of hydrolyzed KPP were determined by changes in KPP and OP concentrations. The method of least squares was used for curve fitting.

The second polyphosphate hydrolysis experiment involved Mex-Mix family 44 (high P accumulator) and XL 390, a hybrid from Dekalb AgriResearch. This choice was based on the amount of seed available and the results of the first hydrolysis experiment. Since Mex-Mix familes were similar in their ability to hydrolyze PPP, another experiment was necessary to compare two genotypes of different genetic background. All procedures were followed as described earlier except that 5 mls of KPP solution were sampled every 5 hours from each container from 4 replications to make a composite sample of 20 ml for OP and PP determinations.

RESULTS AND DISCUSSION

Field Experiments

Phosphorus accumulation of 100 Mex-Mix maize families under high nitrogen fertilization regime. (Experiment 1)

Plant parameters for the 100 Mex-Mix maize families are shown in Appendix Table II. Large parameter variations were noted among families. This was expected because varieties of different origin were used to form the heterogenous population. There were highly significant differences in grain yield per plant, dry matter yield per plant, total phosphorus uptake at silking and total phosphorus translocated into grain. Significant differences were observed for phosphorus concentration in the above-ground parts of plants at silking. (Table 2).

Although plots received 200 kgs N/ha as NH_4NO_3, the families did not show differences of nitrogen concentrations in the plant, total nitrogen uptake at silking, nitrogen concentrations in the plant at maturity, nitrogen concentrations and phosphorus concentrations in the grain.

Frequencies of phosphorus relative uptake and grain yield per plant are presented in Figs. 1 and 2. Grain yield per plant was in the range of 53-156 grams. Forty-eight families yielded in the range of 51-70% of the maximum (153 gms) while 44 yielded over 70% and only 8 families yielded less than 50% of the maximum. As shown in Fig. 1, most of the families yielded in the range of 51-70% of the maximum (712 mgs) for phosphorus uptake. Most of the response of the Mex-Mix families was observed in terms of dry matter accumulation because of their sensitivity to light. In reaction to photoperiod, the families produced more vegetative parts and less grain.

Table 2. Summary of the analysis of variance for various plant parameters of the 100 Mex-Mix maize families, St. John, Kansas, 1974. (Experiment 1)

Source of variance	Mean squares	$LSD_{.05}$
1. Grain yield per plant (GYP)	794.500**	35.52
2. Dry matter yield per plant (DMYP[a])	995.932**	50.15
3. Phosphorus concentrations in the plant (PCP[a])	11673×10^{-7}*	0.04
4. Phosphorus concentrations in the grain (PCG)	1663×10^{-7}	NS
5. Total phosphorus uptake (TPU[a])	13009.850**	189.55
6. Total phosphorus translocated in the grain (TPTG)[a]	10837.960	157.42
7. Nitrogen concentration in the plant (NCP[a])	32132×10^{-7}	NS
8. Nitrogen concentrations at maturity (NCM)	31861×10^{-7}	NS
9. Nitrogen concentrations in the grain (NCC)	95066×10^{-7}	NS
10. Total nitrogen uptake (TNU[a])	30110×10^{-7}	NS

[a] at silking

* and ** denote significance at 5% and 1% level of probability, respectively

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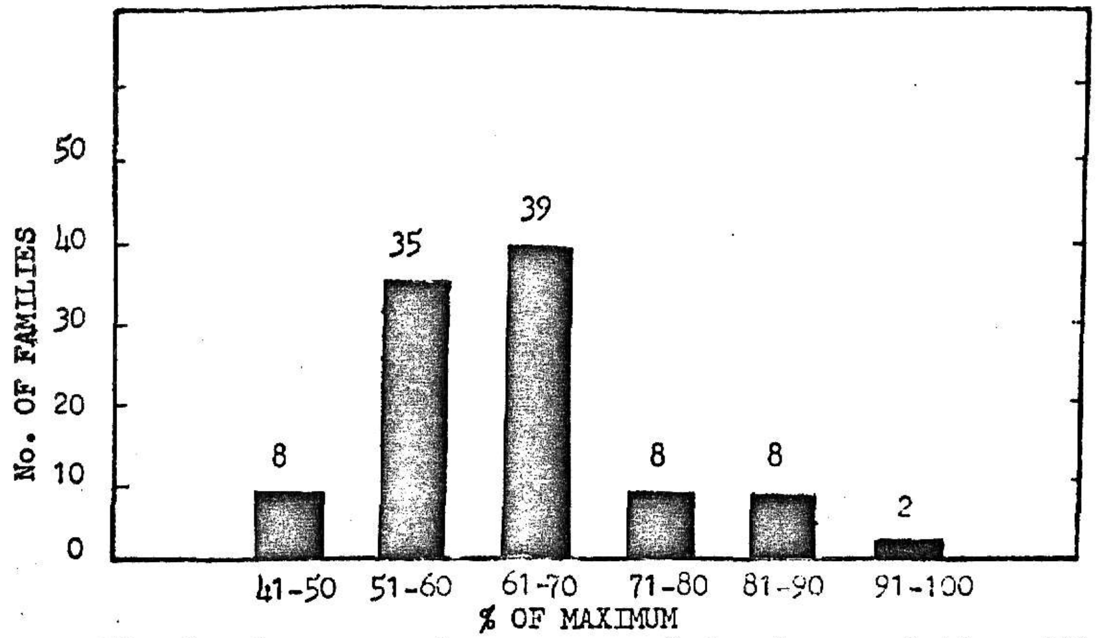

Fig. 1. Frequency of occurrence of phosphorus relative efficiencies (PRE) in aerial portions of 100 Mex-Mix maize families expressed as % of the maximum (712 mg P/plant), St John, Kansas, 1974. (Experiment 1)

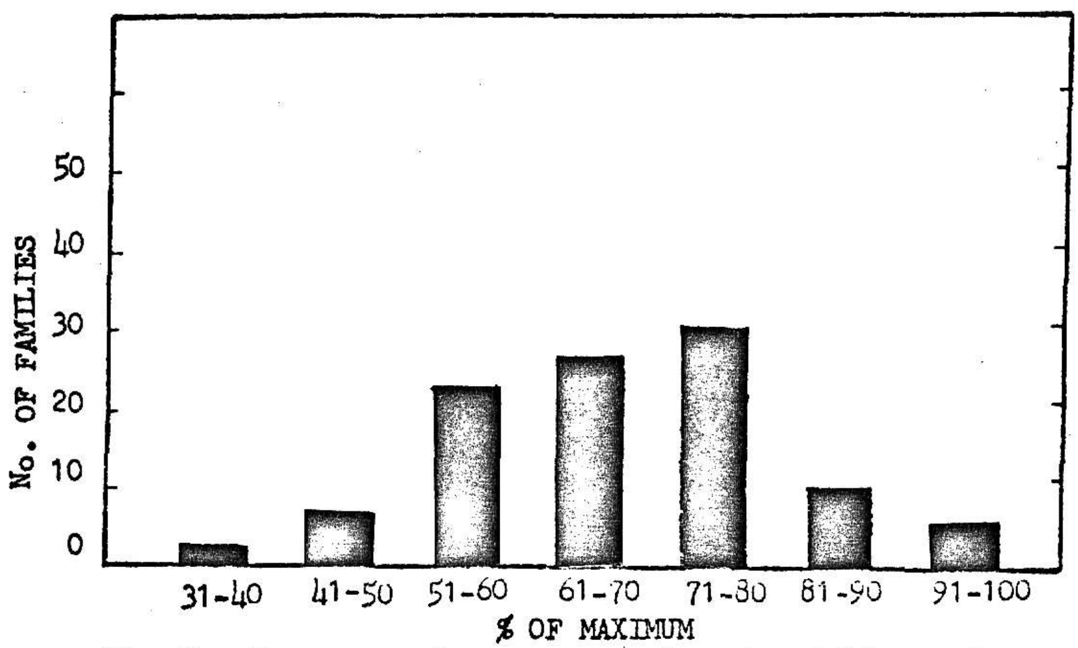

Fig. 2. Frequency of occurrence of grain yield per plant of the 100 Mex-Mix maize families expressed as % of the maximum (156 gm per plant), St John, Kansas, 1974. (Experiment 1)

Total phosphorus translocated into grain also showed a great variation and ranged from 612 mg P/plant for the most efficient family to 396 mg P/plant for the least. Phosphorus concentrations at silking ranged from 0.21% to 0.34% whereas total phosphorus uptake ranged from 302 to 712 mg P/plant.

On the basis of their phosphorus concentrations at silking, families 8, 61, 70, 72 and 98 which had an average of 0.21% P were considered as low P accumulators. Families 1, 20, 41 and 73 with 0.34%, 0.31%, 0.29% and 0.29% P, respectively, were classified as high P accumulators since phosphorus concentrations in the plant at silking were significantly different. (Table 2).

Comparative values of some plants parameters of high and low P accumulators are given in Table 3. It is apparent that considerable variation existed among those selected families. At harvest, grain yields per plant of high P accumulators were generally higher than for low P accumulators. However, while family 44 produced less grain per plant despite its high total phosphorus uptake at silking, families 8 and 70 (low P accumulators) outyielded all others. Apparently, superiority of those 2 families may have been due to their ability to absorb P (high PCP[a]) and to translocate more P into grain (high TPTG) or to their efficiency for grain formation. Further work on evaluating the ability to translocate P or other nutrients is needed.

Dry matter yields were slightly higher for high than for low P accumulators and large variations were present within each group of accumulators. Family 1 (high P accumulator) yielded only 148 gm/plant and family 70 (low P accumulator) reached 200 gm/plant. These apparent conflicting results indicate that differences observed in terms of phosphorus concentrations

Table 3. *Comparison of some plant parameter characteristics of selected families differing in phosphorus concentrations at silking, St. John, Kansas, 1974. (Experiment 1)

Family	NCP[a]	NCG	PCP[a]	PCG	TPU[a]	TPTG	DMYP[a]	GYP	PRE[a]
	------ % ------		------ % ------		--- mg P/plt ---		---- gm/plt ---		%
			---------- High P accumulators ----------						
1	1.71	1.67	0.34	0.36	499	470	148	131	70
20	1.30	1.65	0.32	0.41	647	424	205	103	91
41	1.47	1.80	0.29	0.34	640	441	215	108	90
44**	1.54	1.81	0.28	0.38	712	319	249	88	100
73	1.61	1.66	0.29	0.34	583	407	199	120	82
			---------- Low P accumulators ----------						
8	1.23	1.73	0.21	0.39	302	467	151	155	42
61	1.51	1.78	0.21	0.31	386	393	191	98	54
70	1.54	1.91	0.21	0.34	333	516	200	151	47
72	1.47	1.71	0.21	0.39	375	432	188	112	53
98	1.35	1.83	0.21	0.38	318	314	157	97	65

[a] at silking (76 days after planting)

* abbreviations used: NCP[a] = nitrogen concentration in the plant at silking; NCG = nitrogen concentrations in the grain; PCP[a] = phosphorus concentrations in the plant at silking; PCG = phosphorus concentrations in the grain; TPU[a] = total phosphorus uptake at silking; TPTG = total P translocated into grain; DMYP[a] = dry matter yield per plant at silking; GYP = grain yield per plant; PRE[a] = phosphorus relative efficiency at silking.

** Due to shortage of seeds, this family was not included in other studies.

at silking may not be reflected in grain yield. The use of concentrations values instead of total phosphorus uptake in a selection program is open to the objection that the families with high phosphorus concentrations may show little ability to translocate P to the grain. However, differences found in phosphorus concentrations in the plant at silking were also reflected in total phosphorus uptake.

No evidence of difference between high P accumulators and low P accumulators was shown for nitrogen concentrations in the plant at silking (Table 3). There seemed to be higher concentrations of N in the grain of low P accumulators compared to high P accumulators. However, the differences were not significant.

The data suggest that some families absorbed or utilized more phosphorus than others in the presence of adequate nitrogen but this does not exclude the possibility that the environment may have contributed to some of the variations observed between Mex-Mix families or within each group of accumulators. Gorsline (1964) pointed out the importance of genotype X environment interaction for element concentrations of maize.

Simple correlation coefficients among some parameters of the 100 Mex-Mix families are presented in Table 4. Of the 9 variables studied, total phosphorus translocated into grain was the most highly correlated with grain yield per plant ($r = 0.908$). This suggests that better selection of the Mex-Mix families may have been made on their yielding abilities if TPTG was taken as a criterion of selection. Several studies have shown high correlations of P concentrations at silking and grain yield of maize (Tyner, 1946; Viets et al., 1954). However, in our study no significant correlations were found between phosphorus concentrations at silking and grain yield per plant. A highly significant negative correlation was observed

Table 4. Simple correlation coefficients among some plant parameters of the 100 Mex-Mix families, St. John, Kansas, 1974. (Experiment 1)

+ Plant parameters	1	2	3	4	5	6	7	8	9	10
1. GYP	1.000									
2. NCP[a]	0.197	1.000								
3. NCM	-0.165	0.059	1.000							
4. NCG	-0.109	0.051	0.132	1.000						
5. DMYP[a]	-0.022	-0.209*	0.019	0.005	1.000					
6. PCP[a]	0.176	0.202*	-0.093	0.056	0.109	1.000				
7. PCG	-0.251**	0.169	0.028	0.139	0.096	0.026	1.000			
8. TNU[a]	0.036	0.237**	0.091	0.114	0.839**	0.224**	0.015	1.000		
9. TPU[a]	0.031	-0.078	0.049	-0.021	0.794**	0.644**	0.133	0.370**	1.000	
10. TPTG	0.908**	0.164	-0.198*	-0.038	0.004	0.205	0.151	0.151	0.031	1.000

a: at silking (76 days after planting)

* and ** denote significance at 5% and 1% level of probability respectively

+ Abbreviations are explained in Appendix Table I.

between phosphorus concentrations in the grain and grain yield per plant, similar to the findings of Bennett et al., (1953).

