

PHOSPHORUS MOVEMENT IN SOME CALCAREOUS AND NONCALCAREOUS MANITOBA SOILS

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## ABSTRACT

Manitoba contains large acreages of calcareous soils as well as noncalcareous soils. Most of these soils are deficient in available phosphorus and phosphorus fertilization is an important aspect in crop production. The behaviour of applied phosphorus in Manitoba soils, especially the movement of phosphorus in soils, is not well known. This project was initiated to study the movement of applied phosphorus in some Manitoba soils. Ten surface soils varying in texture and calcium carbonate content were selected for the studies.

Phosphorus movement from a monoammonium phosphate pellet was found to be slightly greater than from a diammonium phosphate pellet. This observation was more noticeable in the calcareous soils than in the noncalcareous soils. Phosphorus movement was found to be greater in noncalcareous soils than in calcareous soils for both sources of phosphorus when added as a pellet or in granular form on the surface of soils in columns and leached with water. Phosphorus movement was greater in the coarse-textured soils than in the fine-textured soils when the phosphorus fertilizer was added in granular form to the surface of soil columns and leached with water. Soil texture had very little or no effect on phosphorus movement when the fertilizer was added as a pellet.

The movement of phosphorus was slightly retarded in both a calcareous and a noncalcareous soil when  $P^{32}$  "tagged" monoammonium phosphate was mixed with  $CaCl_2$ ,  $MgCl_2$ ,  $KCl$ ,  $NaCl$  and  $NH_4Cl$ . In soils saturated with  $Na$ ,  $K$ ,  $NH_4$ ,  $Ca$  or  $Mg$  phosphorus movement was greatest when  $Na$ ,  $K$  or  $NH_4$  was on the soil exchange complex. Saturation of the soils with calcium reduced phosphorus movement whereas saturation of the soils

with magnesium increased phosphorus movement when compared to the untreated soil.

Rate of phosphorus movement studies indicated that movement of phosphorus was more rapid in noncalcareous soils than in calcareous soils. Solubility studies showed that the soil solutions of the phosphorus treated calcareous soils contained greater amounts of calcium and magnesium than did the soil solutions of phosphorus treated noncalcareous soils. It is suggested that the large amounts of calcium and magnesium in the calcareous soils precipitated the added phosphorus very close to the pellet site and thus the movement of phosphorus was restricted. Since the supply of calcium and magnesium in the noncalcareous soils was not as great as in the calcareous soils, added phosphorus was able to move farther away from the pellet site before it was precipitated by calcium and/or magnesium.

DEDICATION

This thesis is dedicated to my wife, Fern.

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## I INTRODUCTION

A proper understanding of the importance of applied phosphorus in crop nutrition cannot be obtained unless the behaviour of applied phosphorus is clearly understood. An essential part of this behaviour is the mechanism by which plants obtain phosphorus from the soil surrounding a phosphorus fertilizer pellet. The movement of phosphorus in soil systems is an essential part of this mechanism. Greenhouse experiments conducted at the University of Manitoba have shown that flax grown on a calcareous soil utilized greater amounts of fertilizer phosphorus as the volume of soil fertilized was increased. This trend was not very evident when flax was grown on a noncalcareous soil suggesting that phosphorus movement from a fertilizer pellet may be greater in noncalcareous than calcareous soils.

The information on phosphorus movement in soil systems is limited. Research on this topic has been limited to acid and noncalcareous soils. Manitoba contains large acreages of calcareous soils which have to be treated with phosphorus fertilizers if crop yields are to be increased. Since the movement of phosphorus in calcareous soils has not been studied extensively and plant growth studies have suggested that phosphorus movement in noncalcareous and calcareous soils may be different, a comprehensive study of phosphorus movement is essential to better understand the behaviour of applied phosphorus in our soils.

The objectives of the work reported, were as follows:

- (a) To devise an experimental technique for determining phosphorus movement in soil systems.
- (b) To determine the effect of phosphorus source, soil calcium

carbonate level and soil texture on movement of phosphorus from a fertilizer pellet.

(c) To determine the effect of incorporating  $\text{CaCl}_2$ ,  $\text{MgCl}_2$ ,  $\text{KCl}$ ,  $\text{NH}_4\text{Cl}$  and  $\text{NaCl}$  with the phosphorus fertilizer pellet on phosphorus movement.

(d) To measure movement of phosphorus from a phosphorus pellet placed in soils saturated with  $\text{Ca}$ ,  $\text{Mg}$ ,  $\text{K}$ ,  $\text{NH}_4$  and  $\text{Na}$ .

(e) To determine the solubility of added phosphorus and the rate of movement of phosphorus from a pellet in different soil systems.

## II REVIEW OF LITERATURE

The importance of the element phosphorus in plant nutrition has been known for a long time. The mechanisms by which phosphorus moves through the soil have become of interest to soil scientists in recent years. Consequently, a great deal of time and research have been spent in elucidating the problem of phosphorus movement through soil systems. Soil and fertilizer phosphorus may be transported in three ways:

(a) by the action of soil organisms, (b) with flowing water (mass flow), and (c) by thermal movement along a concentration gradient (diffusion). The magnitude of phosphorus movement depends upon the fraction of soil phosphorus involved and the rate of movement of that fraction (22).

Lehr et al. (23) studied the chemical behaviour of monocalcium phosphate monohydrate in soils and concluded that capillary flow was a principal mechanism in the movement of phosphate solution away from the tablet of fertilizer.

Henderson and Jones (13) found that phosphorus does not penetrate very far from the source of application. They noted that the majority of the phosphorus remained in the upper  $1\frac{1}{2}$  inches (3.81 cm) of soil. In a Cecil clay, which had a high fixation for phosphorus, not more than 5 percent of the added  $\text{Ca}(\text{H}_2\text{PO}_4)_2$  penetrated beyond one inch, and more than fifty percent remained in the top  $\frac{3}{8}$  inch (0.95 cm). They also found that when  $\text{Ca}(\text{H}_2\text{PO}_4)_2$  containing radioactivated phosphorus was applied to the surface of the soil and washed down with water equivalent to precipitation of 2.5 inches (6.35 cm), the penetration of phosphorus ranged from  $1\frac{1}{4}$  inches (3.18 cm) for Cecil clay to about four inches (10.16 cm) for Crosby silt loam. The addition of KCl caused the

radioactive phosphorus to move farther into the soil than where no KCl was added, but  $(\text{NH}_4)_2 \text{SO}_4$  had no immediate effect.

Hannapel et al. (10) studied the movement of calcium and phosphorus in the soil solution of a calcareous soil. They found that additions of organic residues increased the amount of total phosphorus movement. They concluded that the increase in phosphorus movement resulted from an increase in organic phosphorus in the soil solution. In contrast, they reported that additions of inorganic phosphorus in amounts equivalent to that added in the plant residues failed to elicit any increase in phosphorus movement in the absence of simultaneous additions of organic materials.

Bouldin and Sample (2) studied the movement of phosphorus from monocalcium, monoammonium and diammonium phosphates. They found the radial movement of phosphate from the three sources increased in the order  $\text{Ca}(\text{H}_2\text{PO}_4)_2 \cdot \text{H}_2\text{O} < \text{NH}_4\text{H}_2\text{PO}_4 < (\text{NH}_4)_2\text{HPO}_4$ , whereas the concentration of phosphorus adjacent to the granule differed in the reverse order. They used a Hartsells fine sandy loam (pH 5.2) and a Webster silty clay loam (pH 8.3) and found that the distribution of total fertilizer phosphorus did not change appreciably 3 weeks to 5 weeks after the fertilizer was added. Fertilizer phosphorus moved about 2.5 and 1.5 cm from the center of the pellets with the Hartsells and Webster soils, respectively. Differences among phosphate sources in the same soil were relatively small. Diammonium phosphate was superior to monocalcium phosphate in the Hartsells soils, but monocalcium phosphate was much superior to diammonium phosphate in the Webster soil in providing phosphorus to growing plants. Monoammonium phosphate was intermediate in supplying phosphorus to plants in the Hartsells soil, but was roughly equivalent



to monocalcium phosphate in the Webster soil. The distance of phosphorus movement in the Webster soil with all phosphorus sources was much less than in the Hartsells. The phosphorus concentration immediately adjacent to the pellet site was higher in the Webster soil than in the Hartsells soil. From their work, they hypothesized that the increase in the availability of phosphorus in a soil resulting from the addition of phosphate fertilizer, was dependent primarily upon the volume of soil directly influenced by the phosphorus additions and the increase in availability of phosphorus in each segment of soil in the volume of influence.

Dehghan and Williams (6) applied phosphoric acid "tagged" with  $P^{32}$  two inches (5.08 cm) below the surface of a Glendale clay loam and a Banbar sandy loam at four moisture levels (5.2, 20, 40, and 60 percent of saturation) and allowed reaction for one week. Leachates were collected at weekly intervals for five weeks. They found that the amount of phosphorus removed by leaching showed no relation to the original moisture content of the Glendale loam. Removal of phosphorus from the Banbar sandy loam decreased with increasing original moisture content. Removal of phosphorus from both soils increased with an increase in leaching. The distribution of phosphorus in the soil columns after leaching showed restricted movement in the Glendale soil and extensive movement in the Banbar soil.

Mackay and Eaton (29) determined the penetration of phosphorus, applied as superphosphate, into a podzolic soil. They incorporated monocalcium phosphate containing  $P^{32}$  in the surface inch (2.54 cm) and then estimated the activity in 1-inch (2.54 cm) segments of core samples. They found that downward movement of the applied phosphorus was very

slight in spite of the coarse texture of the soil. Approximately 5% of the added phosphorus was located in the 2-6 inch (5.08 - 15.24 cm) zone after two weeks and only 8.5% had reached that depth in 6 weeks.

Gunary (8) found that movement of phosphate from orthophosphate was greater than from a pyrophosphate source.

Heck (12) reported that the greatest penetration of phosphorus from monocalcium phosphate occurred in soils of neutral to slightly acid reaction which contained little active iron or aluminum. He also found that active calcium, iron or aluminum in the soil inhibited the downward movement of phosphorus in proportion to the amounts present, but inversely proportional to the solubilities of their compounds with phosphorus. He found that in the slightly acid Miami silt loam which contained little active iron or aluminum, maximum penetration of phosphorus resulted whereas in laterites, which contained large amounts of active iron and aluminum, there was very little phosphorus penetration. He concluded that in soils containing large amounts of active iron or aluminum, the phosphorus was fixed and held in difficultly available forms within a few millimeters of the point of application.

Jordan et al. (18) reported that two inches (5.08 cm) of irrigation water moved phosphorus applied as superphosphate from the surface into the first inch (2.54 cm) of soil, and six inches (15.24 cm) of irrigation water moved the fertilizer phosphorus into the second inch (2.54 cm) of soil. The 6-inch (15.24 cm) irrigation moved significantly more fertilizer phosphorus from the surface than did the 2-inch (5.08 cm) irrigation. Significantly more fertilizer phosphorus was moved from the surface half-inch (1.27 cm) of soil by 15 inches (38.10 cm) of irrigation water than by the smaller irrigation rates.

Stephenson and Chapman (47) found that phosphorus accumulated in the soil horizons in which it was incorporated, and that in most soils movement away from the zone of application was very slow. They also reported that in open loosely compacted soils there was evidence of phosphate movement below the first foot (30.48 cm). A marked penetration of phosphate was found into the second (60.96 cm) and third foot (91.44 cm) horizons when considerable quantities of soluble phosphate were supplied to the surface. They found that phosphate penetrated below the first foot (30.48 cm) when moderately compacted soils were fertilized for many years with phosphate. They also found that the more soluble the phosphorus source, the greater the penetration of phosphorus.

Midgley (33) found that under field conditions most of the phosphate applied as superphosphate was retained within the surface inch (2.54 cm) even after an interval of six months. There was slower movement of phosphorus from superphosphate than from ammonium, potassium or sodium phosphates.  $(\text{NH}_4)_2\text{SO}_4$  and  $\text{K}_2\text{SO}_4$  mixed with equal amounts of superphosphate retarded the movement of phosphate, while  $\text{NaNO}_3$  greatly increased phosphorus movement in a Miami silt loam soil. He suggested that the action of the salts in replacing certain bases from the base exchange compounds of the soil could be used to explain the results obtained. Potassium and ammonium were more active in this respect than sodium, and thus had a tendency to replace calcium which was then free to form the more difficultly soluble tri-calcium phosphate. He stated that there would be a tendency to form a more soluble phosphate when a sodium salt was used as the base exchange compounds seemed to have a greater affinity for ammonium and potassium than sodium ions.

Many workers (9, 24, 25, 26, 36, 46) have utilized diffusion

coefficients in studying the diffusion of phosphorus and uptake or availability of phosphorus to plants. Lewis and Quirk (24) found that the chloride ion moves about 100 times faster than the phosphate ion in most soils. Schofield and Graham-Bryce (46) utilized the principle of the Gaussian distribution function in studying the diffusion of ions in the soil. They found that compaction had a significant influence on rates of diffusion, which had a maximum at 1.5 gm. per ml. for the soil they investigated. Olsen et al. (36) utilized diffusion equations and demonstrated theoretically that phosphate can diffuse fast enough to account for the observed uptake by plants.

Bouldin and Black (3) studied the one-dimensional diffusion of "tagged" phosphorus from  $\text{Ca}(\text{H}_2\text{PO}_4)_2$  and  $\text{KH}_2\text{PO}_4$  and estimated the resulting distribution of diffused phosphorus by the use of X-ray film and Geiger tubes. The X-ray film showed many local areas of  $\text{P}^{32}$  concentrations. They also observed large-scale irregularities in the curves relating phosphorus concentration in the soil column to distance from the source. In both a Miami silt loam and a Muscatine silt loam with  $\text{Ca}(\text{H}_2\text{PO}_4)_2$ , peaks in phosphorus concentration were noted at 4 cm. intervals. One peak about 1 cm. from the source of phosphorus was found when  $\text{KH}_2\text{PO}_4$  was added to the Miami silt loam soil. They also noted that the distribution of diffused calcium was similar to phosphorus distribution in the two soils when  $\text{Ca}(\text{H}_2\text{PO}_4)_2$  was applied.

