

STUDY OF PHOSPHATE REACTION PRODUCTS
IN EUFAULA SOIL

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CHAPTER I

INTRODUCTION

Phosphorus is frequently the limiting plant nutrient in crop production. A deficiency of this element may prevent other nutrients such as nitrogen from being acquired by plants. Both inorganic and organic forms of phosphorus can be found in soils and they are important to plants as sources of this element. Phosphorus reactions in soils are known to be more complex than of any other nutrient element. The availability of inorganic phosphorus in soils is largely determined by soil factors such as soil pH, soluble iron, aluminum and manganese, presence of iron, aluminum, and manganese containing compounds, available calcium and calcium compounds, amount and decomposition rate of organic matter, soil texture and type of clay, and the activities of microorganisms. The rapid rate at which phosphorus becomes fixed in soils is explained by most investigators as due to formation of aluminum, iron, or calcium phosphates.

Eufaula loamy sand (Psammentic Paleustalfs) from McAlester, Oklahoma, was investigated in this study. A previous study on Eufaula soil (Norwood, 1969), showed that this soil was not suited to Chang and Jackson's fractionation procedure (1957) after phosphorus was applied. Some phosphorus as CSP $[\text{Ca}(\text{H}_2\text{PO}_4)_2]$ was fixed after it was applied to the soil and was not recovered in any fraction. The previous study

also showed that sorghum did not respond to phosphate fertilization on Eufaula soil.

The objectives of the study were: (1) to study the cause of the unrecovered $\text{Ca}(\text{H}_2\text{PO}_4)_2$ after concentrated super-phosphate is applied to Eufaula soil, (2) to evaluate the modification of the Chang and Jackson fractionation procedure in determining the conversion of applied phosphate in Eufaula soil, (3) to study the response of sugar drip sorghum (Sorghum bicolor (L.) Moench) to fertilization by different phosphate sources, (4) to study the extent and rate of conversion of different sources of phosphate into various normal soil phosphate compounds, and (5) to compare Bray #1 (20:1) available phosphate with phosphate fractions in soils.

CHAPTER II

REVIEW OF LITERATURE

Mechanism of Phosphate Fixation

When phosphate is added to soils, it soon becomes fixed or immobilized. Study of phosphate fixation in soils is important since the extent to which a particular soil will fix added phosphate will determine the efficiency and economics of phosphate fertilizer use on the soil over a period of several years.

Phosphate fixation has been defined in different ways. Dean (1949) defines fixed phosphate as the soil phosphate which has become attached to the solid phase of soils. Midgley (1940) defines phosphate fixation as the conversion of soluble forms to less soluble forms. Wild (1950, p. 221) states "Phosphate fixation is used to describe any change that phosphate undergoes in contact with the soil, which reduces the amount that the plant roots can absorb". According to Dean (1949), changes in availability are not sufficiently specific to warrant quantitative interpretation. It does not necessarily follow that a change in solubility will mean a change in availability (Dean, 1949).

The phosphate fixation mechanisms are as varied as the definitions given for phosphate fixation itself. Davis (1935) postulated the following mechanisms: (a) Cations of soluble salts present in the soil, or cations replaced from the soil by those present in the solution,

form precipitates with the phosphate ions. (b) By double decomposition, relatively insoluble soil minerals react to form insoluble phosphates. (c) Phosphates are adsorbed at the extensive soil-solution interface. (d) Phosphates are adsorbed by the soil minerals to form complex systems in one or more of the solid soil phases. Kardos (1964) places the types of reactions by which phosphates become fixed in three general groups: adsorption, isomorphous replacement, and double decomposition involving solubility product relations.

From a consideration of the ionization constants of phosphoric acid (H_3PO_4), Beuhrer (1932) has calculated the relation of pH to the relative concentration of the undissociated H_3PO_4 and the three ionic species H_2PO_4^- , HPO_4^{--} , and PO_4^{---} . His work shows that all phosphate reaction systems will be fundamentally influenced by the hydrogen ion activity in the systems.

Murphy (1939) found that grinding greatly increased the capacity of kaolinite to retain applied phosphate, which is quite indicative of adsorption.

Low and Black (1950) plotted the amount of phosphate fixed by kaolinite against the equilibrium concentration of phosphate in dilute solutions and found the data to fit a typical adsorption curve which could be represented by a Freundlich adsorption equation having the form $x/m = KC^{\frac{1}{n}}$ where x/m = amount of phosphorus adsorbed as $\mu\text{g P}/100\text{g}$, C = amount of phosphate remaining in solution as millimoles P/100g, K and n = constants. They further found that the degree of adsorption was increased by increasing temperature, and hence, concluded that adsorption was chemical.

Kurtz, DeTurk and Bray (1946) found that phosphate adsorption curves for different soils were similar in shape and could be expressed by an equation of the Freundlich type.

In acid soils most phosphate fixation is primarily due to the formation of iron and aluminum phosphate compounds. Many investigators (Benavides, 1963; Coleman, 1944; Coleman, 1945; Doughty, 1935; Ellis and Truog, 1955; and Volk and McLean, 1963) have shown that the ability of acid soils to fix phosphate is directly related to their contents of iron and aluminum. Most of these workers were able to show conclusively that removal of the iron and aluminum oxides from the soil samples studied drastically reduced the phosphate fixing capacity of the soils. Coleman et al. (1960) observed that the amounts of phosphate sorbed by sixty subsoil samples from the North Carolina Piedmont were correlated with exchangeable aluminum content. The removal of exchangeable aluminum by salt-leaching reduced phosphate sorption.

The phosphorus fixed as iron or aluminum phosphate could be further immobilized by the formation of occluded phosphate as described by Chang and Jackson (1957).

Phosphate fixation in calcereous soils is usually attributed to the formation of phosphate compounds of calcium. In addition, however, the iron and aluminum compounds responsible for fixation in acid soils are also responsible for some fixation in soils of higher pH (Midgley, 1940). Cole et al. (1953) studied the sorption of phosphate on calcium carbonate and suggested that when soluble phosphate fertilizers are added to calcereous soils, the reactions with calcium carbonate consisted of rapid monolayer sorption of HPO_4^- on calcium carbonate surfaces.

There has not been very much agreement among research workers on the possible roles of organic matter in phosphate fixation.

Doughty (1935) studied phosphate fixation as influenced by organic matter and concluded that soil organic matter as such had only a minor role, if any, in the fixation of phosphates in difficultly available forms when soluble phosphatic fertilizers were added to the soil.

Rennie and McKercher (1959) stated that organic matter appeared to be equally as important as the inorganic colloids in determining the phosphate adsorption capacity of the soils. Benavides (1963) in studying the phosphate sorption capacity of some tropical soils of Colombia, South America, found that there was a highly significant correlation between phosphate sorption capacity and organic carbon, and that organic matter had a very important role in the retention of phosphate.

According to Kardos (1964), in general, the overall effect of the organic phase in soils has been found to be such as to decrease phosphate fixation.

Kinetics of Phosphate Adsorption

The concept of phosphate adsorption whereby the phosphate is retained by soils is defined by Hsu (1965) as a process in which phosphate is chemically held on the surface of amorphous aluminum hydroxides or iron oxides.

Kittrick and Jackson (1957) suggested that adsorption and precipitation are basically the same mechanism, both resulting from the attraction between Al or Fe and phosphate. Adsorption is a special case of precipitation in which Al or Fe remains as the constituent atom

of the corresponding hydroxides or oxides but reacts with phosphate by its residual reaction force on the surface.

Hsu (1965) studied the adsorption of phosphate by Al and Fe in soils. He concluded that the phosphate is not fixed as variscite or strengite-type compounds at pH 7 in a relatively dilute phosphate solution, but is adsorbed on amorphous aluminum hydroxides and iron oxides or hydroxides in soils. The rapid reaction which is completed in a few hours is due to the native surface reactive amorphous aluminum hydroxides and iron oxides already present in soils. The subsequent slow reaction is due to the similar surface reactive components developed during the aging process.

The relationship between amount of phosphate adsorbed or released and time has often been described by a first-order kinetic equation (Fried et al. 1957, Larsen, Gunary, and Sulton, 1965) or a series of exponential terms (Amer et al. 1955; Li et al. 1972, Probert and Larsen, 1972).

Kuo and Lotse (1972) proposed a second-order kinetic equation, based on a simple physical model, to describe phosphate adsorption which fits the Langmuir adsorption isotherm. Atkinson et al. (1970) found that a modified form of Elovich equation successfully described the isotopic exchange of phosphate between the surface of goethite and the solution phase. The two relationships above are not obeyed, however, when the exchange process approaches equilibrium, Probert and Larsen (1972) reported that the modified Elovich equation was not applicable to heterogenous isotopic exchange of phosphate between soil and solution. According to this equation the ratio of fraction adsorbed and fraction remaining in solution will approach infinity when

fraction adsorbed approaches one. This equation does not appear to be applicable for adsorption data which is within region one as defined by Muljadi et al. (1966).

Kuo and Lotse (1974) found that the phosphate adsorption by hematite and gibbsite conformed to the Freundlich equation. The rate of phosphate adsorption was rapid initially and decreased with prolonged reaction time. They developed a two-constant rate equation which successfully described the rate of phosphate adsorption. The low activation energy of phosphate adsorption indicated that the adsorption was a diffusion-controlled process. They added, however, that the rate of phosphate release was similar to the rate of phosphate adsorption and could be described by the proposed two-constant rate equation. The complexing agent, EDTA, was more effective than oxalate, hydroxyl, and fluoride anions in releasing adsorbed phosphate.

Kinetic equations for phosphate adsorption by minerals were investigated by some workers. Cole et al. (1953) found that phosphate adsorption by CaCO_3 at low phosphate concentrations can be described by the Langmuir adsorption isotherm. Low and Black (1950) and Russell and Low (1954) found that phosphate adsorption by kaolinite fits the Freundlich equation. Olsen and Watanabe (1957) reported that adsorption of phosphate by soils from dilute solutions showed a closer agreement with the Langmuir isotherm than with the Freundlich isotherm.

Kuo and Lotse (1972) explained the mechanism of phosphate adsorption by calcium carbonate and Ca-kaolinite. In the calcite structure each Ca ion is coordinated by six oxygen atoms of six different CO_3^{2-} groups, and each such oxygen atom is bound to two Ca ions. In a water suspension of CaCO_3 crystallites, oxygen atoms of water molecules,

bicarbonate ions, and hydroxyl ions may fill the vacant coordinate position of exposed surface Ca ions. Phosphate ions may replace adsorbed water molecules, bicarbonate ions, and hydroxyl ions. The relative adsorption strength of the phosphate ions and other anions present will depend upon the solubility of the compound formed with surface Ca ions. Since the solubility constants of CaHPO_4 , Ca(OH)_2 , and CaHCO_3^+ are $10^{-6.66}$, $10^{-5.43}$, and $10^{-1.25}$, respectively, phosphate ions will be more strongly adsorbed to Ca ions than bicarbonate and hydroxyl ions. They concluded that the adsorption process is chemical in nature.

The mechanism of the phosphate adsorption by kaolinite is incompletely understood. Exchange of edge hydroxyl groups of the crystal lattice by phosphate ions was suggested by Low and Black (1950), Lutz et al. (1966), Muljadi, Pasner and Quirk (1966), and Kafkafi, Pasner and Quirk (1967). Russell and Low (1954) did not favor the hypothesis of an exchange reaction between phosphate and hydroxyl ions but concluded that adsorbed aluminum precipitates the phosphate as an aluminum phosphate on the kaolinite surface. Olsen and Watanabe (1957) suggested that phosphate ions become attached to exchangeable iron, aluminum and Ca ions or to these same ions held in the outer edges of the lattice.

Kuo and Lotse (1972) reported that the phosphate adsorption by kaolinite did not significantly increase the pH. Secondly, the phosphate adsorption increases with decreasing pH (Muljadi et al. 1966) i.e., with increasing number of edge H_2O groups. They, therefore, favor the idea of Hsu (1968) that phosphate ions are adsorbed by replacing coordinated H_2O groups rather than hydroxyl groups.

Fractionation of Soil Phosphate

Many investigations by soil scientists have been attempted to characterize soil phosphate compounds.

Fisher and Thomas (1935) classified the phosphate compounds in soils by a method based on the relative rates of solution of soil phosphate compounds in buffered acid extractants. They differentiated the following groups of compounds: (a) amorphous and finely divided crystalline phosphates of calcium, magnesium and manganese, (b) amorphous phosphates of aluminum and iron, (c) phosphates adsorbed upon hydrous oxides and those present in the form of apatite, and (d) phosphorus present in crystalline phosphates of aluminum and iron determined by difference.

Williams (1937) classified the phosphate compounds of the soil into three categories on the basis of their solubility in sodium hydroxide as follows: (a) soluble-phosphates in combination with sesquioxide, organic phosphorus, exchangeable phosphates of clay complexes, phosphates of calcium compounds such as CaHPO_4 , and phosphates of water soluble compounds; (b) insoluble-phosphates in compounds of the apatite class; (c) soluble-phosphates in the interior of the clay lattice, and phosphates of titanium compounds.

Dean (1938) divided the soil phosphate compounds in three fractions by using two extraction solutions, sodium hydroxide followed by an acid. These fractions are: (1) organic phosphate compounds soluble in sodium hydroxide; (2) inorganic phosphate compounds dissolved by extraction with sodium hydroxide followed by acid; and (3) insoluble phosphate compounds.

Ghani (1943) divided soil phosphates into five groups as follows:

- (1) acetic acid-soluble; mono-, di- and tricalcium phosphates;
- (3) alkali-soluble organic:soil organic phosphorus (nucleic acid, phytin, lecithin, etc.);
- (4) sulfuric acid-soluble: phosphates of the apatite type;
- and (5) insoluble phosphates.

Ghani (1943) modified his first method when it was found that some of the phosphate brought into solution by acetic acid was reabsorbed by the soil and then extracted in sodium hydroxide. He suggested the use of 8-hydroxyquinoline as a means of blocking reabsorption or precipitation of phosphate by active iron and aluminum during acetic acid extraction.

Bhangoo and Smith (1957) studied chemical characterization of phosphorus present in various Kansas soils and grouped the forms into four categories: (a) phosphates soluble in 0.1 N HCl (calcium phosphates); (b) cold alkali soluble phosphates (adsorbed phosphates); (c) hot alkali soluble phosphates (iron and aluminum phosphates); and (d) organic phosphates.

Chang and Jackson (1957) developed a procedure for fractionation of soil phosphates into general chemical forms; aluminum phosphate extracted with neutral 0.5 N NH_4F ; iron phosphate extracted with 0.1 N NaOH; calcium phosphate extracted with 0.5 N H_2SO_4 ; reductant soluble iron phosphate (occluded iron oxide) extracted with a basic dithionitecitrate solution; and occluded aluminum phosphate extracted with neutral 0.5 N NH_4F after the dithionite treatment.

Fife (1959) made a study in non-soil systems of the solubility characteristics of iron-bound and aluminum-bound phosphate in 0.5 N NH_4F over a range of pH. It was shown that the fluo-ferrate ion is not

completely reacted until the pH rises to a value of approximately 8.0 in 0.5 N NH_4F . He concluded that a satisfactory delineation of aluminum-bound soil phosphate is likely to be attained by the use of 0.5 N NH_4F at pH 8.5 instead of pH 7 as proposed by Chang and Jackson (1957). Fife (1959) reached the same conclusion with soil systems.

Glenn et al. (1959) made the following modifications in the Chang and Jackson (1957) procedure: iron phosphate extracted with 0.1 N NaOH for 9 to 12 hours instead of 17 hours as originally proposed; followed by extraction of all occluded phosphate before removal of calcium phosphates since the 0.5 N H_2SO_4 used to extract calcium phosphates tends to remove some of the occluded phosphate.

Chang (1961) made the following modifications in the Chang and Jackson (1957) procedure: (1) aluminum phosphate extracted with 0.5 N NH_4F at pH 7 for one hour for paddy soils and at pH 8.2 for one hour for upland soils; (2) iron phosphate extracted with 0.1 N NaOH for 9 to 12 hours; and (3) calcium phosphate extracted with 0.5 N H_2SO_4 for one hour after the extraction of occluded phosphates. Williams et al. (1967) modified the phosphate fractionation procedure of Chang and Jackson (1957). The modification included the determination of residual inorganic phosphates and introduced a revised nomenclature for the other fractions. The phosphate sorbed during the fluoride extraction was completely recovered in the succeeding sodium hydroxide extraction. In the determination of calcium phosphates, HCl was substituted for H_2SO_4 . As a result, phosphate in the extract was determined by the colorimetric procedure of Dickman and Bray (1940), which tolerates ferric iron better than sulfomolybdic acid procedures (Jackson, 1958) the former of which, moreover, is used for determining

most of the other fractions. A second acid treatment removed additional amounts of phosphate from soils high in calcium phosphates.

Phosphorus Transformations

The transformation of phosphorus in the soil has been investigated by several workers to determine the relative soil weathering intensities (Al-Abbas and Barber 1964; Chang and Kuo 1963; and Westin and Buntley 1967). Godfrey and Riecken (1954) reported the quantities of total and organic phosphorus in a soil development sequence for soils spanning southwest Iowa and northeast Missouri. Organic phosphorus decreases as profile development increases. The distribution of organic phosphorus also changes, dropping at a progressively greater rate with depth as profile development advances. Total phosphorus in their study decreased from approximately 700 ppm to 450 ppm as the soils became more weathered.

Smbeck and Runge (1971) fractionated inorganic phosphates into calcium, aluminum, iron, and occluded (reductant-soluble) forms. Aluminum, iron, and occluded phosphates increased whereas calcium phosphates decreased as profile development advanced. The greatest change was in the reductant-soluble form, which increased from 75 ppm to 450 ppm in the B horizon of the most weakly expressed profile.

Williams and Walker (1969) studied the changes in the forms of soil phosphates as a result of progressive soil development. They found that the total phosphate and occluded inorganic phosphate had declined as the soil developed, while non-occluded inorganic phosphate and organic phosphate increased with soil development but they decreased

in the same period along with the total phosphate and occluded inorganic phosphate.

CHAPTER III

METHODS AND MATERIALS

Eufaula Soil, fine sandy loam (Psammentic Paleustalfs), from McAlester was collected in the spring of 1974. The soil was mixed thoroughly, air dried, and passed through one-fourth inch screen. The soil was weighed into pots on an oven dry basis, half of the pots receiving 3,000 grams, half the pots receiving 1,500 grams. Nine different phosphate sources: calcium metaphosphate $\text{Ca}(\text{PO}_3)_2$, mono-calcium phosphate $[\text{Ca}(\text{H}_2\text{PO}_4)_2]$, potassium monohydrogen phosphate (K_2HPO_4), potassium dihydrogen phosphate (KH_2PO_4), ammonium monohydrogen phosphate $[(\text{NH}_4)_2\text{HPO}_4]$, potassium pyrophosphate ($\text{K}_4\text{P}_2\text{O}_7$), ammonium polyphosphate (granular 15-62-0), ammonium polyphosphate (liquid 11-37-0), and phosphoric acid (H_3PO_4 , 0-72-0) were mixed with the soil to supply four replications for each pot size for each of the nine treatments: 0, 10, 25, 50, 75, 100, 150, 200, 250, and 300 ppm P. The two groups of pots were arranged in separate randomized block designs in the greenhouse. The pots containing 3,000 grams of soil were planted to sugar drip sorghum (Sorghum bicolor) and watered to field capacity with distilled water on June 21, 1974. The pots containing 1,500 grams of soil were watered to field capacity on this same date and remained barren throughout the experiment. After emergence the plants were thinned to three plants per pot. The cropped pots were watered when necessary, usually on a daily basis; the noncropped pots

were covered and maintained at near field capacity for the entire experiment. The first crop was harvested on July 19, 1974, and the moist and oven dry (80°C) weights recorded. The same soils were cropped two more times, the second planting and harvest dates being July 21 and August 19; the third planting and harvest dates being August 21 and September 20, 1974, respectively. Duncan's multiple range test was used to evaluate the response of sugar drip sorghum to phosphate application. Nitrogen at rates of 100 ppm N as NH_4NO_3 was added before planting each crop except for those receiving N in the phosphate fertilizer, the needed N was added to make up 100 ppm N or at a later period for the higher P rate treatments. Potassium at rates 40 ppm as KCl was added prior to each planting.

A composite of two soil samples of each pot, both cropped and noncropped, was taken at the beginning of the growth period (one week after the initial watering) of the first crop and after each of the three crops were harvested. The noncropped pots were sampled again after six months had elapsed. The soil samples were dried, ground, and kept frozen until they could be analyzed to minimize phosphate reactions in the soil during the waiting period.

Soil Analysis

The soil phosphate fractionation reagents used in sequence and the soil test methods for determining available phosphorus are shown in Table I.

The colorimetric procedure of Watanabe and Olsen (1965) with ascorbic acid was used for all P extracts except for the citrate-dithionite-bicarbonate and HClO_4 extracts for occluded iron phosphate

TABLE I
REAGENTS USED FOR SOIL ANALYSIS

Extractants	Soil: Solution Ratio	Shaking Time	Rates Analyzed	Sampling Dates	Soils Analyzed	
					Cropped	Non-cropped
0.5 M NH_4Cl ¹	1:50	30 min.	0,50,100,200,300	All	X	X
0.5 M NH_4F (pH 8.2) ¹	1:50	24 hr.	0,50,100,200,300	All	X	X
0.1 N NaOH + 1 M NaCl ¹	1:50	17 hr.	0,50,100,200,300	All	X	X
0.3 M Na-Citrate + 1.0 M NaHCO_3 + $\text{Na}_2\text{S}_2\text{O}_4$ ^{1,6}	1:60	-	0,50,100,200,300	All	X	X
1.0 M NaOH ¹	1:50	17 hr.	0,50,100,200,300	All	X	X
0.5 N HCl ¹	1:50	1 hr.	0,50,100,200,300	All	X	X
1.0 N HCl ¹	1:50	4 hr.	0,50,100,200,300	All	X	X
Bray #1 ²	1:20	5 min.	0,100	All	X	X
North Carolina ³	1:10	5 min.	Control	1st	X	
0.5 N NaHCO_3 ⁴	1:20	30 min.	Control	1st	X	
HClO_4 ⁵ (Total P)	-	-	Control	1st		

¹Williams *et al.* (1967)

²0.025 N HCl .N 0.03 N NH_4F , Bray and Kurtz (1945),
1:20 soil to solution ratio.

³0.05 N HCl .N 0.025 N H_2SO_4 , Melich (1953)

⁴Olsen (1954)

⁵Olsen and Dean (1965)

⁶Jackson (1956)

and the total phosphorus for which the stannous chloride method of Watanabe and Olsen (1962) and the vanadomolybdo-phosphoric acid method of Jackson (1968), respectively, were used.