A stepwise deletion equation was calculated between grain yield per plant and other plant parameters as follows:

$$GYP = 134 - 26.11\ (NCP) + 5.92\ (NCM) + 0.139\ (TNU) + 150.72\ (PCP^a) - 0.083\ (TPU^a) - 360.12\ (TPG) + 0.266\ (TPTG).$$

This equation accounted surprisingly for almost all the total variation ($r = 0.99$). Dry matter yield at silking and nitrogen concentrations in the grain were deleted. This also showed that grain yield per plant could have been satisfactorily predicted by this equation.

Response of selected families to applied phosphorus.

Dry matter yield data for selected families at silking are shown in Table 5. No differential response to applied P appeared between high and low P accumulators in 1975. Both groups were similar in the efficiency with which they utilized P for dry matter production and showed higher dry matter yield at 40 kg P/ha. Differences, however, were not significant at 5% level of probability.

Phosphorus concentrations of high and low P accumulators were not different at the two sampling dates, but a trend of response to rates was observed for TPU^a (Fig. 3). Total phosphorus uptake of controls varied from 77 mg P/plant to 97 mg P/plant for low P accumulators and from 89 mg P/plant to 110 mg P/plant for high P accumulators.

Similarity of family response in terms of TPU^a may possibly be explained as follows: (a) the families were not P-efficient or P-inefficient because selection was not made on a sufficiently P-stressed medium. (b) The limited number of replications (2) on which plant tissue analysis was based did not

Table 5. Phosphorus concentrations (%) at two sampling dates, total phosphorus uptake (TPU[a]) at silking, dry matter yield at silking (DMYP[a]), total phosphorus translocated into grain (TPTG) and grain yield per plant of high and low P accumulators as affected by phosphorus applications in the field, St. John, Kansas, 1975. (Experiment 2)

Family	Applied P Kg/ha	Phosphorus (%) Date 1	Date 2	TPU[a] mg P/plant	DMYP[a] gm/plant	TPTG mg P/plant	GYP gm/plant
1	0	0.24	0.15	106	71	275	96
	20	0.31	0.16	114	72	260	110
	40	0.25	0.15	126	85	254	96
20	0	0.24	0.13	89	69	230	102
	20	0.24	0.18	167	89	309	93
	40	0.31	0.15	141	92	229	102
41	0	0.25	0.14	100	69	-	-
	20	0.28	0.12	84	70	-	-
	40	0.25	0.14	133	91	-	-
73	0	0.30	0.15	110	70	232	119
	20	0.33	0.14	126	88	247	114
	40	0.38	0.18	138	74	209	129
8	0	0.27	0.15	97	63	214	86
	20	0.28	0.19	131	67	258	60
	40	0.31	0.16	148	92	262	90
61	0	0.28	0.15	93	61	219	113
	20	0.24	0.16	92	59	189	93
	40	0.27	0.17	154	88	225	77
70	0	0.26	0.13	91	65	273	104
	20	0.19	0.16	120	69	213	111
	40	0.25	0.16	125	78	238	119
72	0	0.24	0.15	92	59	222	73
	20	0.32	0.14	101	71	165	69
	40	0.32	0.18	128	71	205	117
98	0	0.26	0.14	77	51	181	102
	20	0.24	0.13	81	63	198	79
	40	0.31	0.14	94	65	222	84
$LSD_{.05}$							
Family (F)		ns	ns	ns	ns	ns	ns
Treatment (T)		ns	ns	ns	12.5	ns	ns
F X T		ns	ns	ns	ns	ns	ns

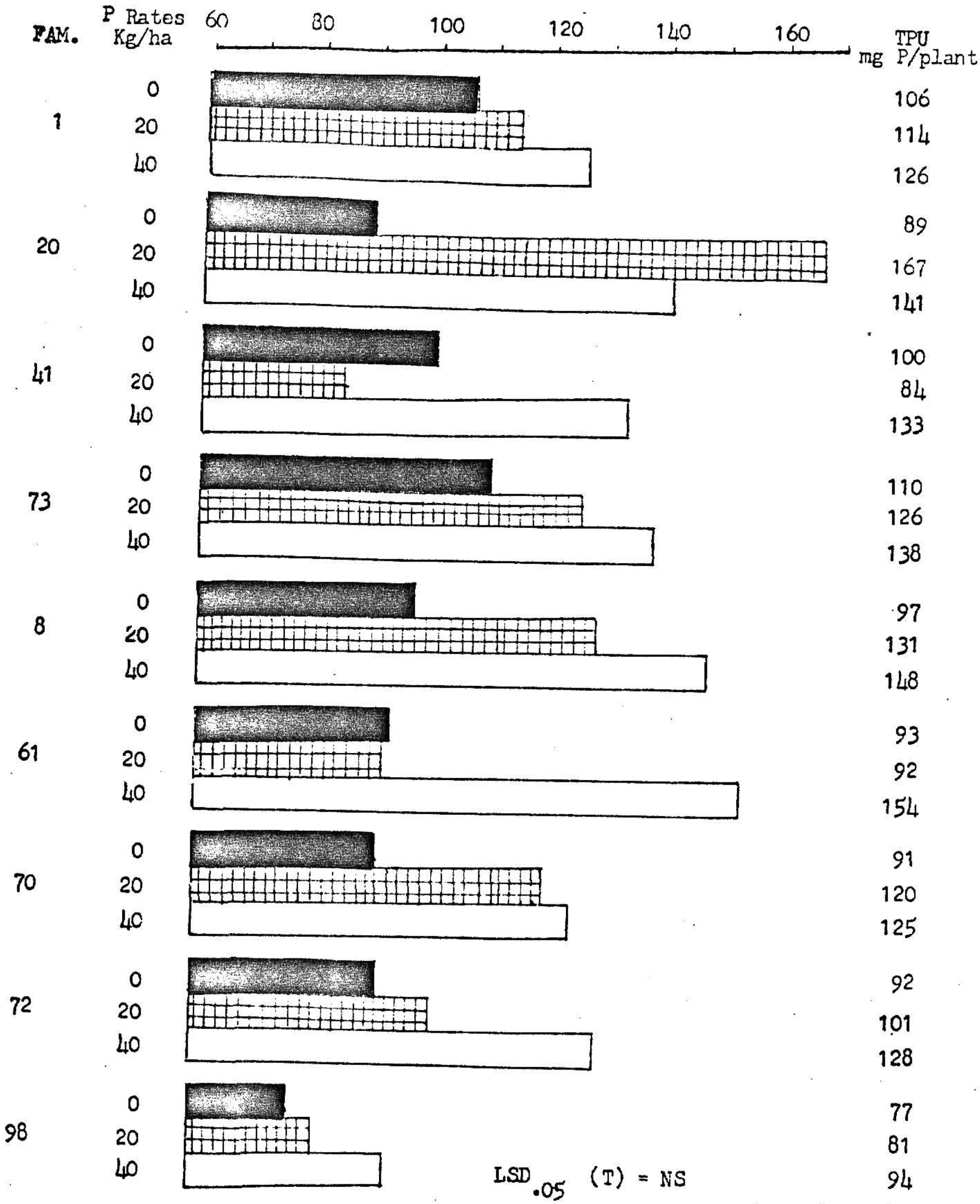

Fig. 3. Total phosphorus uptake of selected families (mg P/plant) as affected by phosphorus applications in the field, St John, Kansas, 1975. (Experiment 2)

allow an adequate estimation of the P status of different families at silking. Better evaluation or better selection may have been made across several locations using 3 or 4 replications.

Some differences were apparent in nitrogen concentrations at the first sampling but few differences were noted in K concentrations. Plant nitrogen and potassium concentrations generally decreased by the second sampling date and P response of low and high P accumulators was of the same magnitude and not significantly different.

Zinc concentrations were critical (below 15 ppm) for both groups of accumulators at the first sampling and increased by the second sampling date (Table 6) indicating better availability of Zn probably due to a greater mineralization of corn stalks plowed down before planting. This was confirmed by the disappearance of interveinal chlorosis symptoms by silking.

Grain yield per plant were generally inconclusive and were not affected by the rates of applied P because of the heavy southwestern corn borer damage during the growing season. Phosphorus concentrations of the grain and total phosphorus translocated into grain were not significantly different for families and rates of applied P.

Greenhouse Experiments

Response of selected maize families to soil applied phosphorus.

Greenhouse investigations comparing the responsiveness of low and high P accumulators were conducted on a low P Muir silt loam soil with four P variables from MCP. Corn plant heights taken 24 days after planting are shown in Appendix Table III. Significant differences in plant height were found between families and between P rates, but no differential response was apparent between P accumulators. All the treatments produced apparent P response over the controls. (Fig. 4).

Table 6. Nitrogen, potassium concentrations (%), zinc concentrations (ppm) and zinc uptake (ug/plant) of high and low P accumulators as affected by phosphorus applications in the field, St. John, Kansas, 1975. (Experiment 2)

Family	Applied P Kg/ha	N	K	Zn	N	K	Zn	Zn
		--- % ---		ppm	--- % ---		ppm	ug/plant
		Date 1			Date 2			
1	0	3.48	2.24	20	1.88	1.24	39	275
	20	3.75	2.24	17	1.75	1.23	36	260
	40	3.68	2.19	18	1.64	1.18	30	254
20	0	4.02	2.02	24	1.73	1.23	34	230
	20	3.49	2.25	21	1.74	1.40	35	309
	40	3.64	2.08	14	1.67	1.51	25	229
41	0	3.71	2.13	27	1.60	1.23	29	197
	20	3.71	2.19	26	1.59	1.12	23	164
	40	3.47	2.25	18	1.55	1.12	25	221
73	0	4.05	2.25	27	1.75	1.23	34	232
	20	3.69	2.19	18	1.63	1.29	29	247
	40	3.65	1.90	24	1.60	1.00	29	209
8	0	3.77	2.25	27	1.72	1.46	34	214
	20	3.97	2.30	29	1.70	1.45	39	258
	40	3.69	1.85	20	1.71	1.12	29	262
61	0	3.44	2.24	21	1.90	1.23	35	219
	20	3.58	2.47	18	1.81	1.18	34	189
	40	3.73	1.91	11	1.65	1.17	26	225
70	0	3.64	1.92	16	1.51	1.18	42	273
	20	3.44	2.25	15	1.85	1.23	32	213
	40	3.58	2.19	21	1.83	1.47	31	238
72	0	3.30	2.19	17	1.66	1.23	38	222
	20	3.49	1.91	17	1.70	1.34	24	165
	40	3.66	2.02	13	1.68	1.40	30	205
98	0	3.72	2.02	23	1.65	1.40	36	181
	20	3.43	2.13	17	1.59	1.45	32	198
	40	3.65	1.91	24	1.61	1.12	35	222
$LSD_{.05}$								
Family (F)	=	0.18	ns	4.60	ns	ns	5.64	ns
Treatment (T)	=	ns	ns	2.66	ns	ns	3.26	ns
F X T	=	0.31	ns	6.51	ns	ns	ns	ns

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Fig. 4. Growth response of high and low P accumulators to phosphorus applications in the greenhouse (Experiment 1). In the upper photo, a low P accumulator (61) and a high P accumulator (20) showed about the same response. Similar results are demonstrated in the lower picture with low P accumulator (98) and high P accumulator (41).

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FAMILY RESPONSE TO PHOSPHORUS APPLICATIONS
FAMILY
61
0
61
60 PPM P
20
0
20
60


FAMILY
98
0
98
60 PPM P
41
0
41
60

Effects of P rates on plant dry weights are presented in detail in the Appendix, Table III. Increasing phosphorus applications increased significantly dry weights of 25 day-old maize seedlings (Fig. 5). Approximately twice as much dry matter was produced at the 60 ppm P rate compared to the controls. The lowest dry weight (2.65 gm/pot) was produced in a control pot of a low P accumulator and the highest (5.70 gm/pot) was produced at 60 ppm P of a high P accumulator. Both groups, however, did not differ significantly in means of dry matter and yielded about equally at 60 ppm P. Family by P rate interactions were not significant indicating similar responses of selected families to varying P applications.

Fig. 6 shows P concentrations and total phosphorus uptake by the aerial portions of the selected families. The same trends were observed for P concentrations as for dry matter production. Phosphorus concentrations were significantly increased by increased P rates. High P accumulators had slightly higher P concentrations and total phosphorus uptake at low P treatment than at higher P levels. Phosphorus concentrations ranged from 0.11% to 0.29% P. Total P uptake in the plants varied from 35 mg P/pot in control pot to 15 mg P/pot at 60 ppm for high P accumulators. Similarly, low P accumulators increased their P concentrations from 0.11% to 0.29% P whereas total P uptake ranged from 3.07 mg P/pot in the control pot to 15.85 mg P/pot at 60 ppm P (Fig. 7; Appendix Table IV).