Heslep and Black (14) found that phosphorus diffusion increased with an increase in the water content of the soil. They found that phosphorus diffusion from superphosphate was reduced by admixture with nitrogenous and potassium salts. They also found that the distance of diffusion increased with time. The fertilizer phosphorus did not diffuse

more than 3 or 4 cm. in 4 weeks, with more than 50 percent of the phosphorus diffusing within the first week, and more than 90 percent diffusing within the first three weeks. They also reported that the extent of diffusion of phosphorus differed between soils, being considerably more restricted in calcareous than acid soils. The extent of diffusion of different phosphatic fertilizers increased with an increase in the phosphorus in water soluble form.

Satchell (44) working under field and laboratory conditions, reported that there was an increase in phosphorus movement with increased rate of application and increased soil moisture content. Superphosphate was the only source that gave a measurable movement when dicalcium phosphate, calcium metaphosphate, superphosphate and fused rock phosphate were added. He also noted that phosphorus moved farther in the Norfolk sandy loam soil than in the Cecil clay loam soil. His results suggested that the distribution curves obtained contained irregularities rather than being smooth as would be predicted.

Lawton and Vomcil (22) studied the dissolution and migration of phosphorus from granular superphosphate. They concluded from their study that most of the water soluble phosphorus in the superphosphate moved out of the granule in a relatively short period of time and that the dissolution rate and diffusion of phosphorus was high in soils having a low or high moisture content. Due to the hygroscopic nature of superphosphate an interesting redistribution of moisture was found to take place between the soil and fertilizer granule. Moisture was drawn from the relatively dry soil toward the granule within a period of hours, forming a moist soil shell around the granule. The effect was equivalent to placing the granule in a soil at a higher moisture content, allowing the granule to

absorb more moisture, and thus increasing the rate of dissolution. They observed a rapid diffusion of phosphorus from the granule in the early stages of dissolution in a moist soil indicating that a very high concentration gradient existed between the solution within the fertilizer and the adjacent soil. The difference in phosphorus concentration was enhanced by a small outward spherical movement. They also found that phosphorus diffused over a relatively short distance. Maximum movement, over a period of 3 to 4 weeks, was found to be 1 inch (2.54 cm) or less, even in a coarse-textured soil. Both rate of movement and distance of movement were greater for the more acid and coarser soil. They also substantiated the work of other workers (3, 14, 44) who found that diffusion from soluble phosphorus sources increased with increased rates of phosphorus application and soil moisture content.

Phillips et al. (38) studied the self-diffusion of phosphorus in clays and soils. Their results were in agreement with those of Heslep and Black (14). They found that the calculated diffusion coefficients and phosphorus rates were linearly and positively correlated. They found a highly significant relationship between the diffusion coefficients and water soluble phosphorus and/or aluminum phosphate content of the soil.

Sample (45) made comparisons of the rates and distances of phosphorus movement from spot placements of  $\text{NH}_4\text{H}_2\text{PO}_4$  and  $(\text{NH}_4)_3\text{HP}_2\text{O}_7 \cdot \text{H}_2\text{O}$  and a 50:50 mixture of these two compounds in ten soils. Rates and distances of phosphorus movement were estimated by exposing autoradiographs periodically. In seven fine-textured soils, phosphorus had moved substantially farther from monoammonium phosphate than from triple ammonium pyrophosphate when sampled for a period of six weeks. Phosphorus from both compounds reached the edge of the container (5 cm. diameter) in two

weeks when three soils of a sandy texture were studied. The presence of monoammonium phosphate in the mixture had little effect on the outer limit of phosphorus movement from triple ammonium pyrophosphate, however, most of the phosphorus from monoammonium phosphate was found beyond the zone influenced by triple ammonium pyrophosphate. The phosphorus from monoammonium phosphate was apparently free to move through the zone of soil which had reacted with triple ammonium pyrophosphate.

Hossner and Richards (15) studied the effect of phosphorus source on the movement of band applied phosphorus. Phosphorus movement from the fertilizer zone was similar when ammonium pyrophosphate, diammonium phosphate or monoammonium phosphate were the sources. The movement of phosphorus from monocalcium phosphate was considerably less. The quantity of applied phosphorus recovered from the soil was greatest for monoammonium phosphate, intermediate for diammonium phosphate and smallest for ammonium pyrophosphate and monocalcium phosphate. They also noted that the pH of soil layers immediately adjacent to ammonium pyrophosphate and monoammonium phosphate fertilizers was 4.0 and 4.2 respectively, and increased as the distance from the fertilizer source increased.

Lai and Mortland (19) reported that two kinds of diffusions dependent on whether the clay mineral was a 1:1 lattice type, collapsed 2:1 lattice type or the 2:1 lattice type was possible in clay minerals.

Rowell et al. (43) found that there was no movement of phosphate in the exchangeable form. They also suggested that where a plant is removing phosphate from a soil, this nutrient must pass into solution in order to move towards a plant root. The presence of exchangeable phosphorus formed a large reserve in the soil, buffering the solution concentration, but no movement could occur in the exchangeable form to supply the needs

of plants. This would be of special importance at low moisture contents where movement in soil solution becomes very restricted.

Bouldin and Sample (1) studied the effects of associated salts on the availability of phosphorus. They reported that phosphorus distribution in the soil depended only on distance from the center of the pellet and not upon direction. They concluded, too, that phosphorus distribution in the soil had reached a relatively stable value after three weeks reaction in a Hartsells sandy loam soil. They also reported that salts in intimate contact with concentrated superphosphate had an influence on the fraction of  $\text{Ca}(\text{H}_2\text{PO}_4)_2 \cdot \text{H}_2\text{O}$  which reverted to  $\text{CaHPO}_4$  at the pellet site as well as on the distribution of fertilizer phosphorus in the soil. Salts also had an effect on the solubility of soil fertilizer phosphorus reaction products. The relative magnitudes of these effects depended on soil properties.

Lindsay and Stephenson (28) investigated the reactions of monocalcium phosphate monohydrate in a slightly calcareous soil and found that it resulted in an increase in pH and precipitation of iron, aluminum and calcium phosphates from solution. They reported that when monocalcium phosphate was placed in the soil it dissolved readily, the dissolution being dependent only on the rate at which water could reach the fertilizer granule. They noted that during the dissolution process much of the water entering the granules moves in by vapour diffusion while the  $\text{CaHPO}_4 \cdot 2\text{H}_2\text{O}$  which was formed moved out as a liquid into the surrounding soil due to the capillary gradient that was established.

Lehr et al. (23) reported that a significant part of phosphorus applied as monocalcium phosphate monohydrate remained at the tablet site as dicalcium phosphate anhydrate or dicalcium phosphate dihydrate. The



extent of movement of phosphorus solution, formed upon dissolution of monocalcium phosphate, into the soil was nearly the same for all the soils studied. The liquid in the wet zone persisted throughout the experiment (9 days) in the acid soils, but in the calcareous soil, the solution reacted rapidly to form a precipitate of anhydrous and dicalcium phosphate dihydrate on soil granules. They believed that the initial dissolution of the phosphorus was governed primarily by the rate of dissolution of the monocalcium phosphate and by the rates of subsequent interactions between soil and phosphate solution. These factors collectively, rather than 'diffusion' alone, controlled the phosphorus concentration gradient.

Many workers (3, 14, 17, 22, 38, 44) have used various methods for determining the rate of phosphorus movement as well as the extent of movement of phosphorus. Johnston (17) stated that the commonly used methods were not entirely satisfactory. The usual procedure involved analyzing for phosphorus in successive cross-sectional segments of a soil column or leachates from a soil column that had been treated with a phosphatic fertilizer. He further stated that the first method was inadequate because of the impossibility of obtaining a series of infinitely thin soil sections to find the exact distribution of phosphorus with depth. Moreover, the change in concentration with depth may, in many cases, be so small as to be beyond the sensitivity of ordinary methods of analysis. The second method tells nothing of the distribution of phosphorus with depth in the soil column but only whether the phosphorus has moved out of the column as a result of leaching. He devised a method of sectioning the soil into thin sections and taking radioautographs.

Although his method provided findings no different than provided by methods used by other workers (3, 14, 22, 38, 44), he felt it was a better method.

Some workers (21, 32) had indicated that the error involved in using  $P^{32}$  measurements to indicate phosphorus distribution was substantial. To investigate this aspect of phosphorus study, Bouldin and Black (3) made detailed distribution studies. They found significant changes in the apparent specific activity of the diffusing phosphorus. They accounted for the above results by assuming exchange between diffusing  $P^{32}$  and native soil phosphorus. They concluded from their study that despite the observed changes, the overall picture of phosphorus diffusion obtained from activity measurements was not substantially different from that obtained by ordinary phosphorus analysis.

Hall and Mackenzie (11) have suggested that when a solid precipitation of a radioactive sample is to be made, care must be paid to the geometric configuration of the sample. The geometry of the sample should be uniform and reproducible within narrow limits. Since all portions of the counting tube are not equally sensitive, the geometry of the sample must be uniform and its shape must not differ radically from the counter tube opening. Provision should be made such that the sample could be rotated and all parts exposed to the counter if the samples being counted were not uniform or if the shape of the samples were different from that of the counting tube.

### III MATERIALS AND METHODS

The experimental methods used for the several individual studies reported in this manuscript are discussed with the results obtained in the appropriate section. The analytical procedures along with the final experimental method of studying phosphorus movement are presented in this section. The results of investigations required to develop the selected method of studying phosphorus movement are presented in Section IV.

#### (1) Soils

Soil carbonate level and texture were the two basic criteria used in the selection of the soils studied. A subgroup designation, mechanical analysis and textural class names are presented in Table I. Other soil characteristics are presented in Table II.

#### (2) Chemicals

The  $P^{32}$  used in all investigations was carrierfree  $P^{32}$  in the form of  $H_3PO_4$  obtained from Atomic Energy of Canada Ltd., Ottawa. Other chemicals, such as  $NH_4H_2PO_4$  and  $(NH_4)_2HPO_4$ , were of reagent grade.

#### (3) Preparation of $P^{32}$ "tagged" Fertilizer

The inactive phosphorus carrier was dissolved in a small volume of water in a polyethylene container.  $P^{32}$  (usually 10 uc./0.1g  $NH_4H_2PO_4$ ) was then added and the solution mixed and evaporated to dryness on a sand bath. After evaporation, the  $P^{32}$  "tagged" phosphorus fertilizer crust was transferred to a beaker and ground.

#### (4) Soil pH

The pH of the soil samples or solutions was determined electrometrically by the use of the glass and calomel electrodes on a Universal

TABLE I SUBGROUP DESIGNATION, MECHANICAL ANALYSIS AND TEXTURAL CLASS OF SOILS STUDIED.

SOIL NAME	SUB GROUP	MECHANICAL ANALYSIS			TEXTURAL NAME
		% Sand	% Silt	% Clay	
Stockton II	Orthic Black	92.72	2.91	4.37	Sand
Wellwood	Orthic Black	22.30	45.94	31.76	Clay Loam
Lakeland I	Gleyed Carbonated Rego Black	23.50	66.28	10.22	Silt Loam
Stockton I	Orthic Black	73.92	14.67	11.41	Sandy Loam
Lakeland II	Gleyed Carbonated Rego Black	14.60	78.11	7.29	Silt Loam
Pine Ridge	Gleyed Carbonated Rego Black	64.96	29.69	5.35	Sandy Loam
Tarno	Carbonated Rego Humic Gleysol	3.40	89.41	7.19	Silt
Plum Ridge	Gleyed Carbonated Rego Black	66.16	17.35	16.49	Sandy Loam
Firdale	Orthic Dark Grey	35.87	33.75	30.38	Clay Loam
St. Norbert	Solonetzic Dark Grey	5.88	20.47	73.65	Clay

TABLE II SOME CHEMICAL CHARACTERISTICS OF SOILS STUDIED.

Soil	pH	Organic Matter (%)	Conductivity (mmhos/cm. <sup>2</sup> )	Inorganic Carbonate (% CaCO <sub>3</sub> )	Moisture Content at Field Capacity (%)	NaHCO <sub>3</sub> Extractable P (ppm)	NH <sub>4</sub> Ac Displaceable (meg./100g.)			
							Na	K	Ca	Mg
Stockton II	6.9	2.16	0.22	0.26	24.98	-	-	0.21	9.70	2.12
Wellwood	5.5	8.06	0.82	0.19	28.93	4.1	1.48	0.72	35.74	9.11
Lakeland I	8.1	9.94	6.97	23.8	35.20	1.0	4.52	0.76	46.99	49.84
Stockton I	7.2	2.96	0.60	0.70	16.99	2.1	1.43	0.56	20.43	4.46
Lakeland II	7.8	8.87	1.19	13.5	34.75	2.5	0.96	1.13	66.43	24.00
Pine Ridge	7.8	1.88	0.41	8.8	17.94	-	0.52	0.35	27.93	3.44
Tarno	7.7	13.97	4.90	12.4	49.82	5.9	2.35	0.75	71.91	46.21
Plum Ridge	8.0	6.45	2.68	19.8	24.64	4.4	0.96	0.25	47.06	21.45
Firdale	7.5	3.76	0.57	0.85	23.67	2.0	1.70	0.51	37.42	88.32
St. Norbert	6.0	9.40	0.36	0.50	51.77	6.1	1.26	0.92	52.03	24.42

pH meter 22. A soil-water saturated paste was used in determining the soil pH's listed in Table II.