CHAPTER IV

RESULTS AND DISCUSSION

Soil Phosphate Fractionation

Eufaula soil from cropped and noncropped treatments were subjected to phosphate fractionation by a modification of Chang and Jackson's procedure (Williams, et al., 1967). The phosphate fractions were extracted as ammonium chloride phosphate ($\text{NH}_4\text{Cl-P}$), aluminum phosphate (Al-P), iron phosphate (Fe-P), occluded iron phosphate (Ocl. Fe-P), and calcium phosphate (Ca-P). The physical, chemical, and the phosphate fractionation analyses for Eufaula soil measured before phosphate application are reported in Table II. The amounts and the percentage of phosphate recovered from the noncropped and the cropped soils by the fractionation procedure for each phosphate source and application rate are reported in Table III to XI. It is obvious that the amounts of phosphate recovered seldom equal the phosphate initially present in the soil (Table II) plus the amount applied. Laverty and MacLean (1961) found a range of 95 to 125 percent recovery of applied phosphorus and suspected both solubilization and random fluctuation as causes. Chang and Chu (1961) reported both a lack of recovery and excess recovery of applied phosphate. In a later study Volk and McLean (1963) used ^{32}P and found that fertilizer phosphorus did indeed have an action on native phosphorus solubility. The studies by Lindsay, et al., (1959)

TABLE II
 THE CHEMICAL AND TEXTURAL PROPERTIES
 OF EUFAULA SOIL¹

		P from Phosphate Fractionation - ppm					
NH ₄ Cl-P	Al-P	Fe-P	Occl. Fe-P	Ca-P		Sum	
9	22	67	25	15		138	
CEC meq/100g	pH (1:1)	O.M %	PPM				
			Ca	Mg	Fe	Available P	Total P
4.5	5.5	0.5	45	50	35	40	180
% Sand		% Silt		% Clay			
74		18		8			

¹Analyses determined on control soil.

which demonstrated solubilization of Fe and Al compounds by the triple point solution (reaction of concentrated superphosphate with water to form the system $(CaO - H_2O - P_2O_5)$) is well known. Further work by MacKenzie and Cambell (1963) showed that the triple point solution could act on silicate clays, causing decreases of Al and Fe in the clay minerals.

In the present study a satisfactory phosphate recovery is obtained except in the treatment of calcium metaphosphate $(Ca(PO_3)_2)$ which ranged from 100 to 65 percent for the noncropped soils after one week of phosphate application. The recovery in this treatment was decreased by increasing the rate of phosphate application from 50 ppm to 300 ppm, this lack of phosphate recovery in this situation is likely due to the very low solubility of calcium metaphosphate. But after twenty-six weeks, the recovery increased to 94 to 95 percent, indicating that a soil reactive process had occurred. The rest of phosphate fertilizers show a higher degree of recovery, noncropped treatments giving a range of 83 to 116 percent over all the sampling dates, sources and rates. It was found that the recovery of phosphate increased by increasing the rate of applied phosphate. However, Williams, et al. (1967) suggested that there will be random errors as high as 20 to 30 ppm possible in the determination of individual fractions, and random errors of 3 percent or more in the determination of total inorganic phosphorus.

The Yield of Sugar Drip Sorghum

Sugar drip sorghum yields vs. phosphate application rates for each of the three crops are given in Table XII.

TABLE III

NET PHOSPHATE RECOVERED BY FRACTION AND PERCENT RECOVERY, NONCROPPED SOILS (ONE WEEK)¹

Treatment	ppm P Applied	NH ₄ Cl-P	Al-P	Fe-P	Ocl. Fe-P	Ca-P	ppm P Recovered	% Recovery
Zero Time	0	9	22	67	25	15	138	-
Control	0	8	22	68	25	14	137	-
Ca(PO ₃) ₂	50	1	- 5	43	3	6	48	96
	100	3	0	70	8	8	89	89
	200	5	13	98	11	13	140	70
	300	8	28	133	13	14	196	65
Ca(H ₂ PO ₄) ₂	50	21	26	- 5	- 5	12	49	98
	100	47	58	-15	- 3	12	99	99
	200	81	98	8	10	18	215	107
	300	97	130	23	29	18	297	99
K ₂ HPO ₄	50	15	17	0	6	12	50	100
	100	37	38	5	8	12	100	100
	200	53	78	40	13	12	196	98
	300	72	126	55	19	28	300	100
KH ₂ PO ₄	50	18	18	- 3	3	12	48	96
	100	24	62	0	3	12	98	98
	200	85	98	0	3	13	199	99
	300	113	140	10	3	25	291	97
(NH ₄) ₂ HPO ₄	50	15	28	7	0	0	50	100
	100	34	50	14	0	0	98	98
	200	75	100	20	0	0	195	98
	300	119	148	25	0	1	293	98
K ₄ P ₂ O ₇	50	15	18	20	- 5	0	48	96
	100	34	30	37	- 5	0	96	96
	200	81	56	63	- 5	6	201	100
	300	121	68	69	3	6	267	89
15-62-0	50	18	28	8	- 5	0	49	98
	100	24	62	10	2	0	98	98
	200	66	88	32	2	6	194	97
	300	101	143	39	11	6	300	100
11-37-0	50	31	28	3	-11	- 3	48	96
	100	53	51	4	- 9	0	98	99
	200	101	88	5	- 5	0	189	95
	300	111	149	34	0	0	294	98
0-72-0	50	22	27	10	- 8	- 2	49	98
	100	34	56	12	- 4	1	99	99
	200	72	97	25	- 2	2	194	97
	300	97	142	40	3	4	286	95

¹After phosphate application.

TABLE IV

NET PHOSPHATE RECOVERED BY FRACTION AND PERCENT RECOVERY, CROPPED SOILS (ONE WEEK)¹

Treatment	ppm P Applied	NH ₄ Cl-P	Al-P	Fe-P	Ocl. Fe-P	Ca-P	ppm P Recovered	% Recovery
Zero Time	0	9	22	67	25	15	138	-
Control	0	6	15	57	22	12	112	-
Ca(PO ₃) ₂	50	0	0	18	3	8	29	58
	100	0	3	43	5	10	61	61
	200	0	3	43	8	15	69	35
	300	3	7	36	11	16	73	24
Ca(H ₂ PO ₄) ₂	50	18	25	-17	- 6	13	33	66
	100	44	33	-10	- 2	14	79	79
	200	80	82	13	0	15	190	95
	300	94	130	29	3	16	272	91
K ₂ HPO ₄	50	14	10	3	3	13	43	86
	100	30	35	13	6	14	98	98
	200	50	63	53	9	14	189	95
	300	64	125	63	16	23	291	97
KH ₂ PO ₄	50	12	15	4	- 2	13	42	84
	100	18	56	8	- 2	14	94	94
	200	63	95	9	- 2	15	180	90
	300	78	135	17	- 2	23	251	84
(NH ₄) ₂ HPO ₄	50	15	27	15	- 6	0	51	102
	100	31	54	21	- 6	0	100	100
	200	72	104	23	- 6	0	193	97
	300	104	150	32	- 2	3	287	96
K ₄ P ₂ O ₇	50	14	25	3	- 6	0	36	72
	100	27	34	25	- 6	1	81	81
	200	59	45	68	- 6	3	169	85
	300	71	53	73	- 2	3	198	66
15-62-0	50	9	25	13	- 9	- 3	35	70
	100	21	59	15	- 2	3	96	96
	200	59	90	37	3	3	192	96
	300	94	135	43	6	3	281	94
11-37-0	50	18	30	8	-10	0	46	92
	100	40	50	9	- 9	3	93	93
	200	94	85	12	- 3	3	191	96
	300	104	145	42	1	3	295	98
0-72-0	50	15	28	14	- 6	- 3	48	96
	100	29	55	17	- 6	3	98	98
	200	69	85	20	- 6	3	171	86
	300	75	123	43	- 2	3	242	81

¹After phosphate application.

TABLE V

NET PHOSPHATE RECOVERED BY FRACTION AND PERCENT
RECOVERY, NONCROPPED SOILS (FOUR WEEKS)¹

Treatment	ppm P Applied	NH ₄ Cl- P	Al-P	Fe-P	Ocl. Fe-P	Ca-P	ppm P Recovered	% Recovery
Zero Time	0	9	22	67	25	15	138	-
Control	0	11	26	58	28	15	138	-
Ca(PO ₃) ₂	50	- 4	- 4	58	- 8	- 3	39	78
	100	- 4	1	93	- 6	0	84	84
	200	- 1	2	103	- 4	1	101	51
	300	3	8	123	- 3	1	132	44
Ca(H ₂ PO ₄) ₂	50	18	5	36	-16	0	43	86
	100	37	27	43	-14	3	96	96
	200	63	56	67	-11	4	179	90
	300	81	113	79	- 9	6	270	90
K ₂ HPO ₄	50	7	24	38	-12	- 6	51	102
	100	28	48	43	-10	- 3	106	106
	200	75	78	54	- 9	3	214	107
	300	91	94	79	- 8	5	261	87
KH ₂ PO ₄	50	15	29	22	-11	- 3	52	104
	100	28	48	33	-10	0	99	99
	200	53	98	48	- 9	3	193	97
	300	63	117	73	- 8	9	254	85
(NH ₄) ₂ HPO ₄	50	15	24	18	- 6	- 6	45	90
	100	24	48	28	- 5	- 5	90	90
	200	56	68	49	- 5	- 2	179	90
	300	166	103	57	- 4	0	322	107
K ₄ P ₂ O ₇	50	17	18	32	-11	- 5	51	102
	100	44	31	41	-11	0	105	105
	200	88	63	64	-11	2	206	103
	300	134	72	75	-11	3	273	91
15-62-0	50	15	18	18	- 2	- 1	48	96
	100	21	24	43	- 3	- 1	84	84
	200	47	70	58	- 2	0	172	86
	300	53	78	113	2	3	249	83
11-37-0	50	21	40	- 4	- 9	- 2	46	92
	100	37	40	20	- 3	0	94	94
	200	59	56	75	- 1	0	189	94
	300	85	75	113	2	0	275	91
0-72-0	50	18	27	3	1	- 2	47	94
	100	40	37	13	2	- 2	90	90
	200	61	48	73	3	- 1	184	92
	300	77	72	121	3	1	274	91

¹After phosphate application.

TABLE VI
NET PHOSPHATE RECOVERED BY FRACTION AND PERCENT
RECOVERY, CROPPED SOILS (FOUR WEEKS)¹

Treatment	ppm P Applied	NH ₄ Cl- P	Al-P	Fe-P	Ocl. Fe-P	Ca-P	ppm P Recovered	% Recovery
Zero Time	0	9	22	67	25	15	138	-
Control	0	3	8	52	22	10	95	-
Ca(PO ₃) ₂	50	- 1	- 6	38	- 8	- 3	20	40
	100	- 1	- 6	40	- 7	- 2	25	25
	200	- 1	0	42	- 6	0	35	18
	300	- 1	3	78	- 5	0	75	25
Ca(H ₂ PO ₄) ₂	50	12	12	28	-13	0	39	78
	100	31	31	41	-12	0	91	91
	200	56	47	77	-10	0	173	87
	300	72	75	89	- 7	0	237	79
K ₂ HPO ₄	50	6	5	19	- 9	- 3	18	36
	100	12	25	29	- 7	0	59	59
	200	37	40	50	- 6	3	124	62
	300	53	66	58	- 5	6	178	59
KH ₂ PO ₄	50	15	9	26	- 8	- 3	39	78
	100	24	28	35	- 7	0	80	80
	200	31	38	45	- 6	3	111	56
	300	43	88	51	- 5	8	185	62
(NH ₄) ₂ HPO ₄	50	12	12	16	- 4	- 5	31	62
	100	21	25	26	- 3	- 3	66	66
	200	34	47	42	- 2	0	121	61
	300	88	91	47	- 1	0	225	75
K ₄ P ₂ O ₇	50	9	0	29	- 8	- 3	27	54
	100	15	4	37	- 8	0	48	48
	200	37	22	57	- 8	1	109	55
	300	100	28	69	- 8	3	192	64
15-62-0	50	9	22	0	- 2	- 2	27	54
	100	12	28	16	- 1	0	55	55
	200	24	66	25	2	1	118	59
	300	53	72	35	5	3	168	56
11-37-0	50	9	28	3	- 7	- 3	30	60
	100	19	31	30	- 2	- 2	76	76
	200	40	47	73	- 1	0	159	80
	300	63	68	114	5	0	250	83
0-72-0	50	9	28	8	2	- 2	45	90
	100	18	34	13	3	0	68	68
	200	27	42	63	4	0	136	68
	300	27	63	113	4	3	210	70

¹After phosphate application.

TABLE VII

NET PHOSPHATE RECOVERED BY FRACTION AND PERCENT RECOVERY, NONCROPPED SOILS (EIGHT WEEKS)¹

Treatment	ppm P Applied	NH ₄ Cl-P	Al-P	Fe-P	Ocl. Fe-P	Ca-P	ppm P Recovered	% Recovery
Zero Time	0	9	22	67	25	15	138	-
Control	0	5	15	78	25	15	138	-
Ca(PO ₃) ₂	50	- 4	- 4	65	- 8	- 3	46	92
	100	- 4	- 2	113	- 8	0	99	99
	200	- 2	- 1	153	- 8	1	143	72
	300	- 2	2	223	- 8	3	218	73
Ca(H ₂ PO ₄) ₂	50	15	15	49	-15	- 6	58	116
	100	34	24	56	-15	- 6	93	93
	200	72	68	80	-15	- 6	199	99
	300	72	113	93	- 8	- 2	268	89
K ₂ HPO ₄	50	15	24	26	-10	- 6	49	98
	100	17	34	38	3	- 5	87	87
	200	50	68	68	10	- 4	187	94
	300	100	90	93	15	- 3	295	98
KH ₂ PO ₄	50	13	23	17	- 2	- 8	43	86
	100	40	33	25	2	- 6	94	94
	200	44	98	48	4	- 4	190	95
	300	72	113	98	5	- 3	285	95
(NH ₄) ₂ HPO ₄	50	7	23	15	2	- 6	41	82
	100	18	38	29	11	- 3	93	93
	200	36	65	73	19	- 5	188	94
	300	70	110	190	24	- 5	321	107
K ₄ P ₂ O ₇	50	6	3	32	6	- 6	41	82
	100	40	15	32	10	- 3	94	94
	200	88	34	67	11	- 2	198	99
	300	100	60	83	16	- 2	257	86
15-62-0	50	9	15	20	7	- 3	48	96
	100	15	18	53	11	0	97	97
	200	31	50	97	15	0	193	97
	300	34	94	133	20	0	281	94
11-37-0	50	19	8	20	1	- 5	43	86
	100	34	39	25	1	- 3	96	96
	200	78	45	53	16	- 3	189	94
	300	124	88	63	20	0	295	98
0-72-0	50	12	15	23	7	- 3	54	108
	100	26	21	39	7	0	93	93
	200	45	68	72	7	0	192	96
	300	66	97	123	7	0	293	98

¹After phosphate application.

TABLE VIII

NET PHOSPHATE RECOVERED BY FRACTION AND PERCENT
RECOVERY, CROPPED SOILS (EIGHT WEEKS)¹

Treatment	ppm P Applied	NH ₄ Cl- P	Al-P	Fe-P	Ocl. Fe-P	Ca-P	ppm P Recovered	% Recovery
Zero Time	0	9	22	67	25	15	138	-
Control	0	4	5	48	19	8	84	-
Ca(PO ₃) ₂	50	- 1	0	64	-14	- 3	46	92
	100	- 1	3	103	-12	- 2	91	91
	200	- 1	4	150	-12	- 2	139	70
	300	- 1	5	230	- 7	- 2	225	75
Ca(H ₂ PO ₄) ₂	50	6	9	41	-12	- 8	36	72
	100	21	15	54	-12	- 7	71	71
	200	27	34	73	-12	- 3	119	60
	300	59	85	83	-12	0	215	72
K ₂ HPO ₄	50	14	15	35	-10	- 6	48	96
	100	18	25	45	- 3	- 5	80	80
	200	39	34	48	0	- 4	117	59
	300	66	41	58	5	- 3	167	56
KH ₂ PO ₄	50	4	3	23	0	- 7	23	46
	100	12	22	25	0	- 5	54	54
	200	31	47	26	0	- 5	99	50
	300	43	75	29	2	- 5	144	48
(NH ₄) ₂ HPO ₄	50	3	9	7	5	- 5	19	38
	100	10	28	16	8	- 3	59	59
	200	24	50	22	12	- 3	105	53
	300	50	85	36	14	- 2	183	62
K ₄ P ₂ O ₇	50	4	0	33	6	- 3	40	80
	100	9	9	33	3	- 2	52	52
	200	26	18	68	11	- 2	121	61
	300	54	28	83	14	- 2	177	59
15-62-0	50	4	- 3	23	8	- 3	29	58
	100	8	22	53	10	0	93	93
	200	14	54	93	10	0	171	86
	300	19	79	123	14	0	239	78
11-37-0	50	9	9	23	8	- 3	46	92
	100	21	31	28	10	- 3	87	87
	200	40	54	53	1	- 3	145	73
	300	75	83	63	- 3	- 3	215	72
0-72-0	50	12	9	21	10	- 3	49	98
	100	16	15	33	10	- 3	71	71
	200	31	75	63	5	- 3	171	85
	300	41	82	113	1	- 3	234	78

¹After phosphate applied.

TABLE IX

NET PHOSPHATE RECOVERED BY FRACTION AND PERCENT
RECOVERY, NONCROPPED SOILS (TWELVE WEEKS)¹

Treatment	ppm P Applied	NH ₄ Cl- P	Al-P	Fe-P	Ocl. Fe-P	Ca-P	ppm P Recovered	T Recovery
Zero Time	0	9	22	67	25	15	138	-
Control	0	4	10	93	20	10	137	-
Ca(PO ₃) ₂	50	- 4	-10	63	1	0	50	100
	100	- 4	- 7	103	1	3	96	96
	200	- 2	- 7	187	1	9	188	94
	300	- 2	- 6	280	1	9	284	94
Ca(H ₂ PO ₄) ₂	50	12	- 2	43	1	0	54	108
	100	34	8	47	5	3	97	97
	200	53	40	80	10	7	190	95
	300	75	65	120	15	9	284	95
K ₂ HPO ₄	50	13	- 2	46	- 5	- 6	46	92
	100	34	11	48	10	- 3	95	95
	200	60	27	80	24	1	192	96
	300	80	68	110	29	1	288	96
KH ₂ PO ₄	50	6	2	18	25	- 3	48	96
	100	24	18	30	30	1	96	96
	200	47	34	42	42	3	190	95
	300	72	71	50	50	5	291	97
(NH ₄) ₂ HPO ₄	50	9	- 3	28	19	- 3	50	100
	100	15	24	34	24	0	97	97
	200	37	59	76	24	0	196	98
	300	62	103	94	29	1	289	97
K ₄ P ₂ O ₇	50	12	- 1	17	19	0	47	94
	100	42	13	23	19	3	100	100
	200	66	20	77	24	3	190	95
	300	83	27	140	29	3	272	91
15-62-0	50	10	- 4	37	5	0	48	96
	100	18	1	67	10	0	96	96
	200	34	32	110	15	0	191	96
	300	78	65	130	15	0	288	96
11-37-0	50	28	- 1	6	15	0	48	96
	100	47	25	13	17	0	102	102
	200	62	90	25	19	0	196	98
	300	76	158	42	24	5	305	101
0-72-0	50	12	- 3	42	0	- 3	48	96
	100	13	25	57	5	- 2	98	98
	200	60	60	85	10	- 2	213	106
	300	82	82	127	24	0	315	105

¹After phosphate application.

TABLE X

NET PHOSPHATE RECOVERED BY FRACTION AND PERCENT
RECOVERY, CROPPED SOILS (TWELVE WEEKS)¹

Treatment	ppm P Applied	NH ₄ Cl- P	Al-P	Fe-P	Ocl. Fe-P	Ca-P	ppm P Recovered	% Recovery
Zero Time	0	9	22	67	25	15	138	-
Control	0	3	5	47	16	5	76	+
Ca(PO ₃) ₂	50	- 2	- 6	53	3	0	48	96
	100	- 2	- 6	103	4	0	99	99
	200	- 2	- 3	143	- 6	4	136	68
	300	- 2	- 3	243	- 8	4	234	78
Ca(H ₂ PO ₄) ₂	50	4	1	43	3	- 3	48	96
	100	18	5	56	- 2	0	77	77
	200	24	23	83	- 6	0	124	62
	300	56	54	123	- 8	4	229	76
K ₂ HPO ₄	50	12	3	38	- 2	- 3	48	96
	100	14	12	53	- 2	0	77	77
	200	34	20	63	8	3	128	64
	300	54	31	103	13	3	204	68
KH ₂ PO ₄	50	1	- 3	23	22	- 3	46	92
	100	4	0	28	38	0	70	70
	200	14	18	38	41	1	112	56
	300	29	41	73	51	8	202	67
(NH ₄) ₂ HPO ₄	50	- 2	3	33	8	0	42	84
	100	7	15	41	13	1	77	77
	200	16	34	73	13	3	139	70
	300	43	40	83	18	3	187	62
K ₄ P ₂ O ₇	50	1	0	23	13	3	40	80
	100	4	15	30	8	3	60	60
	200	36	15	74	3	0	128	64
	300	54	25	126	3	0	208	69
15-62-0	50	1	- 5	35	3	0	34	68
	100	14	4	53	8	0	79	79
	200	32	26	93	10	0	161	80
	300	44	46	115	15	0	220	73
11-37-0	50	2	3	12	13	3	33	66
	100	14	6	18	8	3	49	49
	200	30	45	33	3	3	114	57
	300	63	65	48	3	3	182	61
0-72-0	50	6	- 2	43	- 4	0	43	86
	100	11	0	53	1	0	65	65
	200	23	50	75	8	0	156	78
	300	24	69	114	10	0	217	72

¹After phosphate application.

TABLE XI

NET PHOSPHATE RECOVERED BY FRACTION AND PERCENT RECOVERY, NONCROPPED SOILS (TWENTY-SIX WEEKS)¹

Treatment	ppm P Applied	NH ₄ Cl-P	Al-P	Fe-P	Ocl. Fe-P	Ca-P	ppm P Recovered	% Recovery
Zero Time	0	9	22	67	25	15	138	-
Control	0	4	10	93	20	10	137	-
Ca(PO ₃) ₂	50	- 2	-14	44	24	- 5	47	94
	100	- 2	-14	90	25	- 4	95	95
	200	- 2	-12	183	25	- 4	190	95
	300	- 2	- 9	270	25	- 2	282	94
Ca(H ₂ PO ₄)	50	16	- 4	27	16	- 4	51	102
	100	29	6	48	17	- 4	96	96
	200	66	49	68	17	- 4	196	98
	300	72	109	97	20	- 4	294	98
K ₂ HPO ₄	50	11	2	25	16	- 6	48	96
	100	28	18	42	16	- 6	98	98
	200	60	75	50	17	- 4	198	99
	300	85	118	77	20	- 4	296	99
KH ₂ PO ₄	50	15	- 2	22	19	- 6	48	96
	100	21	11	42	24	- 4	94	94
	200	37	65	79	24	- 4	205	102
	300	56	102	99	25	- 4	278	93
(NH ₄) ₂ HPO ₄	50	10	3	20	19	- 4	48	96
	100	18	18	44	21	- 5	96	96
	200	28	58	85	23	- 6	188	94
	300	53	118	96	25	- 6	286	95
K ₄ P ₂ O ₇	50	11	15	17	13	- 6	50	100
	100	34	20	34	13	- 6	95	95
	200	66	62	57	19	- 6	198	99
	300	116	97	60	27	- 6	294	98
15-62-0	50	6	3	30	15	- 4	50	100
	100	9	15	60	15	- 4	95	95
	200	33	60	87	15	- 4	191	96
	300	40	127	108	24	- 4	295	98
11-37-0	50	21	4	12	15	- 4	48	96
	100	21	22	41	15	- 4	95	95
	200	64	59	60	17	- 4	196	98
	300	103	88	84	20	- 4	291	97
0-72-0	50	1	2	27	23	- 5	48	96
	100	23	18	37	23	- 5	96	96
	200	44	58	70	24	- 4	192	96
	300	66	118	87	25	- 4	292	97

¹After phosphate application.