The results of this experiment agree with the work of Bradford et al. (1966) who reported that growth yield of various hybrids grown under different soil fertility levels was about equal for low and high level P accumulators. Baker and Woodruff (1962) reported earlier that phosphorus evaluation in the greenhouse may be altered by the environment and accumulation by young plants in the greenhouse may not reflect the relative accumulation

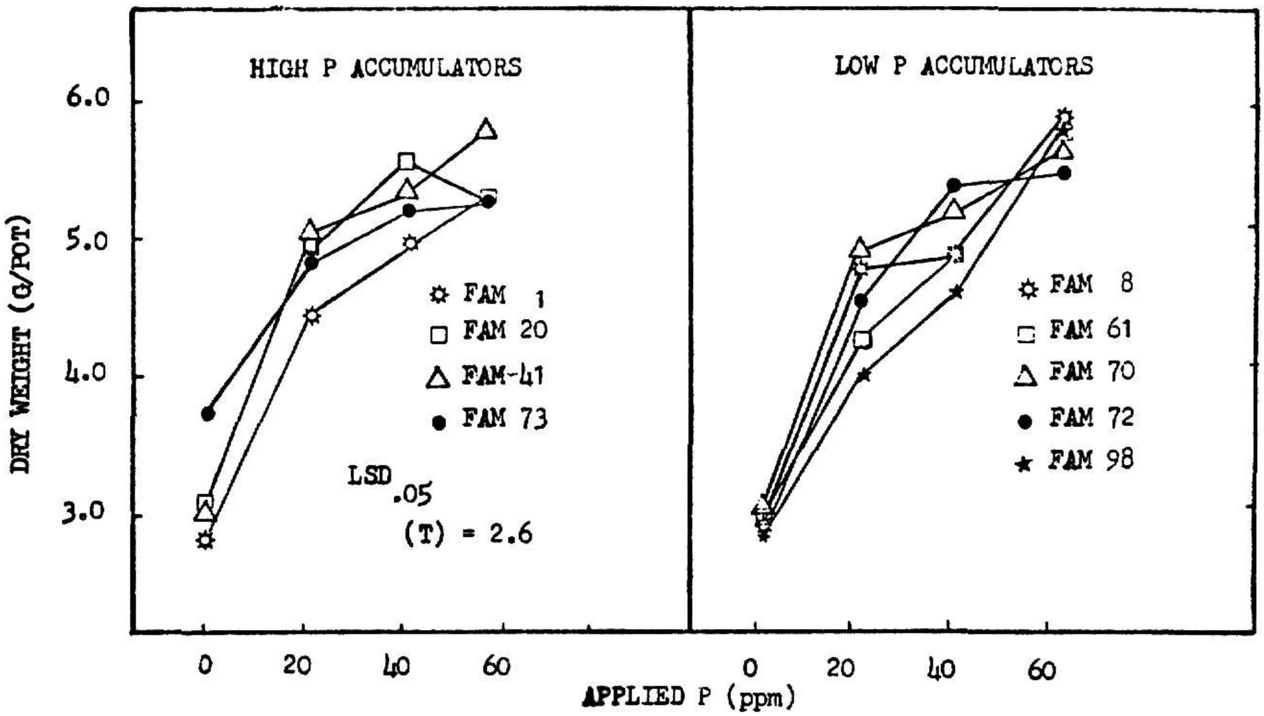


Fig. 5. Dry weight (g/pot) of 25 day-old maize seedlings of high and low P accumulators as affected by phosphorus applications. (Greenhouse, Experiment 1)

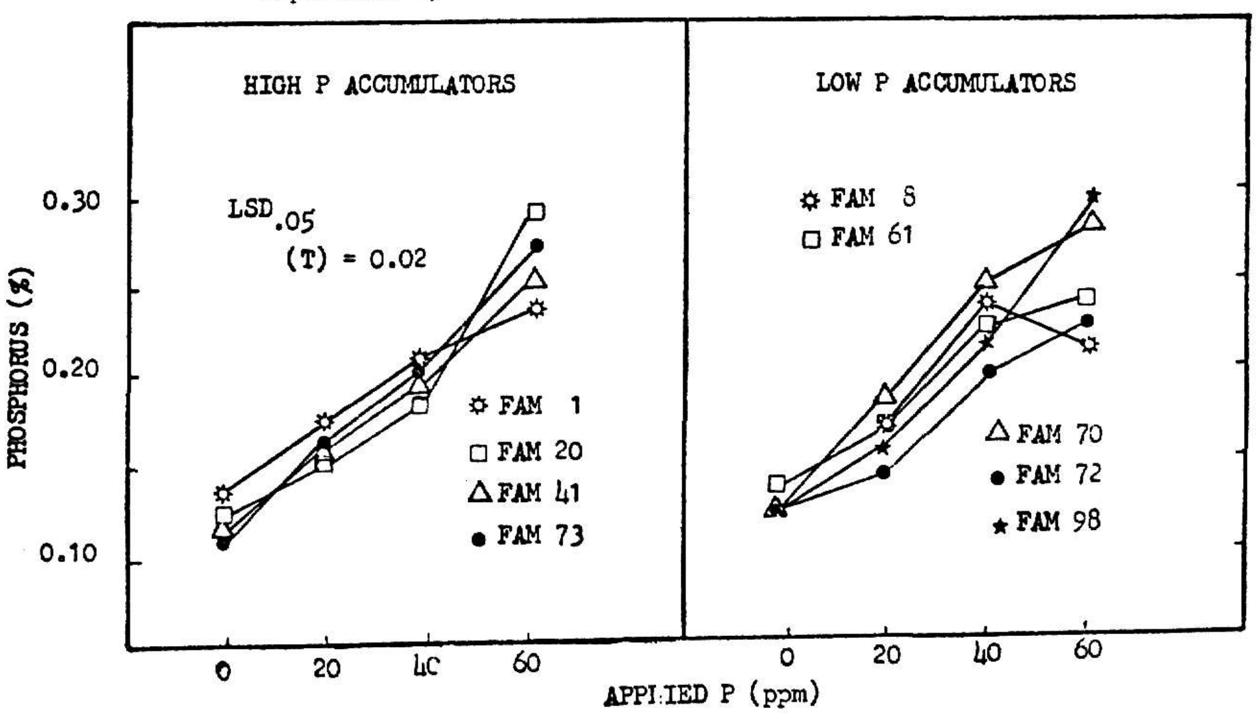


Fig. 6. Phosphorus concentrations (%) of 25 day-old maize seedlings of high and low P accumulators as affected by phosphorus applications. (Greenhouse, Experiment 1)

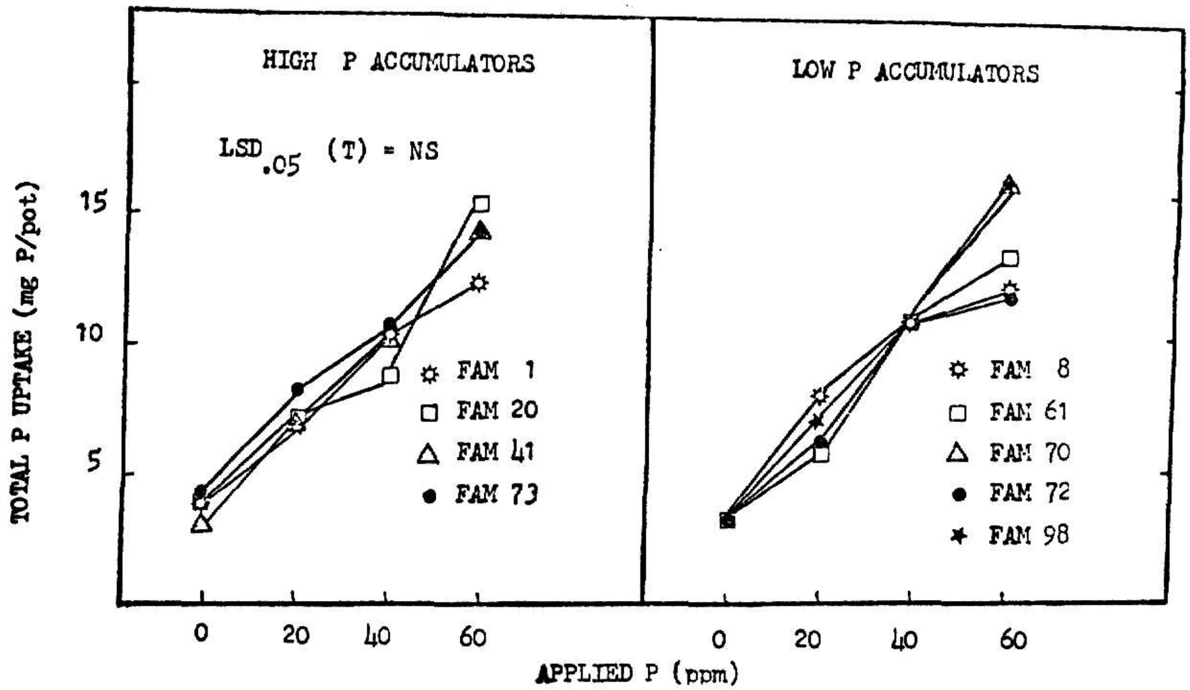


Fig. 7. Total phosphorus uptake (mg P/pot) of 25 day-old maize seedlings of high and low P accumulators as affected by phosphorus applications. (Greenhouse, Experiment 1)

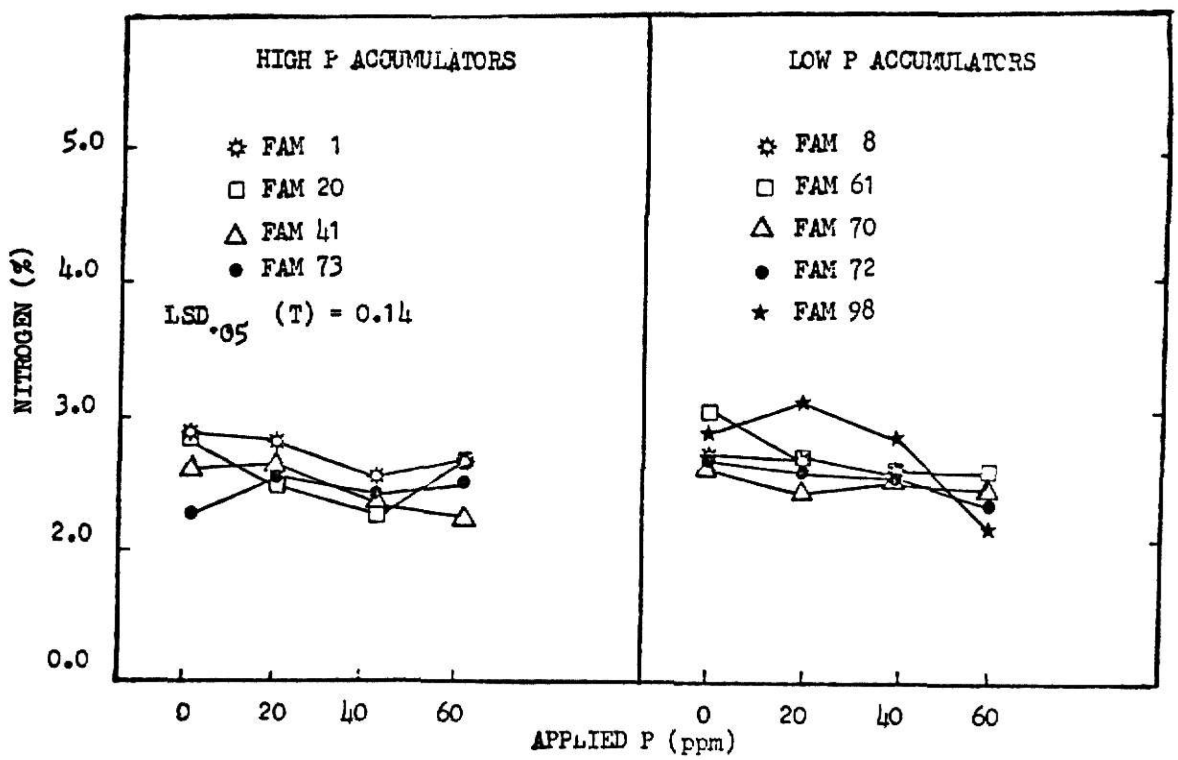


Fig. 8. Nitrogen concentrations (%) of 25 day-old maize seedlings of high and low P accumulators as affected by phosphorus applications. (Greenhouse, Experiment 1)

by the same hybrids grown to maturity in the field.

Nitrogen concentrations varied from 2.10% to 3.00% N and was decreased significantly (dilution effect) by increased rates of applied phosphorus (Fig. 8; Appendix Table V). Plant potassium concentrations ranged from 4.77% to 6.57% K and were considered to be in the luxury consumption range due to applied K (80 ppm K) and higher soil K as revealed by 1N NH_4OAc soil test (117 ppm K). Consequently, rates of applied P did not greatly affect K absorption (Fig. 9).

Zinc concentrations were significantly depressed by applications of phosphorus. Zinc concentrations were generally lower at 40 and 60 ppm P rates than at 0 and 20 ppm P treatments (Fig. 10; Appendix Table VI). There was, however, no indication that low P accumulators absorbed more Zn than high P accumulators to confirm that this depression occured in the plant rather than in the soil as was pointed out by Stukenholtz (1966). Zinc uptake, however, increased and apparently was not affected by P rates. It may be concluded that P-Zn interactions were present but the range was not critical.

Visual symptoms of phosphorus deficiency were observed on the control pots and some of the 20 ppm P treatments 18 days after emergence on high as well as low P accumulators. Those symptoms indicated probably that phosphorus concentrations were critical for those treatments.

Dry matter yields were plotted against phosphorus concentrations, total phosphorus uptake and N and K concentrations according to Ulrich and Hills (1967) to study the dry matter-nutrient relationships. Relationship of dry matter yield to P concentrations and dry matter to total P uptake were essentially the same (Fig. 11) and suggested that growth was not yet seriously affected by the deficiency symptoms.