(5) Soil Organic Matter

Soil organic matter was determined according to the method described by Walkley and Black (50). Excess potassium dichromate was used to oxidize the organic carbon followed by titration of the unreacted potassium dichromate with ferrous sulphate.

(6) Conductivity

The electrical conductivity of a soil-water saturated paste extract was measured using a Conductivity Bridge, Model RC16 B2.

(7) Carbonate Content

The method described by Ridley (42) was used. A one gram soil sample was digested in ten percent HCl for ten minutes. The carbon-dioxide evolved was sucked through a drying and adsorption train, then absorbed by Ascarite in a Nesbitt tube. The weight of carbondioxide absorbed was determined and expressed as percent calcium carbonate.

(8) Calcium and Magnesium in Solution

The procedure as outlined by Tucker and Kurtz (49) was followed. The calcium plus magnesium content of the filtrate was first determined on an aliquot by titration with ethylene diamine tetracetic acid (EDTA). Eriochrome Black T was used as indicator. On another aliquot, the magnesium was first precipitated as the hydroxide by use of a sodium hydroxide solution and the calcium in solution titrated with EDTA using Calcon as indicator. The magnesium present in the extracts was obtained by difference.

(9) Ammonium Acetate Displaceable Calcium, Magnesium, Sodium and Potassium

Twenty-five grams of air-dried soil was shaken in 100ml neutral

ammonium acetate solution for one hour. The suspension was then filtered through Whatman No. 1 filter paper. The calcium, magnesium, sodium and potassium contents of the filtrate were then determined and the contents of these elements in the soil calculated.

(10) Sodium and Potassium in Solution

The sodium and potassium contents of the filtrates were determined by use of a Baird Atomic photometer Model KY 2.

(11) 0.5 M  $\text{NaHCO}_3$  - extractable Phosphorus

$\text{NaHCO}_3$  extractable phosphorus was determined as outlined by Olsen et al. (37). Five grams of soil was shaken with 100ml. of the 0.5 M  $\text{NaHCO}_3$  extracting solution for thirty minutes. The suspension was filtered through Whatman No. 1 filter paper and a 50ml. aliquot transferred to a 100ml. volumetric flask. 1.5ml. concentrated HCl was added slowly with shaking, followed by the addition of twenty milliliters ammonium molybdate-HCl solution. Ten milliliters of dilute stannous chloride was then added and the total volume made up to 100ml. with distilled water. The colour intensity was read on a Coleman Junior Spectrophotometer Model 6A after five minutes at 660 m $\mu$ . By comparison of these readings with those from a standard curve and making the appropriate calculations, the phosphorus contents of the soils were determined.

(12) Phosphorus Content of Water Extracts

The colorimetric procedure as outlined by Jackson (16) was followed. A suitable aliquot was adjusted to a pH of 3.0 with 4N  $\text{NH}_4\text{OH}$  or 4N HCl, using 2-4-dinitrophenol as indicator. One milliliter of sulphomolybdic acid was added and the volume made up to 50 ml. with distilled water. One milliliter of dilute stannous chloride was then added and the colour intensity read on a Coleman Junior Spectrophotometer

Model 6A after 6 minutes at 660 mu. These readings were compared to those obtained for a standard curve and the phosphorus contents of the solutions calculated.

(13) Mechanical Analysis

The pipette method for particle size analysis was used. Duplicate ten-gram soil samples were used. The organic matter was destroyed by oxidation with 30% hydrogen peroxide. One milliliter of glacial acetic acid was added. After the reaction became less violent, the samples were placed on a hot plate to complete the reaction. Ten milliliters of a Calgon solution was added and the sample stirred mechanically for thirty minutes. The sand fraction was obtained by sieving the suspension through a 300 mesh sieve. The eluate was collected in a 1000ml. cylinder and made up to volume with distilled water. Aliquots were taken at a depth of 10cm. for estimation of silt plus clay and clay fractions after allowing for the appropriate settling times. The percent sand, silt and clay were then calculated.

(14) Determination of Water Content at Field Capacity

The water content of the soils at field capacity was determined as follows: Soil, sieved through a 2mm. sieve, was placed in 400ml. beakers and sufficient water added to wet the surface one-half of soil. The samples were enclosed in polyethylene bags and allowed to equilibrate for several days. Soil samples were then taken above the wetted front, weighed and placed in preweighed 100ml. beakers. The samples were placed in an oven at 100°C for 24 hours, removed, cooled and reweighed. The percent moisture, expressed on an oven dry basis, was then calculated.

(15) Method used in Studying Phosphorus Movement

Sealright one-pint cardboard cartons (8.89cm. in diameter and



9.65 cm. long) were used throughout the investigation unless otherwise stated. The cartons were pre-cut horizontally 0.95 cm. above and below the point where the  $P^{32}$  "tagged" phosphorus fertilizer was to be placed and rejoined by taping. These cuts were made so that a 1.91 cm. slice of soil could easily be taken for sectioning from the phosphorus reaction zone. The cartons were half-filled with soil, watered to field capacity and allowed to stand overnight. A small opening was made at the centre of the soil surface and 0.1 g.  $NH_4H_2PO_4$  containing 10  $\mu$ c.  $P^{32}$  or another phosphorus fertilizer at an equivalent phosphorus rate placed into the opening. The carton was then packed with soil and watered to field capacity. The cartons were placed in a polyethylene-lined box and allowed to incubate for three weeks at room temperature.

The box was frequently opened to allow for aeration of the soils. Small amounts of distilled water were added periodically to the samples to maintain them at field capacity. After three weeks of incubation, the tape was removed from the cartons and a 1.91 cm. slice of soil removed from the fertilizer phosphorus reaction zone. Soil samples were taken at 0.00 to 0.64, 0.64 to 0.95, 0.95 to 1.27, 1.27 to 1.59, 1.59 to 1.91, 1.91 to 2.22, 2.22 to 2.54, 2.54 to 3.18, 3.18 to 3.81, and 3.81 to 4.45 cms. from the site of phosphorus application using sampling rings of appropriate sizes. The samples were air-dried, ground and thoroughly mixed. A one-gram sample was placed in a steel die and pressed for five minutes at 15,000 lb. per square inch on a Carver Press. The activity in the pressed soil-briquet was measured on a Geiger Mueller End Window Counting Unit. The counts were corrected for background and radioactive decay, and recorded. Samples with a count rate less than or equal to background activity plus the counts attributed to error in counting were

considered statistically insignificant (51). Using this criterion, it could be assumed that no fertilizer phosphorus was present in a sample when the count rate dropped to less than five counts per minute above background countrate. However, in determining the extent of phosphorus movement from the site of application values below one percent concentration were considered insignificant.

The activities of the soil-briquets were also expressed as percent concentration and percent distribution. Expressing the activity of the soil-briquet at any one distance as a percentage of total activity (sum of the activities of all sampling distances) was termed percent concentration. Percent distribution represents the fraction of added phosphorus in radial shells at various distances from the source of phosphorus application. Experimental measurement of the exact value of percent concentration and therefore percent distribution, however, is simply impossible because of the inability to sample shell volumes. Since soil samples were taken as cylinders, as has been explained previously, the true percent concentration of  $P^{32}$  will be greater than the experimental value. However, in the calculations conducted, the percent concentration of  $P^{32}$  in a particular shell was expressed by the value determined experimentally.

Percent distribution was calculated as follows: first, the activity of each soil-briquet, which represents the concentration of added phosphorus in the soil, was multiplied by the radial shell volume. Since samples were taken at 0.00 to 0.64, 0.64 to 0.95, 0.95 to 1.27, 1.27 to 1.59, 1.59 to 1.91, 1.91 to 2.22, 2.22 to 2.54, 2.54 to 3.18, 3.18 to 3.81, and 3.81 to 4.45 cm. from the pellet, the radial shell volumes sampled or factors were 1.07, 2.55, 4.95, 8.19, 12.18, 17.05, 22.62, 65.40, 97.56 and 137.53, respectively. These counts per minute  $\times$   $cm^3$  were then totalled and the activity of each soil-

briquet expressed as a percentage of the total count. The calculated percent distribution values are a function of the volumes of the spherical shells sampled. Also, the true value of percent distribution cannot be obtained due to the inability to sample exact shell volumes as explained above. However, expressing the results by these two methods should help to illustrate differences in phosphorus movement and also aid in determining the fraction of added phosphorus that is present at specific distances from the site of fertilizer phosphorus application.

It was found that in some soils the fraction of added phosphorus (percent distribution) decreased as the distance from the site of phosphorus application was increased. In other soils, the percent distribution values increased then decreased with an increase in distance from the site of phosphorus application. In many of these soils, however, a further increase in percent distribution after the initial decrease was noted. This increase in percent distribution values was assumed to be error as they represented very low values of percent concentration and therefore these percent distribution values were not included in the final calculations of percent distribution.

#### IV RESULTS AND DISCUSSION

##### A. Method of Studying Phosphorus Movement

The reviewed methods for studying the degree of movement and penetration of phosphorus in soils may be summarized as follows:

(a) Analysis for phosphorus of successive cross-sectional segments of a soil column previously treated with a phosphatic fertilizer.

(b) Analysis of the leachates from soil columns for phosphorus.

(c) Determination of phosphorus diffusion coefficients by the use of  $P^{32}$  and application of Ficks Laws of Diffusion.

(d) Application of  $P^{32}$  "tagged" phosphorus to the soil sample, freezing and then taking thin sections for autoradiography (17).

(e) Measurement of  $P^{32}$  by direct counting of an air-dried sample, soil extract, or a precipitate formed by evaporating soil extracts.

The techniques used in (a) and (b) are limited by the detection limits of chemical methods used in extracting and measuring the amount of phosphorus in soils. The determination of diffusion coefficients, of all techniques reviewed, is possibly the only method by which a finite limit can be placed on the distance of phosphorus movement, but it was not the objective of this study to deal with this aspect of phosphorus movement. The application of autoradiography in phosphorus movement studies gives only a qualitative estimation of phosphorus movement. It also suffers from poor resolution, especially when used for beta particles with low specific ionization which traverse a long irregular path through the emulsion giving rise to a diffuse image. Extremely thin samples are needed for optimal resolution. Films used in autoradiography also have the disadvantages of relatively poor resolution and a high

sensitivity for background radiation (51).

Since the reviewed methods could be used mainly for qualitative measurements or were laborious, a new technique, involving the use of  $P^{32}$  was developed. The method involved the placement of  $P^{32}$  "tagged" phosphorus fertilizer into the soil. Soil samples were then taken at specific distances from the site of fertilizer application, air-dried, ground, pressed into soil-briquets and the activity of the soil-briquets measured. It was assumed that if sampling and counting procedures could be standardized, the radioactivity of a soil-briquet would represent the concentration of fertilizer phosphorus in the soil. Since the concentration of phosphorus within the soil could be determined, information on the amount of added phosphorus present at various distances from the site of fertilizer application could also be obtained. Prior to application of this technique it was necessary to determine the following:

- (a) the amount of  $P^{32}$  required to give a relatively high counting rate.
- (b) the weight of soil necessary to give an infinite or saturation thickness to the soil-briquet.
- (c) the reproducibility of counts obtained on one sample.

#### Determination of Infinite (Saturation) Thickness.

A considerable fraction of the radiation emitted in the direction of a detector may be absorbed before it reaches the sensitive volume of the detector. This absorption may occur in the sample itself, in the intervening air space or in the window of the detector. Absorption of beta particles in air space or in the windows of the detector are usually low or negligible in Geiger-Mueller detectors (51). However, when radioactivity measurements are made on a series of beta-emitting

samples of increasing thickness but of constant specific activity, the phenomenon of self-absorption takes place. The absence of self-absorption should result in a counting rate which increases linearly as the amount of sample increased. However, with thick samples beta particles from the lower layers are absorbed by the overlying sample material. Eventually, a sample thickness is reached where only the beta particles from the topmost layers are being counted. A plot of such counting data would show that the observed activity does not increase linearly with sample weight or thickness, but bends away from the calculated activity curve and approaches a limiting value. This value is called the infinite (or saturation) thickness. The countrate of samples when only the top layer of soil is being counted would not be affected by small errors in weighing and countrates on several samples could be compared if the geometry of counting was standardized.

The amount of soil required to produce an infinitely thick briquet was determined as follows: one-half gram of  $P^{32}$  "tagged" monoammonium-phosphate was thoroughly mixed into 60 grams of soil. One half, 0.75, 1.00, 1.25, 1.50, 1.75 and 2.00 grams of soil were pressed into briquets, as previously described, and counted on the Geiger-Mueller Counter. The results of this study, summarized in Table III indicate that a relatively small soil sample could be used. The activity of the samples increased as sample weight was increased. This increase, however, was not very large and may have been due to the geometry of counting. Since the larger sample weights produced thicker briquets, increasing the sample weight also decreased the distance between the end window counting tube and the briquet. In order to overcome difficulties in obtaining a stable briquet in coarse-textured soils, a 1.00 gram sample weight was selected.

TABLE III ACTIVITY OF SOIL BRIQUETS AS INFLUENCED BY THICKNESS OF BRIQUET.

SAMPLE	WEIGHT OF SOIL	Mean cpm
1	0.50	12352
2	0.75	14345
3	1.00	13786
4	1.25	14458
5	1.50	16987
6	1.75	16892
7	2.00	18208

#### REPRODUCIBILITY OF SAMPLE COUNTS

The decision to measure the activity of the soil in the form of briquets required that the sample counted represent the activity of all the soil sampled and therefore samples would have to be homogeneously mixed. An experiment was conducted to determine if the count on a soil sample could be reproduced after air-drying, grinding and mixing. Ten one-gram samples taken from a soil treated with  $P^{32}$  "tagged" phosphorus were pressed into briquets and counted on both sides. A high reproducibility of counts was obtained (Table IV), indicating that an accurate measure of the activity of soils treated with  $P^{32}$  "tagged" phosphorus could be made providing the samples were thoroughly mixed. There was some variation between the counting rates on different sides of the briquet. However, this was not statistically significant. The standard deviation for the counts on side one was  $\pm 450$  and the coefficient of variability 3.10. The standard deviation and coefficient of variability for side 2 were  $\pm 358$  and 2.46, respectively. Since counting on either side would result in high reproducibility, the briquets were counted only on one side in other studies.