TABLE XII
 THE RESPONSE OF SUGAR DRIP SORGHUM TO PHOSPHATE
 SOURCES BY APPLICATION RATES

Treatment	ppm P Applied	Grams of Dry Matter Harvest Number			Sum	Rates Grouping ¹
		1	2	3		
Control	0	7.06	0.60	0.13	7.79	-
Ca(PO ₃) ₂	10	7.80	0.69	0.19	8.68	G
	25	7.90	0.70	0.23	8.83	F
	50	8.20	0.69	0.26	0.15	E
	75	8.50	0.73	0.28	9.51	B
	100	8.30	0.76	0.34	9.40	C
	150	8.10	0.68	0.35	9.13	E
	200	8.17	0.70	0.36	9.23	D
	250	8.20	0.78	0.38	9.36	C
Ca(H ₂ PO ₄) ₂	300	8.40	0.91	0.38	9.69	A
	10	9.40	0.77	0.30	10.47	G
	25	9.53	0.81	0.36	10.70	F
	50	9.52	0.84	0.38	10.74	F
	75	9.60	0.89	0.38	10.88	E
	100	9.63	0.92	0.40	10.95	D, E
	150	9.65	0.96	0.42	11.03	D
	200	9.68	1.00	0.43	11.11	C
K ₂ HPO ₄	250	9.84	1.04	0.46	11.34	B
	300	10.53	1.30	0.51	12.34	A
	10	8.50	0.62	0.35	9.47	I
	25	8.58	0.71	0.37	9.66	H
	50	8.63	0.93	0.50	10.06	G
	75	8.65	1.12	0.54	10.31	F
	100	8.70	1.22	0.60	10.52	E
	150	9.28	1.83	0.71	11.82	D
KH ₂ PO ₄	200	9.46	2.10	1.20	11.76	B
	250	9.88	2.30	1.10	13.28	A
	300	9.13	2.30	0.85	12.28	C
	10	8.50	0.94	0.47	9.91	H
	25	8.53	1.00	0.43	9.96	G, H
	50	8.56	1.07	0.38	10.01	G
	75	8.88	1.15	0.36	10.39	F
	100	9.33	1.18	0.36	10.87	E
	150	9.40	1.20	0.37	10.97	D
	200	9.73	1.23	0.48	11.34	C
	250	10.53	1.38	0.58	12.49	B
	300	10.62	1.41	0.64	12.67	A

TABLE XII (Con't)

Treatment	ppm P Applied	Grams of Dry Matter Harvest Number			Sum	Rates ¹ Grouping
		1	2	3		
(NH ₄) ₂ HPO ₄	10	9.80	0.64	0.40	10.84	H
	25	11.25	0.71	0.48	12.44	E
	50	11.78	0.72	0.52	13.02	C
	75	12.18	0.75	0.42	13.35	B
	100	12.41	0.84	0.45	13.70	A
	150	11.60	0.91	0.33	12.84	D
	200	10.38	0.85	0.33	11.56	F
	250	9.55	1.41	0.14	11.10	G
	300	6.50	1.40	0.10	8.00	I
K ₄ P ₂ O ₇	10	8.90	0.61	0.33	9.84	I
	25	9.20	0.81	0.37	10.38	H
	50	9.30	0.87	0.42	10.59	G
	75	9.42	0.97	0.46	10.85	F
	100	9.46	1.30	0.54	11.30	E
	150	9.48	2.31	1.04	12.83	D
	200	9.50	2.39	1.06	12.95	C
	250	10.27	2.71	1.16	14.14	B
	300	10.58	2.87	1.65	15.10	A
15-62-0	10	8.45	0.66	0.33	9.44	F
	25	9.30	0.71	0.37	10.38	C
	50	9.37	0.84	0.40	10.61	B
	75	9.40	0.94	0.43	10.77	A
	100	9.23	0.95	0.46	10.64	B
	150	9.10	1.01	0.48	10.59	B
	200	8.80	1.14	0.47	10.41	C
	250	8.50	1.37	0.42	10.29	D
	300	8.48	1.27	0.37	10.12	E
11-370	10	8.43	0.59	0.34	9.36	F
	25	8.51	0.62	0.37	9.50	E
	50	8.50	0.75	0.39	9.64	D
	75	8.53	0.92	0.43	9.88	C
	100	8.59	0.84	0.45	9.88	C
	150	8.57	0.97	0.42	9.96	C
	200	8.78	1.54	0.42	10.74	A
	250	7.73	0.91	0.68	10.32	B
	300	7.43	1.22	0.83	9.48	E
0-72-0	10	8.22	0.59	0.33	9.14	G
	25	8.30	0.67	0.41	9.38	F
	50	8.33	0.86	0.44	9.63	E
	75	8.44	0.92	0.47	9.83	C
	100	9.81	1.45	0.51	11.77	A
	150	8.49	1.60	0.53	10.62	B
	200	7.35	1.79	0.58	9.72	D
	250	6.86	1.73	0.49	9.08	G
	300	6.21	1.68	0.47	8.36	H

¹Sums followed by the same letter are not different statistically at odds of 19 to 1 (Duncan multiple range test).

Duncan's multiple range test was used to determine if the yield differences between rates for each treatment and between treatments for each rate were significant and the results are shown in Tables XII and XIII, respectively. The analyses of variance is given in Table XIV. Many of the phosphate treatments have a significant effect on yield as is shown in Table XIII. It was found that calcium metaphosphate $\text{Ca}(\text{PO}_3)_2$, at all rates, did not produce a significant increase in yield due to its very low solubility.

The effect of phosphate rates 50, 100, 200, and 300 ppm on the yield of sugar drip sorghum are shown in Figures 1 to 4. It is apparent that the application of phosphate increased yields at low phosphate application rates which was closely related to phosphate source solubility, increasing rate of fertilization, generally, increased yields with notable exceptions at higher rates of ammonium monohydrogen phosphate $(\text{NH}_4)\text{HPO}_4$, 15-62-0, 11-37-0 and 0-72-0. The decrease in yields for these compounds at the higher fertilization rates are not completely understood. The possibility of initial NH_3 toxicity from the materials excepting 0-72-0 because of a high NH_4^+ -N presence in these treatments and acidification or Al toxicity are possibilities, the later the likely main effect from 0-72-0. However, because of the high solubilities of these fertilizer materials, the possibility of detrimental salt effect must also be considered, especially for the first crop. This possibility for $(\text{NH}_4)_2\text{HPO}_4$ is particularly of concern because of the higher than 100 ppm N present for the first two crops at the 300 ppm P rate since it is added in the P compound.

In the case of phosphoric acid (0-72-0), the decrease in yield with the rate 300 ppm is probably due to soil acidity and soil

TABLE XIII

THE RESPONSE OF SUGAR DRIP SORGHUM TO PHOSPHATE
RATES RELATED TO SOURCE

Rate ppm P	Treatment	Sum	Treatments ¹ Grouping
10	(NH ₄) ₂ HPO ₄	10.84	A
	Ca(H ₂ PO ₄) ₂	10.47	B
	KH ₂ PO ₄	9.91	C
	K ₄ P ₂ O ₇	9.84	C
	K ₂ HPO ₄	9.47	D
	15-62-0	9.44	E
	11-37-0	9.36	E
	0-72-0	9.14	F
	Ca(PO ₃) ₂	8.68	G
25	(NH ₄) ₂ HPO ₄	12.44	A
	Ca(H ₂ PO ₄) ₂	10.70	B
	K ₄ P ₂ O ₇	10.38	C
	15-62-0	10.38	C
	KH ₂ PO ₄	9.96	D
	K ₂ HPO ₄	9.66	E
	11-37-0	9.50	F
	0-72-0	9.38	G
	Ca(PO ₃) ₂	8.83	H
50	(NH ₄) ₂ HPO ₄	13.02	A
	Ca(H ₂ PO ₄) ₂	10.74	B
	15-62-0	10.61	C
	K ₄ P ₂ O ₇	10.59	C
	K ₂ HPO ₄	10.06	D
	KH ₂ PO ₄	10.01	D
	11-37-0	9.64	E
	0-72-0	9.63	E
	Ca(PO ₃) ₂	9.15	F
75	(NH ₄) ₂ HPO ₄	13.35	A
	Ca(H ₂ PO ₄) ₂	10.88	B
	K ₄ P ₂ O ₇	10.85	B
	15-62-0	10.77	C
	KH ₂ PO ₄	10.39	D
	K ₂ HPO ₄	10.31	D
	11-37-0	9.88	E
	0-72-0	9.83	E
	Ca(PO ₃) ₂	9.51	F
100	(NH ₄) ₂ HPO ₄	13.70	A
	0-72-0	11.77	B
	K ₄ P ₂ O ₇	11.30	C
	Ca(H ₂ PO ₄) ₂	10.95	D
	KH ₂ PO ₄	10.87	E

TABLE XIII (Con't)

Rate ppm P	Treatment	Sum	Treatments ¹ Grouping
100 (cont'd)	15-62-0	10.64	F
	K ₂ HPO ₄	10.52	G
	11-37-0	9.88	H
	Ca(PO ₃) ₂	9.40	I
150	(NH ₄) ₂ HPO ₄	12.84	A
	K ₄ P ₂ O ₇	12.83	A
	K ₂ HPO ₄	11.82	B
	Ca(H ₂ PO ₄) ₂	11.03	C
	KH ₂ PO ₄	10.97	C
	0-72-0	10.62	D
	15-62-0	10.59	D
	11-37-0	9.96	E
	Ca(PO ₃) ₂	9.13	F
200	K ₄ P ₂ O ₇	12.95	A
	K ₂ HPO ₄	11.76	B
	(NH ₄) ₂ HPO ₄	11.56	C
	KH ₂ PO ₄	11.34	D
	Ca(H ₂ PO ₄) ₂	11.11	E
	11-37-0	10.74	F
	15-62-0	10.41	G
	0-72-0	9.72	H
	Ca(PO ₃) ₂	9.23	I
250	K ₄ P ₂ O ₇	14.14	A
	K ₂ HPO ₄	13.28	B
	KH ₂ PO ₄	12.49	C
	Ca(H ₂ PO ₄) ₂	11.34	D
	(NH ₄) ₂ HPO ₄	11.10	E
	11-37-0	10.32	F
	15-62-0	10.29	F
	Ca(PO ₃) ₂	9.36	G
	0-72-0	9.08	H
300	K ₄ P ₂ O ₇	15.10	A
	KH ₂ PO ₄	12.67	B
	Ca(H ₂ PO ₄) ₂	12.34	C
	K ₂ HPO ₄	12.28	C
	15-62-0	10.12	D
	Ca(PO ₃) ₂	9.69	E
	11-37-0	9.48	F
	0-72-0	8.36	G
	(NH ₄) ₂ HPO ₄	8.00	H

¹Sums followed by the same letter are not different statistically at odds of 19 to 1 (Duncan multiple range test).

TABLE XIV
ANALYSIS OF VARIANCE FOR SUGAR DRIP SORGHUM YIELDS
IN RESPONSE TO PHOSPHATE APPLICATION

Source	DF	MSS	MS
Treatments (Source of P)	8	88.8602	11.10753**
Rate	8	76.6866	3.33582*
Rate-Treatment	64	93.9460	1.46791*
Error-A	243	0.2620	0.00108
Period	2	14837.3470	7418.67349**
Period-Treatment	16	142.7481	8.92176*
Period-Rate	16	36.8014	2.30009*
Period-Rate-Treatment	128	114.8434	0.89721*
Error-B	486	0.5334	0.00110
Corrected Total	971	15342.0281	15.80023

*Significant at 5% level.

**Significant at 1% level.

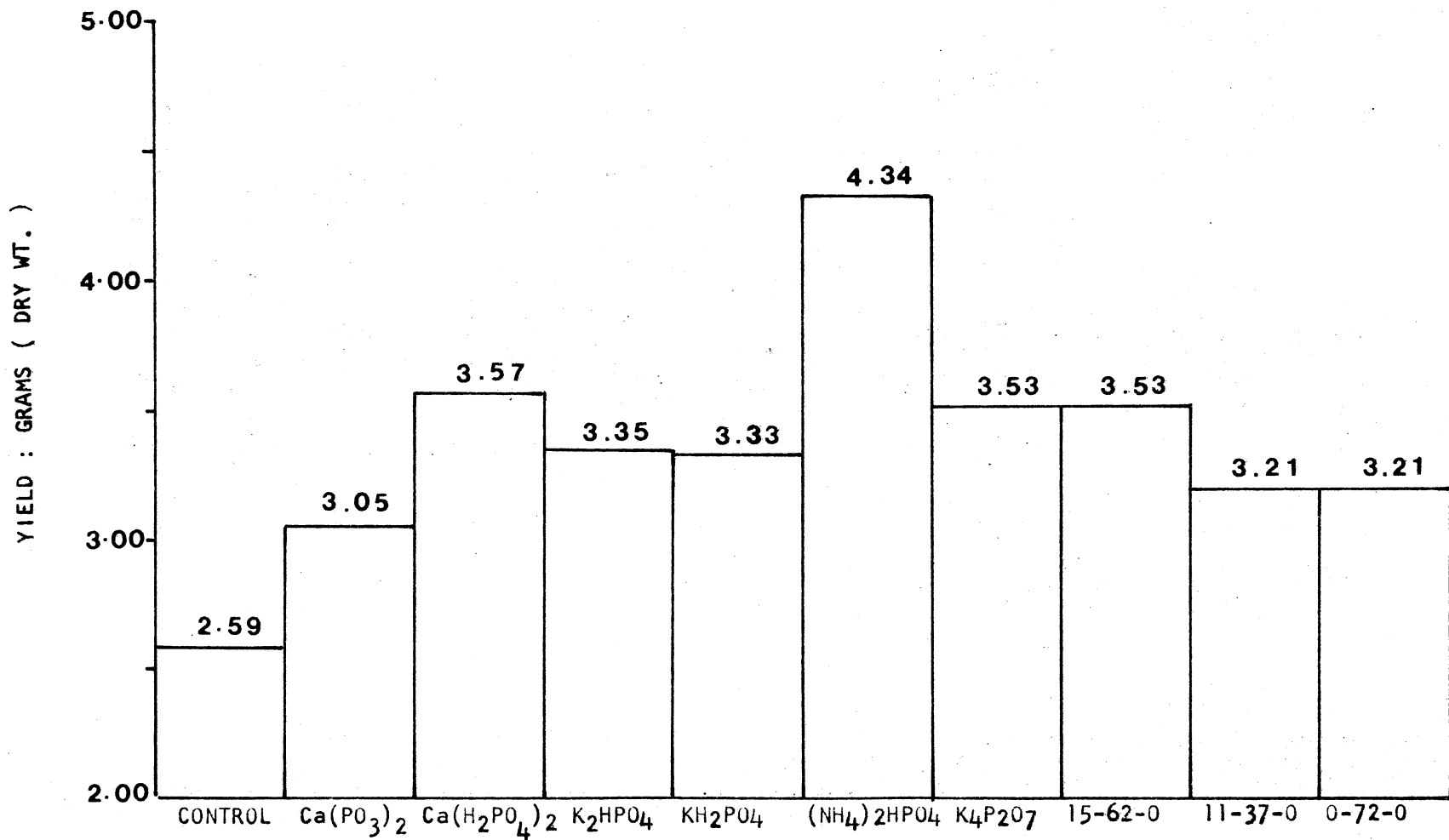


Figure 1. The Effect of 50 ppm P on the Yield of Sugar Drip Sorghum.

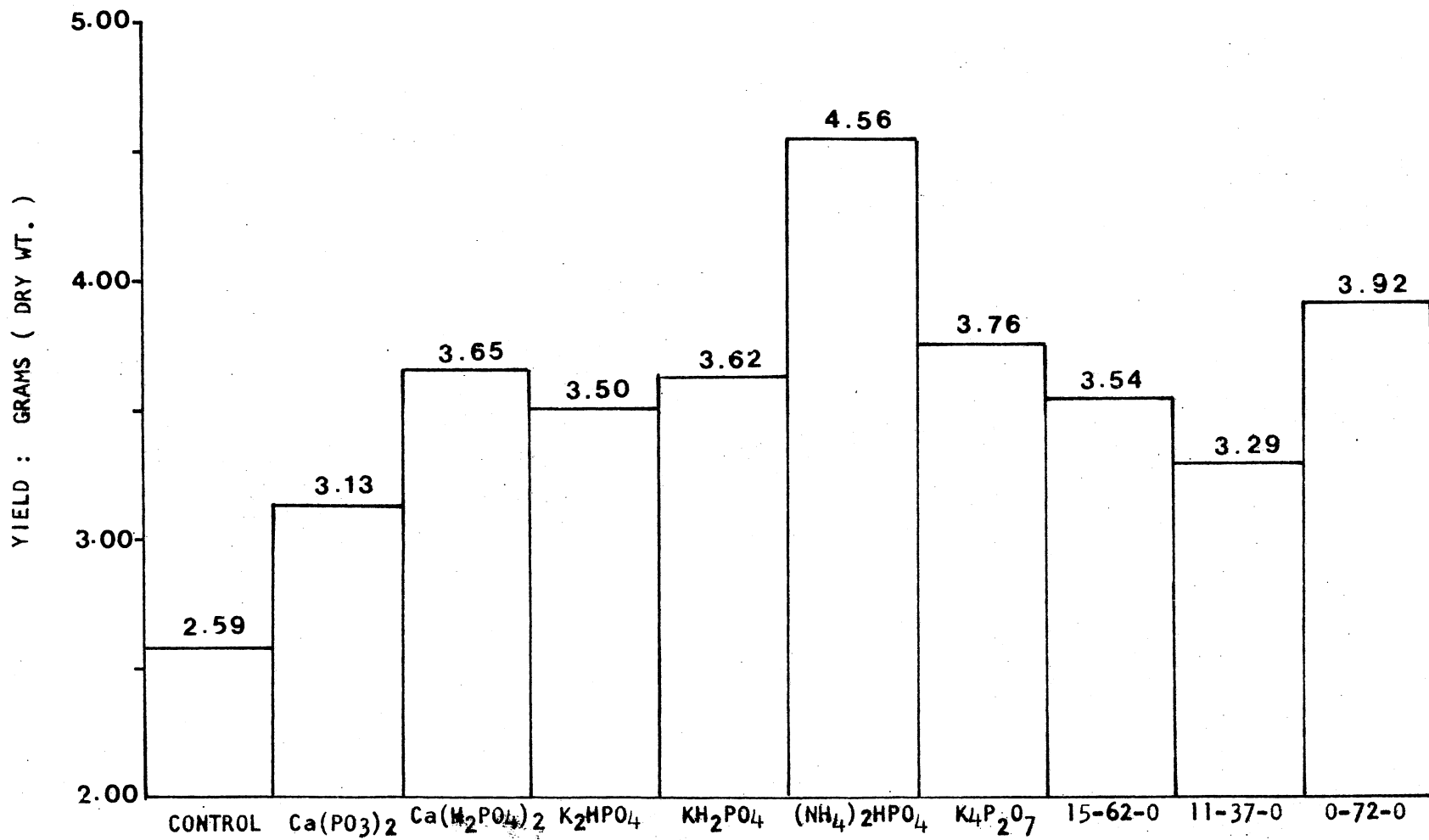


Figure 2. The Effect of 100 ppm P on the Yield of Sugar Drip Sorghum.

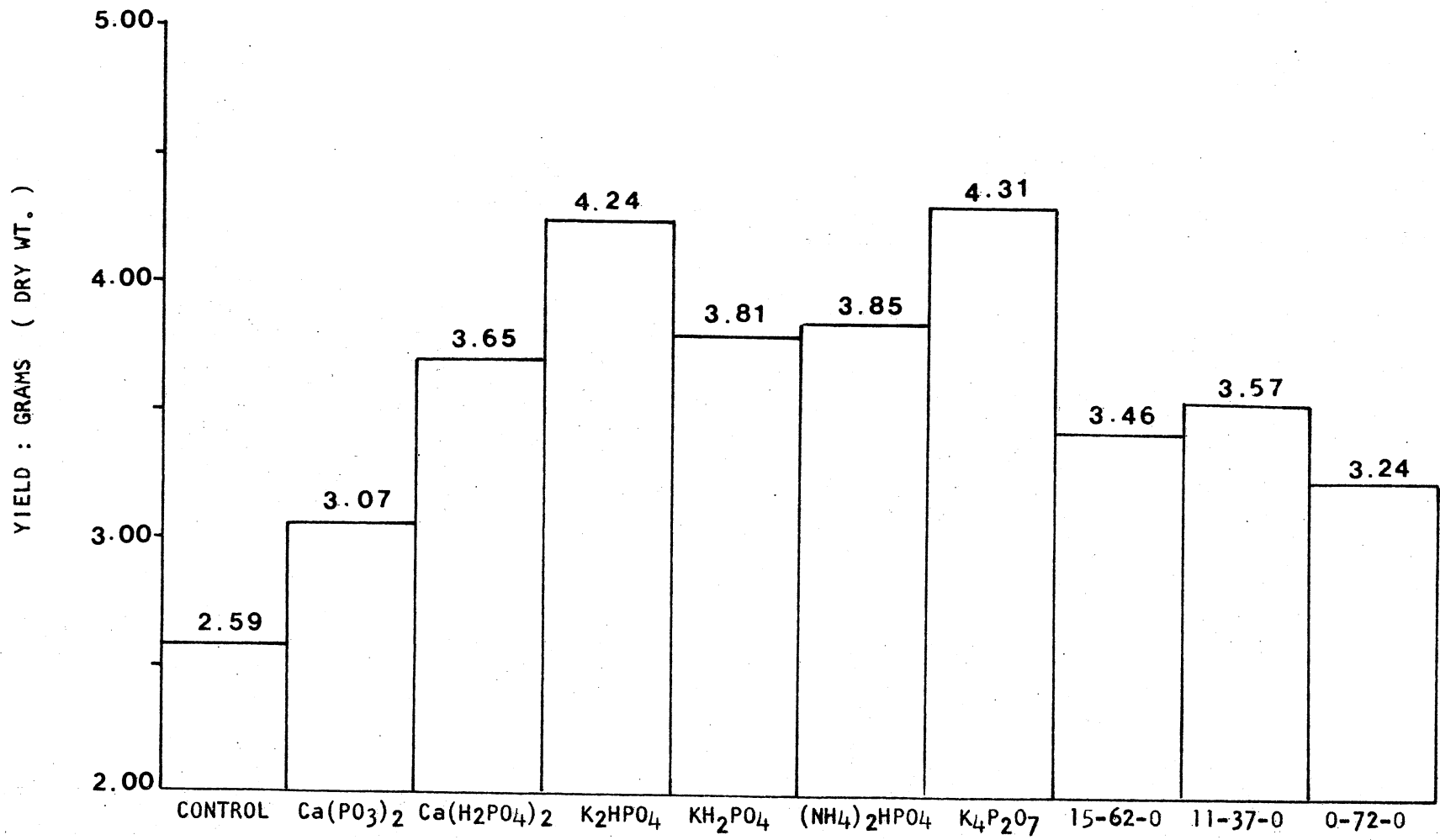


Figure 3. The Effect of 200 ppm P on the Yield of Sugar Drip Sorghum.