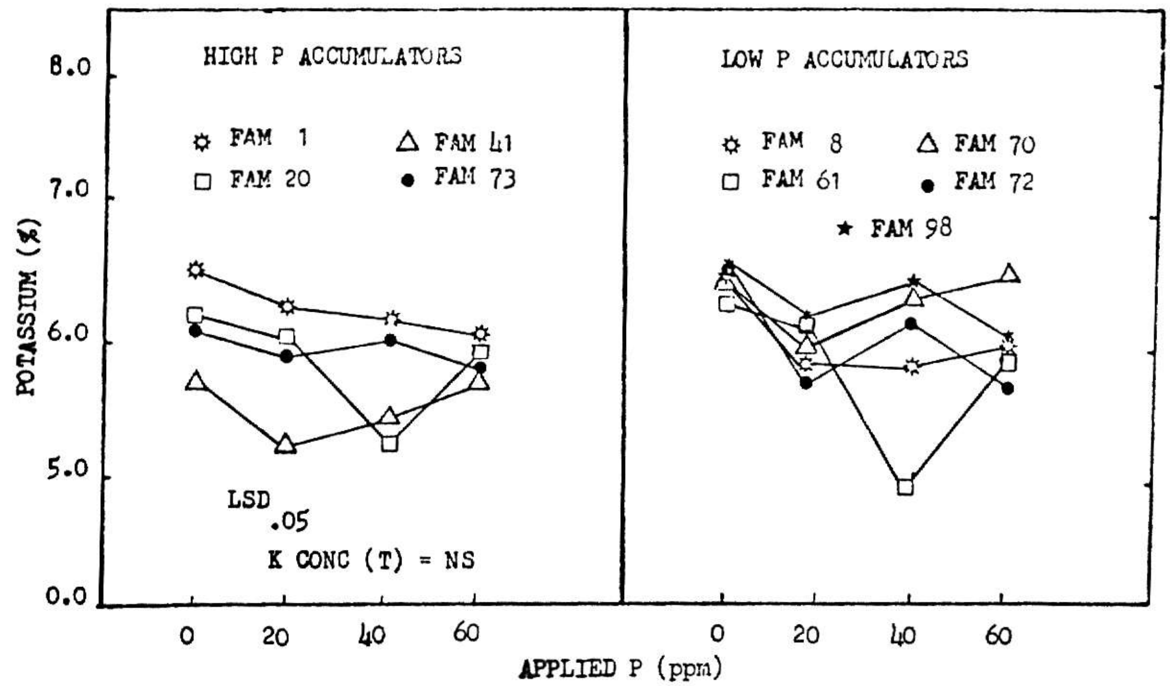


Fig. 9. Potassium concentrations (%) of 25 day-old maize seedlings of high and low P accumulators as affected by phosphorus applications. (Greenhouse, Experiment 1)

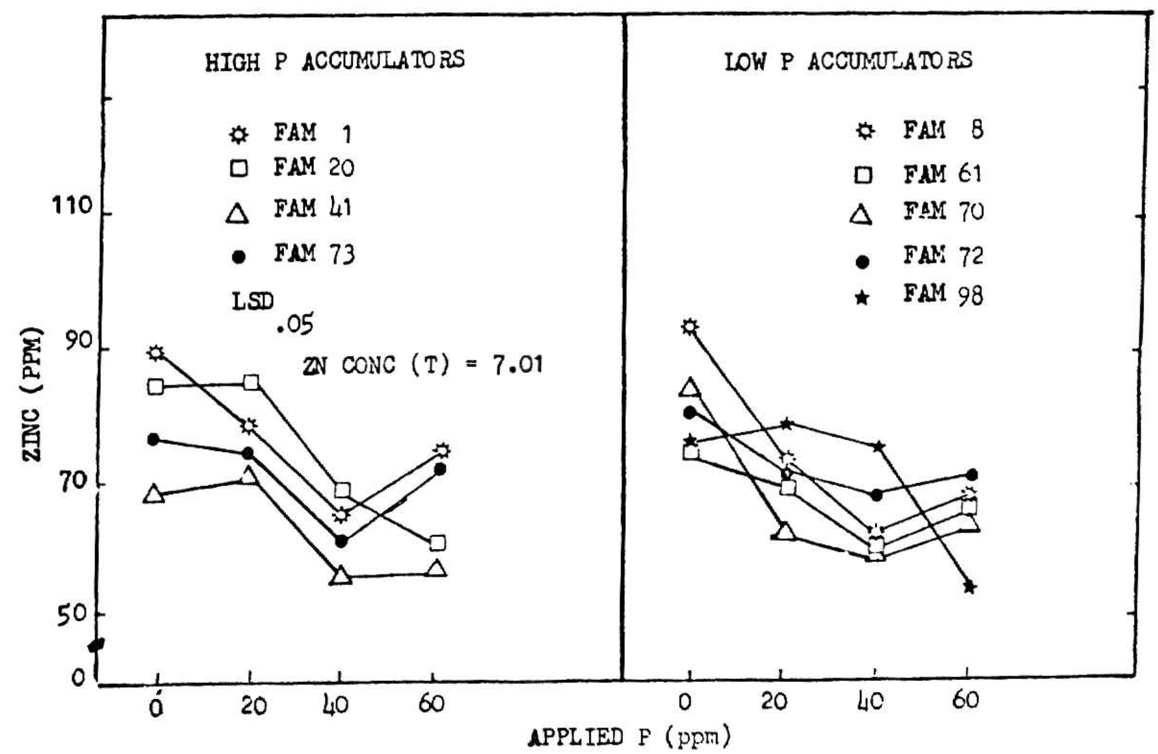


Fig. 10. Zinc concentrations (ppm) of 25 day-old maize seedlings of high and low P accumulators as affected by phosphorus applications. (Greenhouse, Experiment 1)

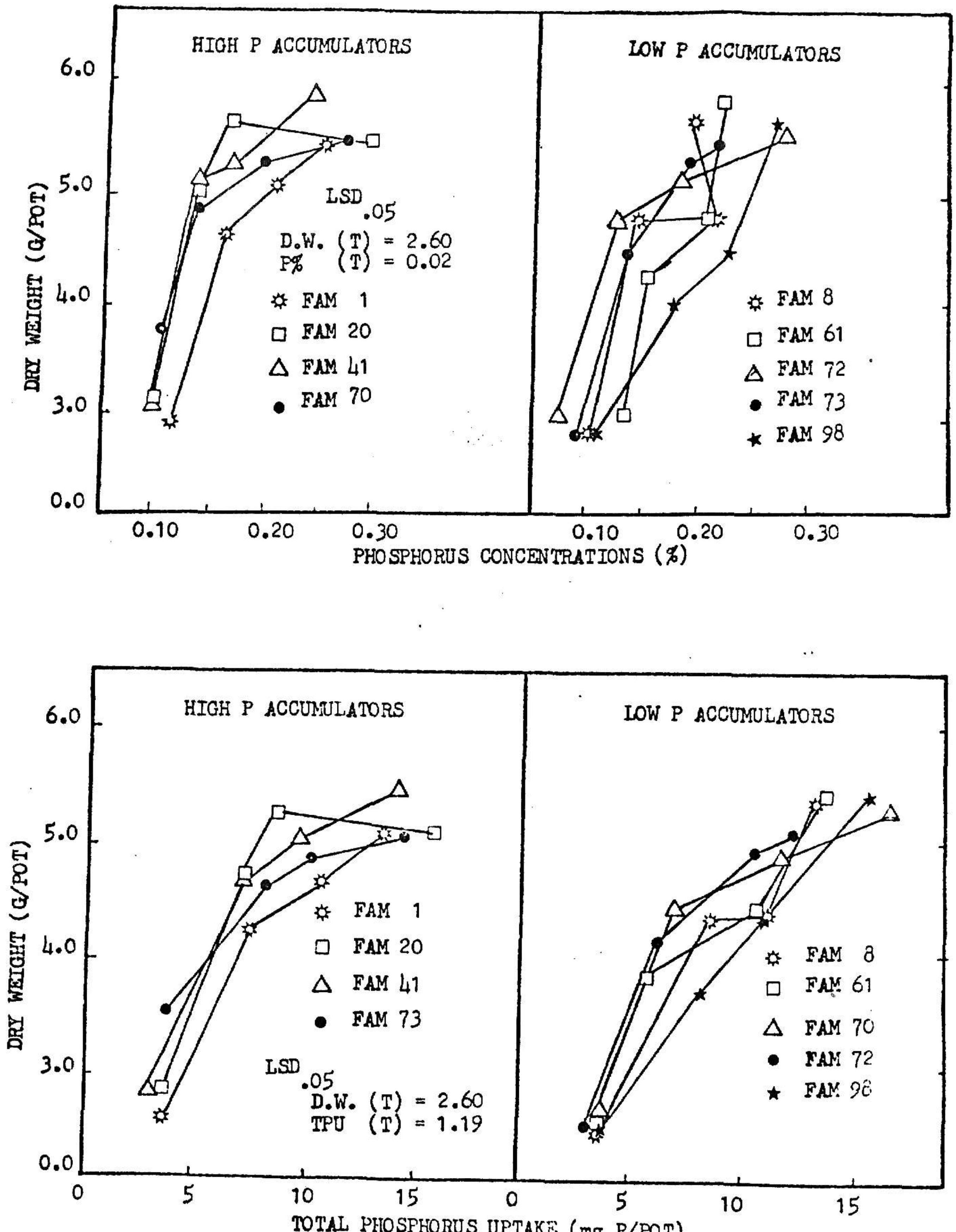


Fig. 11. Dry weight-phosphorus concentrations and dry weight-total phosphorus upta relationships of high and low P accumulators. (Greenhouse, Experiment 1)

A different pattern was observed for N and K concentrations and dry matter which were apparently depressed (Fig. 12). This decrease indicates that N and K concentrations were diluted with yield response to P. Terman and Allen (1974) found that N, K, Ca and Mg were diluted in corn with response to applied P. Terman and Bengston (1973) also reported a dilution effect due to P applied to loblolly pine seedlings (Pinus L.) as dry matter yield increases from 3 gm/pot without applied P to 58 gm/pot with fine TSP. In our experiment, however, plants made very little growth since dry weight increased from 2.66 gm/pot in the control pot (low P accumulator) to only 5.70 gm/pot at 60 ppm P (high P accumulator).

Comparative response of selected maize families to potassium ortho (KOP) and potassium pyrophosphate (KPP).

The second greenhouse experiment was designed to evaluate the responsiveness of low and high P accumulators to KOP and KPP, at 0, 20, 40 and 60 ppm P. Comparative data for KOP and KPP as sources of P are presented in Appendix Tables VII-IX and in Figs. 13 through 16). Plant dry weights were low for both P carriers and could be due to inefficient utilization of phosphorus by Mex-Mix families. This was possibly confirmed in later hydrolysis studies in solution culture. Generally, high P accumulators had higher dry weight and total phosphorus uptake in tops than low P accumulators. Phosphorus applications of both P carriers significantly raised phosphorus concentrations and total P uptake by plant tops. However, both carriers were equally effective in supplying P for low and high P accumulators. Significantly differing total P uptake was noted between all P rates of both carriers. The increasing order of families in terms of total P uptake were >3 >20 >98 >61.