#### RATE OF $P^{32}$ APPLICATION

The amount of  $P^{32}$  required for each phosphorus fertilizer placement had to be determined prior to the application of the technique. One-tenth gram samples of  $NH_4H_2PO_4$  were labelled with 2.5, 5.0 and 10.0  $\mu c. P^{32}$ . Weighed quantities of  $NH_4H_2PO_4$  were dissolved in distilled water and sufficient  $P^{32}$  added such that 0.1 gram samples of  $NH_4H_2PO_4$  would contain 2.5, 5.0 and 10.0  $\mu c. P^{32}$  after evaporation. The prepared  $NH_4H_2PO_4$  fertilizers were added to the Stockton II, Pine Ridge, St. Norbert and



TABLE IV REPRODUCIBILITY OF SAMPLE COUNTS

SAMPLE	SIDE 1 cpm	SIDE 2 cpm	MEAN cpm
1	14669	14675	14672
2	14866	14928	14897
3	14761	14659	14710
4	15174	15148	15161
5	14727	14710	14719
6	14787	14672	14730
7	14763	14668	14716
8	14730	14663	14682
9	14814	15281	15048
10	14773	14724	14749

Tarno soils. The soils were placed into cartons, the "tagged" phosphorus added, soil samples surrounding the phosphate pellet obtained and the activity of the soil samples measured as previously described.

The results, shown in Table V, indicate that 2.5 and 5.0  $\mu\text{c P}^{32}$  per 0.1 gram  $\text{NH}_4\text{H}_2\text{PO}_4$  were insufficient to indicate the movement of small amounts of phosphorus beyond 1.59 and 1.91 cm. distance in the St. Norbert and Tarno soils, respectively. Although rates higher than 10  $\mu\text{c P}^{32}$  were not investigated, a rate of 10  $\mu\text{c P}^{32}$  per 0.1 gram of fertilizer material was selected for subsequent studies. This rate of  $\text{P}^{32}$  gave a relatively high count on most soil samples, would not create a health hazard, and would result in detection of small amounts of phosphorus that had moved large distances.

#### LEACHING STUDY

This experiment was initiated to obtain information on movement of surface applied phosphorus into soils. Five calcareous and five non-calcareous soils of varying texture were selected for the study. The experimental method employed was similar to that used by Lewis (27). Plastic tubes of 6.73 cm. in diameter by 5.09 cm. were cut into 0.32 cm. rings, rejoined with tape and filled with air-dried soil. Phosphorus at a rate of 100 lb.  $\text{NH}_4\text{H}_2\text{PO}_4$  per acre was spread evenly over the surface of the soil in the columns. The  $\text{NH}_4\text{H}_2\text{PO}_4$  was "tagged" with 100  $\mu\text{c P}^{32}$ . The columns were then leached with water equivalent to 7.62 cm. of precipitation at a rate of approximately 1 cm. per minute. After leaching the tape was removed from the soil columns, and the soil sections removed. The soil samples were air-dried, ground, thoroughly mixed, and the activity of the samples measured.

TABLE V COUNT RATE OF UNIT SOIL WEIGHT AT VARIOUS RATES OF APPLIED P<sup>32</sup>

Distance (cm)	Stockton II Sand			Pine Ridge Sandy Loam			St. Norbert Clay			Tarno Silt		
	2.5 UC cpm	5.0 UC cpm	10.0 UC cpm	2.5 UC cpm	5.0 UC cpm	10.0 UC cpm	2.5 UC cpm	5.0 UC cpm	10.0 UC cpm	2.5 UC cpm	5.0 UC cpm	10.0 UC cpm
0.00 - 0.64	139	272	779	315	1045	2962	706	1253	1213	318	2956	5317
0.64 - 0.95	159	97	627	153	282	349	391	875	448	94	506	2395
0.95 - 1.27	129	157	346	14	57	65	118	37	923	105	45	296
1.27 - 1.59	156	95	191	19	23	30	36	14	740	146	-	17
1.59 - 1.91	82	95	174	12	10	15	20	14	68	-	-	8
1.91 - 2.22	40	55	82	2	18	28	-	-	25	-	-	6
2.22 - 2.54	17	2	31	-	-	-	-	-	8	-	-	28
2.54 - 3.18	12	15	34	-	-	-	-	-	3	-	-	-
3.18 - 3.81												
3.81 - 4.45												

The leachates from each soil column were also collected for radio-assay using a DM 6 liquid Geiger-Mueller Tube. Phosphorus movement was greater in the coarse-textured noncalcareous soils than in the finer-textured noncalcareous soils (Table VI). Some of the applied phosphorus moved completely through the column in the two Stockton soils. Some of the applied phosphorus moved to the 3 cm. depth in the Firdale and Wellwood soils and to about the 2.5 cm. depth in the heavy-textured St. Norbert clay. This greater movement of applied phosphorus in coarse-textured soils was less apparent in the calcareous Lakeland, Plum Ridge, Pine Ridge and Tarno soils. However, the applied phosphorus moved to a greater depth in the calcareous Pine Ridge sandy loam than in the other calcareous soils which contained more silt and/or clay. The percent concentration is generally higher adjacent to the phosphorus pellet in the calcareous soils than in the noncalcareous soils when soils of comparable texture are compared. This indicates that phosphorus may move more readily in non-calcareous soils than in calcareous soils and that the carbonates present in soils restrict the movement of phosphorus. The results of the counting rate on the soil leachates are not presented. However, the activity of the leachates obtained from the noncalcareous soils were very much greater than those from the calcareous soils. The activity of the leachates obtained from the coarse-textured soils were also much greater than those obtained from the heavy-textured soils. These results confirm the results obtained by measuring the activity of the soil at various depths.

THE MOVEMENT OF PHOSPHORUS FROM MONOAMMONIUM PHOSPHATE (MAP) AND DIAMMONIUM PHOSPHATE (DAP) Pellets in Calcareous and Noncalcareous Soils.

Phosphorus fertilizers are added to soils in pellet form and placed

TABLE VI DISTRIBUTION OF P<sup>32</sup> "TAGGED" MONOAMMONIUM PHOSPHATE IN SOIL COLUMNS AFTER APPLICATION OF 7.62 cm. EQUIVALENT OF DISTILLED WATER AT THE RATE OF 1 cm. PER MINUTE.

Distance (cm)	Firdale Clay Loam		Stockton II Sand		Stockton I Sandy Loam		Wellwood Clay Loam		St. Norbert Clay	
	cpm	% Conc.	cpm	% Conc.	cpm	% Conc.	cpm	% Conc.	cpm	% Conc.
0.00 - 0.32	6669	27.22	1113	8.46	3256	13.04	7344	27.04	10478	43.42
0.32 - 0.64	5570	22.73	1064	8.09	2638	10.57	5379	19.80	6080	25.19
0.64 - 0.95	4317	17.62	845	6.42	2528	10.13	4269	15.72	3865	16.02
0.95 - 1.27	3426	13.98	802	6.10	2434	9.75	3635	13.38	2271	9.41
1.27 - 1.59	2222	9.07	652	4.96	2174	8.71	2560	9.43	1004	4.16
1.59 - 1.91	1198	4.89	644	4.90	1972	7.90	1684	6.20	351	1.45
1.91 - 2.22	721	2.94	746	5.67	1759	7.05	1205	4.44	50	0.21
2.22 - 2.54	276	1.13	694	5.28	1598	6.40	668	2.46	33	0.14
2.54 - 2.86	86	0.35	894	6.80	1375	5.51	324	1.19		
2.86 - 3.18	18	0.07	1080	8.21	1319	5.28	55	0.20		
3.18 - 3.50			989	7.52	1020	4.09	37	0.14		
3.50 - 3.82			896	6.81	890	3.56				
3.82 - 4.13			739	5.62	757	3.03				
4.13 - 4.45			809	6.15	571	2.29				
4.45 - 4.77			516	3.92	428	1.71				
4.77 - 5.09			673	5.12	248	1.00				

TABLE VI (Continued)

Distance (cm)	Lakeland I Silt Loam		Plum Ridge Sandy Loam		Lakeland II Silt Loam		Pine Ridge Sandy Loam		Tarno Silt	
	cpm	% Conc.	cpm	% Conc.	cpm	% Conc.	cpm	% Conc.	cpm	% Conc.
0.00 - 0.32	11625	43.63	12313	67.51	14283	48.71	7540	26.24	13021	46.92
0.32 - 0.64	5918	22.21	3378	18.52	7113	24.26	4360	15.17	5508	19.85
0.64 - 0.95	3929	14.75	1556	8.53	4240	14.46	3308	11.51	3680	13.26
0.95 - 1.27	2082	7.81	773	4.24	2491	8.50	2625	9.13	2378	8.57
1.27 - 1.59	1333	5.00	159	0.87	932	3.18	2261	7.87	1322	4.76
1.59 - 1.91	742	2.78	46	0.25	236	0.80	2051	7.14	731	2.63
1.91 - 2.23	524	1.97	7	0.04	25	0.09	1754	6.10	404	1.46
2.23 - 2.54	226	0.85	6	0.03			1261	4.39	400	1.44
2.54 - 2.86	195	0.73					832	2.90	183	0.66
2.86 - 3.18	55	0.21					905	3.15	74	0.27
3.18 - 3.50	16	0.06					533	1.85	52	0.19
3.50 - 3.82							5529	1.84		
3.82 - 4.13							359	1.25		
4.13 - 4.45							190	0.66		
4.45 - 4.77							144	0.50		
4.77 - 5.09							87	0.30		

into the soil when annual crops are fertilized. Since a leaching experiment does not give information on the movement of phosphorus adjacent to a phosphorus fertilizer pellet, an experiment was conducted to determine the movement of phosphorus adjacent to a monoammonium phosphate (MAP) and diammonium phosphate (DAP) pellet when placed into calcareous and noncalcareous soils of varying texture.

Monoammonium phosphate (MAP) and diammonium phosphate (DAP) at rates of 0.1000 gram and 0.1150 gram, respectively, were added as a pellet treatment to ten soils and incubated for three weeks. The details of experimental and radioassay procedures have been described earlier. The results of this experiment are presented in Table VII and Figures 1 to 10. Calcareous and noncalcareous soils of similar texture were paired so that an easy comparison could be made between the behaviour of phosphorus in calcareous and noncalcareous soils. Since the results have been expressed in terms of percent concentration and percent distribution, the following criteria can be used to detect differences in phosphorus movement.

(a) The lower the percent concentration or percent distribution of phosphorus remaining at the pellet site (0.00 - 0.64 cm. distance) the greater the movement of phosphorus.

(b) The higher the percent concentration or percent distribution of phosphorus at a relatively large distance (eg. 1.91 cm. ) from the pellet site, the greater the movement of phosphorus.

The results obtained for the Stockton II and Pine Ridge soils are shown in Figures 1 and 2 as well as in Table VII. Phosphorus from monoammonium phosphate (MAP) and diammonium phosphate (DAP) moved to a distance of approximately 3.8 and 3.0 cm., respectively, in the Stockton II soil. The movement of phosphorus in the calcareous Pine Ridge

TABLE VII MOVEMENT OF PHOSPHORUS 21 DAYS AFTER APPLICATION OF MAP AND DAP PELLETS.

Distance (cm)	Stockton II						Stockton I					
	M A P			D A P			M A P			D A P		
	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.
0.00 - 0.64	1187	35.35	12.82	514	32.15	10.21	1365	33.32	8.60	3174	37.78	10.82
0.64 - 0.95	802	23.88	20.64	411	25.70	19.45	1389	33.90	20.86	2722	32.40	22.12
0.95 - 1.27	456	13.58	22.77	236	14.76	21.68	588	14.35	17.14	1202	14.31	18.96
1.27 - 1.59	320	9.53	26.45	164	10.26	24.93	303	7.40	14.61	601	7.15	15.68
1.59 - 1.91	141	4.20	17.33	105	6.57	23.74	199	4.86	14.27	292	3.48	11.33
1.91 - 2.22	150	4.47		66	4.13		1138	3.37	13.86	193	2.30	10.49
2.22 - 2.54	147	4.38		67	4.19		80	1.95	10.66	147	1.75	10.60
2.54 - 3.18	91	2.71		25	1.56		21	0.50		39	0.46	
3.18 - 3.81	51	1.52		11	0.69		10	0.24		16	0.19	
3.81 - 4.45	13	0.39					4	0.10		15	0.18	

MA P =  $\text{NH}_4 \text{H}_2 \text{HPO}_4$  (monoammonium phosphate)

DA P =  $(\text{NH}_4)_2 \text{HPO}_4$  (diammonium phosphate)



TABLE VII (Continued)

Distance (cm)	Wellwood						Firdale					
	M A P			D A P			M A P			D A P		
	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.
0.00 - 0.64	4331	43.21	12.66	5902	51.44	17.66	5568	54.22	22.31	4560	53.65	21.85
0.64 - 0.95	2601	25.95	18.12	2773	24.17	19.78	2900	28.24	27.69	2316	27.25	26.45
0.95 - 1.27	1481	14.78	20.03	1411	12.30	19.53	1041	10.14	19.29	1021	12.01	22.63
1.27 - 1.59	771	7.69	17.25	742	6.47	17.00	437	4.26	13.40	334	3.93	12.25
1.59 - 1.91	417	4.16	13.88	394	3.43	13.42	215	2.09	9.81	185	2.18	10.09
1.91 - 2.22	243	2.42	11.32	145	1.26	6.91	79	0.77	5.04	71	0.84	5.42
2.22 - 2.54	109	1.09	6.74	90	0.78	5.69	29	0.28	2.46	13	0.15	1.32
2.54 - 3.18	70	0.70		17	0.15							
3.18 - 3.81												
3.81 - 4.45												