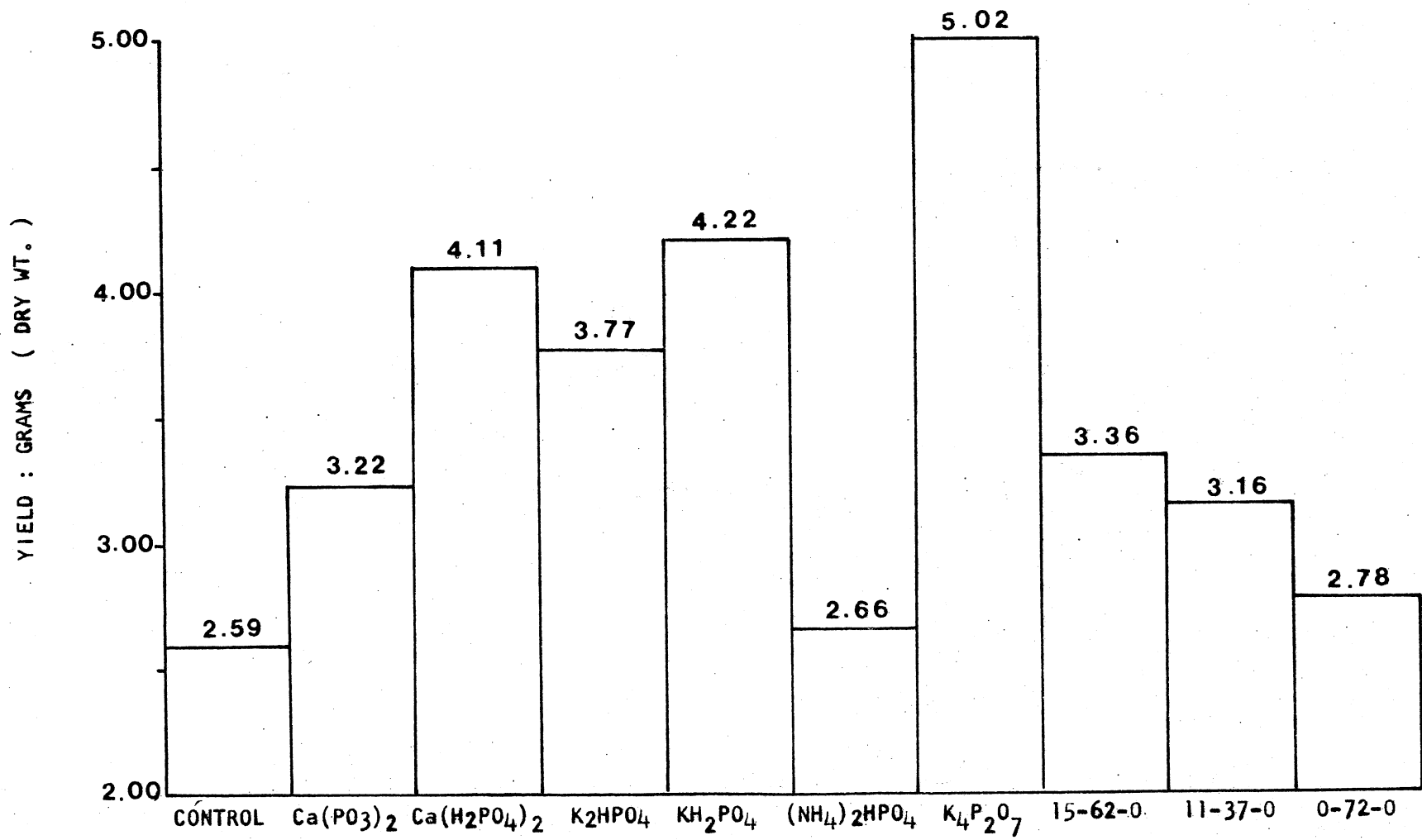


Figure 4. The Effect of 300 ppm P on the Yield of Sugar Drip Sorghum.

aluminum compounds. These results agree with the studies made by Burgess (1923) and Pierre (1931). However, there are few reports in the recent literature on the relationship between crop damage and soil aluminum. Of these, Ragland and Coleman (1959) reported that the growth of roots into unlimed subsoils was inversely related to exchangeable Al. Moreover, Ligon and Pierre (1932) demonstrated that the poor growth on acid soils was due to high concentrations of soluble Al compounds. Research conducted by Wright (1943), however, suggested that Al may also precipitate phosphate within plant roots. More recent work by Clarkson (1966) suggested that the interaction between Al and phosphate was an adsorption-precipitation reaction at the cell wall surface or in the free space of the root which results in the fixation of phosphate.

Crop Removal of Phosphate and Change
in Phosphorus Fraction as a
Function of Time

Figures 5 through 22 are plots of the amounts of ammonium chloride-phosphate ($\text{NH}_4\text{Cl-P}$), aluminum-phosphate (Al-P), iron-phosphate (Fe-P), occluded iron-phosphate (Ocl. Fe-P), and calcium-phosphate (Ca-P) fractions found in treatments as measured by a modification of Chang and Jackson's procedure vs. time for 100 ppm P application rate for both noncropped and cropped treatments. Figures 23 and 24 are plots of the same phosphate fractions for the zero treatment vs. time. The treatments were sampled one week after phosphate application and after the harvest of each crop. The noncropped treatments were sampled again twenty-six weeks after phosphate application. These sampling

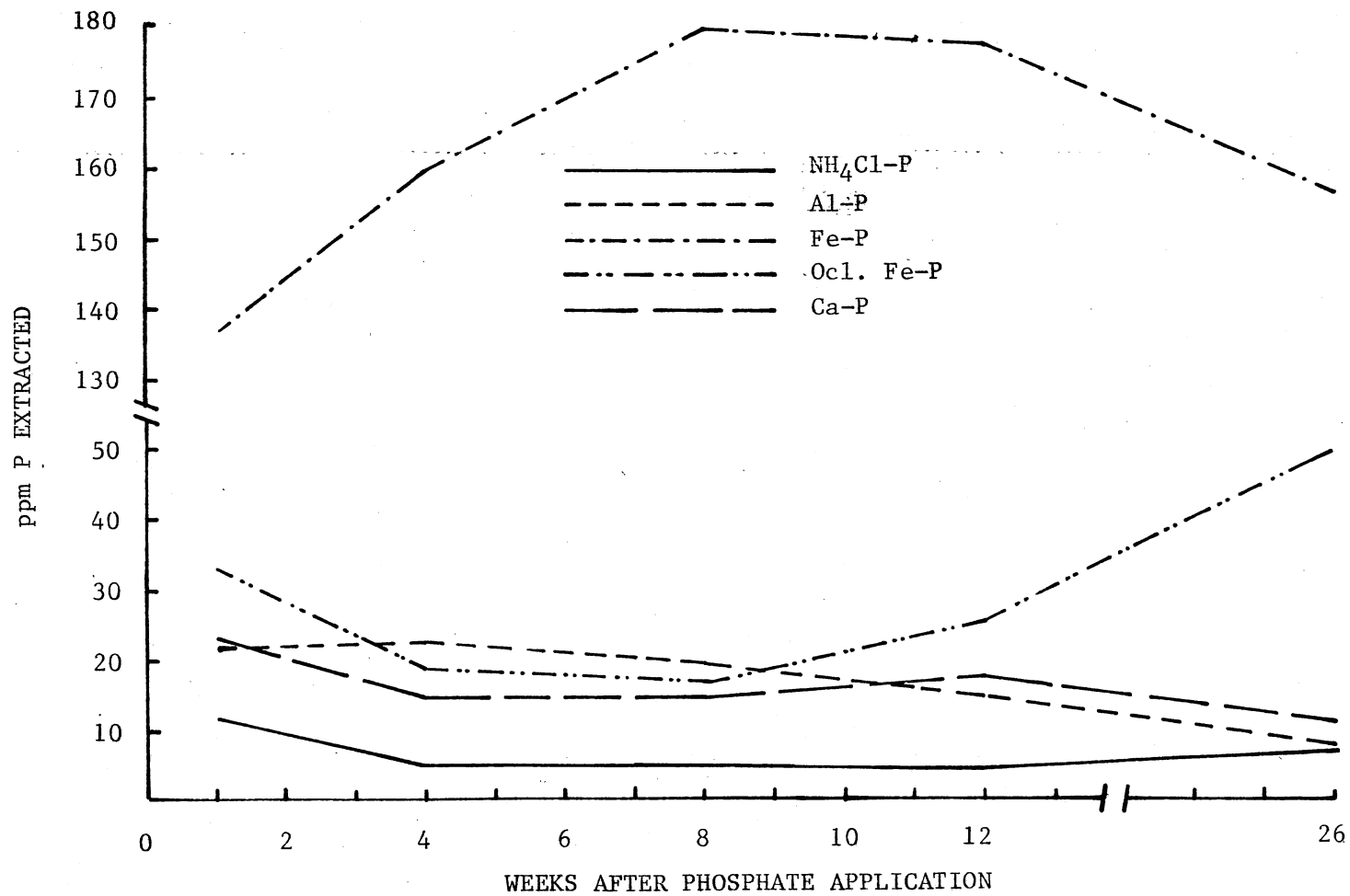


Figure 5. The Phosphate Fractions Extracted from Noncropped Soil of $\text{Ca}(\text{PO}_3)_2$ Treatment as a Function of Time

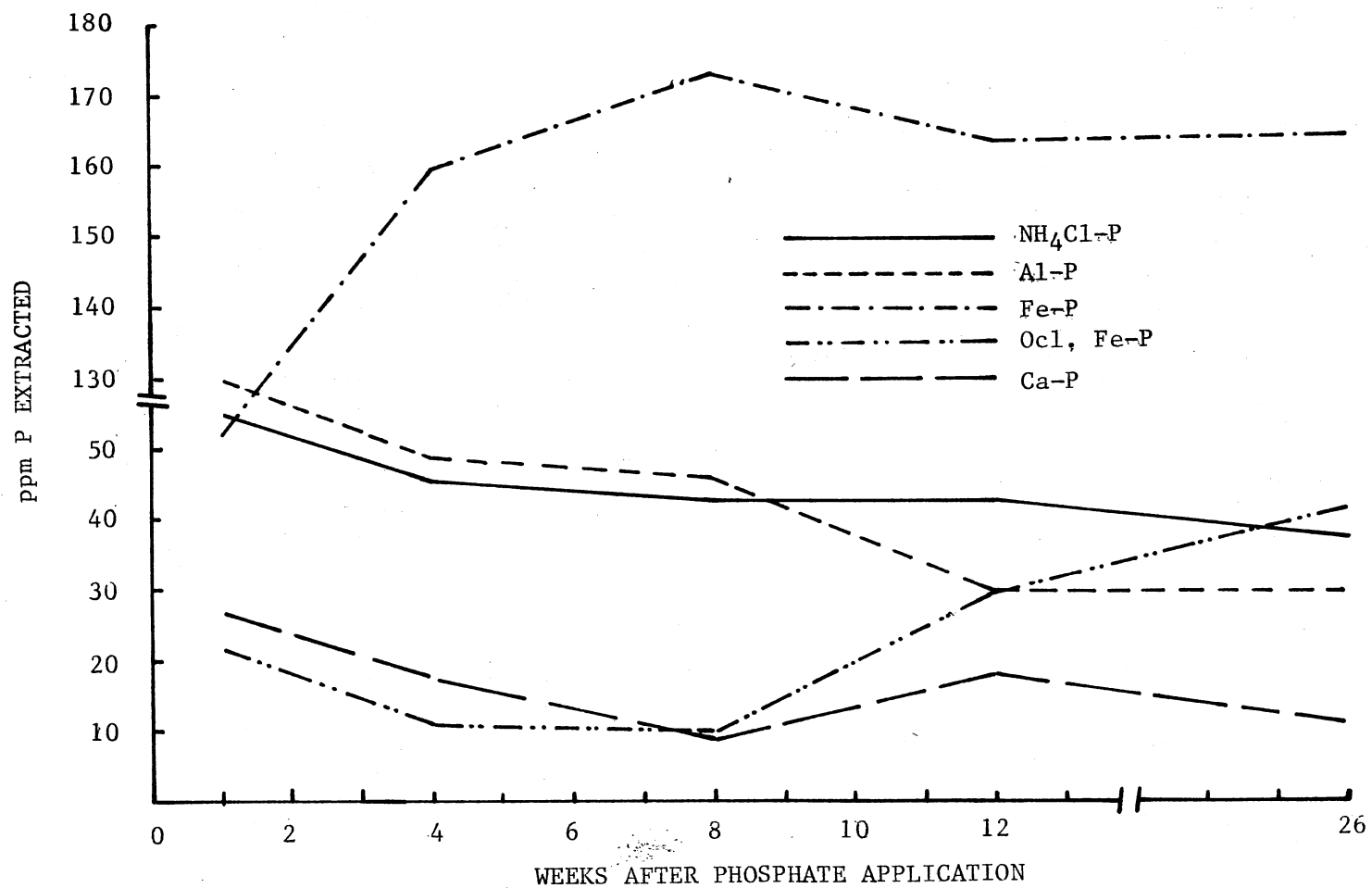


Figure 6. The Phosphate Fractions Extracted from Noncropped Soil of $\text{Ca}(\text{H}_2\text{PO}_4)_2$ Treatment as a Function of Time

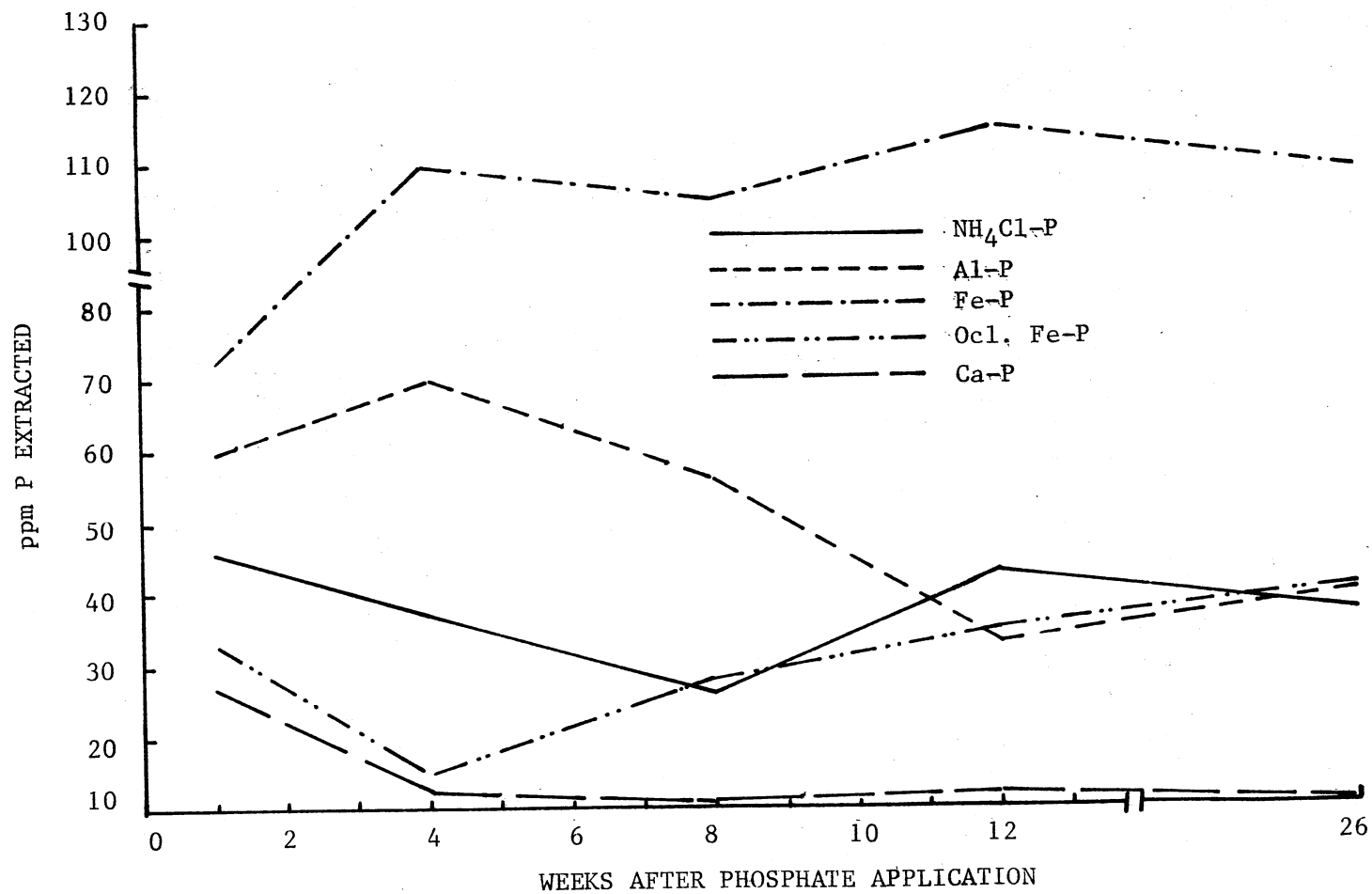


Figure 7. The Phosphate Fractions Extracted from Noncropped Soil of K_2HPO_4 Treatment as a Function of Time

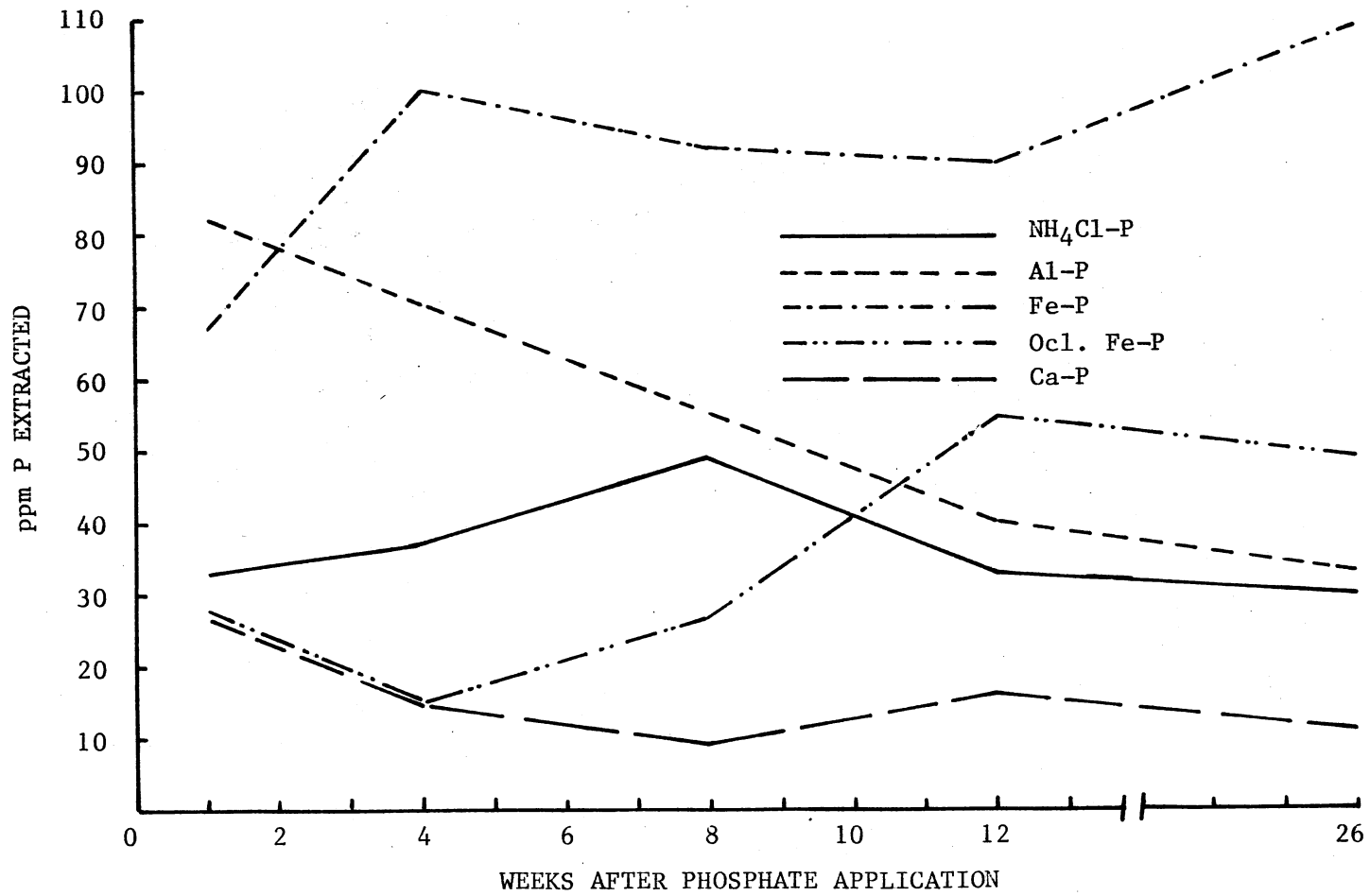


Figure 8. The Phosphate Fractions Extracted from Noncropped Soil of KH_2PO_4 Treatment as a Function of Time

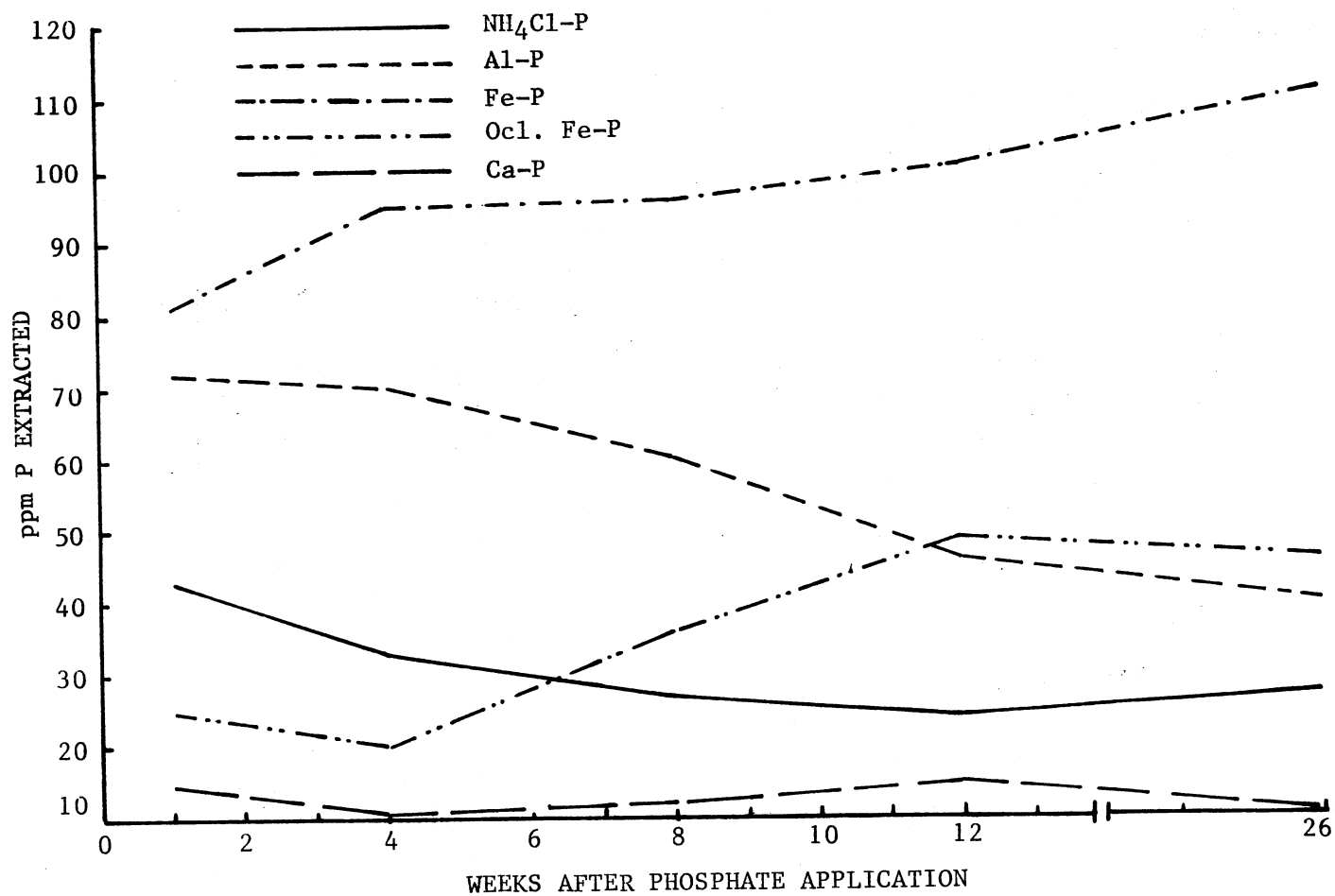


Figure 9. The Phosphate Fractions Extracted from Noncropped Soil of $(\text{NH}_4)_2\text{HPO}_4$ Treatment as a Function of Time