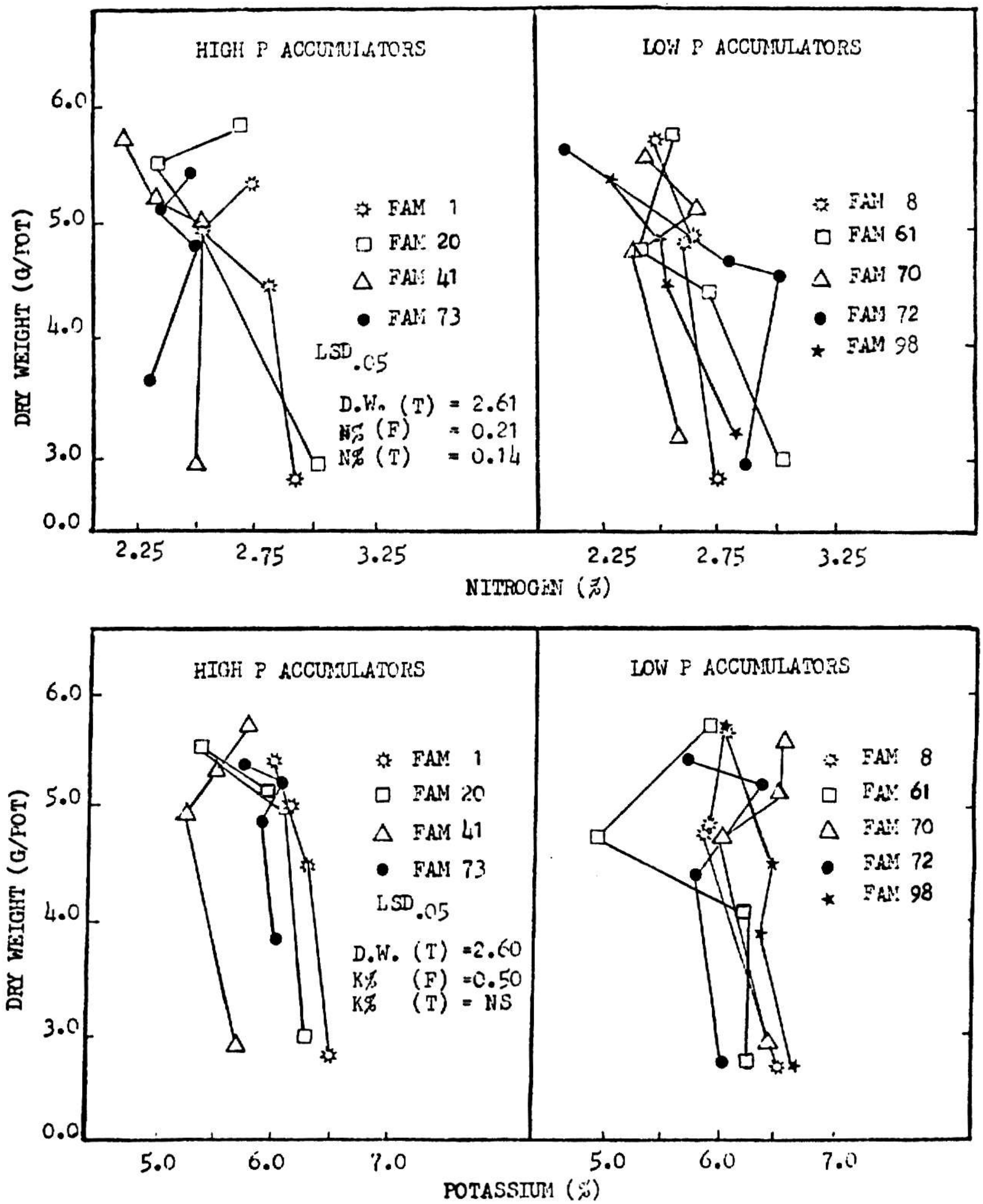
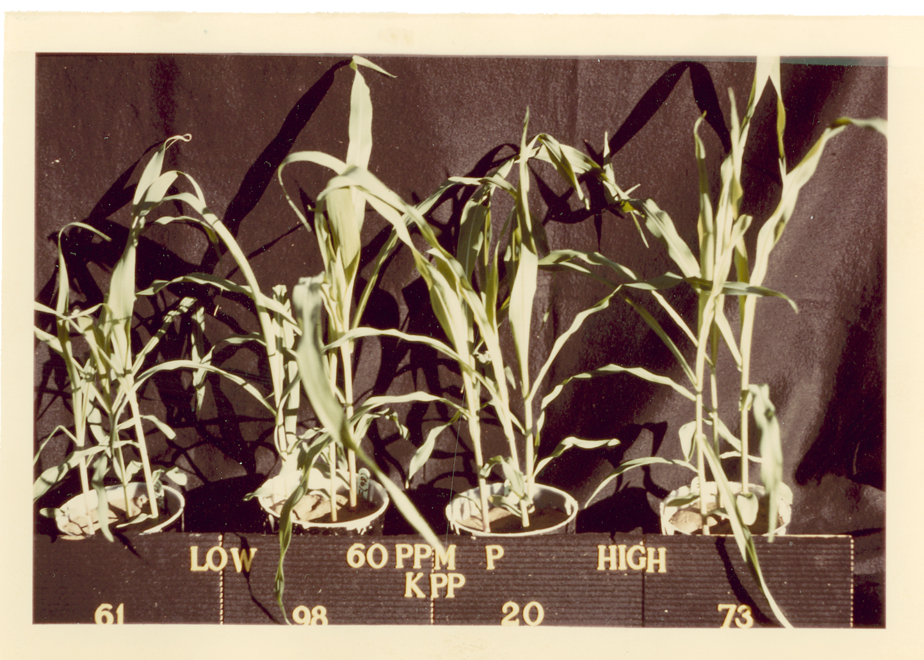


Fig. 12. Dry weight-nitrogen and dry weight-potassium concentrations relationships of high and low P accumulators. (Greenhouse, Experiment 1)

Fig. 13. Growth of low and high P accumulators as affected by two phosphorus carriers at 60 ppm P. KOP and KPP designations refer to potassium ortho and pyrophosphate, respectively.


LOW
60 PPM P
KOP
HIGH
61
98
20
73


LOW
60 PPM P
KPP
HIGH
61
98
20
73

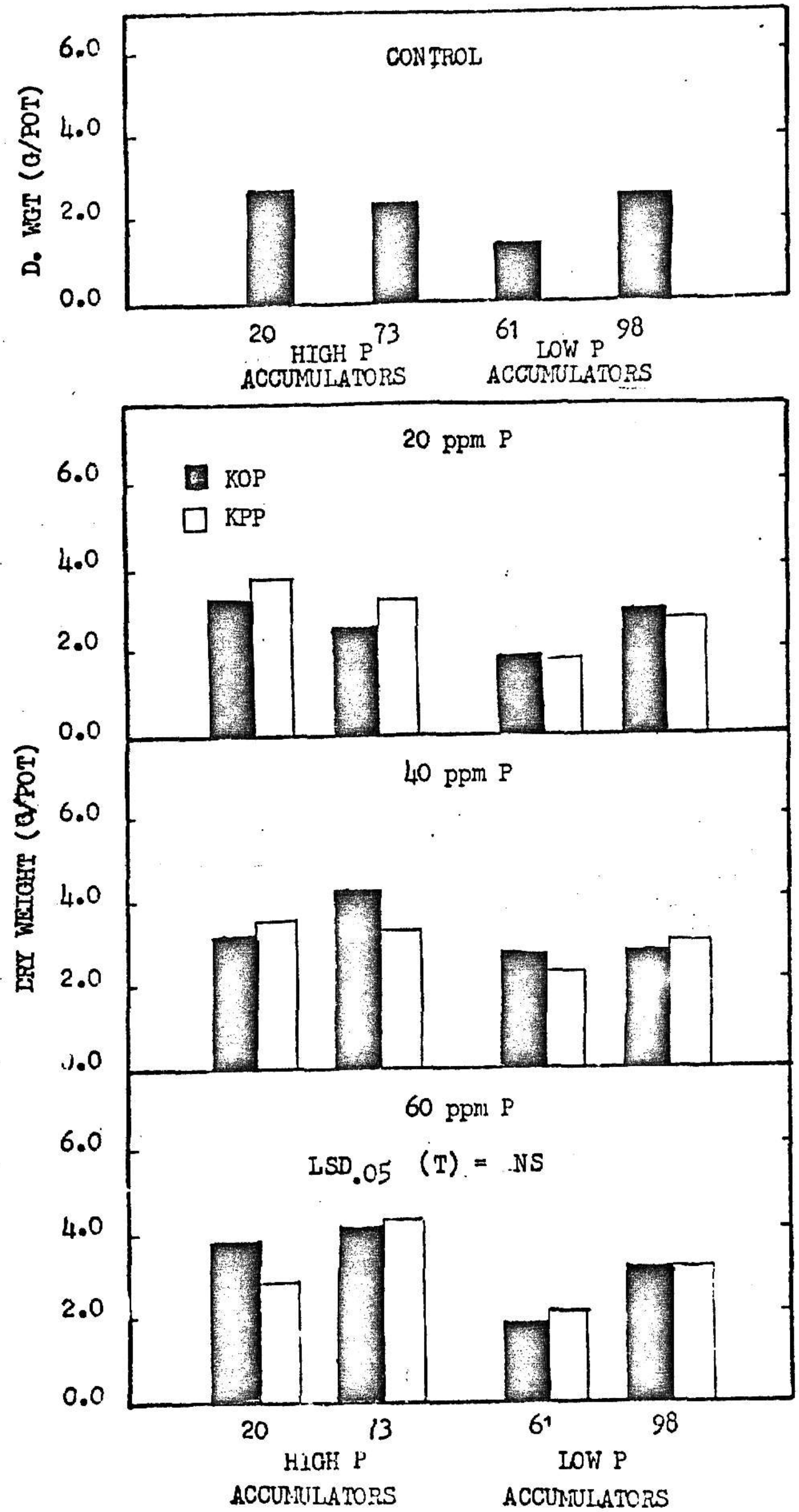


Fig. 14. Dry weight (g/pot) of 20 day-old maize seedlings of high and low P accumulators as affected by P sources and rates of applied P. (Greenhouse, Experiment 2).

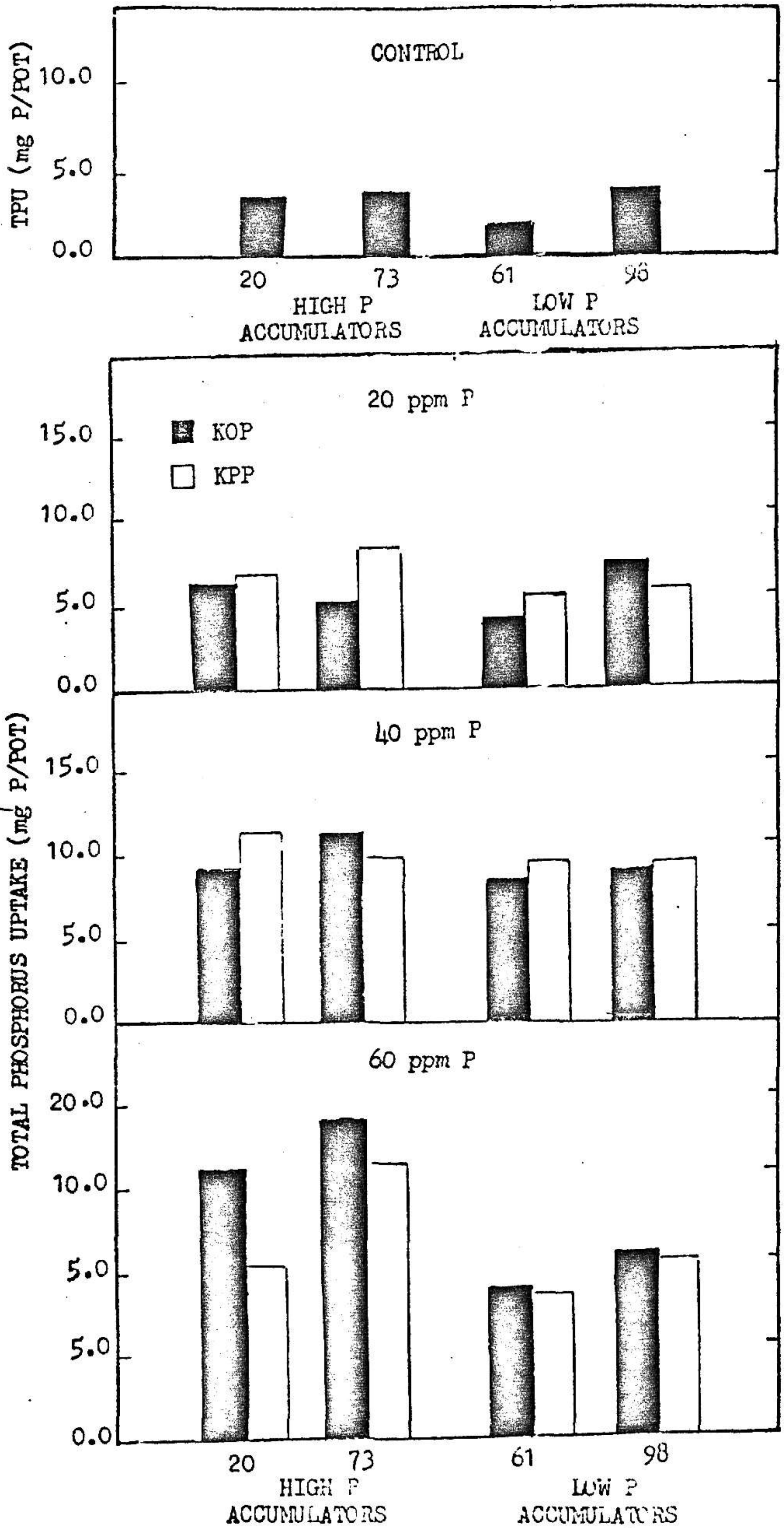


Fig.15. Total phosphorus uptake (mg P/pot) of 20 day-old maize seedlings of high and low P accumulators as affected by P sources and rates of applied P.(Greenhouse, Experiment 2).

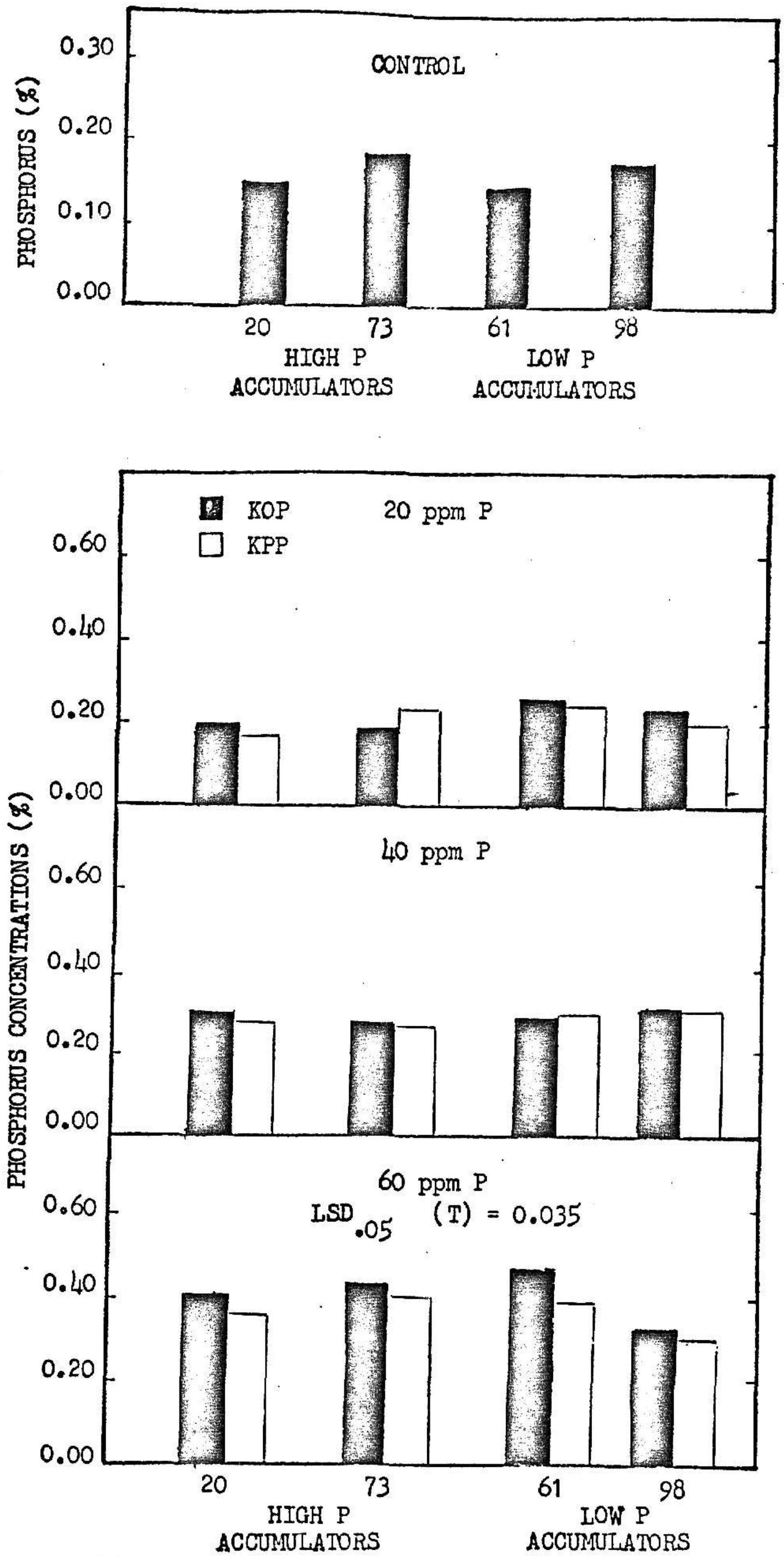


Fig. 16. Phosphorus concentrations (%) of 20 day-old maize seedlings of high and low P accumulators as affected by P sources and rates of applied P. (Greenhouse, Experiment 2).