M A P =  $\text{NH}_4\text{H}_2\text{PO}_4$  (monoammonium phosphate)  
 D A P =  $(\text{NH}_4)_2\text{HPO}_4$  (diammonium phosphate)

TABLE VII (Continued)

Distance (cm)	St. Norbert						Lakeland I					
	M A P			D A P			M A P			D A P		
	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.
0.00 - 0.64	4824	37.34	9.57	8744	45.61	13.54	2794	29.74	10.29	24662	83.76	65.93
0.64 - 0.95	3242	25.09	15.33	4513	23.54	16.66	3135	33.37	27.52	4265	14.48	27.18
0.95 - 1.27	2467	19.09	22.65	2935	15.31	21.03	3163	33.67	53.90	464	1.58	5.74
1.27 - 1.59	1073	8.30	16.30	1442	7.52	17.09	236	2.51	6.655	31	0.16	0.63
1.59 - 1.91	771	5.97	17.41	975	5.09	17.19	39	0.42	1.64	17	0.01	0.52
1.91 - 2.22	301	2.33	9.52	407	2.12	10.04	7	0.07		6		
2.22 - 2.54	220	1.70	9.23	136	0.71	4.45	11	0.12				
2.54 - 3.18	22	0.17		18	0.09		5	0.05				
3.18 - 3.81							5	0.05				
3.81 - 4.45												

M A P =  $\text{NH}_4\text{H}_2\text{PO}_4$  (monoammonium phosphate)

D A P =  $(\text{NH}_4)_2\text{HPO}_4$  (diammonium phosphate)

TABLE VII (Continued)

Distance (cm)	Pine Ridge						Tarno					
	M A P			D A P			M A P			D A P		
	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.
0.00 - 0.64	2454	47.54	15.08	2612	48.81	18.51	11053	54.56	21.37	13304	54.60	23.32
0.64 - 0.95	1368	26.50	20.03	1619	30.26	27.34	5087	25.11	23.44	5745	23.58	24.00
0.95 - 1.27	601	11.64	17.08	670	12.52	21.97	2507	12.37	22.43	4159	17.07	33.73
1.27 - 1.59	3825	7.40	17.97	266	4.97	14.43	805	3.97	11.91	772	3.17	10.36
1.59 - 1.91	188	3.64	13.15	114	2.13	9.20	494	2.44	10.87	297	1.22	5.93
1.91 - 2.22	95	1.84	9.30	53	0.99	5.98	211	1.04	6.50	75	0.31	2.10
2.22 - 2.54	57	1.10	7.40	17	0.32	2.55	85	0.43	3.47	15	0.06	0.56
2.54 - 3.18	17	0.33					17	0.08				
3.18 - 3.81												
3.81 - 4.45												

M A P =  $\text{NH}_4\text{H}_2\text{PO}_4$  (monoammonium phosphate)  
 D A P =  $(\text{NH}_4)_2\text{HPO}_4$  (diammonium phosphate)

TABLE VII (Continued)

Distance (cm)	Plum Ridge						Lakeland II					
	M A P			D A P			M A P			D A P		
	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.
0.00 - 0.64	10556	73.49	48.29	8594	70.01	42.70	7608	61.35	34.12	14893	69.79	45.18
0.64 - 0.95	3033	21.11	33.07	2722	22.17	32.23	3829	30.88	40.92	5580	26.15	40.34
0.95 - 1.27	546	3.80	11.56	794	6.47	18.25	678	5.47	14.07	651	3.05	9.13
1.27 - 1.59	156	1.09	5.46	123	1.00	4.68	219	1.77	7.52	178	0.83	4.13
1.59 - 1.91	31	0.22	1.62	38	0.31	2.15	66	0.533	3.37	35	0.16	1.21
1.91 - 2.22	25	0.17		5	0.04					4	0.02	
2.22 - 2.54	11	0.08										
2.54 - 3.18	5	0.03										
3.18 - 3.81												
3.81 - 4.45												

M A P =  $\text{NH}_4\text{H}_2\text{PO}_4$  (monoammonium phosphate)  
 D A P =  $(\text{NH}_4)_2\text{HPO}_4$  (diammonium phosphate)

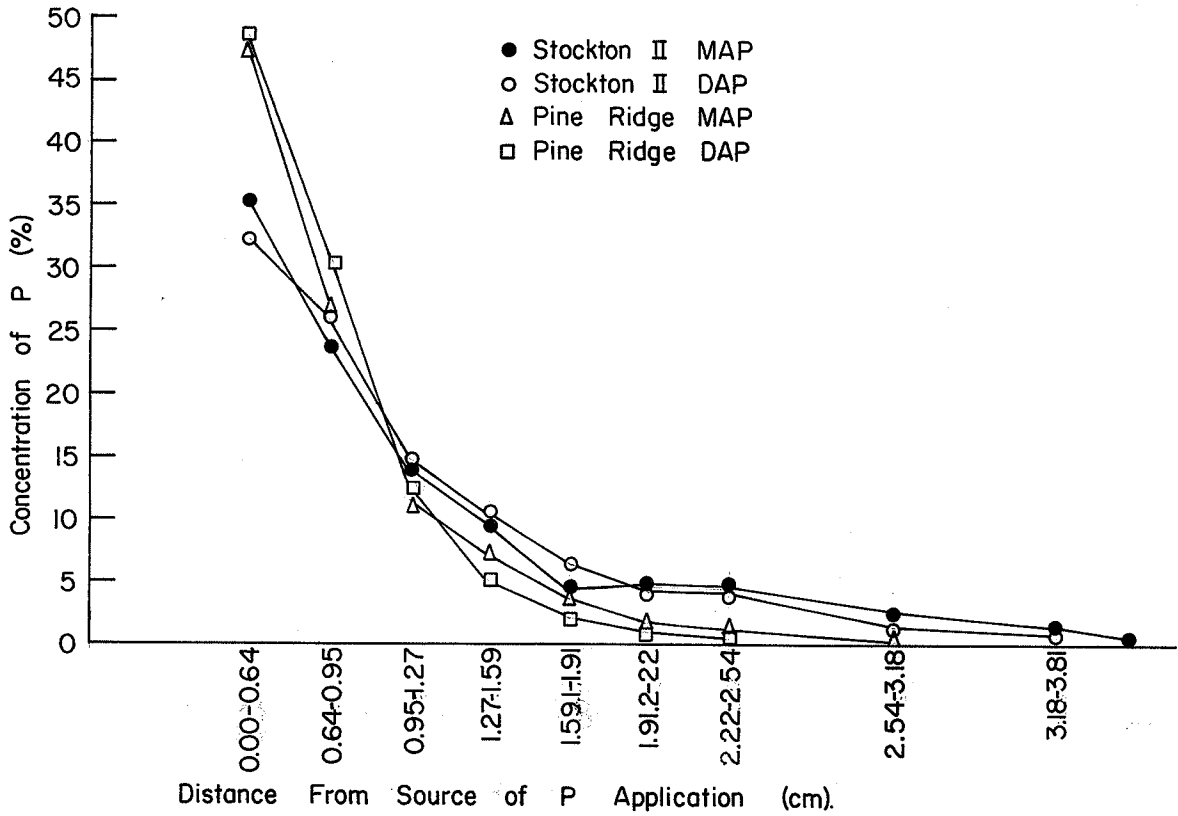


FIGURE 1 Concentration of Fertilizer Phosphorus at Various Distances from the Site of Phosphorus Application in the Stockton II and Pine Ridge Soils (%)

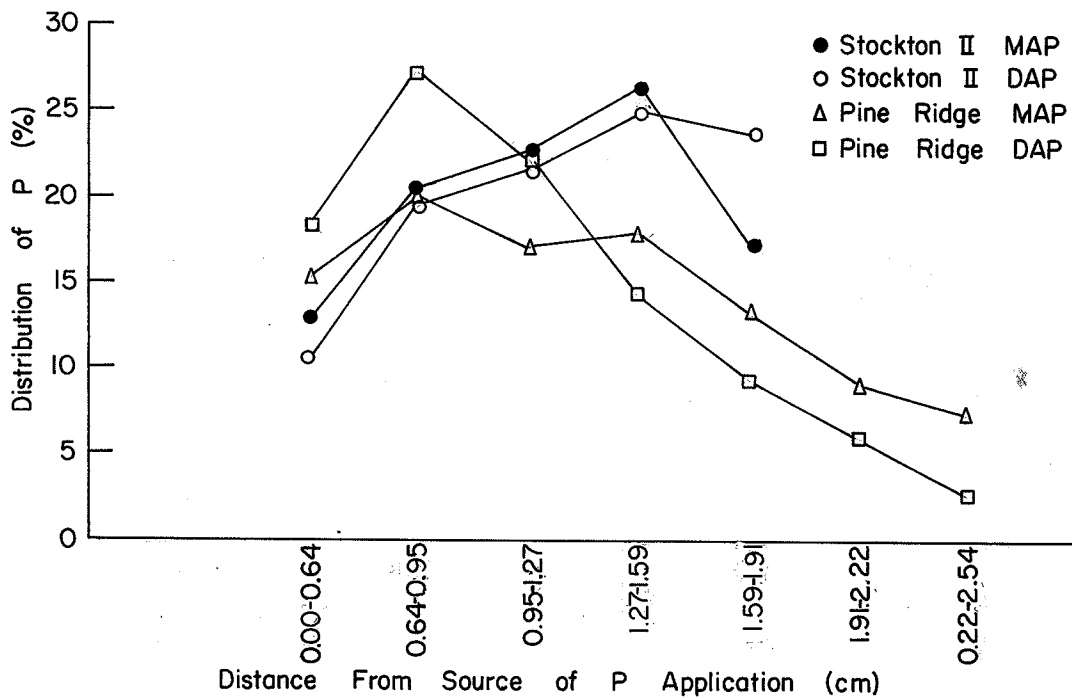


FIGURE 2 Distribution of Applied Fertilizer Phosphorus at Various Distances from the Site of Phosphorus Application in the Stockton II and Pine Ridge Soils (%)

soil was less than in the noncalcareous Stockton II soil. Phosphorus from monoammonium phosphate (MAP) and diammonium phosphate (DAP) moved to a distance of 2.5 and 2.2 cm. in the Pine Ridge soil, respectively. Although the concentration of phosphorus (expressed as a percentage) appear very similar for both soils and phosphorus sources, there were higher amounts of phosphorus present adjacent to the phosphorus pellet in the calcareous Pine Ridge soil than in the noncalcareous Stockton II soil (Figure 1). The movement of phosphorus did not appear to be affected by the form of phosphorus fertilizer added.

The fraction of applied phosphorus found at various distances from the site of application was very similar for the phosphorus sources added (Figure 2). However, a larger fraction of the applied phosphorus was found closer to the site of fertilizer application when diammonium phosphate (DAP) rather than monoammonium phosphate (MAP) was added to the Pine Ridge soil. Phosphorus from both sources distributed itself over a greater distance in the Pine Ridge soil than in the Stockton II soil. However, a larger fraction of the applied phosphorus was found closer to the site of phosphorus application in the calcareous Pine Ridge soil than in the noncalcareous Stockton II soil.

Phosphorus from monoammonium phosphate (MAP) and diammonium phosphate (DAP) moved to approximately 2.5 and 2.2 cm., respectively, in the Wellwood soil (Table VII). Phosphorus from monoammonium phosphate (MAP) and diammonium phosphate (DAP) moved to about 1.6 cm. in the Lakeland II soil. The concentration of phosphorus immediately adjacent to the fertilizer pellet was higher in both soils when diammonium phosphate (DAP) rather than monoammonium phosphate (MAP) was applied (Figure 3). This observation is also evident from the data in Figure 4 where the fraction of applied

FIGURE 3 Concentration of Fertilizer Phosphorus at Various Distances from the Site of Phosphorus Application in the Wellwood and Lakeland II Soils (%)