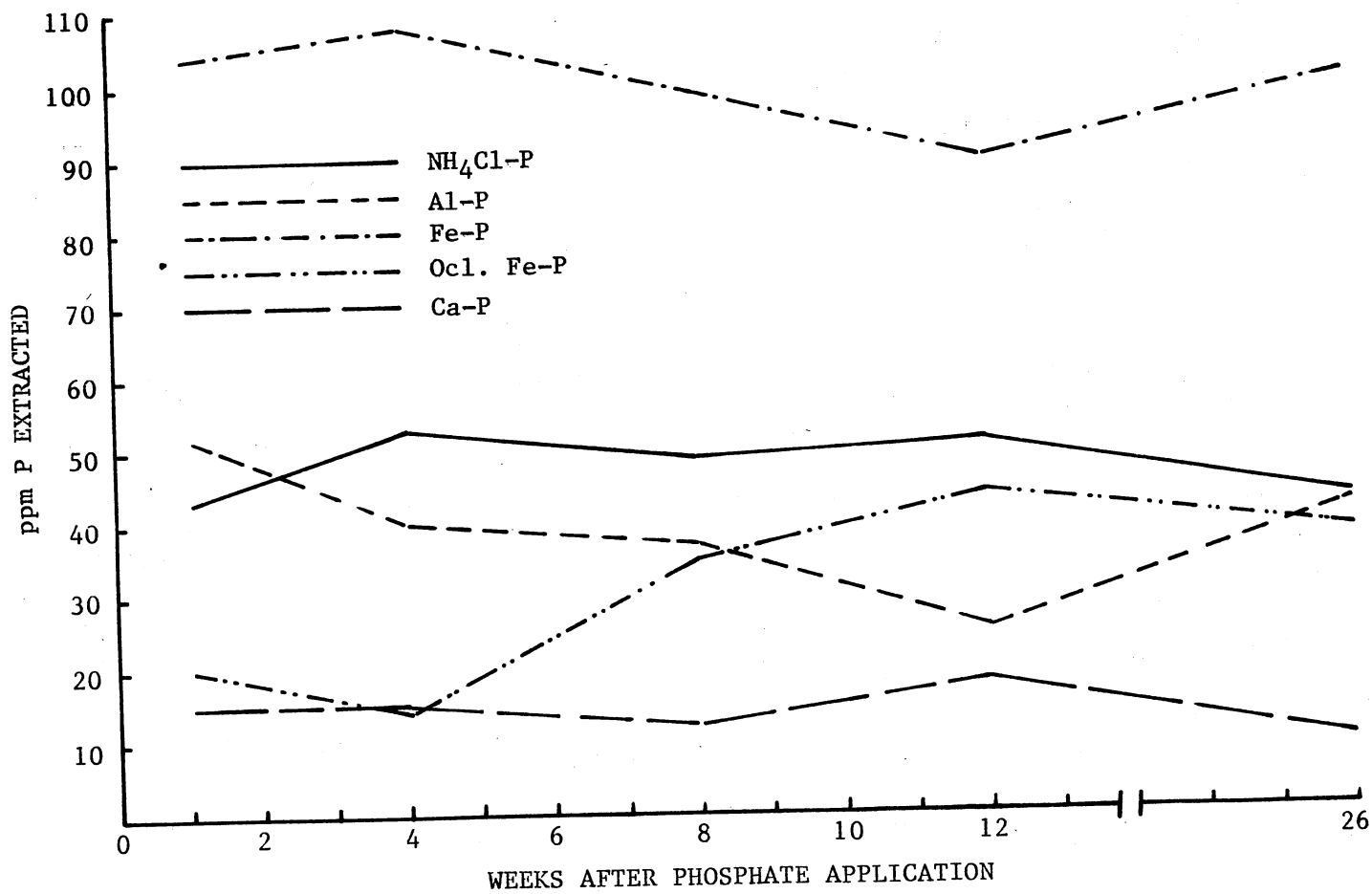


Figure 10. The Phosphate Fractions Extracted from Noncropped Soil of $K_4P_2O_7$ Treatment as a Function of Time

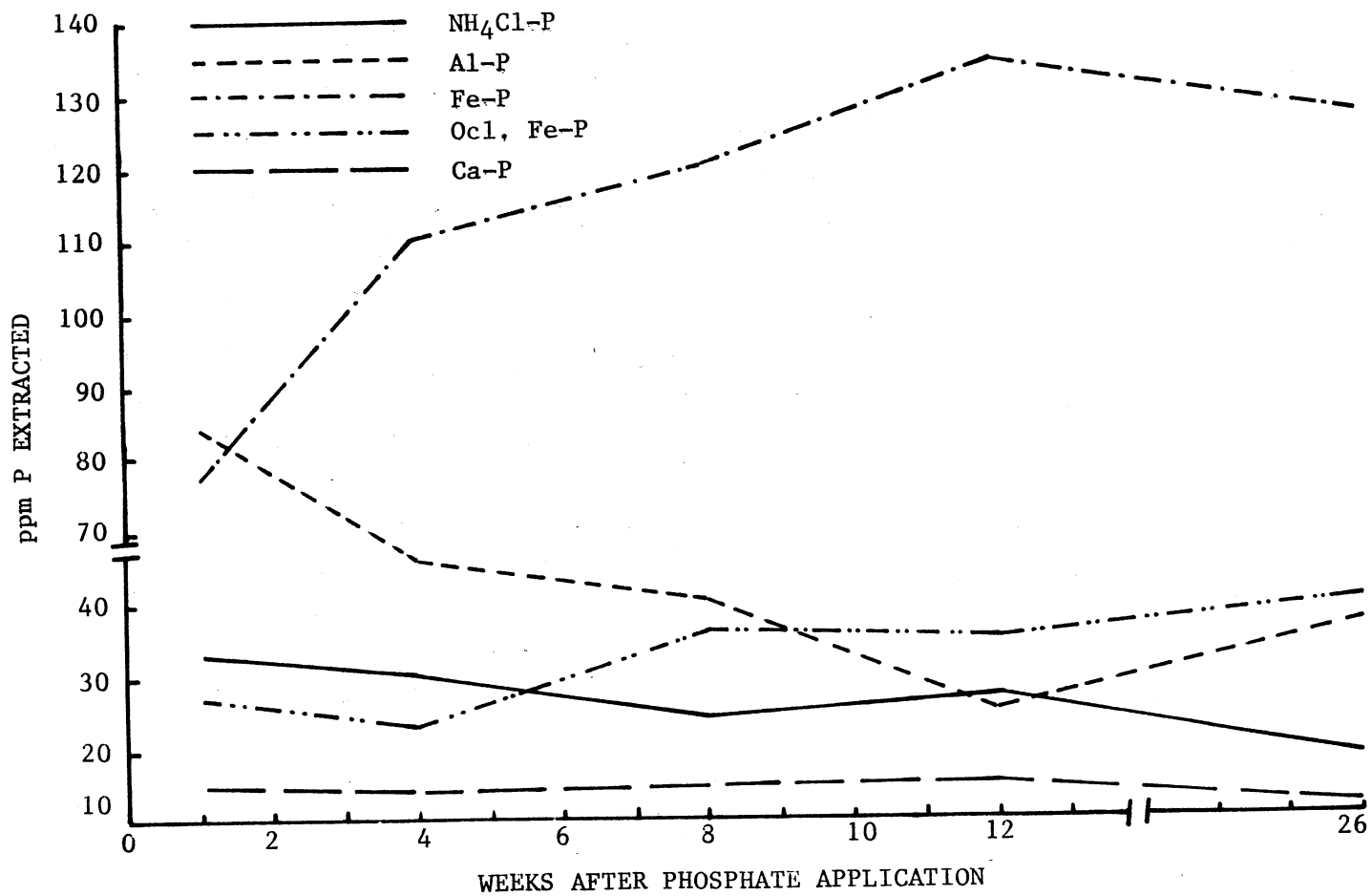


Figure 11. The Phosphate Fractions Extracted from Noncropped Soil of 15-62-0 Treatment as a Function of Time

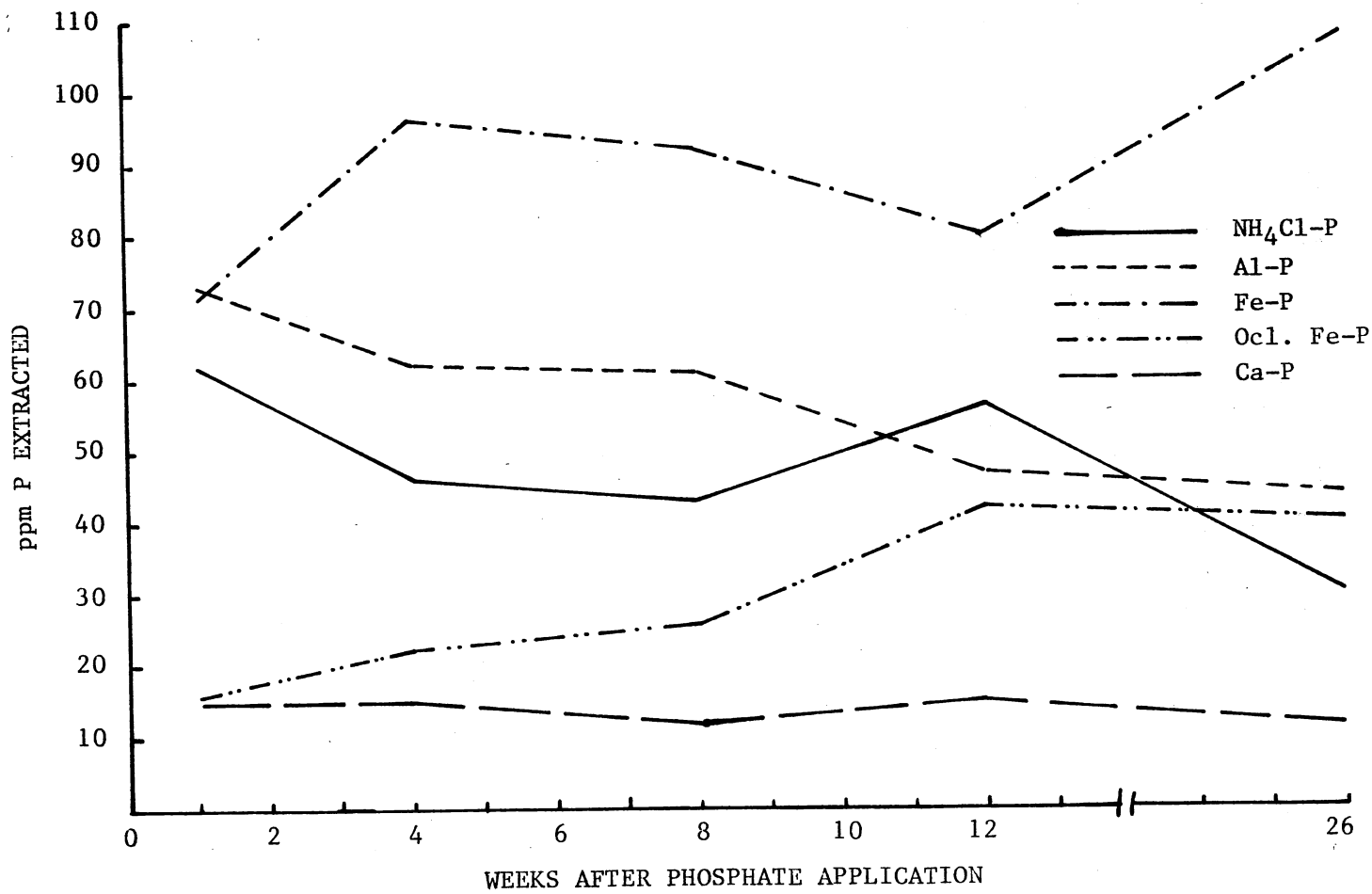


Figure 12. The Phosphate Fractions Extracted from Noncropped Soil of 11-37-0 Treatment as a Function of Time

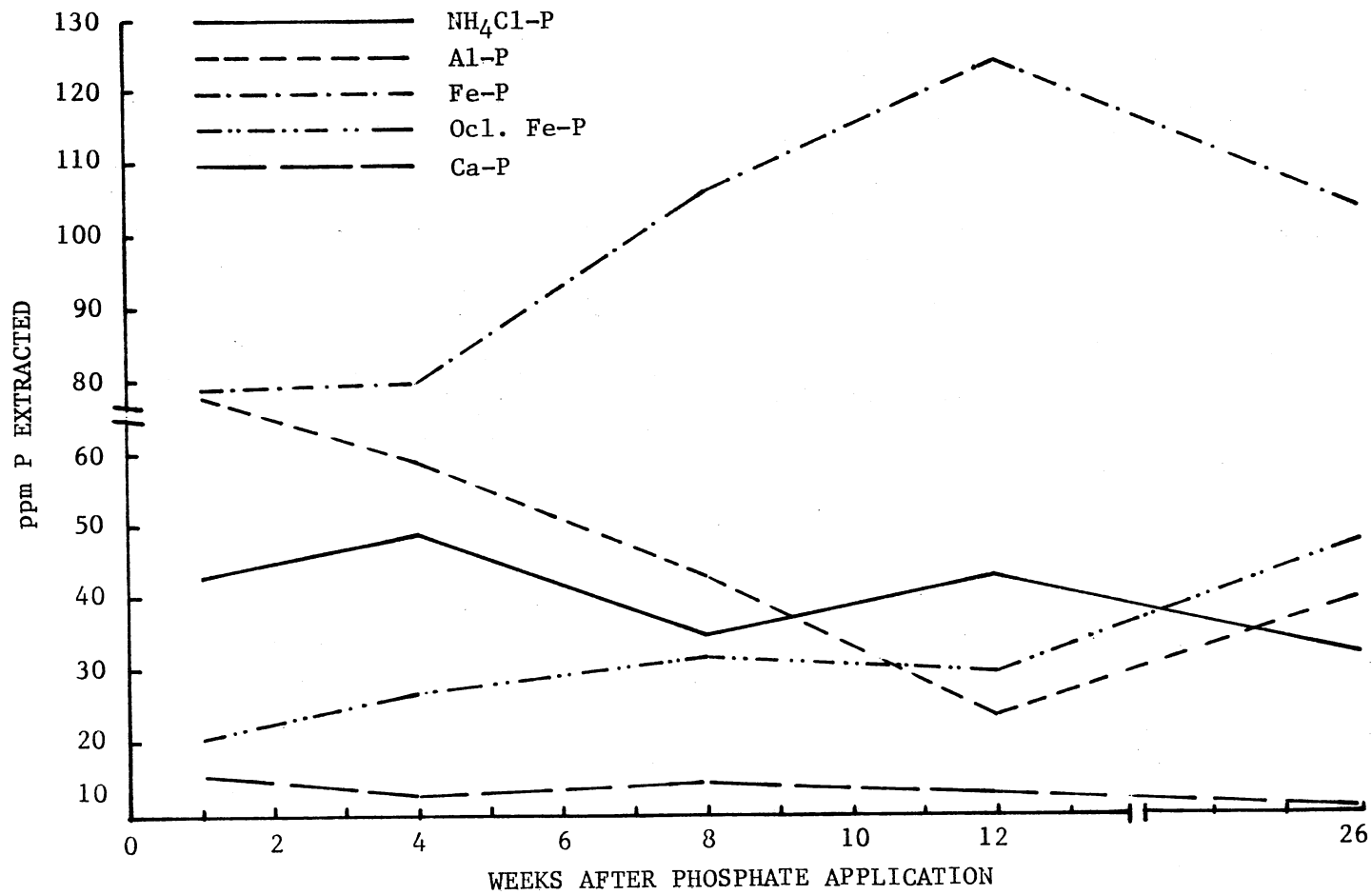


Figure 13. The Phosphate Fractions Extracted from Noncropped Soil of 0-72-0 Treatment as a Function of Time

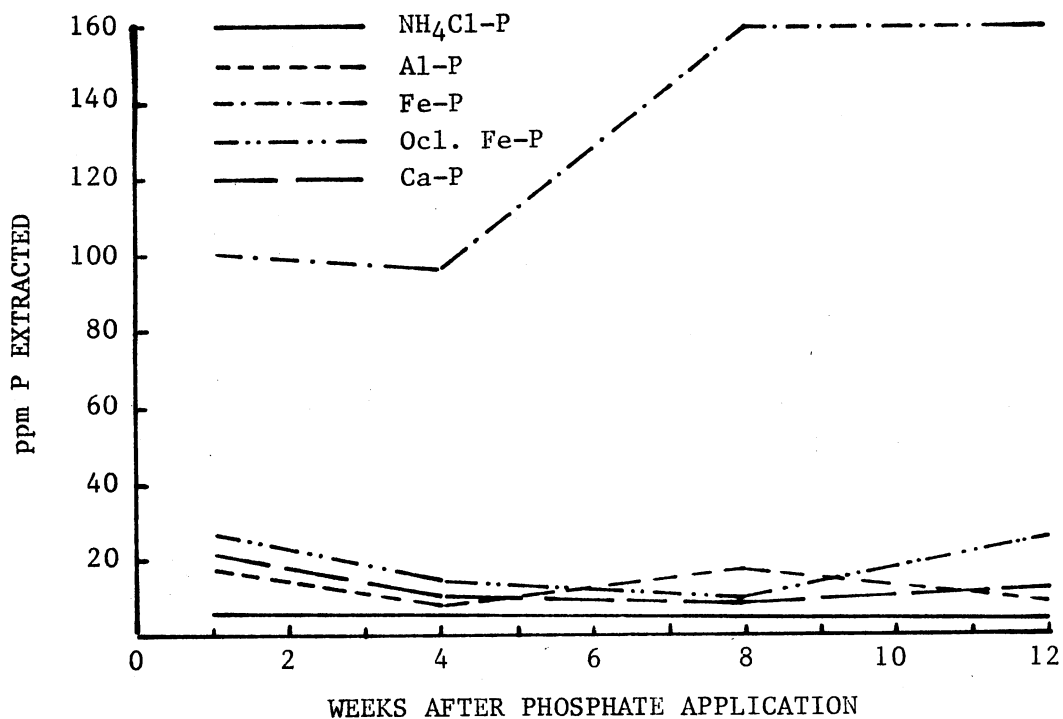


Figure 14. The Phosphate Fractions Extracted from Cropped Soil of $\text{Ca}(\text{PO}_3)_2$ Treatment as a Function of Time

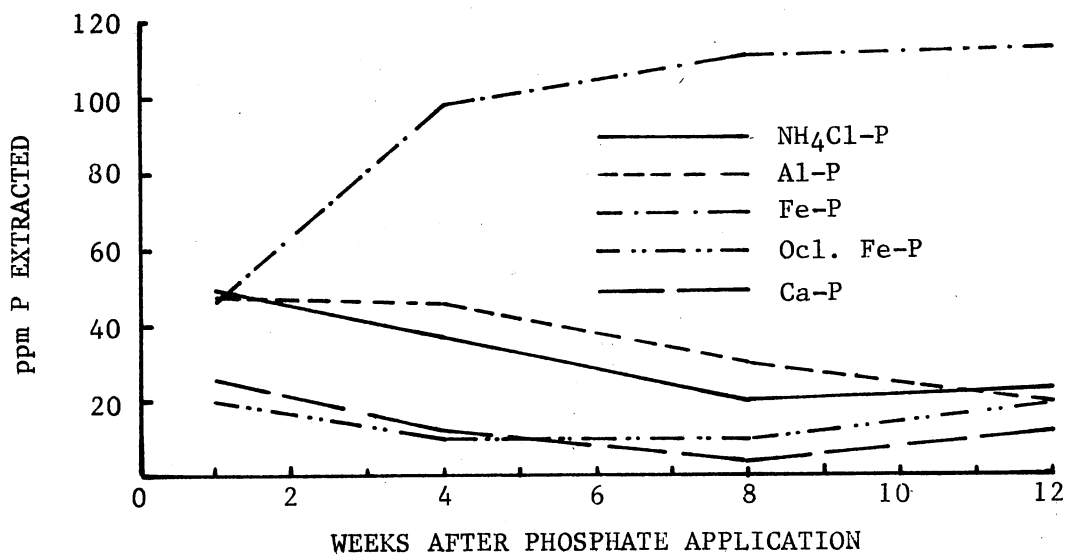


Figure 15. The Phosphate Fractions Extracted from Cropped Soil of $\text{Ca}(\text{H}_2\text{PO}_4)_2$ Treatment as a Function of Time

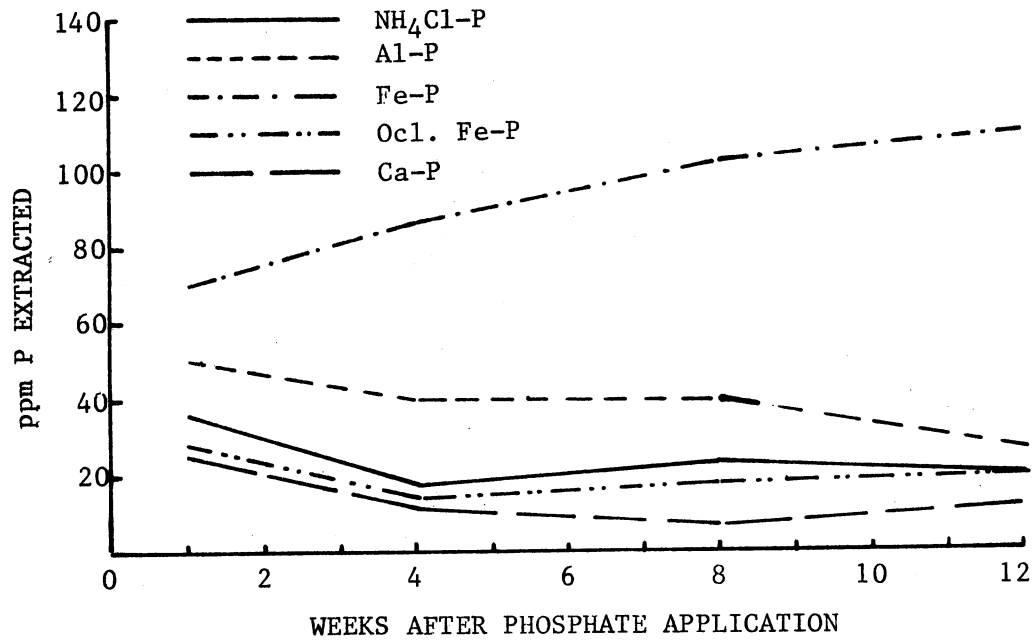


Figure 16. The Phosphate Fractions Extracted from Cropped Soil of K_2HPO_4 Treatment as a Function of Time