Nitrogen and potassium concentrations were variable and were not increased by phosphorus applications (Appendix Table VIII). KPP produced significantly greater depressions of Zn concentrations and Zn uptake in plant tissue at high P rates than did KOP (Appendix Table IX). Adriano and Murphy (1972) found that Zn uptake was depressed more by applications of ammonium polyphosphate (APP) than by monoammonium polypholyphosphate (MAP).

Results of this experiment showed that utilization of P from both carriers was similar on a slightly acid soil. Sutton and Larsen (1964) found that PP was inferior to OP as sources of P for plant uptake and reported that when rapid hydrolysis occured there was no difference in P uptake from the two sources.

Soil pH ranged from 4.1 to 5.0 at the termination of the experiment (initial pH was 5.9). The lowered pH, together with the higher temperature in the greenhouse (most important hydrolysis factors; Van Wazer, 1952) suggests that a fairly rapid hydrolysis occured (Hossner and Melton, 1970; El Reweiny, 1976).

Available P extracted by the weak Bray method revealed that where KPP was applied soil analysis showed high P availability (Table 7). Supporting the hypothesis of rapid P hydrolysis.El Reweiny et al. (1976) observed that an increase of OP in condensed-phosphate-treated soil was a measure of the rate of hydrolysis of condensed phosphates. Since the rate of hydrolysis was fairly rapid, the hydrolysis could not be solely attributed to the ability of Mex-Mix families to hydrolyze KPP in soil. Sutton and Larsen (1964) reported that hydrolysis of PP in soil was largely dependent on an enzymatic process.

Table 7. *Residual available P (ppm) from cropped soils, as affected by P carriers and rates of applied P at the termination of the experiment. (Experiment 2)

		KH_2PO_4 (KOP)			$K_4P_2O_7$ (KPP)		
		Applied P (ppm)			Applied P (ppm)		
Family	Control	20	40	60	20	40	60
		**Available P, ppm					
20	19	--	--	--	--	--	57
73	19	35	--	56	--	--	58
61	20	28	32	52	25	17	46
98	12	--	--	--	27	--	--

* Chemical analyses were performed on a few samples only.

** Available P was determined by extraction with 0.025 N HCl in 0.03 N NH_4F.

Growth Chamber Experiments

Potassium pyrophosphate hydrolysis rates of selected families, in solution culture.

Kinetics of PP hydrolysis by roots of low and high P accumulators were compared at a substrate concentration of 60 ppm P in the growth chamber. Appearance of OP in KPP is shown in Fig. 17 and Table 10 for the four families. The zero order plot patterns were quite similar for all the families and are only presented for families 61 (low P accumulator) and 20 (high P accumulator). The zero order rate constants for KPP hydrolysis were 9.15×10^{-3}, 10.87×10^{-3}, 9.27×10^{-3} and 7.70×10^{-3} mmoles/hr/gm of fresh roots respectively for families 8, 61, 20 and 73.

Hydrolytic abilities of the families may be rated in the order 61 > 8 > 20 > 73. In general, approximately 50% of the supplied PP was hydrolyzed after 30 hours by low as well as by high P accumulators.

The linear equations fitted by the least squares method were: $Y = 0.159 + 0.1054X$, $Y = 0.014 + 0.1196X$, $Y = 0.0085 + 0.1019X$ and $Y = 0.549 + 0.0920X$ respectively for families 8, 61, 20 and 73. All the correlation coefficients were high (above 0.98). Test of slopes (b values) showed that they were homogeneous and therefore confirms the similarity of the hydrolytic abilities of the selected families.

Since the families were not different in their PP hydrolytic abilities, no attempts was made to study the phosphatase activity of the roots. Clark and Brown (1974) found that phosphatase activities of the roots of corn inbred lines was responsible for greater P availability for transport to the tops.

This experiment, however, substantiates results obtained in the earlier greenhouse studies which showed that Mex-Mix maize families were essentially equal in absorbing P and took up the same amounts of P from MCP, they were

Table 8. Hydrolysis of KPP* at several time intervals by high and low P accumulators in the growth chamber.

Time (hours)	Low				High			
	P accumulators							
	8		61		20		73	
	OP**	PP	OP**	PP	OP**	PP	OP**	PP
0	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00
5	0.11	0.89	0.12	0.88	0.11	0.89	0.14	0.86
10	0.20	0.80	0.18	0.82	0.15	0.85	0.26	0.74
15	0.33	0.67	0.26	0.74	0.30	0.70	0.36	0.64
20	0.38	0.62	0.37	0.63	0.49	0.51+	0.40	0.60
25	0.43	0.57	0.49	0.51	0.43	0.57	0.48	0.52
30	0.52	0.48	0.59	0.41	0.49	0.51	0.53	0.47

* Data from composite samples from 2 replications with 5 plants/container.

** Data are expressed as fraction of PP, assuming that KPP = 1.00 at 0 time.

+ Not included in the fitted linear equation.

Table 9. Hydrolysis of KPP* at several time intervals by Mex-Mix family 44 and Dekalb XL 390 maize seedlings in the growth chamber.

Time (hours)	Mex-Mix family 44			Dekalb XL 390		
	OP**	PP	ln PPo/PP	OP**	PP	ln PPo/PP
0	0.01	0.99	0.00	0.01	0.99	0.00
5	0.13	0.87	0.13	0.14	0.86	0.14
10	0.19	0.81	0.20	0.25	0.75	0.28
15	0.27	0.73	0.30	0.35	0.65	0.42
20	0.34	0.66	0.41	0.42	0.58	0.54
25	0.40	0.60	0.50	0.49	0.51	0.66
30	0.49	0.51	0.66	0.55	0.45	0.79

* Data from composite samples from 4 replications with 5 plants/container.

** Data are expressed as fraction of PP, assuming that KPP = 1.00 at 0 time. PP = concentration of pyrophosphate at 0 time; PP = concentration of pyrophosphate at any given time T. Amount of OP in the blank at 0 time.

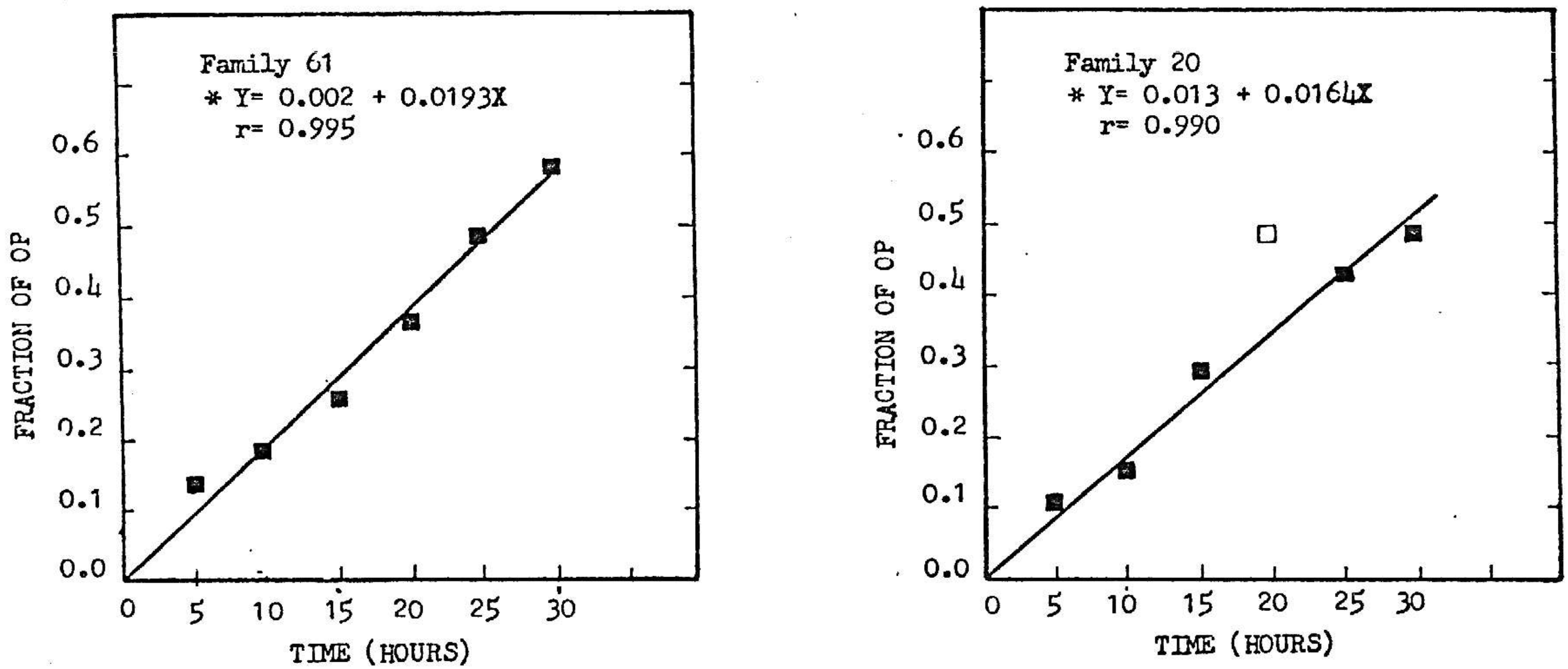
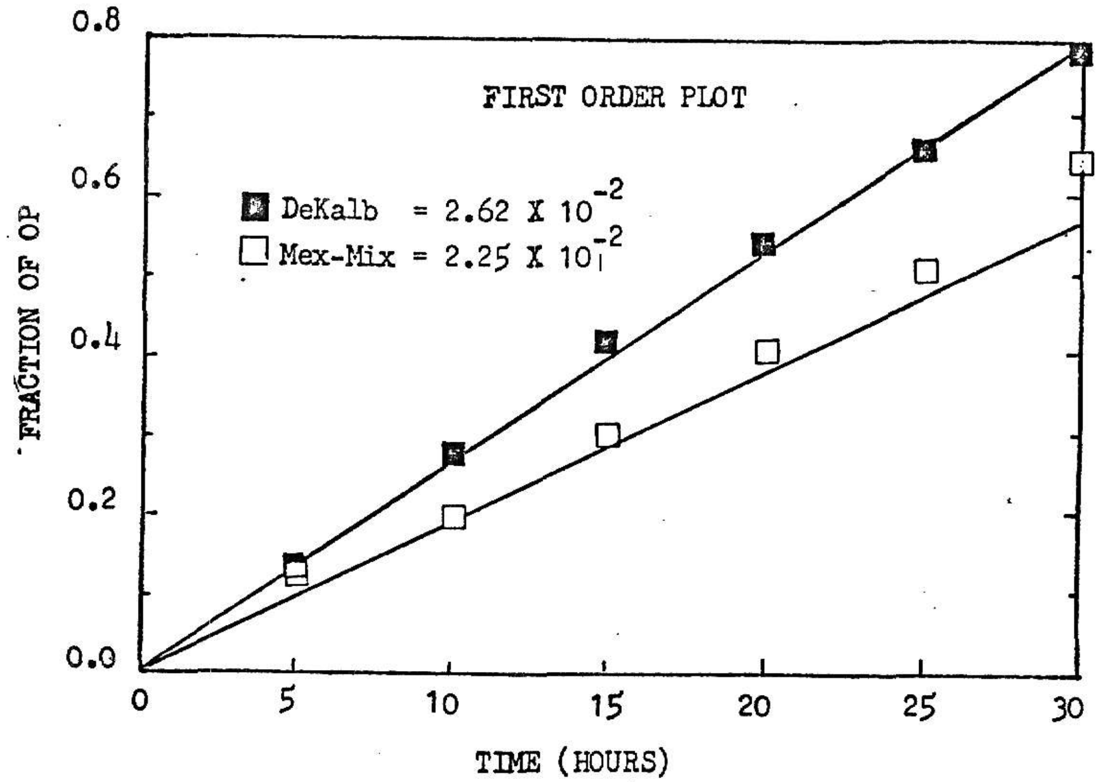