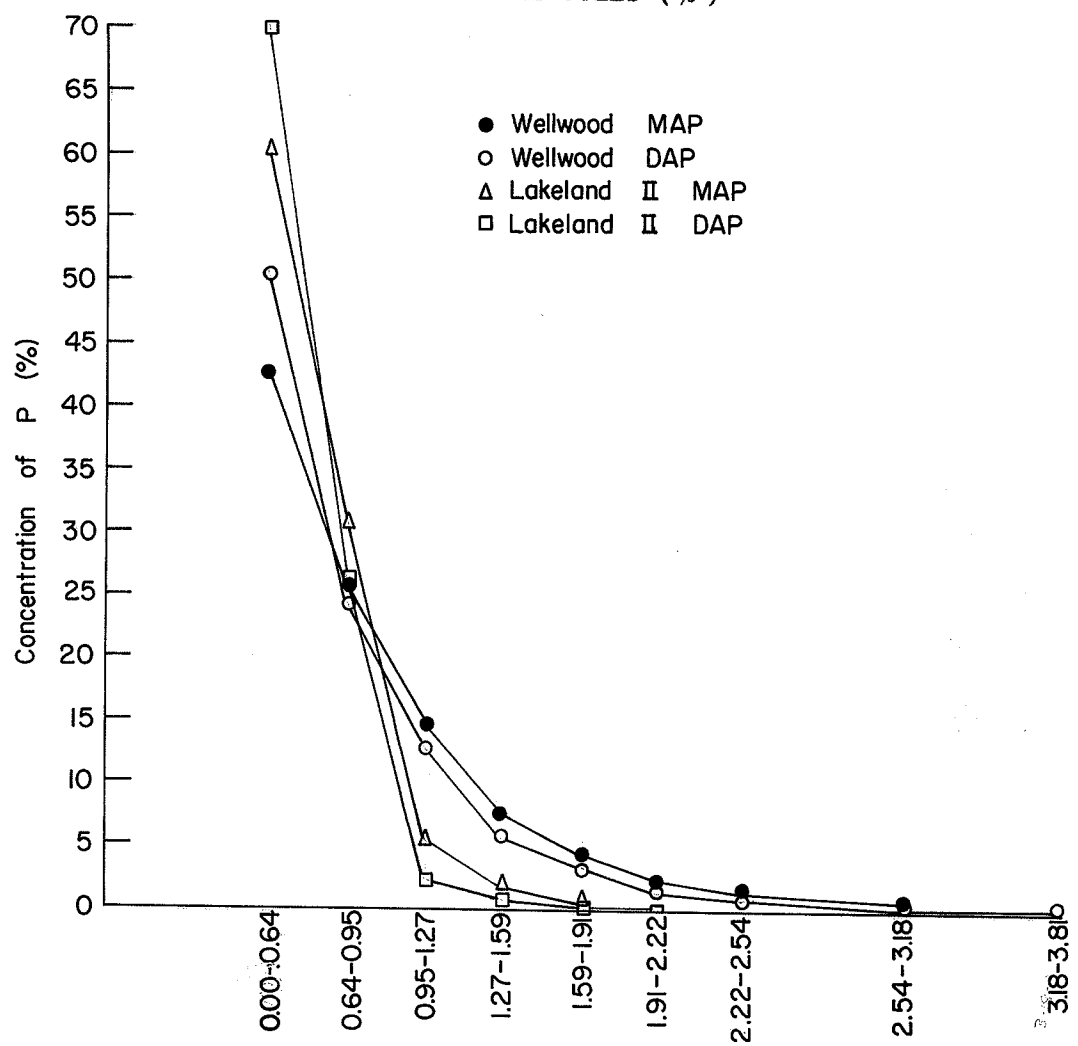
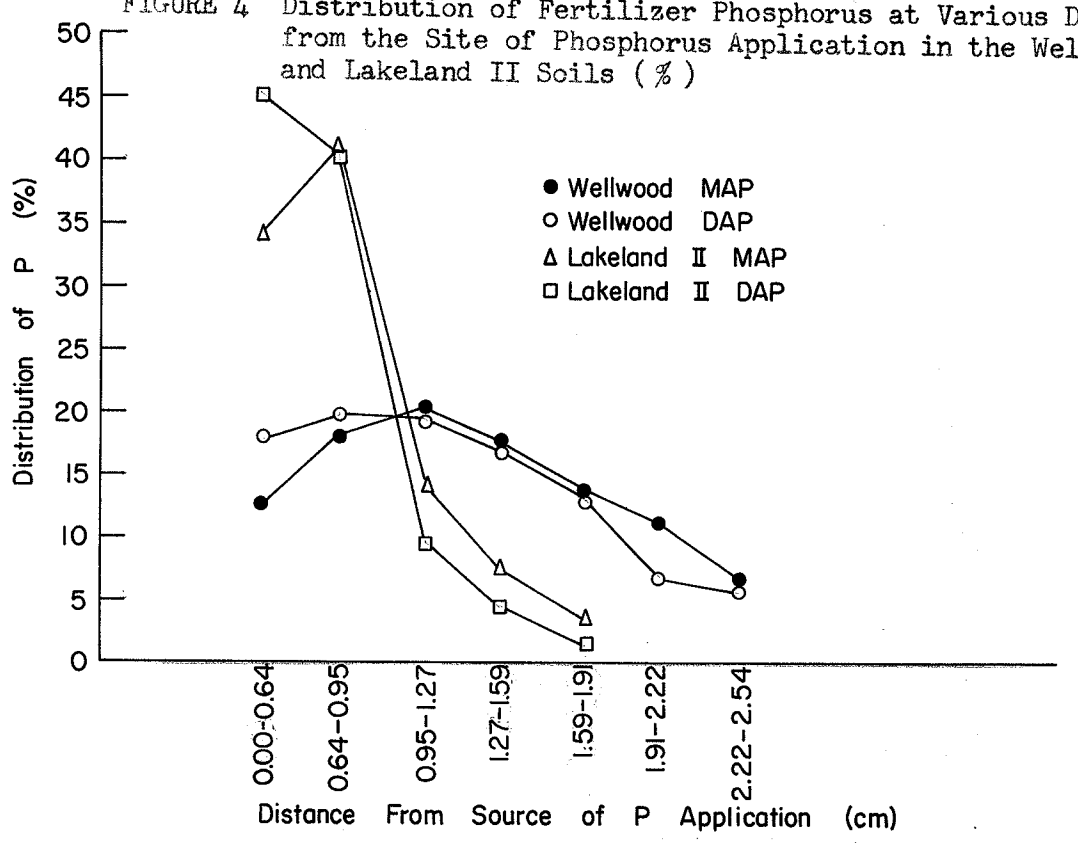


FIGURE 4 Distribution of Fertilizer Phosphorus at Various Distances from the Site of Phosphorus Application in the Wellwood and Lakeland II Soils (%)



phosphorus immediately adjacent to the phosphorus pellet is higher when diammonium phosphate (DAP) rather than monoammonium phosphate (MAP) is applied. The concentration of phosphorus immediately adjacent to the phosphorus pellet decreases in the order Lakeland II diammonium phosphate (DAP), Lakeland II monoammonium phosphate (MAP), Wellwood diammonium phosphate (DAP) and Wellwood monoammonium phosphate (MAP). The concentration of phosphorus and fraction of added phosphorus found in the reaction zone of the phosphorus pellet, both indicate that monoammonium phosphate (MAP) or diammonium phosphate (DAP) moved more readily in the noncalcareous Wellwood soil than in the calcareous Lakeland II soil.

Phosphorus from both sources moved to a distance of about 2.5 and 1.6 cm. in the Stockton I and Plum Ridge soils, respectively (Table VII). The concentration of phosphorus and fraction of applied phosphorus found in the phosphorus fertilizer reaction zone were very similar when monoammonium phosphate (MAP) and diammonium phosphate (DAP) were used (Figures 5 and 6). This indicates that phosphorus from diammonium phosphate (DAP) moved as readily as phosphorus from monoammonium phosphate (MAP) in these two soils. The concentration of phosphorus and fraction of added phosphorus were higher immediately adjacent to the monoammonium phosphate (MAP) and diammonium phosphate (DAP) pellets in the calcareous Plum Ridge soil than in the noncalcareous Stockton I soil. This again indicates that the presence of carbonates in a soil restricts the movement of phosphorus in a soil.

Phosphorus from monoammonium phosphate (MAP) and diammonium phosphate (DAP) moved to about the 1.9 cm. distance in the Firdale soil (Table VII). Phosphorus from monoammonium phosphate (MAP) and diammonium phosphate (DAP) moved to the 1.6 and 1.3 cm. distances, respectively, in



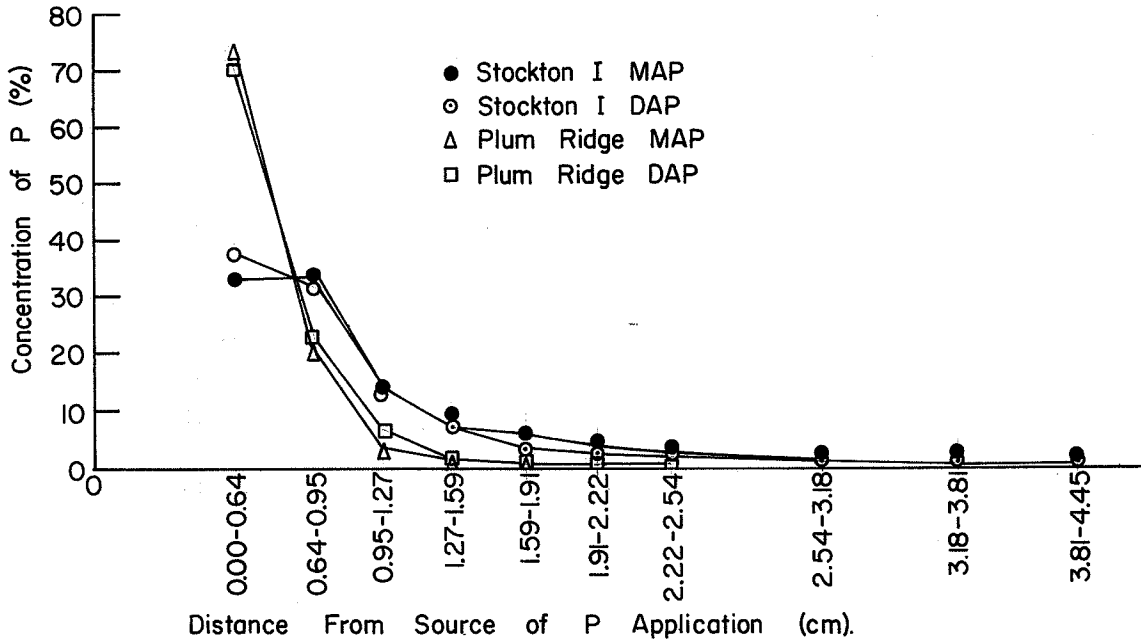


FIGURE 5 Concentration of Fertilizer Phosphorus at Various Distances from the Site of Phosphorus Application in the Stockton I and Plum Ridge Soils (%)

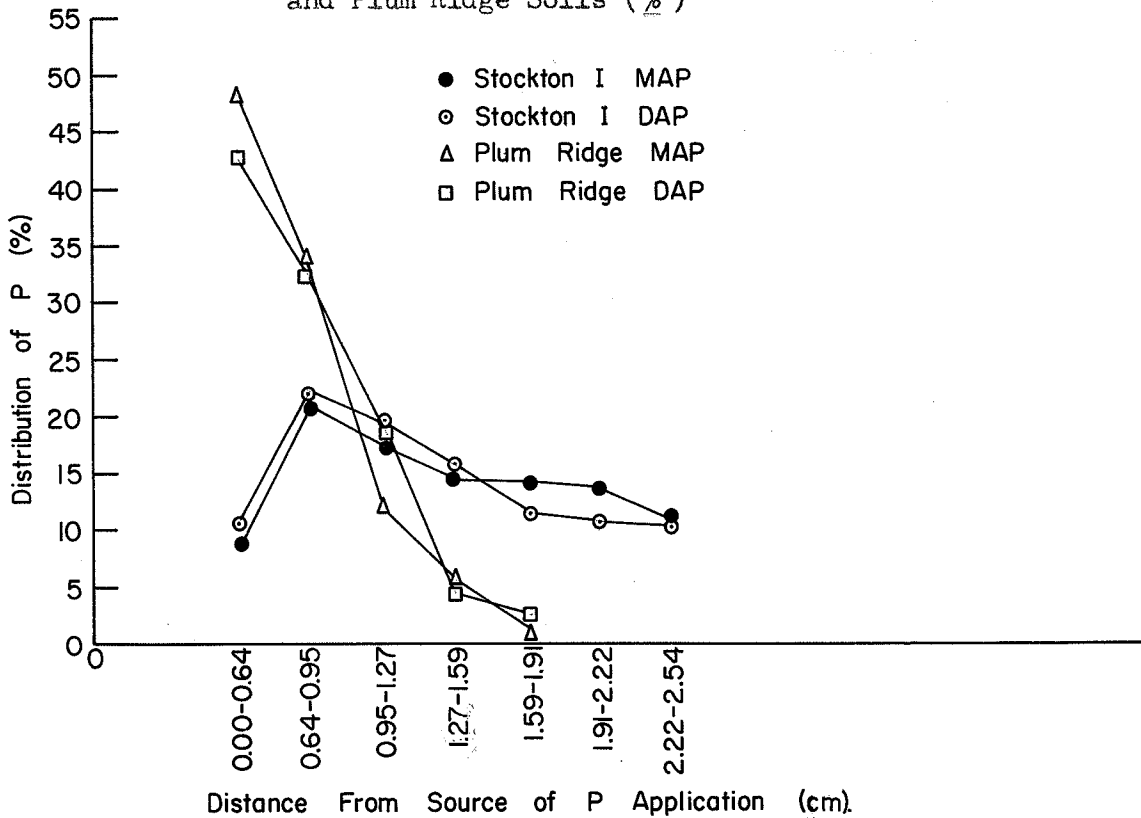


FIGURE 6 Distribution of Fertilizer Phosphorus at Various Distances from the Site of Phosphorus Application in the Stockton I and Plum Ridge Soils (%)

the Lakeland I soil. The concentration of phosphorus and fraction of phosphorus at various distances from the monoammonium phosphate (MAP) and diammonium phosphate (DAP) pellets were very similar in the Firdale soil, indicating that movement of phosphorus from these two phosphorus fertilizers were the same in this soil (Figures 7 and 8). The phosphorus from monoammonium phosphate (MAP) however, moved more readily than phosphorus from diammonium phosphate (DAP) in the calcareous Lakeland soil. The concentration of phosphorus increased slightly then decreased with distance when monoammonium phosphate (MAP) was added to the Lakeland I soil. This increase in phosphorus concentration, not evident in other soils, could be due to the formation of Liesegang rings observed by other workers (3, 41, 44). Phosphorus from diammonium phosphate (DAP) moved more readily in the noncalcareous Firdale soils than in the calcareous Lakeland I soil. Phosphorus from monoammonium phosphate (MAP) moved as readily or more readily in the calcareous soil than in the noncalcareous soil.

Phosphorus from monoammonium phosphate (MAP) and diammonium phosphate (DAP) applied to the St. Norbert soil moved approximately 2.5 and 2.2 cm., respectively (Table VII). Phosphorus from monoammonium phosphate (MAP) and diammonium phosphate (DAP) applied to the Tarno soil moved approximately 2.2 and 1.9 cm., respectively. The movement of phosphorus from both monoammonium phosphate (MAP) and diammonium phosphate (DAP) was greater in the noncalcareous St. Norbert soil than in the calcareous Tarno soil (Figures 9 and 10).