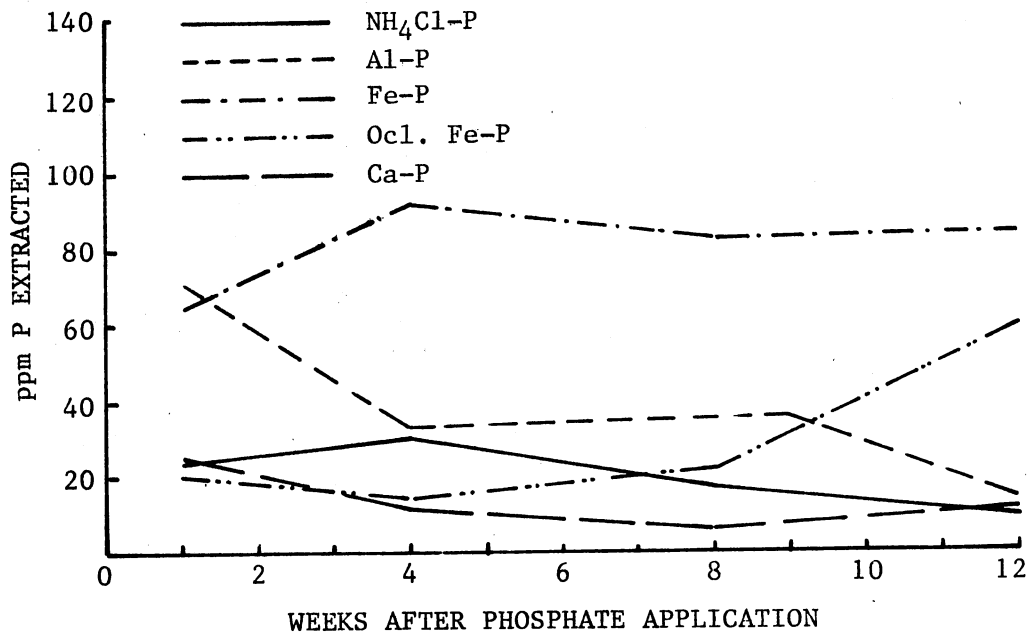


Figure 17. The Phosphate Fractions Extracted from Cropped Soil of KH_2PO_4 Treatment as a Function of Time

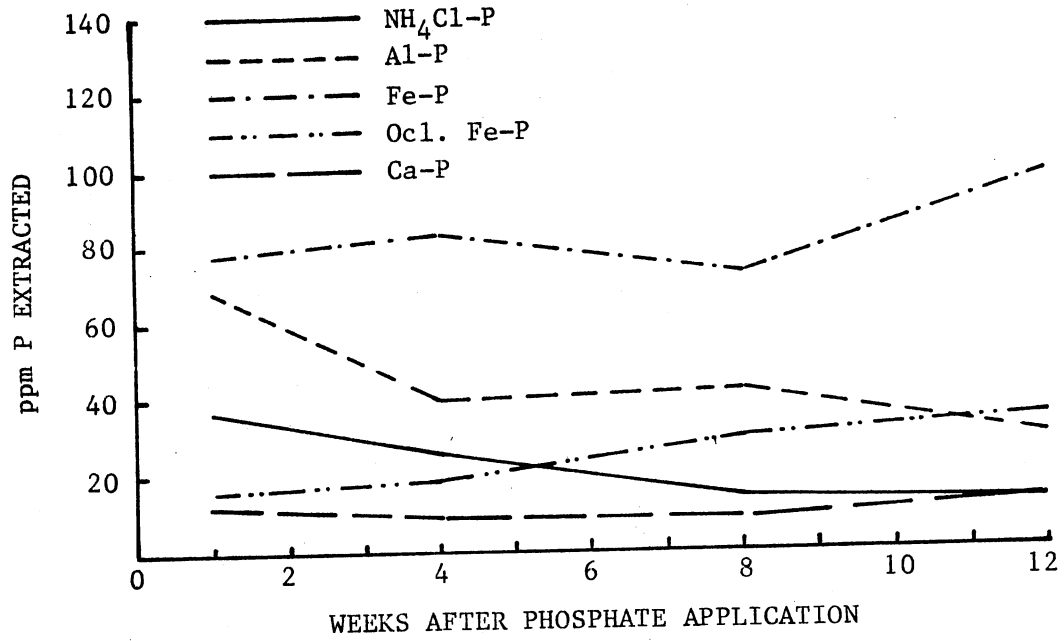


Figure 18. The Phosphate Fractions Extracted from Cropped Soil of $(\text{NH}_4)_2\text{HPO}_4$ Treatment as a Function of Time

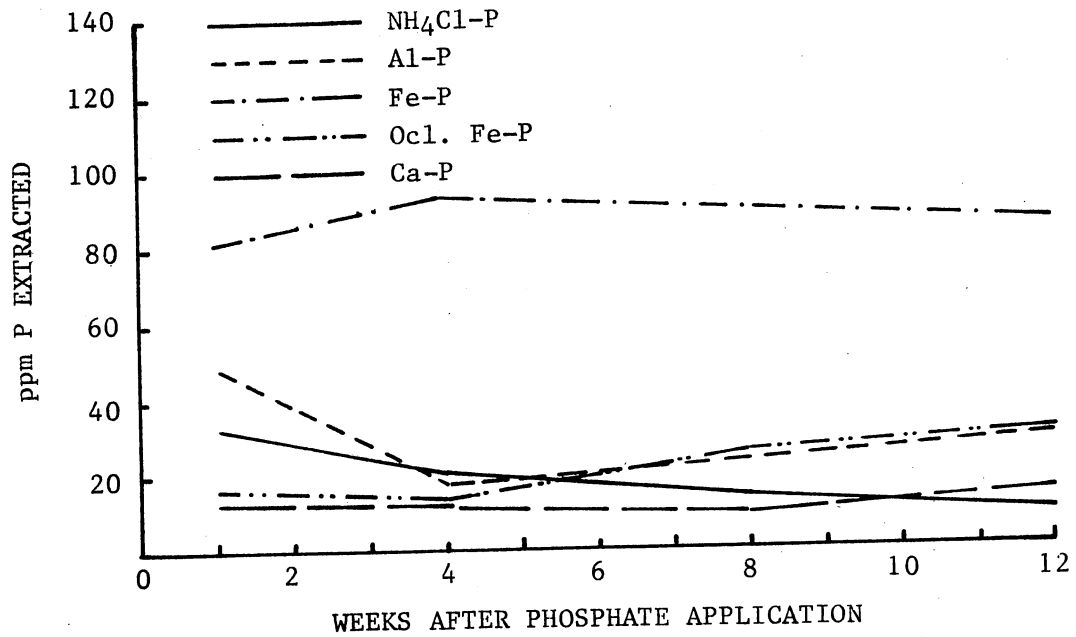


Figure 19. The Phosphate Fractions Extracted from Cropped Soil of $\text{K}_4\text{P}_2\text{O}_7$ Treatment as a Function of Time

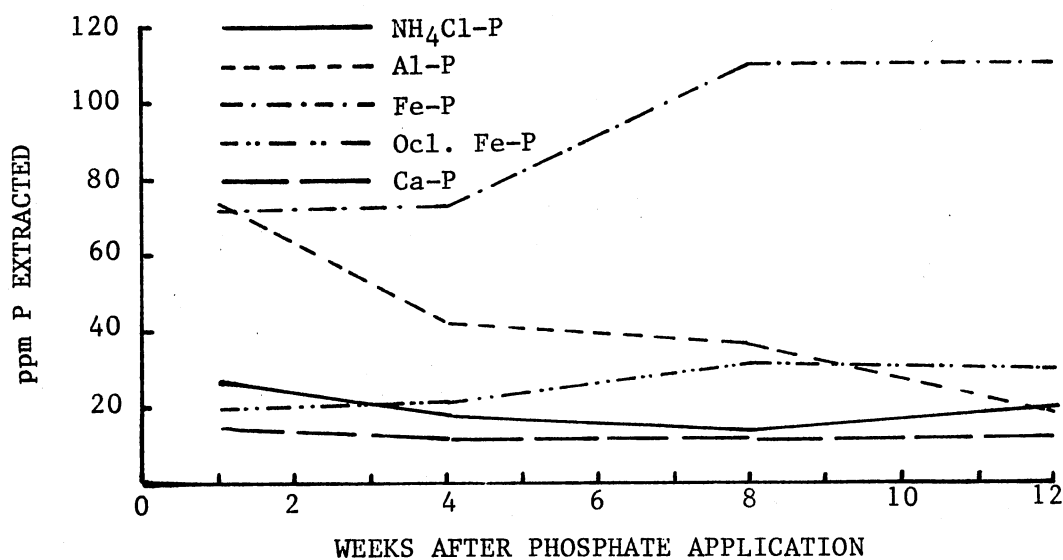


Figure 20. The Phosphate Fractions Extracted from Cropped Soil of 15-62-0 Treatment as a Function of Time

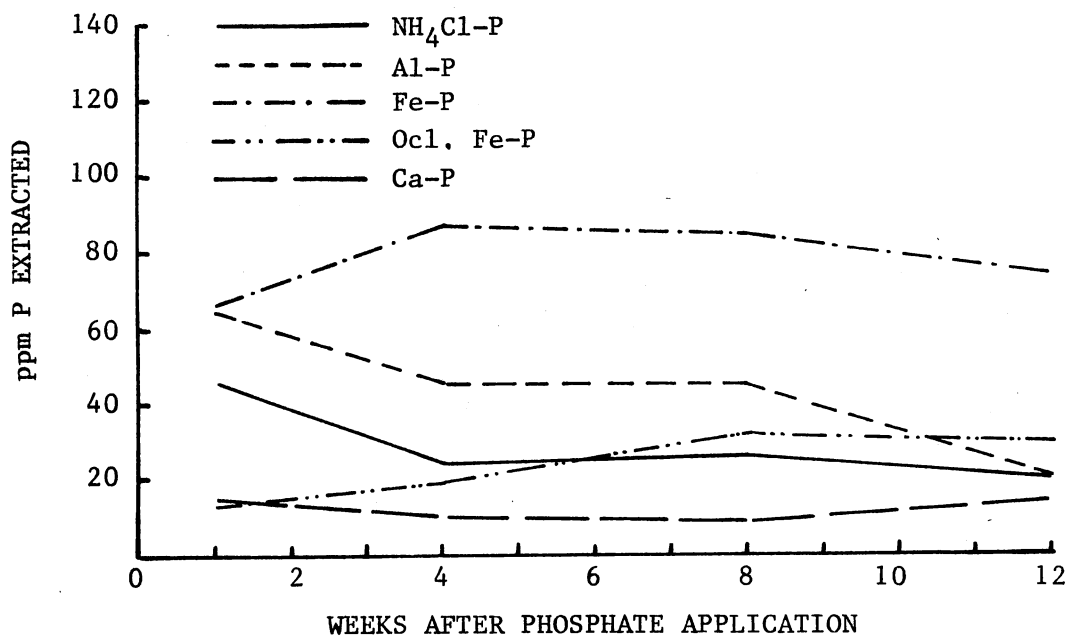


Figure 21. The Phosphate Fractions Extracted from Cropped Soil of 11-37-0 Treatment as a Function of Time

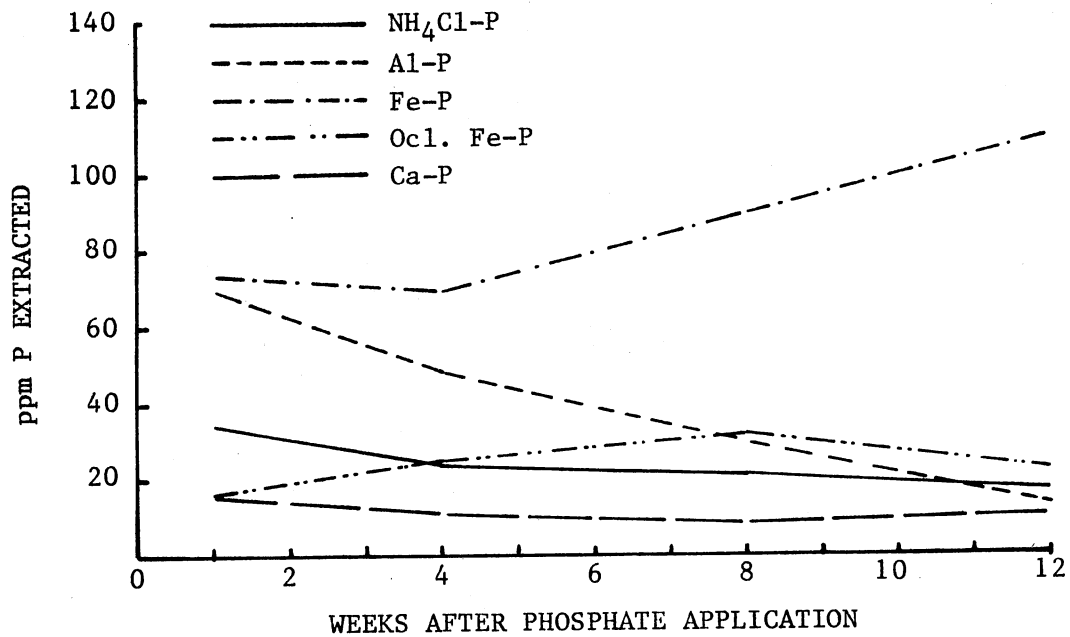


Figure 22. The Phosphate Fractions Extracted from Cropped Soils of 0-72-0 Treatment as a Function of Time

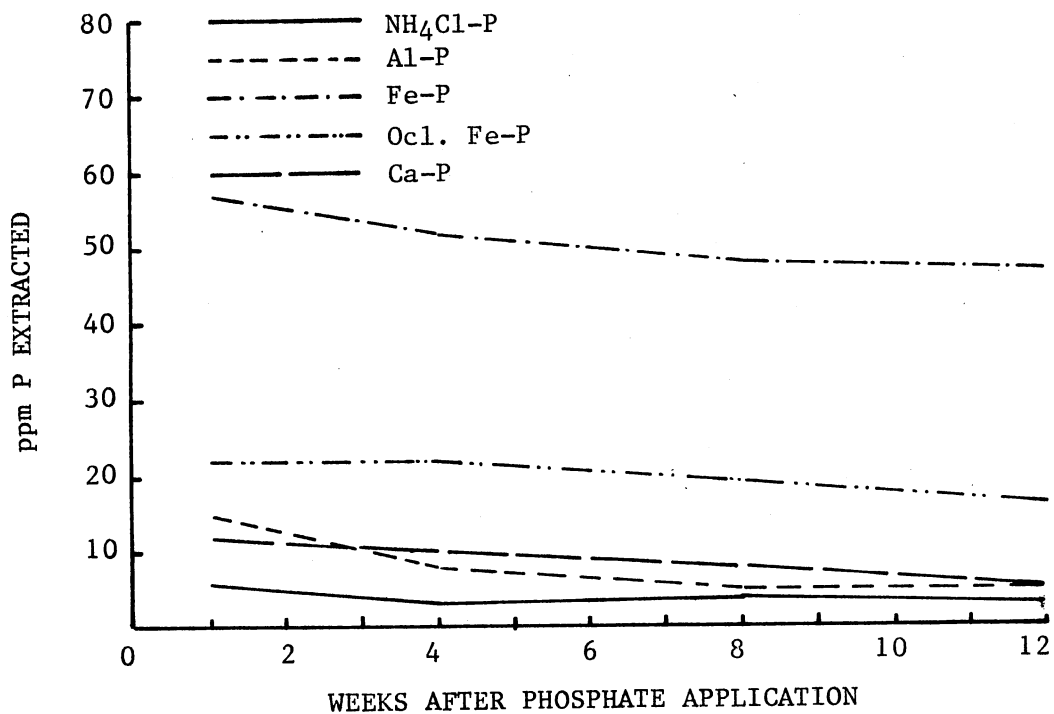


Figure 23. The Phosphate Fractions Extracted from Cropped Soil of Control Treatment as a Function of Time

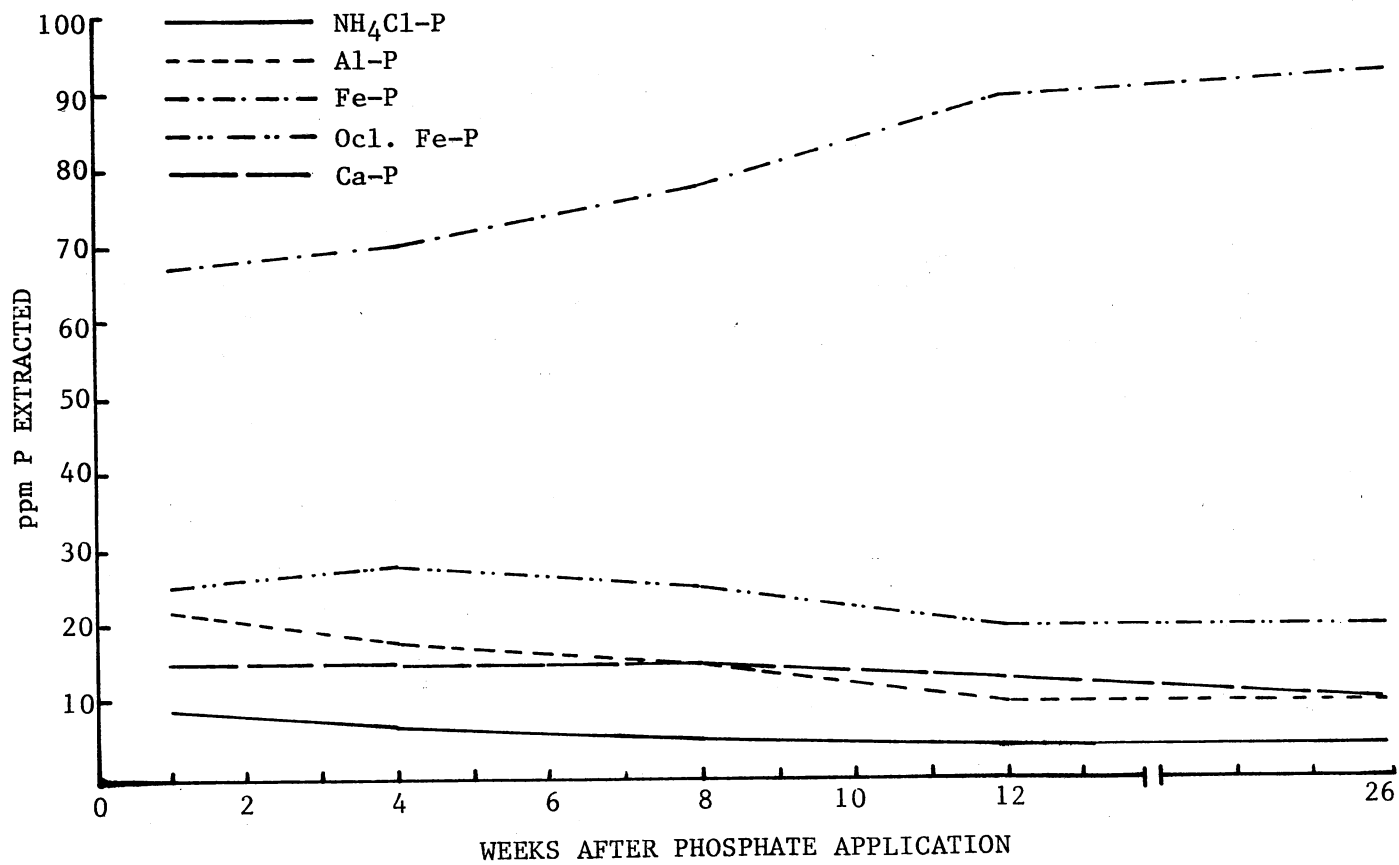


Figure 24. The Phosphate Fractions Extracted from Noncropped Soil of Control Treatment as a Function of Time

dates correspond to one, four, eight, twelve, and twenty-six weeks after phosphate application.

General Discussion

Figures 5 to 22 show that $\text{NH}_4\text{Cl-P}$ and Al-P are the major sources of available P as evidenced by the decline of both with cropping compared to noncropped treatments. Al-P also declines in the noncropped soils as a function of time, but the decline is lower in magnitude. The decline in Fe-P (Figure 23) was found in the zero treatment with cropping, due to the low content of $\text{NH}_4\text{Cl-P}$ and Al-P in the native Eufaula soil. However, the Fe-P decline is less compared to the decline in Al-P . When P is applied to the noncropped soils, increase in Fe-P is accompanied by simultaneous decline in Al-P . Occluded iron phosphate (Ocl. Fe-P) has about the same rate of increase in both cropped and noncropped soils. The pattern of change in Ca-P was small, the lower content of Ca-P is due to the pH of Eufaula soil (5.5) compared to Fe-P . It was found that Ca-P declines with time in the noncropped soils at the lower rates of P application but the decline does not occur to the same extent at higher rates. There was probably enough $\text{NH}_4\text{Cl-P}$ and Al-P present at the higher rates to satisfy the needs of the plants.

In Tables IV, VI, VIII, and X and in Figures 5 to 23, it can be seen that in many treatments $\text{NH}_4\text{Cl-P}$ declines appreciably with time. Normally if the $\text{NH}_4\text{Cl-P}$ fraction included $\text{Ca}(\text{H}_2\text{PO}_4)_2$ and CaHPO_4 , it would show a decline with time, simply through precipitation of compounds such as octacalcium phosphate, or through reactions of $\text{Ca}(\text{H}_2\text{PO}_4)_2$ and CaHPO_4 with Al to form phosphate compounds not soluble

in NH_4Cl , but in this soil because of low pH (5.5) the compounds of octa- or tricalcium phosphates were not expected to any extent.

Changes in Bray-P as a Function of Time

The amounts of Bray-P (P soluble in the Bray #1 extractant, solution to soil ratio 20:1) extracted at 100 ppm P rates vs. time in both cropped and noncropped soils are reported in Table XV. Figures 25 through 33 are plots of Bray-P vs. time in both cropped and noncropped soils at the 100 ppm P rates. Decline in Bray-P in the cropped soils indicate that it is a measure of available P, is well known. The changes in Bray-P with time are correlated with changes in the sum of $\text{NH}_4\text{Cl-P}$ plus Al-P fractions. This is shown in Figures 25 through 34.

In noncropped soils there is some change in Bray-P as a function of time. In treatment 0-72-0, Figure 33, Bray-P declined with time. This decline is due to the acidity of phosphoric acid (0-72-0) increasing rate of fixation of phosphate with Fe. This result correlates well with Figure 42, for the total $\text{NH}_4\text{Cl-P}$ plus Al-P in 0-72-0 treatment.

It was found that the sum of $\text{NH}_4\text{Cl-P}$ plus Al-P is correlated well with the available P as determined by the Bray procedure, the correlations (r) between $\text{NH}_4\text{Cl-P}$ plus Al-P and Bray-P and the yield are reported in Table XVI.