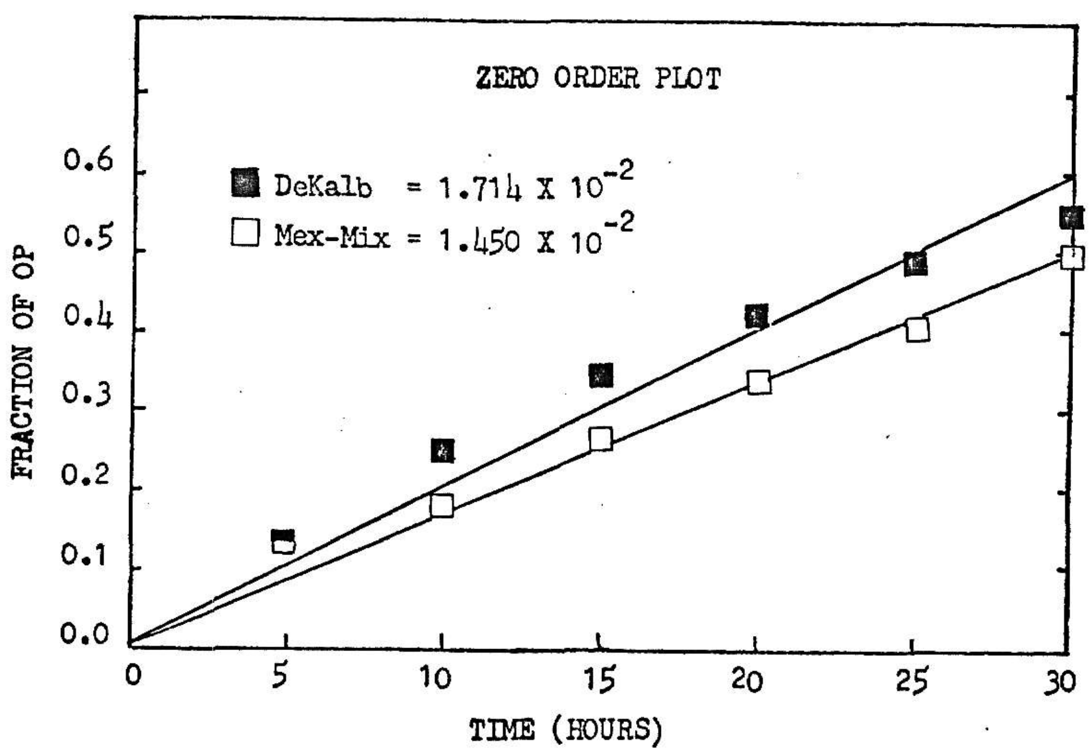
Fig. 17. Appearance of OP in the KPP solution at several time intervals as influenced by two maize families (61, low P accumulator; 20, high P accumulator).
* Linear equations are based on data from Table 8.

Fig. 18. Appearance of OP in the KPP solution at several time intervals as influenced by Mex-Mix (family 44) and Dekalb XL 390 maize seedlings.

Above: Ist order reaction

Below: Zero order reaction


FIRST ORDER PLOT
DeKalb = 2.62 X 10-2
Mex-Mix = 2.25 X 10-2
FRACTION OF OP
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
25
30
TIME (HOURS)


ZERO ORDER PLOT
DeKalb = 1.714 X 10-2
Mex-Mix = 1.450 X 10-2
FRACTION OF OP
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
20
25
30
TIME (HOURS)

also similar in their ability to hydrolyze PP in solution.

The second PP hydrolysis experiment, on the other hand, showed that Dekalb variety XL 390 was approximately 39% more efficient in hydrolyzing KPP than Mex-Mix (Table 9). Mex-Mix fitted the zero-order reaction while XL 390 followed the first order kinetics (Fig. 18). This suggests that the pyrophosphatase enzyme was a limiting factor for Mex-Mix and that in the case of the hybrid the reaction rate was dependent on the substrate concentration (Neidelands, 1958).

The rate constants were 3.685×10^{-4} mmoles/hr/gm of fresh roots and 5.11×10^{-4} hr^{-1} respectively for Mex-Mix and for the hybrid. The slopes were not significantly different at the zero order kinetics. However, phosphorus deficiency symptoms were more pronounced for Mex-Mix and this suggests that Mex-Mix was not able to utilize phosphorus properly from the solution.

This experiment indicates that within the same species, potential differences and abilities to hydrolyze PPP may be detected with intensive screenings and also NMR spectroscopy may be a useful tool in the evaluation of the hydrolytic abilities of genotypes.

SUMMARY AND CONCLUSIONS

Field experiments conducted to study variations in the concentrations and total uptake of phosphorus of 100 Mex-Mix maize families indicated that under a high nitrogen fertilization regime (200 kg N/ha), maize families showed large differences in terms of grain yield per plant (GYP), dry matter yield per plant ($DMYP^a$), phosphorus concentrations (PCP^a) and total phosphorus uptake (TPU^a) at silking. However, differences in nitrogen concentrations at silking (NCP^a), nitrogen concentrations in the plant at maturity (NCM), nitrogen concentrations in the grain (NCG), total nitrogen uptake (TNU^a) at silking and phosphorus concentrations in the grain were small and not significant. Total phosphorus translocated into grain (TPTG) was highly correlated with grain yield per plant (r = 0.908). There was no correlation between PCP^a and $DMYP^a$ with grain yield per plant. Plant parameter characteristics among low and high P accumulators were variable and it appeared that both groups of accumulators were different in their ability to translocate P and in their ability for grain formation.

In a second field experiment, few differences were noted among the same plant parameters of selected P accumulators but a trend toward different response to rates was shown for total phosphorus uptake and phosphorus concentrations of the plant at silking. Differences observed in 1974 field experiment were not repeated in 1975. It was apparent that a survey of germplasm aiming at selection for P efficient genotypes, as well as yield, may be affected by the environment.

Greenhouse studies showed that despite a two-fold dry matter increase from monocalcium phosphate monohydrate (MCP) at 60 ppm P, no variation existed in phosphorus concentrations and total phosphorus uptake among selected families. The only differences in phosphorus concentrations and total phosphorus uptake observed were due to P rates. PCP and TPU of both groups of accumulators were increased by P applications while nitrogen, potassium and Zn concentrations were depressed supporting the evidence of dilution due to response to increased P applications and antagonistic P-Zn effects.

Differential response to soil applied phosphorus was noted under greenhouse conditions with all rates of both carriers but because of rapid hydrolysis, other factors could have been involved. KPP and KOP had similar effects on P concentrations and total P uptake by tops of both groups of accumulators. Zinc concentrations and zinc uptake were more depressed by KPP than by KOP at higher rates of applied P.

Attempts to evaluate kinetics of hydrolytic abilities of families in KPP solution using a split root technique and nuclear magnetic resonance to determine different phosphorus species did not indicate differences among selected Mex-Mix P families. Half-lives of KPP were about 30 hours for all the selected families and test of slopes were not significantly different. The zero order rate constants were 9.15×10^{-3}, 10.87×10^{-3}, 9.27×10^{-3} and 7.70×10^{-3} mmoles/hr/gm of fresh roots respectively for families 8, 61, 20 and 73.

Comparisons of Mex-Mix (family 44) and Dekalb XL 390, a hybrid, produced striking differences in the behaviour of seedlings in KPP solution. The hybrid hydrolyzed more KPP than did Mex-Mix (39%) and fitted a first order reaction (5.11×10^{-4} hr^{-1}). Mex-Mix (family 44) followed a zero order rate reaction (3.685×10^{-4} mmoles/hr/gm). Deficiency symptoms were more pronounced with Mex-Mix than with the hybrid; however, the test of homogeneity of slopes at zero order rate reaction was not significantly different.

These experiments indicate that Mex-Mix maize families differing in

P accumulation at silking may not perform differently when subject to different rates of applied P or in solution culture. This leads to the conclusion that intraspecific variations in the abilities of genotypes to hydrolyze polyphosphates may be found with intensive screenings by NMR spectroscopy. Results also pointed out difficulties which may be encountered by plant breeders attempting to select nutrient efficient genotypes across several environments.

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APPENDIX

Table I: Abbreviations used

A. Plant parameters

1. GYP: grain yield per plant
2. DYMP[a]: dry matter yield per plant at silking
3. TPU[a]: total phosphorus uptake at silking
4. PCP[a]: phosphorus concentrations in the plant at silking
5. PCG: phosphorus concentrations in the grain
6. TPTG: total phosphorus translocated into grain
7. TNU[a]: total nitrogen uptake at silking
8. NCP[a]: nitrogen concentration in the plant at silking
9. NCG: nitrogen concentration in the grain
10. NCM: nitrogen concentration in the plant at maturity
11. PRE[a]: phosphorus relative efficiency at silking

B. Fertilizers

1. MCP: monocalcium phosphate monohydrate
2. KOP: potassium orthophosphate
3. KPP: potassium pyrophosphate
4. TSP: triple superphosphate
5. PP: pyrophosphate
6. OP: orthophosphate
7. PPP: polyphosphate
8. TPP: tripolyphosphate
9. APP: ammonium polyphosphate.

Table II: Performance of 100 Mex-Mix maize families under a high nitrogen fertilization regime[1/], St. John, Kansas, 1974. (Experiment 1)

Family[2/]	PCP[a]	PCG	TPU[a]	TPTG	DMYP[a]	GYP	PRE[a]
	-----%----		-mgP/plant-		--g/plant--		%
1	0.34	0.36	498	470	148	131	70
2	0.24	0.35	403	390	168	110	57
3	0.23	0.33	424	414	187	124	60
4	0.22	0.45	408	353	186	79	57
5	0.24	0.38	478	453	194	119	67
6	0.27	0.37	487	433	184	118	68
7	0.24	0.33	463	368	195	110	65
8	0.21	0.31	302	468	151	156	42
9	0.23	0.40	372	297	161	75	52
10	0.24	0.35	378	254	155	73	53
11	0.24	0.38	373	407	158	106	52
12	0.24	0.36	456	394	161	110	64
13	0.21	0.36	393	411	185	115	55
14	0.25	0.37	464	306	187	82	65
15	0.26	0.37	417	477	164	129	59
16	0.24	0.33	470	464	192	142	66
17	0.26	0.40	429	520	168	129	60
18	0.22	0.36	437	411	199	110	61
19	0.27	0.38	428	356	161	91	60
20	0.31	0.41	647	424	206	103	91
21	0.25	0.36	473	385	187	107	66
22	0.23	0.39	334	337	147	87	47

Table II (Cont.): Performance of 100 Mex-Mix maize families under a high nitrogen fertilization regime[1/], St. John, Kansas, 1974. (Experiment 1)

Family[2/]	PCP[a]	PCG	TPU[a]	TPTG	DMYP[a]	GYP	PRE[a]
	-----%----		-mgP/plant-		--g/plant--		%
23	0.24	0.37	425	307	175	83	60
24	0.29	0.40	551	375	192	94	77
25	0.22	0.41	466	388	204	94	65
26	0.24	0.41	333	530	139	129	47
27	0.23	0.36	404	335	174	93	57
28	0.23	0.36	376	412	164	115	53
29	0.24	0.37	379	354	159	94	53
30	0.22	0.38	485	462	211	121	68
31	0.23	0.38	383	389	169	101	54
32	0.25	0.36	465	287	185	78	65
33	0.27	0.38	595	524	220	136	84
34	0.24	0.33	412	211	173	84	58
35	0.25	0.40	443	266	182	68	62
36	0.25	0.38	414	452	165	119	58
37	0.22	0.34	340	379	183	110	48
38	0.25	0.39	476	439	191	111	67
39	0.27	0.33	394	434	148	131	55
40	0.24	0.40	447	464	192	117	63
41	0.29	0.42	640	441	215	108	90
42	0.30	0.42	463	468	150	110	65
43	0.21	0.43	374	389	178	90	53
44	0.28	0.38	712	319	249	88	100

Table II (Cont.): Performance of 100 Mex-Mix maize families under a high nitrogen fertilization regime[1/], St. John, Kansas, 1974. (Experiment 1)

Family[2/]	PCP[a]	PCG	TPU[a]	TPTG	DMYP[a]	GYP	PRE[a]
	-----%----		-mgP/plant-		--g/plant--		%
45	0.24	0.39	396	474	162	121	56
46	0.25	0.37	485	385	193	103	68
47	0.24	0.33	597	274	242	83	84
48	0.24	0.35	390	317	161	91	55
49	0.25	0.34	432	408	175	121	61
50	0.24	0.38	432	390	180	104	61
51	0.25	0.33	469	473	190	143	66
52	0.22	0.35	365	391	168	111	51
53	0.25	0.43	640	393	226	102	90
54	0.27	0.39	544	378	197	96	76
55	0.28	0.36	573	384	207	105	80
56	0.23	0.38	499	391	212	101	70
57	0.27	0.40	435	368	162	90	61
58	0.25	0.35	543	312	220	90	76
59	0.27	0.33	476	386	176	117	67
60	0.22	0.41	363	234	166	58	51
61	0.20	0.40	386	393	191	98	54
62	0.29	0.39	633	385	216	99	89
63	0.24	0.37	487	282	206	76	68
64	0.23	0.37	392	489	173	130	55
65	0.26	0.38	472	323	178	85	66
66	0.26	0.41	544	421	207	102	76

Table II (Cont.) Performance of 100 Mex-Mix maize families under a high nitrogen fertilization regime[1], St. John, Kansas, 1974. (Experiment 1)

Family[2]	PCP[a]	PCG	TPU[a]	TPTG	DMYP[a]	GYP	PRE[a]
	-----%----		-mgP/plant-		--g/plant--		%
89	0.25	0.39	418	429	167	109	59
90	0.24	0.36	554	410	231	113	78
91	0.26	0.36	457	455	177	124	64
92	0.24	0.34	446	333	194	98	63
93	0.24	0.36	450	479	189	131	63
94	0.24	0.39	475	467	202	120	67
95	0.26	0.37	476	390	186	105	67
96	0.23	0.42	402	454	178	106	56
97	0.27	0.37	444	450	170	120	62
98	0.20	0.37	318	364	157	97	65
99	0.25	0.37	455	311	179	83	64
100	0.25	0.32	352	411	144	115	49

1/ Each plot received 200 kg N/ha, as NH_4NO_3 and 15 kg P/ha as triple superphosphate.