Several conclusions can be drawn from the results obtained in this experiment. Phosphorus from monoammonium phosphate (MAP) moved more readily than phosphorus from diammonium phosphate (DAP). This was more

FIGURE 7 Concentration of Fertilizer Phosphorus at Various Distances from the Site of Phosphorus Application in the Firdale and Lakeland I Soils (%)

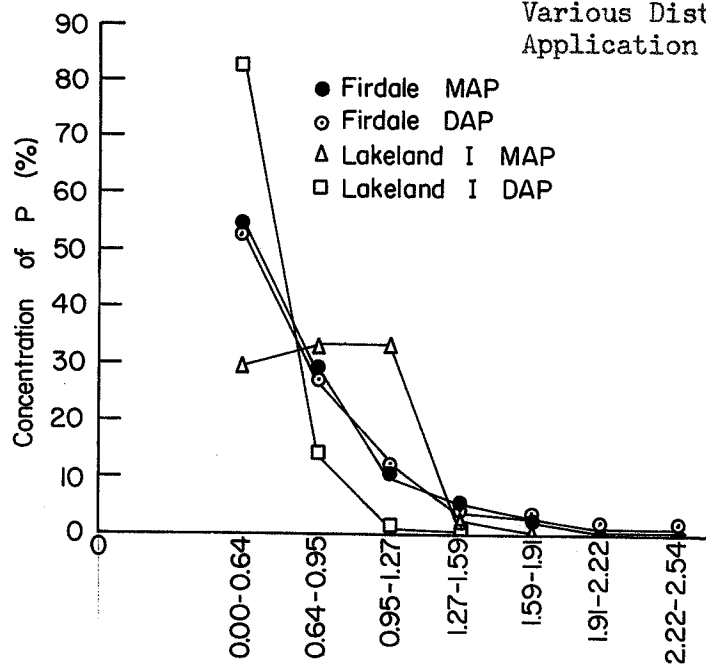
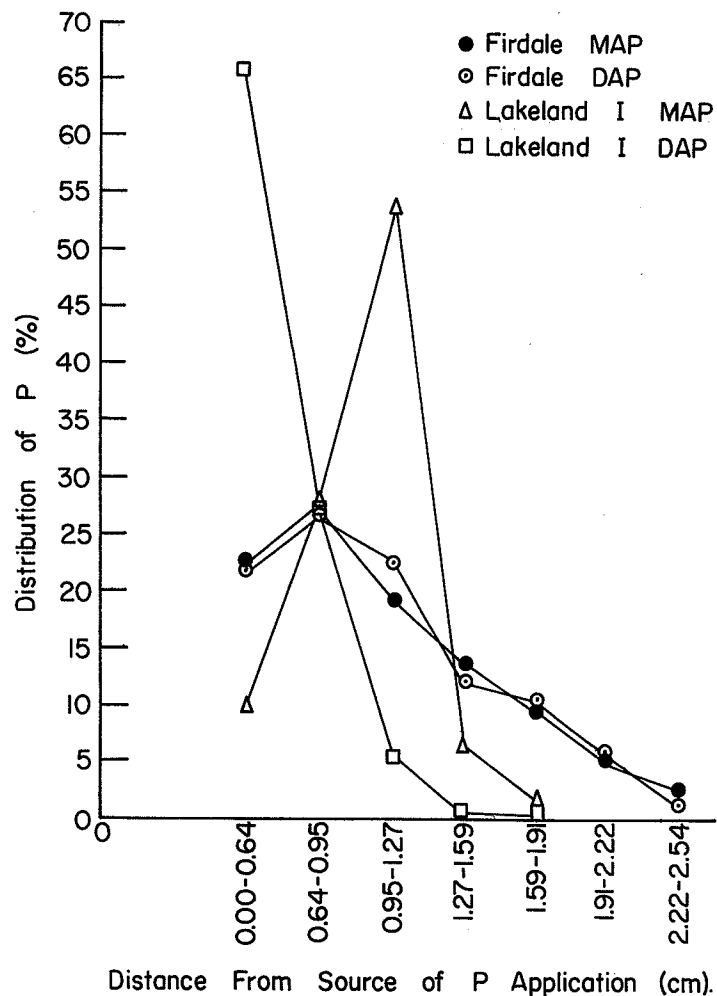


FIGURE 8 Distribution of Fertilizer Phosphorus at Various Distances from the Site of Phosphorus Application in the Firdale and Lakeland I Soils (%)



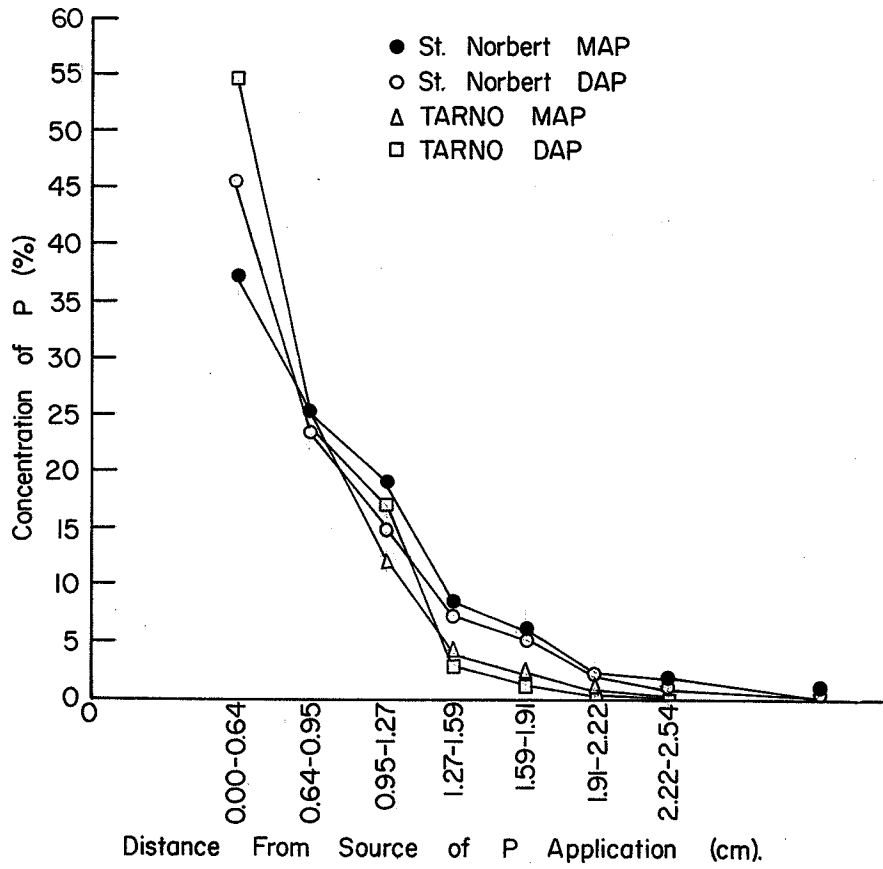


FIGURE 9 Concentration of Fertilizer Phosphorus at Various Distances from the Site of Phosphorus Application in the St. Norbert and Tarno Soils (%)

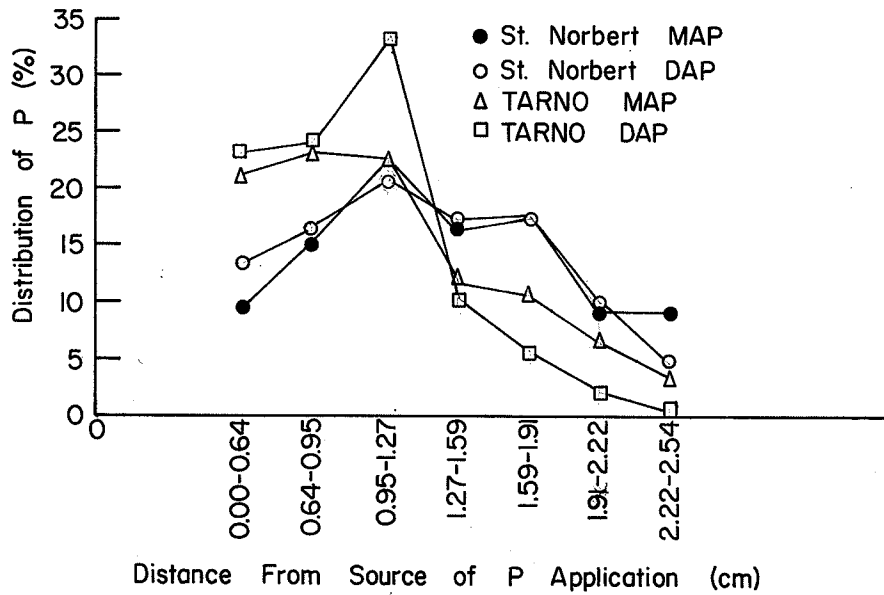


FIGURE 10 Distribution of Fertilizer Phosphorus at Various Distances from the Site of Phosphorus Application in the St. Norbert and Tarno Soils (%)

evident in the calcareous soils than in the noncalcareous soils. It is possible that the addition of diammonium phosphate (DAP) resulted in the formation of less soluble phosphorus compounds than when monoammonium phosphate (MAP) was added (23, 28). If the solubility of the added phosphorus was less when diammonium phosphate (DAP) was the source, then a decrease in phosphorus movement would be expected. Racz and Soper (40), however, have shown that both diammonium phosphate (DAP) and monoammonium phosphate (MAP) added as a pellet to Manitoba soils, form the same reaction product, but the pH near the pellet was slightly higher when diammonium phosphate (DAP) was added. Since the pH near the diammonium phosphate (DAP) pellet would be higher than near the monoammonium phosphate (MAP) pellet, less phosphorus would be in the soil solution. This would reduce the movement of phosphorus.

The movement of phosphorus in noncalcareous soils was much greater than in the calcareous soils. This indicates that the presence of carbonates in a soil reduces the movement of phosphorus in soils. The movement of phosphorus from monoammonium phosphate (MAP) and diammonium phosphate (DAP) was not affected to any appreciable extent by soil texture. A greater movement of phosphorus in coarse-textured soils was recorded when phosphorus was added to the surface of these soils and leached with water. Movement of phosphorus when placed as pellets in soils, as was done in this experiment, however, was as great in heavy-textured soils as in light-textured soils. The irregularities observed in some of the percent concentration curves may be due to periodic precipitation of insoluble phosphorus compounds at various distances from the pellet. Bouldin and Black (3) have found similar irregularities and suggested that they represent Liesegang rings due to periodic precipitation of  $\text{CaH}_2\text{P}_2\text{O}_7$  from

solutions supersaturated with respect to  $\text{Ca}^{++}$  and  $\text{HPO}_4^{--}$ .

#### THE EFFECT OF SALTS ON THE MOVEMENT OF ADDED PHOSPHORUS

It is a practice to add salts containing elements such as nitrogen and potassium along with a phosphorus fertilizer when fertilizing crops. Since these salts may affect the movement of the applied phosphorus, the effect of adding  $\text{NH}_4\text{Cl}$ ,  $\text{NaCl}$ ,  $\text{KCl}$ ,  $\text{MgCl}_2$  and  $\text{CaCl}_2$  on phosphorus movement was investigated.

Two medium-textured soils, calcareous Lakeland I and noncalcareous Firdale, were selected for this study. 0.0134 equivalents of granular  $\text{NH}_4\text{Cl}$ ,  $\text{NaCl}$ ,  $\text{KCl}$ ,  $\text{MgCl}_2$  and  $\text{CaCl}_2$  were mixed with  $\text{P}^{32}$  "tagged" monoammonium phosphate (MAP), added to soils as pellets and incubated for three weeks. The movement of phosphorus from monoammonium phosphate (MAP) was slightly reduced in both the calcareous and noncalcareous soils by the addition of salts with the fertilizer (Table VIII and Figures 11 to 14). This trend becomes evident when one considers the percent concentration or percent distribution of phosphorus at a distance of about 2 cm. from the site of phosphorus application. In all instances, the percent concentration and percent distribution of phosphorus at this distance are highest for the soil where only monoammonium phosphate was added.

The calcium, sodium and ammonium salts reduced phosphorus movement to a slightly greater extent than did the magnesium or potassium salts in the Firdale soil. This trend was not evident when the salts were added to the calcareous Lakeland I soil. The effect of these salts on phosphorus movement was very slight and probably of no significance in influencing phosphorus uptake by plants as a result of changing the distribution of phosphorus surrounding a phosphorus fertilizer pellet. The movement of phosphorus was greater in the noncalcareous Firdale soil than in the

TABLE VIII EFFECT OF SALTS ON THE MOVEMENT OF PHOSPHORUS FROM MONOAMMONIUM PHOSPHATE.