Phosphorus Fixation by Aluminum and Iron

The formation of Al-P and Fe-P is thought to occur because of Al and Fe compounds already present in the soil. Phosphorus is fixed more

TABLE XV

THE AMOUNTS OF BRAY-P EXTRACTED FROM 100 PPM FERTILIZER TREATMENT
AS A FUNCTION OF TIME - BOTH CROPPED AND NONCROPPED

Fertilizer	Treatment	Weeks After Application				
		ppm-P				
		1	4	8	12	26
Control	Cropped	76	52	76	64	-
	Noncropped	84	68	88	80	80
Ca(PO ₃) ₂	Cropped	88	56	76	68	-
	Noncropped	92	68	96	88	88
Ca(H ₂ PO ₄) ₂	Cropped	192	160	144	120	-
	Noncropped	224	190	188	172	154
K ₂ HPO ₄	Cropped	196	167	156	160	-
	Noncropped	200	188	168	176	180
KH ₂ PO ₄	Cropped	176	152	112	108	-
	Noncropped	180	176	176	164	176
(NH ₄) ₂ HPO ₄	Cropped	188	164	136	140	-
	Noncropped	196	176	176	176	172
K ₄ P ₂ O ₇	Cropped	132	108	116	132	-
	Noncropped	148	188	168	200	200
15-62-0	Cropped	156	116	168	156	-
	Noncropped	176	196	172	188	176
11-37-0	Cropped	128	148	180	188	-
	Noncropped	180	200	188	200	200
0-72-0	Cropped	172	176	156	164	-
	Noncropped	200	216	216	196	176

TABLE XVI
CORRELATION COEFFICIENTS COMPARING
AVAILABLE P, BRAY-P AND YIELD

	Bray	NH ₄ Cl-P + Al-P	Yield
Bray	1.000	0.866	0.922
NH ₄ Cl-P + Al-P	0.866	1.000	0.917
Yield	0.922	0.917	1.000

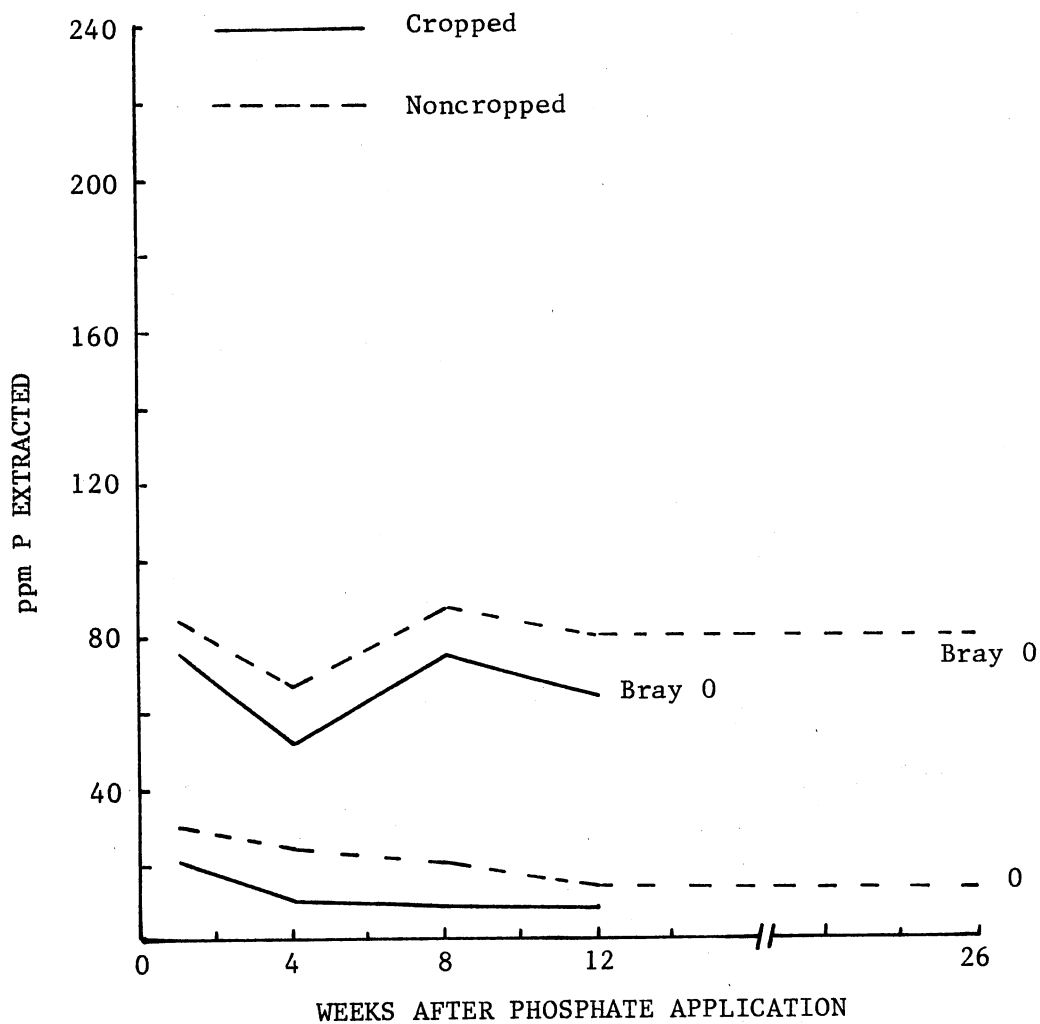


Figure 25. The Amounts of $\text{NH}_4\text{Cl-P}$ plus Al-P Compared with Bray Available P, for Control Treatment as a Function of Time, Both Cropped and Noncropped

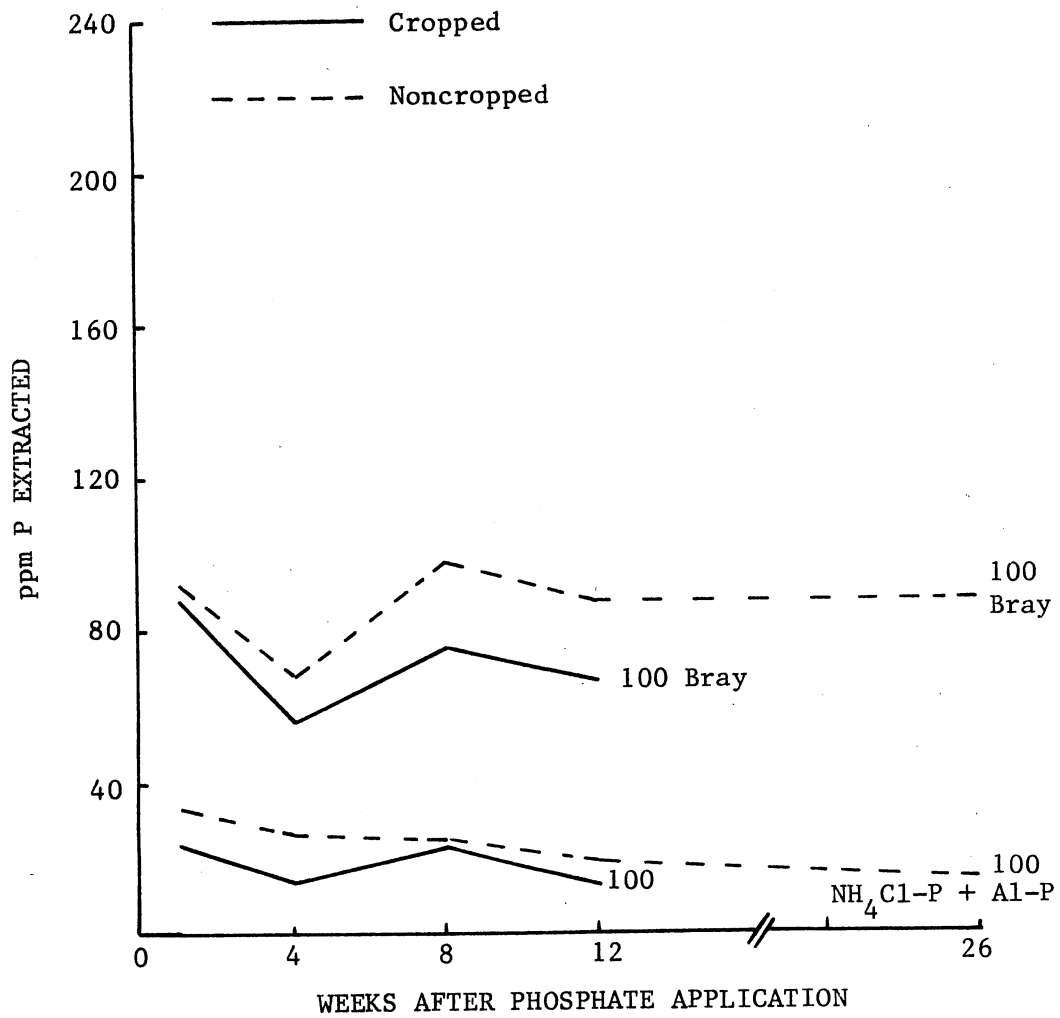


Figure 26. The Amounts of NH₄Cl-P plus Al-P Compared with Bray Available P, for Ca(PO₃)₂ Treatment as a Function of Time, Both Cropped and Noncropped

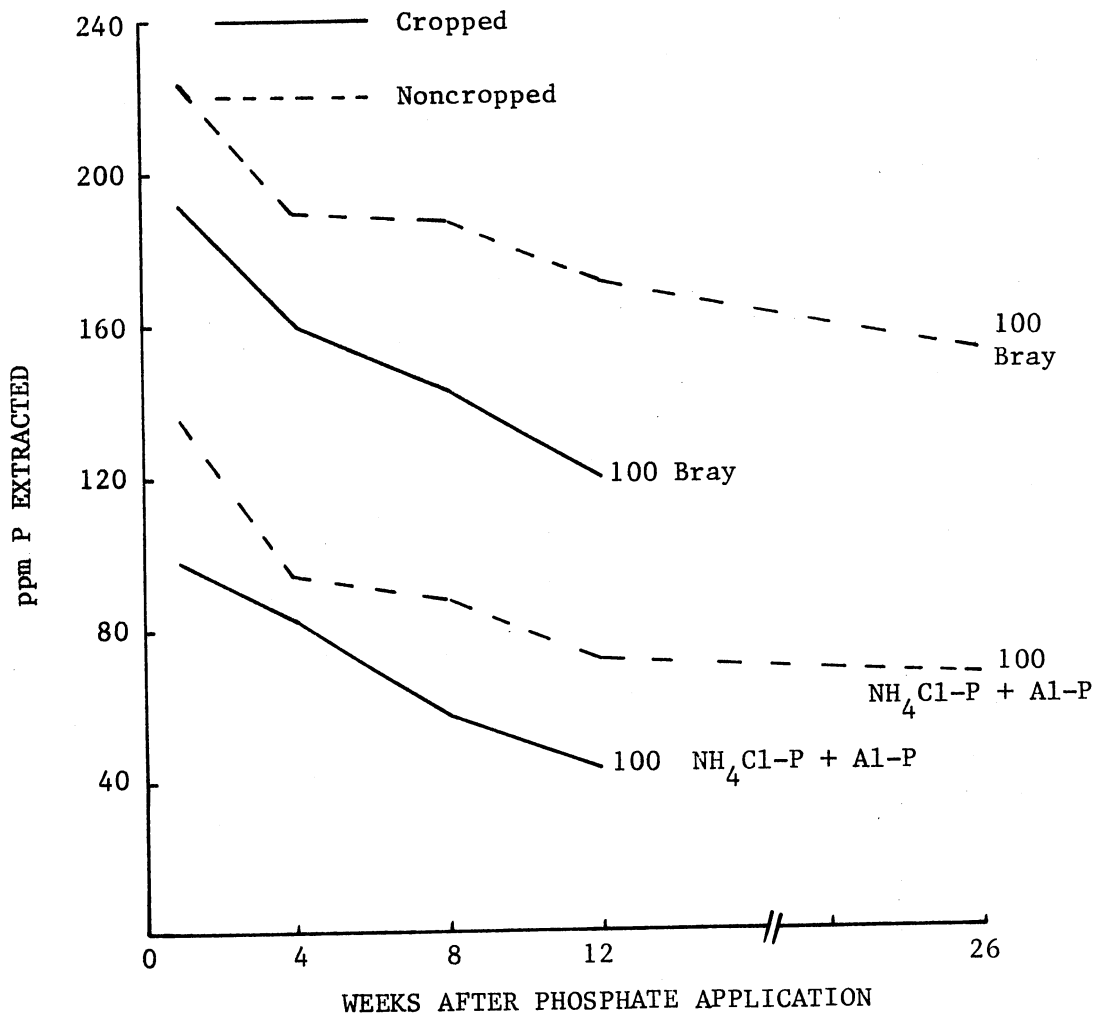


Figure 27. The Amounts of $\text{NH}_4\text{Cl-P}$ plus Al-P Compared with Bray Available P, for $\text{Ca}(\text{H}_2\text{PO}_4)_2$ Treatment as a Function of Time, Both Cropped and Noncropped

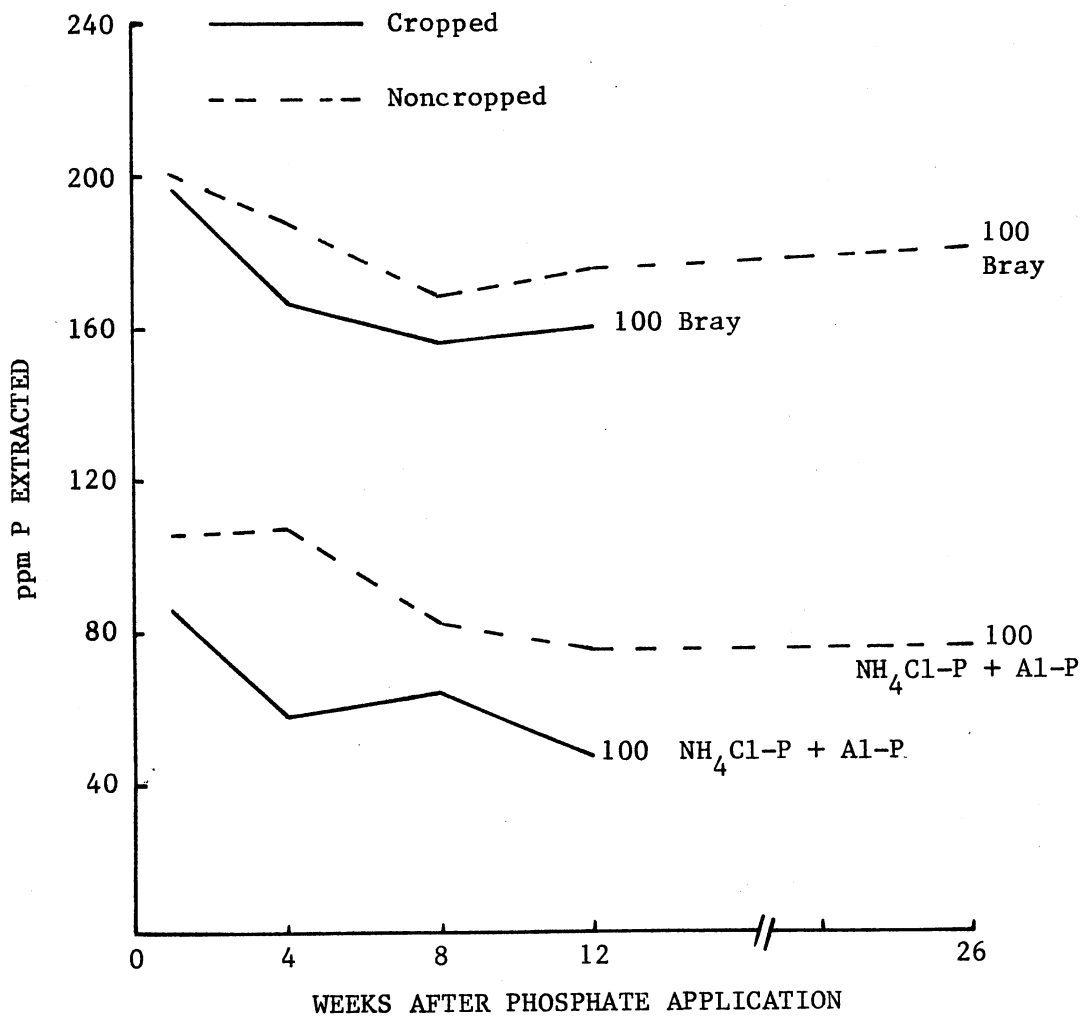


Figure 28. The Amounts of NH₄Cl-P plus Al-P Compared with Bray Available P, for K₂HPO₄ Treatment as a Function of Time, Both Cropped and Noncropped

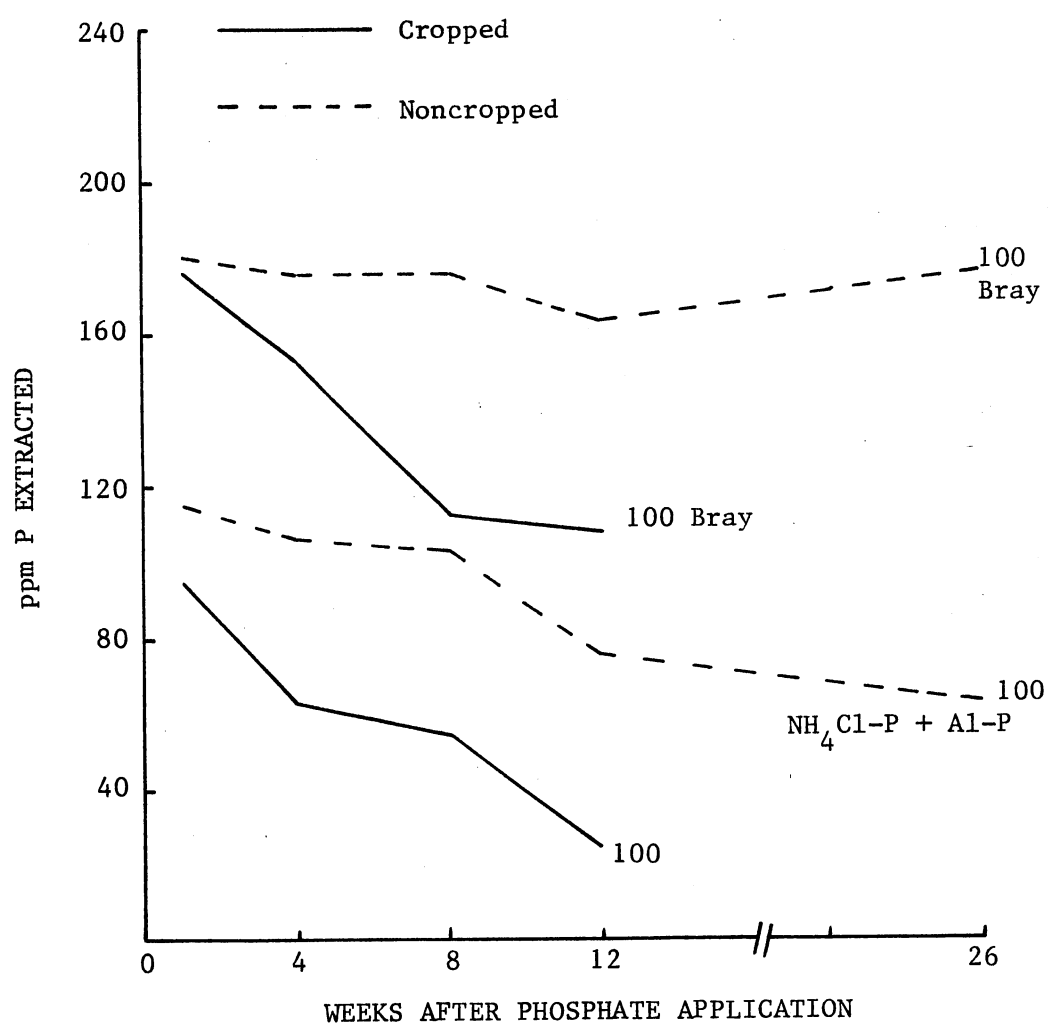


Figure 29. The Amounts of NH₄Cl-P plus Al-P Compared with Bray Available P, for KH₂PO₄ Treatment as a Function of Time, Both Cropped and Noncropped

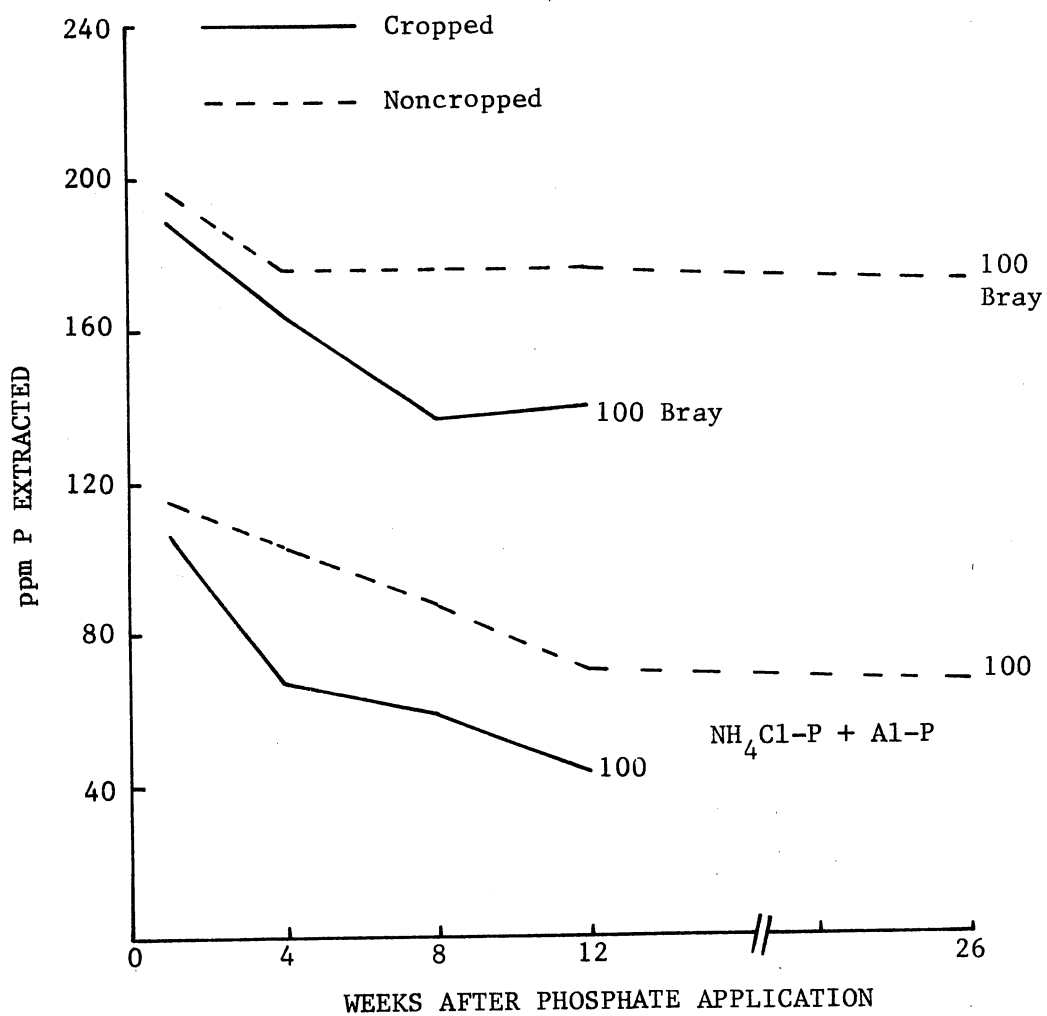


Figure 30. The Amounts of $\text{NH}_4\text{Cl-P}$ plus Al-P Compared with Bray Available P, for $(\text{NH}_4)_2\text{HPO}_4$ Treatment as a Function of Time, Both Cropped and Noncropped

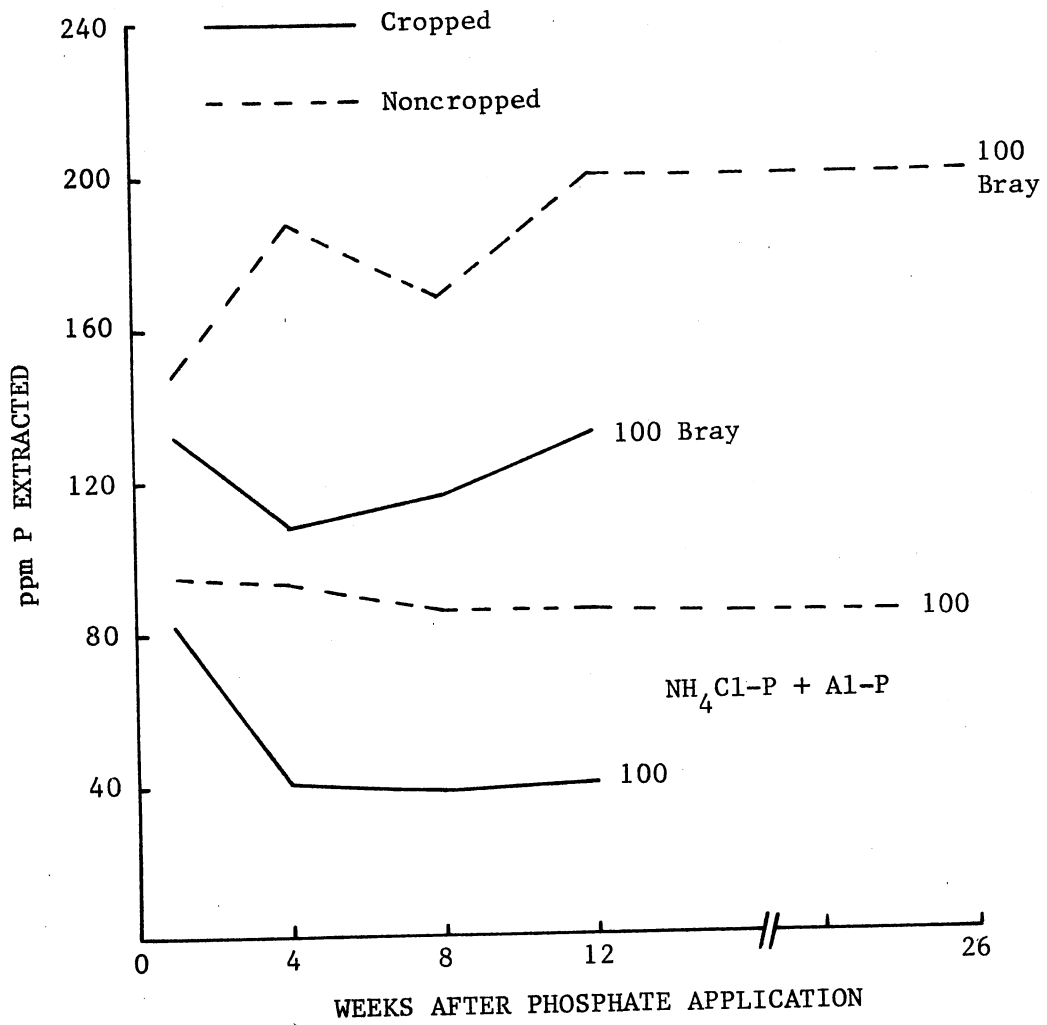


Figure 31. The Amounts of $\text{NH}_4\text{Cl-P}$ plus Al-P Compared with Bray Available P, for $\text{K}_4\text{P}_2\text{O}_7$ Treatment as a Function of Time, Both Cropped and Noncropped.