2/ All data are averages of 2 replications.

Table II (Cont.) Performance of 100 Mex-Mix maize families under a high nitrogen fertilization regime[1], St. John, Kansas, 1974. (Experiment 1)

Family[2]	PCP[a]	PCG	TPU[a]	TPTG	DMYP[a]	GYP	PRE[a]
	-----%-----		-mgP/plant-		--g/plant--		%
67	0.27	0.37	558	287	206	103	78
68	0.22	0.43	472	522	212	121	66
69	0.23	0.39	468	321	204	82	56
70	0.21	0.34	334	516	200	151	47
71	0.27	0.43	587	411	213	142	82
72	0.21	0.38	375	432	188	112	53
73	0.29	0.34	583	407	200	120	82
74	0.21	0.39	387	197	183	53	54
75	0.23	0.40	416	297	181	73	58
76	0.25	0.36	500	450	201	125	70
77	0.23	0.38	423	386	189	101	59
78	0.23	0.36	382	344	167	95	54
79	0.28	0.36	581	470	210	132	82
80	0.27	0.34	495	444	173	130	70
81	0.23	0.41	377	427	167	105	53
82	0.24	0.38	435	328	181	85	61
83	0.25	0.34	551	297	215	85	77
84	0.27	0.41	484	502	177	121	68
85	0.24	0.34	479	336	196	99	67
86	0.25	0.37	376	321	148	86	53
87	0.25	0.40	444	503	176	124	62
88	0.24	0.37	353	394	145	104	50

Table III: Dry weight (g/pot) and plant height (cm) of 25 day old maize seedlings of selected families as affected by phosphorus applications in the greenhouse. (Experiment 1)

Selected Family	Phosphorus treatments (ppm) 0	20	40	60	Phosphorus treatments (ppm) 0	20	40	60
	---------g dry wt/pot---------				---------height in cm ---------			
1	2.80	4.38	4.89	5.28	63.9	78.0	79.6	75.2
20	3.04	4.95	5.51	5.29	57.0	70.9	73.9	69.7
41	2.96	4.86	5.21	5.70	62.5	80.5	82.1	81.8
73	3.74	4.84	5.19	5.28	70.7	77.4	74.2	72.4
8	2.65	4.71	4.67	5.58	63.1	77.9	76.0	77.6
61	2.83	4.10	4.65	5.66	67.6	74.9	78.1	80.7
70	2.87	4.68	5.08	5.47	62.9	80.5	77.1	79.2
72	2.79	4.38	5.16	5.35	64.1	79.1	76.2	74.4
98	2.66	3.91	4.53	5.58	57.6	71.0	76.4	74.6
Treatment Means	2.93	4.53	4.99	5.47	63.3	76.7	77.0	76.2
$LSD_{.05}$								
FAMILY (F)	NS						4.76	
TREATMENT (T)	2.6						3.17	
F X T	NS						NS	

Table IV: Phosphorus concentrations (%) and total phosphorus uptake (mg P/pot) of 25 day old maize seedlings of selected families as affected by phosphorus applications in the greenhouse. (Experiment 1)

Selected	Phosphorus treatments (ppm)				Phosphorus treatments (ppm)			
Family	0	20	40	60	0	20	40	60
	-------------% P	-------------			---------mg P/plant	---------		
1	0.13	0.17	0.21	0.24	3.50	7.27	10.23	12.30
20	0.12	0.15	0.18	0.29	3.87	7.40	8.50	15.47
41	0.12	0.15	0.17	0.25	3.43	7.07	9.67	14.13
73	0.11	0.16	0.20	0.27	4.13	7.97	10.40	13.70
8	0.12	0.16	0.23	0.21	3.07	8.33	10.70	11.90
61	0.15	0.16	0.22	0.23	3.40	5.63	10.03	12.93
70	0.11	0.15	0.21	0.29	3.43	6.80	10.97	15.86
72	0.12	0.14	0.20	0.22	3.20	6.10	10.30	11.73
98	0.12	0.18	0.24	0.28	3.27	7.10	10.77	15.87
Treatment Means	0.12	0.16	0.21	0.25	3.48	7.07	10.17	14.77
$LSD_{.05}$								
FAMILY (F)	NS					NS		
TREATMENT (T)	0.02					1.19		
F X T	NS					NS		

Table V: Nitrogen and potassium concentrations (%) of 25 day old maize seedlings of selected families as affected by phosphorus applications in the greenhouse. (Experiment 1)

Selected	Phosphorus treatments (ppm)				Phosphorus treatments (ppm)			
Family	0	20	40	60	0	20	40	60
	% N				% K			
1	2.93	2.80	2.53	2.70	6.47	6.27	6.10	5.97
20	2.90	2.50	2.30	2.67	6.17	6.00	5.30	5.93
41	2.57	2.60	2.33	2.20	5.70	5.17	5.37	5.33
73	2.27	2.50	2.40	2.47	6.07	5.87	6.03	5.80
8	2.70	2.60	2.63	2.50	6.50	5.77	5.77	5.93
61	3.00	2.73	2.43	2.53	6.17	6.13	4.77	5.77
70	2.57	2.40	2.67	2.43	6.43	5.87	6.47	6.50
72	3.00	2.60	2.50	2.30	6.00	5.70	6.33	5.60
98	2.83	3.10	2.77	2.10	6.57	6.27	6.43	5.97
Treatment Means	2.75	2.65	2.51	2.43	6.23	5.89	5.84	5.86
$LSD_{.05}$								
FAMILY (F)		0.21				0.50		
TREATMENT (T)		0.14				NS		
F X T		0.42				NS		

Table VI: Zinc concentrations (ppm) and Zinc uptake (ug/pot) of 25 day old maize seedlings of selected families as affected by phosphorus applications in the greenhouse. (Experiment 1)

Selected	Phosphorus treatments (ppm)				Phosphorus treatments (ppm)			
Family	0	20	40	60	0	20	40	60
	ppm				ug Zn/pot			
1	89	78	64	73	246	344	309	388
20	84	85	68	61	253	421	336	325
41	68	71	55	57	200	336	285	328
73	77	74	61	74	290	354	319	389
8	94	74	62	69	249	357	291	385
61	75	70	60	68	206	277	278	383
70	84	63	62	65	239	293	303	353
72	81	72	69	72	225	312	353	388
98	76	80	76	55	209	313	344	306
Treatment Means	81	74	64	66	235	334	313	361
$LSD_{.05}$								
FAMILY (F)		NS				NS		
TREATMENT (T)		7.01				34.11		
F X T		NS				NS		

Table VII: Dry weight (g/pot), phosphorus concentrations (%) and total phosphorus uptake (mg P/pot) of 20-day-old maize seedlings of selected families as affected by phosphorus sources and rates of phosphorus application in the greenhouse. (Experiment 2)

		KH_2PO_4 (KOP)			$K_4P_2O_7$ (KPP)		
		Applied P (ppm)			Applied P (ppm)		
Family	Control[1/]	20	40	60	20	40	60
		g dry wt/pot					
20	2.68	3.26	3.07	3.73	3.67	3.60	2.76
73	2.21	2.64	4.05	4.11	3.35	3.36	4.06
61	1.34	1.85	2.71	1.76	1.89	2.31	2.11
98	2.40	2.90	2.68	3.11	2.75	3.00	3.13
$LSD_{.05}$							
	Family (F)	= NS			Treatment (T)		= NS
	Carrier (C)	= NS			F X C X T		= 0.39
		Phosphorus concentrations %					
20	0.16	0.18	0.30	0.41	0.17	0.28	0.37
73	0.19	0.19	0.28	0.43	0.23	0.27	0.41
61	0.15	0.26	0.29	0.48	0.25	0.30	0.40
98	0.18	0.24	0.31	0.34	0.20	0.31	0.31
$LSD_{.05}$							
	Family (F)	= NS			Treatment (T)		= 0.035
	Carrier (C)	= NS			F X C X T		= NS
		Total phosphorus uptake, mg P/pot					
20	3.96	6.01	9.07	15.76	6.50	10.92	10.15
73	4.26	4.96	11.38	18.41	7.66	9.52	16.21
61	2.26	3.88	7.92	8.43	5.03	7.37	8.46
98	4.34	7.62	8.32	10.58	5.46	8.95	9.96
$LSD_{.05}$							
	Family (F)	= 1.82			Treatment (T)		= 1.58
	Carrier (C)	= NS			F X C X T		= NS

1/ Not included in the analysis of variance.

Table VIII: Nitrogen and potassium concentrations (%) of 20-day-old maize seedlings of selected families as affected by phosphorus sources and rates of phosphorus applications in the greenhouse. (Experiment 2)

		KH_2PO_4 (KOP)			$K_4P_2O_7$ (KPP)		
		Applied P (ppm)			Applied P (ppm)		
Family	Control 1/	20	40	60	20	40	60
		------------------Nitrogen %------------------					
20	3.00	3.07	3.07	3.23	3.17	3.27	3.03
73	3.25	3.33	3.14	3.20	3.17	3.24	3.24
61	3.17	3.44	3.34	3.54	3.30	3.32	3.60
98	3.31	2.99	3.43	3.11	3.16	3.28	3.07
$LSD_{.05}$							
	Family (F) = 0.152				Treatment (T) = NS		
	Carrier (C) = NS				F X C X T = NS		
		------------------Potassium %------------------					
20	4.90	4.86	4.82	4.67	5.24	5.12	5.23
73	5.16	5.13	5.38	5.16	5.01	5.35	5.39
61	4.56	4.64	5.20	4.90	4.90	4.56	5.08
98	5.20	5.08	5.24	4.79	4.93	5.12	4.86
$LSD_{.05}$							
	Family (F) = 0.229				Treatment (T) = NS		
	Carrier (C) = NS				F X C X T = NS		

1/ Not included in the analysis of variance.

Table IX: Zinc concentrations (ppm) and zinc uptake (ug/pot) of 20-day-old maize seedlings of selected families as affected by phosphorus sources and rates of phosphorus applications in the greenhouse. (Experiment 2)

		KH_2PO_4 (KOP)			$K_4P_2O_7$ (KPP)		
		Applied P (ppm)			Applied P (ppm)		
Family	Control[1/]	20	40	60	20	40	60
		Zinc ppm					
20	58	62	65	61	57	67	40
73	82	64	68	58	73	64	45
61	74	78	68	61	70	81	47
98	68	68	57	68	57	46	42
$LSD_{.05}$							
	Family (F) = NS				Treatment (T) = 7.54		
	Carrier (C) = 6.16				F X C X T = NS		
		Zinc uptake ug/pot					
20	155	201	194	228	209	235	110
73	181	164	276	242	241	222	182
61	99	146	184	108	134	191	99
98	163	204	150	221	157	137	130
$LSD_{.05}$							
	Family (F) = 35.50				Treatment (T) = NS		
	Carrier (C) = NS				F X C X T = NS		

1/ Not included in the analysis of variance.

VARIATIONS IN PHOSPHORUS ACCUMULATION AND POLYPHOSPHATE HYDROLYSIS BY SELECTED MAIZE FAMILIES (*ZEA MAYS* L.)

by

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A series of experiments was conducted to evaluate variations in the concentrations and total phosphorus uptake of 100 CIMMYT Mex-Mix maize families and selected families differing in phosphorus accumulation at silking. The responses of selected families to different P carriers and their abilities to hydrolyze pyrophosphate in soil and in solution culture were also investigated.

Total phosphorus uptake and phosphorus concentrations, amounts of P translocated into grain and grain yield per plant were significantly different in 100 maize families in the field but P families selected for variations in P concentration did not differ significantly for the same plant parameters the following year. However, a trend of response due to P rates was observed. Variation in response of maize families to applied N and P in the field were probably attributable to the efficiency of translocating phosphorus and of grain formation and/or to the environment.

Under greenhouse conditions, no differences were noted between selected families' responses to applied monocalcium phosphate monohydrate although responses were significant for total phosphorus uptake, dry weight and phosphorus concentrations in plant tops. Similar results were obtained when potassium polyphosphate (KPP) and potassium orthophosphate (KOP) were examined as P sources. Apparent rapid hydrolysis of KPP in the soil could not be attributed to differences in the hydrolytic abilities of selected families alone and was probably influenced by other factors as well as plant roots.

Polyphosphate hydrolytic activity of roots of selected Mex-Mix families in solution culture, as determined by NMR spectroscopy, were similar. Half-lives of KPP at a substrate concentration of 60 ppm P were 30 hours for all the families. Comparisons of Mex-Mix and DeKalb XL 390 showed that the hybrid was 39% more efficient in hydrolyzing KPP, the difference was not significant, however. Mex-Mix families hydrolyzed 3.685×10^{-4} mmoles/hr/gm of fresh root (zero order kinetics) while DeKalb XL 390 hydrolyzed 5.11×10^{-4}/hr (first order kinetics). It seems likely that the pyrophosphatase enzyme was a limiting factor for Mex-Mix, the hydrolytic ability of XL 390 was much more dependent on the substrate concentration.

These experiments showed that potential differences in utilization of phosphorus and polyphosphate hydrolytic efficiencies may exist within the same species but intensive screenings would be necessary to detect efficient genotypes.