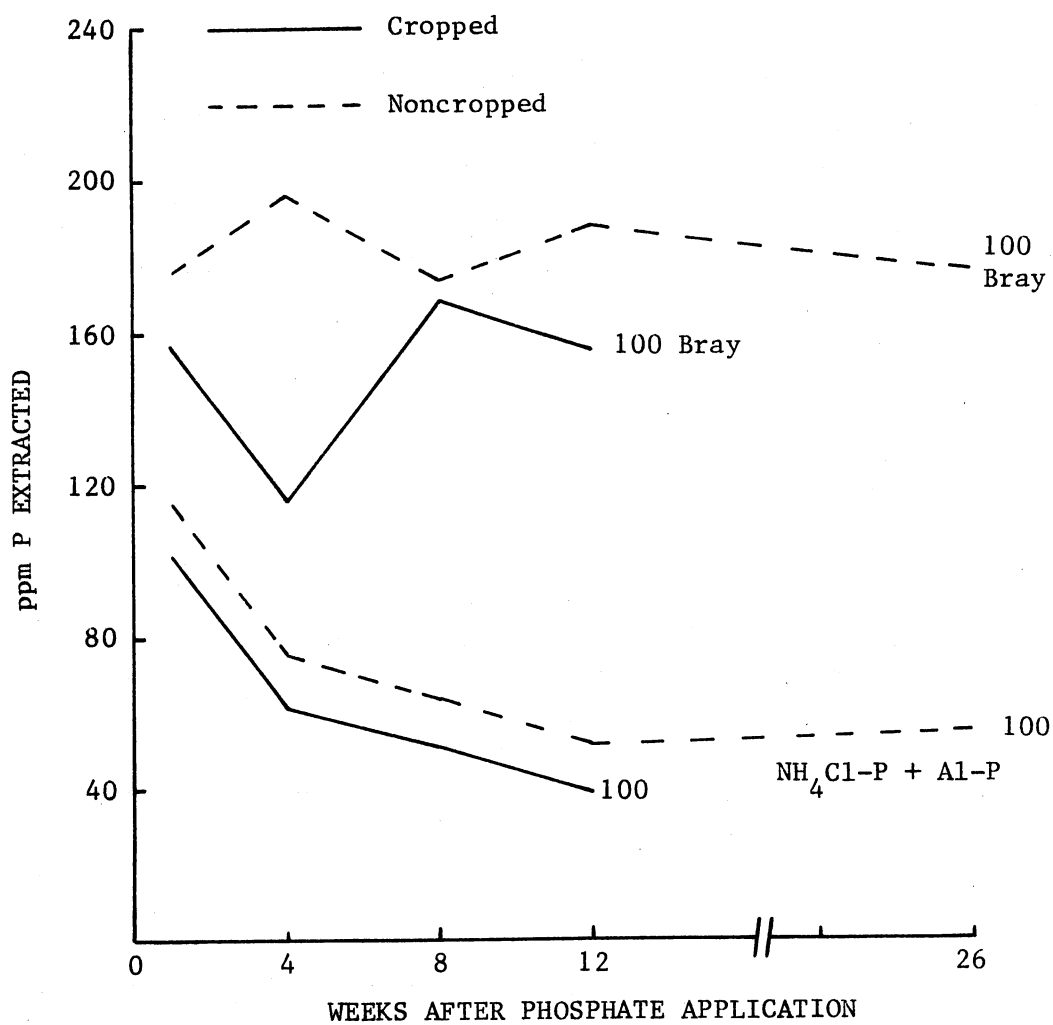


Figure 32. The Amounts of $\text{NH}_4\text{Cl-P}$ plus Al-P Compared with Bray Available P, for 15-62-0 Treatment as a Function of Time, Both Cropped and Noncropped

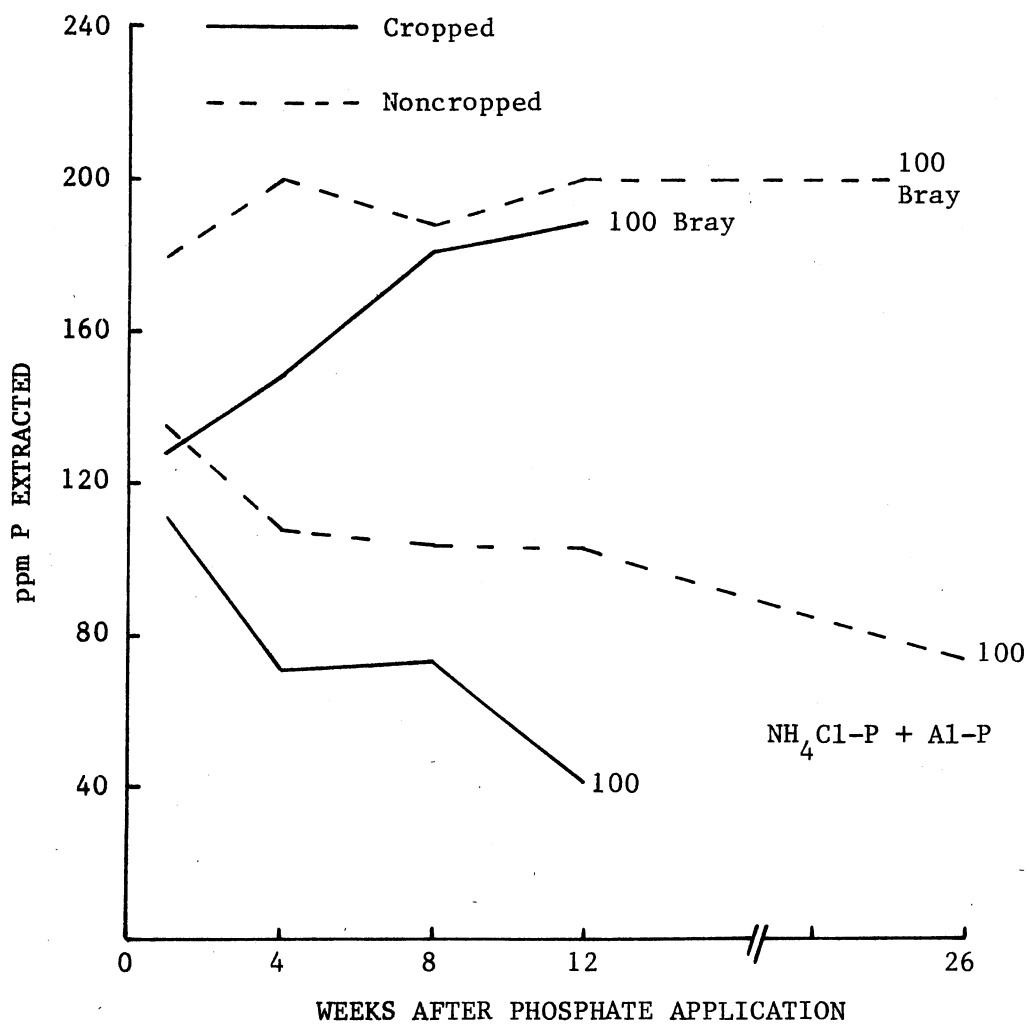


Figure 33. The Amounts of $\text{NH}_4\text{Cl-P}$ plus Al-P Compared with Bray Available P, for 11-37-0 Treatment as a Function of Time, Both Cropped and Noncropped

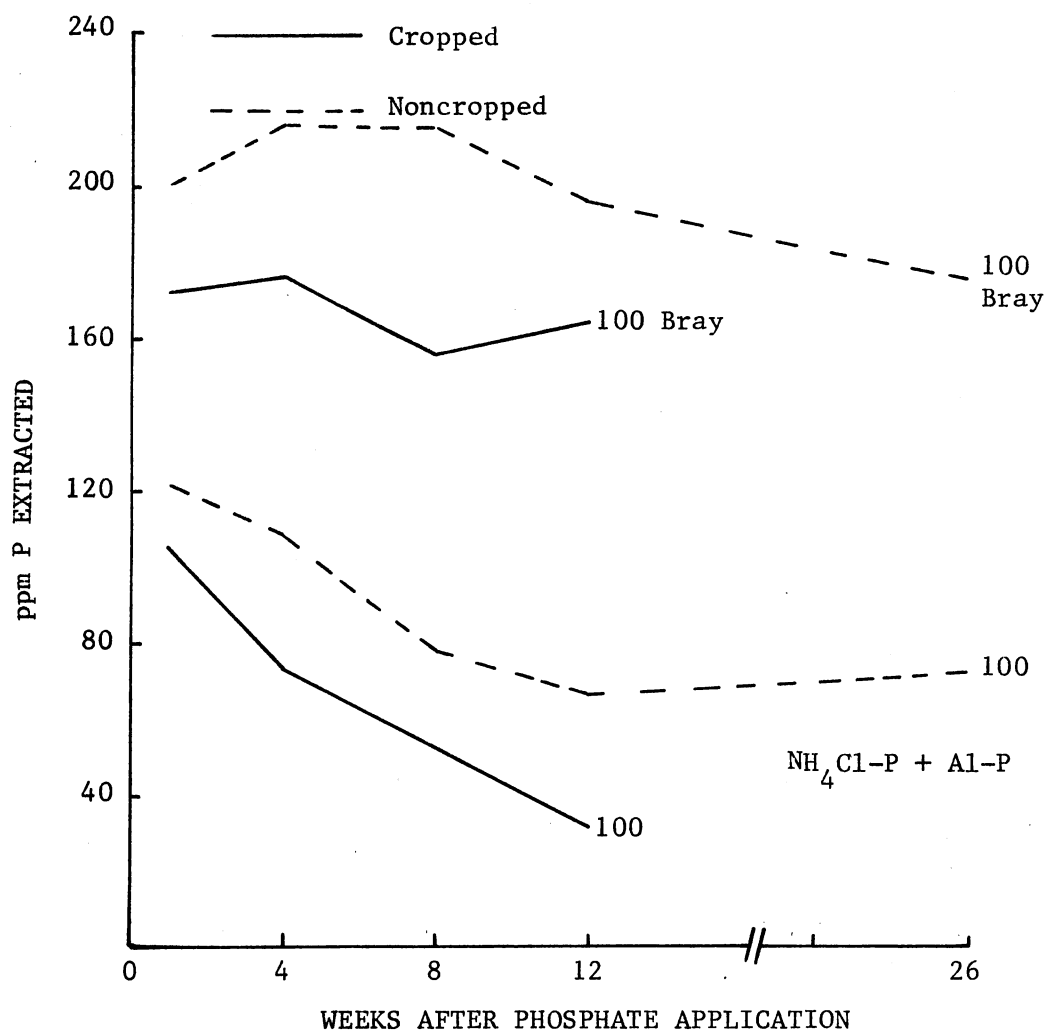


Figure 34. The Amounts of $\text{NH}_4\text{Cl-P}$ plus Al-P Compared with Bray Available P, for 0-72-0 Treatment as a Function of Time, Both Cropped and Noncropped

rapidly by Al, the conversion to Fe-P occurring as P from the Al compounds slowly react with the slower reacting Fe compounds.

There is also evidence that Al may be of more importance at high fertilization rates. The ratios of Al-P:Fe-P at each of 0, 50, 100, 200, and 300 ppm application rates are given in Tables XVII and XVIII for the noncropped and the cropped soils, respectively. The ratios generally increase with fertilization rate but not to the same extent in the noncropped and cropped soils, such increases being pronounced as the rate is increased from 50 ppm to 300 ppm. At the lower rates, there are higher proportions of reactive Fe to P, resulting in a higher percentage of applied P reacting with iron. At the 300 ppm rate, after the very reactive Fe has already reacted with Al, the ratio of reaction of P with the slower reacting iron is less than the rate of reaction of P with Al, resulting in a higher ratio of Al-P:Fe-P. Yuan, et al. (1960) offered a somewhat similar explanation. They also found the ratio of Al-P:Fe-P to increase with the application rate. In their soils Al was more plentiful than Fe, and also more ionized, thus there was a greater reaction of P with Al. Reactions in the present study may also be similar to those observed by Ramulu and Pratt (1970). They observed that reaction of P with Fe seemed to stop or reach a low level when 25 percent of the Fe had reacted. This was believed to be caused by formation of Fe-P over the Fe oxide particles so that no more Fe was available to react with P. The Fe-P contents increased after twelve weeks in the noncropped soils. The increase in Fe-P with time in those treatments is reflected in a decrease in the ratio of Al-P:Fe-P as given in Table XVIII. The decrease in Al-P:Fe-P in noncropped soils is also a result of the conversion of Al-P to Fe-P, while in the cropped

TABLE XVII
 THE RATIO OF Al-P TO Fe-P AS A FUNCTION OF
 APPLICATION RATE AND TIME FOR
 NONCROPPED SOILS

Treatment	ppm P Applied	Weeks After P Application				
		1	4	8	12	26
Control	0	0.32	0.25	0.19	0.11	0.10
Ca(PO ₃) ₂	50	0.15	0.14	0.13	0.09	0.07
	100	0.16	0.14	0.11	0.08	0.05
	200	0.21	0.14	0.09	0.05	0.04
	300	0.25	0.12	0.08	0.04	0.04
Ca(H ₂ PO ₄) ₂	50	1.44	0.26	0.33	0.18	0.21
	100	1.53	0.44	0.37	0.26	0.26
	200	1.60	0.58	0.61	0.42	0.52
	300	1.68	0.92	0.84	0.46	0.79
K ₂ HPO ₄	50	0.58	0.43	0.49	0.17	0.26
	100	0.83	0.63	0.53	0.28	0.36
	200	0.93	0.82	0.69	0.33	0.82
	300	1.21	0.79	0.70	0.50	0.97
KH ₂ PO ₄	50	0.62	0.57	0.53	0.28	0.22
	100	1.22	0.70	0.59	0.44	0.30
	200	1.79	1.04	1.04	0.52	0.59
	300	2.10	0.99	0.81	0.63	0.74
(NH ₄) ₂ HPO ₄	50	0.67	0.54	0.54	0.20	0.28
	100	0.88	0.73	0.62	0.45	0.36
	200	1.40	0.77	0.62	0.56	0.52
	300	1.84	1.00	0.69	0.77	0.85
K ₄ P ₂ O ₇	50	0.45	0.27	0.25	0.25	0.44
	100	0.50	0.37	0.37	0.38	0.41
	200	0.60	0.54	0.41	0.29	0.67
	300	0.66	0.57	0.54	0.23	0.93
15-62-0	50	0.66	0.42	0.42	0.17	0.25
	100	1.09	0.41	0.33	0.18	0.79
	200	1.11	0.73	0.43	0.30	0.53
	300	1.55	0.55	0.58	0.44	0.85
11-37-0	50	0.71	0.98	0.34	0.28	0.32
	100	1.02	0.63	0.66	0.58	0.40
	200	1.52	0.54	0.55	1.21	0.63
	300	1.69	0.53	0.84	1.65	0.72
0-72-0	50	0.63	0.70	0.41	0.17	0.25
	100	0.98	0.73	0.40	0.19	0.38
	200	1.29	0.50	0.64	0.53	0.58
	300	1.53	0.50	0.62	0.53	0.84

TABLE XVIII
 THE RATIO OF Al-P TO Fe-P AS A FUNCTION OF
 APPLICATION RATE AND TIME FOR CROPPED
 SOILS

Treatment	ppm P Applied	Weeks After P Application			
		1	4	8	12
Control	0	0.26	0.15	0.10	0.10
Ca(PO ₃) ₂	50	0.20	0.09	0.12	0.08
	100	0.18	0.09	0.11	0.05
	200	0.18	0.15	0.09	0.06
	300	0.23	0.11	0.06	0.04
Ca(H ₂ PO ₄) ₂	50	1.0	0.31	0.24	0.16
	100	1.02	0.46	0.27	0.17
	200	1.38	0.46	0.37	0.26
	300	1.56	0.61	0.78	0.38
K ₂ HPO ₄	50	0.41	0.26	0.32	0.18
	100	0.71	0.46	0.39	0.24
	200	0.70	0.60	0.46	0.29
	300	1.16	0.70	0.48	0.28
KH ₂ PO ₄	50	0.49	0.28	0.22	0.15
	100	1.09	0.35	0.45	0.17
	200	1.66	0.51	0.74	0.34
	300	2.03	0.95	1.04	0.43
(NH ₄) ₂ HPO ₄	50	0.58	0.36	0.37	0.20
	100	0.88	0.48	0.58	0.30
	200	1.48	0.62	0.82	0.37
	300	1.85	1.01	1.07	0.46
K ₄ P ₂ O ₇	50	0.66	0.17	0.16	0.18
	100	0.59	0.20	0.26	0.34
	200	0.48	0.32	0.26	0.22
	300	0.60	0.34	0.30	0.48
15-62-0	50	0.57	0.64	0.15	0.10
	100	1.02	0.58	0.33	0.17
	200	1.14	0.98	0.46	0.27
	300	1.50	0.94	0.52	0.35
11-37-0	50	0.69	0.71	0.30	0.26
	100	0.98	0.52	0.54	0.28
	200	1.44	0.47	0.62	0.66
	300	1.61	0.48	0.81	0.76
0-72-0	50	0.60	0.66	0.30	0.13
	100	0.94	0.70	0.33	0.13
	200	1.14	0.47	0.75	0.49
	300	1.38	0.45	0.57	0.49

soils, the decrease in the ratios of Al-P:Fe-P, is due to the depletion of Al-P by crop removal as given in Table XVIII.

CHAPTER V

SUMMARY AND CONCLUSIONS

The modified Chang and Jackson's soil phosphate fractionation procedure gave reasonable recoveries of applied phosphate by one week after application to Eufaula soil considering application uniformity and representative sampling difficulties. The modification showed an improvement in recovery based on Norwood's (1969) work. Failure to recover a high percentage of $\text{Ca}(\text{PO}_3)_2$ until the 12-26 week samples and its presence in the Fe-P fraction earlier is attributed to its very low solubility in NH_4Cl and NH_4F reagents and its higher solubility in the Fe-P fraction removing reagents.

The sum of $\text{NH}_4\text{Cl-P}$ and Al-P fractions from the fractionation procedure was highly correlated with dry matter yield response of sugar drip sorghum and also with available P determined with the Bray #1 20:1 procedure. The sum could be used, therefore, as a good measure of available P in Eufaula soil. The fractions Fe-P, Ca-P, and Ocl. Fe-P were available to promote plant growth to a very much lesser extent.

The response of sugar drip sorghum to phosphate fertilization on Eufaula soil varied with the variation of phosphate sources. Increasing rate of fertilization, generally, increased yields with notable exceptions at higher rate of $(\text{NH}_4)_2\text{HPO}_4$, 15-62-0, 11-37-0, and 0-72-0. The decrease in yields for these fertilizers at the higher rates are not completely understood. The possibility of initial NH_3 toxicity from the

materials excepting 0-72-0 because of a higher NH_4^+ -N presence in these treatments and acidification or Al toxicity are possibilities, the latter the likely main effect from 0-72-0. However, because of the high solubilities of these fertilizer materials, the possibility of detrimental salt effect must also be considered, especially for the first crop. The possibility for $(\text{NH}_4)\text{HPO}_4$ is particularly of concern because of the higher than 100 ppm N present for the first two crops at the 300 ppm P rate since it is added in the P compound. The very low solubility of $\text{Ca}(\text{PO}_3)_2$ will account for low yield increases resulting from its addition.

The ratio of Al-P:Fe-P generally increased with increasing fertilization rate in the noncropped soils and to a lesser extent in the cropped soils due to the depletion of $\text{NH}_4\text{Cl-P}$ and Al-P by the growing crop. The decrease in the ratio of Al-P:Fe-P with time corresponds to the increase in Fe-P with time as a result of the conversion of $\text{NH}_4\text{Cl-P}$ and Al-P to Fe-P.

The added phosphate was converted to different forms of soil phosphate compounds. The extent and rate of conversion varied with the individual phosphate fertilizer. High percent of soluble phosphate fertilizers was converted mainly to the soluble phosphate fractions $\text{NH}_4\text{Cl-P}$ and Al-P. These two soluble fractions declined sharply with cropping due to its depletion by growing plants, but to a lesser extent in the noncropped soils. Fe-P and occluded Fe-P showed high increase by time, due to the conversion of $\text{NH}_4\text{Cl-P}$ and Al-P to Fe-P and occluded Fe-P. Ca-P fraction was low initially in Eufaula soil and according to that, not much change was noticed for this fraction.

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