Distance (cm)	FIRDALE CLAY LOAM																	
	Check			NH <sub>4</sub> Cl			NaCl			KCl			MgCl <sub>2</sub>			CaCl <sub>2</sub>		
	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.
0.00-0.64	3306	42.90	11.66	3131	42.70	14.48	4953	49.98	18.10	1574	29.66	7.50	3411	40.18	11.95	5122	58.15	21.00
0.64-0.95	1838	23.85	15.45	1791	24.43	19.74	2810	28.36	24.47	1728	32.57	19.62	2354	27.73	19.65	1395	15.84	13.63
0.95-1.27	1122	14.56	18.31	1767	24.10	37.80	1142	11.52	19.31	968	18.24	21.34	1475	17.38	23.89	1329	15.09	25.20
1.27-1.59	696	9.03	18.79	367	5.01	12.99	544	5.49	15.21	597	11.25	21.77	695	8.19	18.63	528	5.99	16.56
1.59-1.91	400	5.19	16.06	184	2.51	9.68	289	2.92	12.02	186	3.51	10.09	341	4.02	13.59	278	3.16	12.97
1.91-2.22	230	2.98	12.93	72	0.98	5.31	122	1.23	7.10	157	2.96	11.92	162	1.91	9.04	135	1.53	8.82
2.22-2.54	91	1.18	6.79	20	0.27		49	0.49	3.78	77	1.45	7.76	44	0.52	3.26	21	0.24	1.82
2.54-3.18	13	0.17								19	0.36		7	0.08				
3.18-3.81	6	0.08																
3.81-4.45	5	0.06																

TABLE VIII (Continued)

Distance (cm)	LAKELAND I SILT LOAM																	
	Check			NH <sub>4</sub> Cl			NaCl			KCl			MgCl <sub>2</sub>			CaCl <sub>2</sub>		
	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.
0.00-0.64	12905	69.09	35.07	8324	51.44	25.11	15324	75.84	47.61	14890	72.78	43.76	9887	66.01	36.01	13677	64.97	38.06
0.64-0.95	3161	16.92	20.47	6242	38.58	44.88	3330	16.48	24.66	3724	18.20	26.08	3696	24.67	32.08	5940	28.22	39.39
0.95-1.27	1783	9.55	22.42	1133	7.00	15.81	1055	5.22	15.16	1405	6.87	19.10	896	5.98	15.10	1088	5.17	14.01
1.27-1.59	495	2.65	10.30	277	1.71	6.40	447	2.21	10.63	342	1.67	77.69	302	2.02	8.42	252	1.20	5.37
1.59-1.91	201	1.08	6.22	160	0.99	5.50	42	0.21	1.49	88	0.43	2.94	127	0.85	5.27	76	0.36	2.41
1.91-2.22	97	0.52	4.20	36	0.22	1.73	9	0.04	0.44	9	0.04	0.42	54	0.36	3.13	17	0.08	0.75
2.22-2.54	23	0.12	1.32	9	0.06	0.58							17	0.11				
2.54-3.18	7	0.04																
3.18-3.81	6	0.03																
3.81-4.45																		



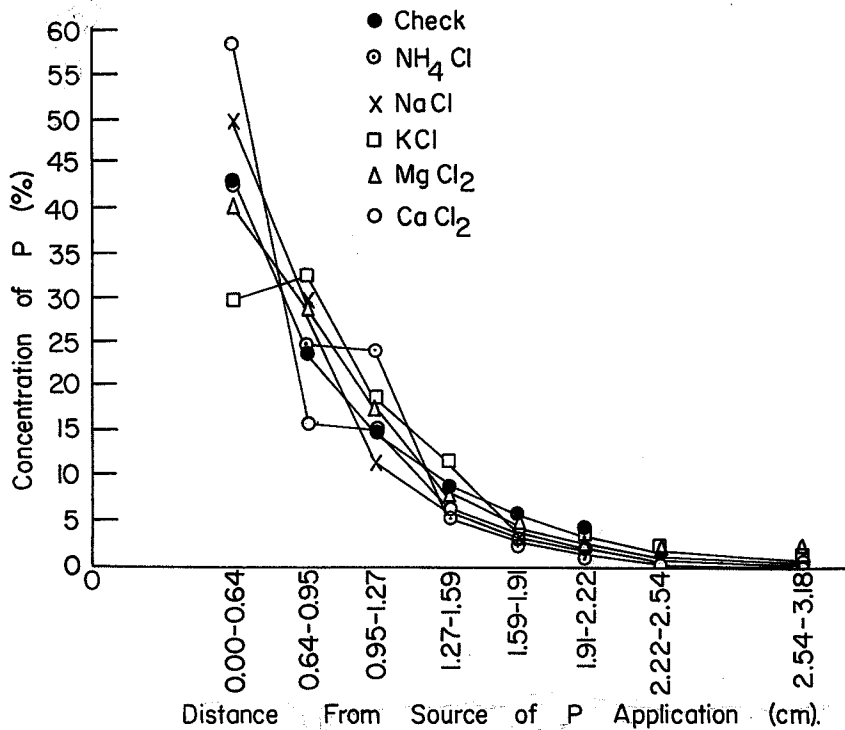


FIGURE 11 The Effect of Various Salts on the Concentration of Fertilizer Phosphorus at Various Distances from the Site of Phosphorus Application in the Firdale Soil.

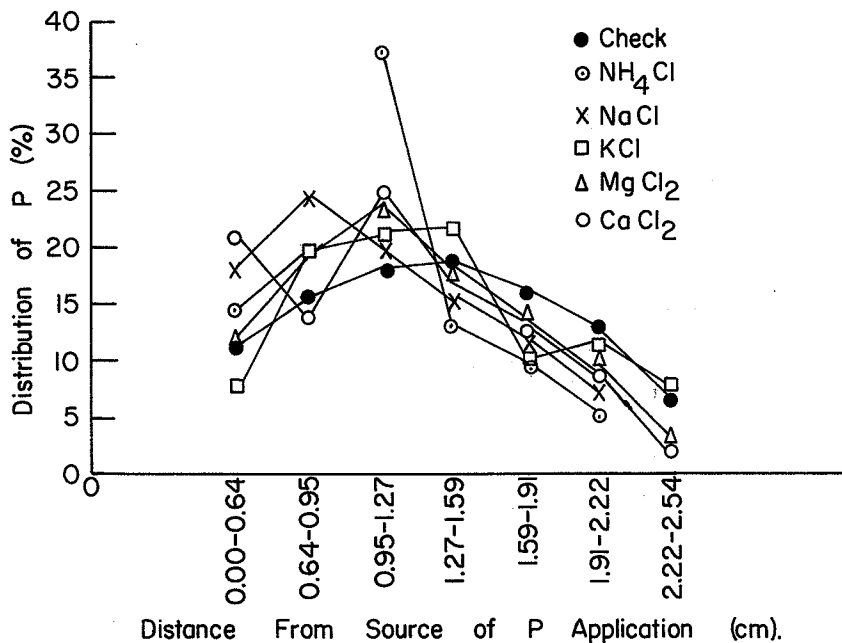


FIGURE 12 The Effect of Various Salts on the Distribution of Fertilizer Phosphorus at Various Distances from the Site of Phosphorus Application in the Firdale Soil.

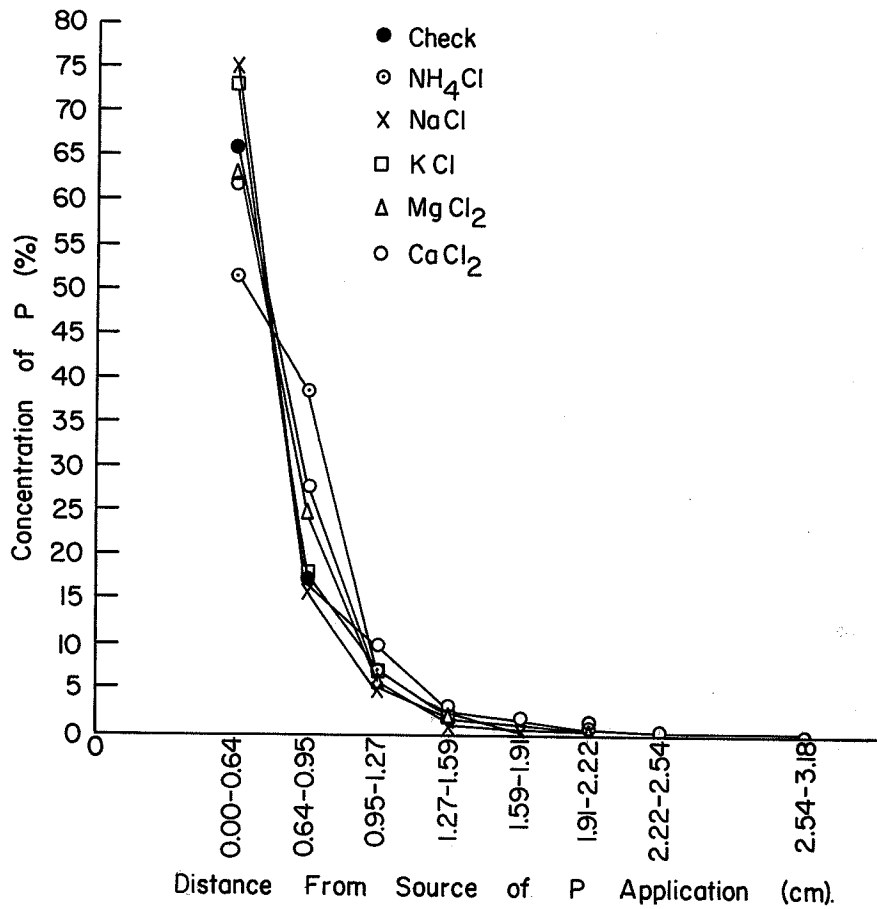


FIGURE 13 The Effect of Various Salts on the Concentration of Fertilizer Phosphorus at Various Distances from the Site of Phosphorus Application in the Lakeland I Soil.

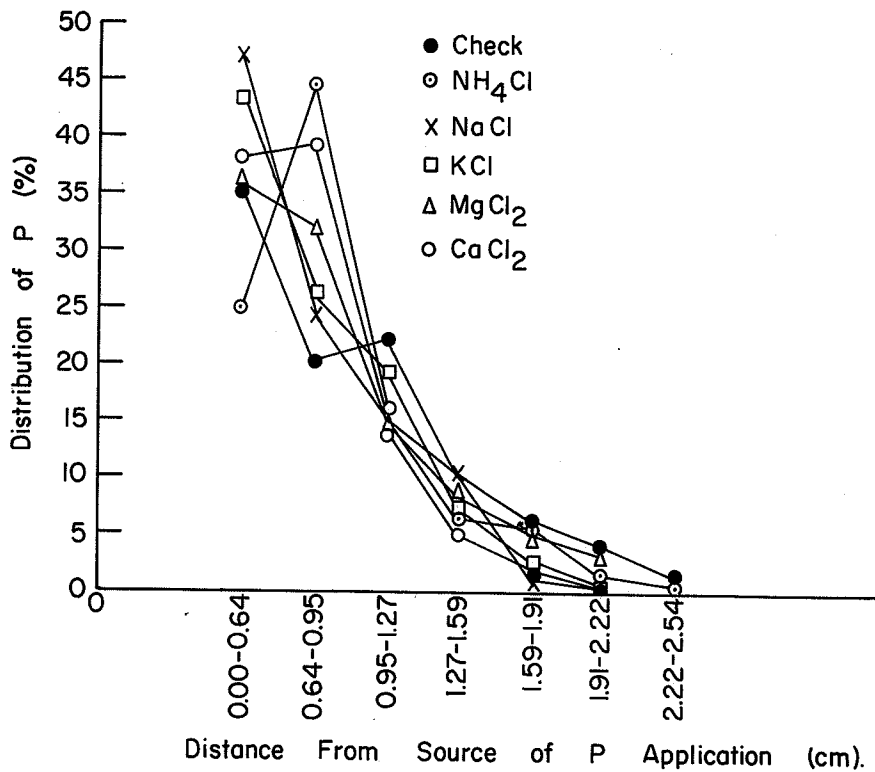


FIGURE 14 The Effect of Various Salts on the Distribution of Fertilizer Phosphorus at Various Distances from the Site of Phosphorus Application in the Lakeland I Soil.

calcareous Lakeland I soil. This result agrees with those obtained in other experiments.

It is probable that the effect of salts on the movement of phosphorus depend on a variety of factors. The amount of salt added, the valency of the cation, the ability of added cation to exchange with cations in the soil, the influence of the salt on the reaction product formed, the effect of the salt on the pH of the soil solution, as well as other factors may influence the effect of added salts on phosphorus movement. One or more of these factors may cause different distribution and concentration patterns. However, the effects of the above factors seem to retard phosphorus movement in both calcareous and noncalcareous soils. Heslep and Black (14) have found that there was a reduction in movement of phosphorus when nitrogenous and potassium salts were added. Bouldin et al. (1) suggested that a variety of reactions, dependent upon the salt added, are possible when nonphosphatic salts are mixed with monocalcium phosphate. Henderson and Jones (13) found that  $(\text{NH}_4)_2 \text{SO}_4$  had no direct effect on the distribution of phosphorus but KCl increased movement of phosphorus. Midgley (33) found that potassium and ammonium salts retarded the movement of phosphorus while addition of  $\text{NaNO}_3$  increased it. Thus, the effect of salts on phosphorus movement appear to be complex and requires further study.

#### THE MOVEMENT OF PHOSPHORUS AS AFFECTED BY THE CATION HELD ON SOIL EXCHANGE SITES

Soils contain cations such as Ca, Mg, Na, K and  $\text{NH}_4$  which are either held on the surfaces of soil colloids or present in mineral form. Since the cation held on the exchange complex of soils influences the reaction product that is formed when phosphorus is added to soils (31), it is

probable that the cation predominating a soil system may influence phosphorus movement as well.

This experiment was devised to study the effect of various exchangeable cations on the movement of applied phosphorus. Two soils, Firdale and Lakeland I, were saturated with ammonium, potassium, sodium, magnesium and calcium ions. Four hundred grams of soil were shaken in one liter of 1N solutions of  $\text{NH}_4\text{Cl}$ ,  $\text{KCl}$ ,  $\text{NaCl}$ ,  $\text{MgCl}_2$  and  $\text{CaCl}_2$  for one day. The solutions were decanted and the process of adding the salt solutions, shaking and decantation repeated five times. The samples were then washed free of chlorides using ethyl alcohol and air-dried. 0.1000 gram of  $\text{P}^{32}$  "tagged" monoammonium phosphate was added to each soil as a pellet and incubated for three weeks.

The results of this experiment are presented in Table IX and Figures 15 to 18. The concentration of phosphorus remaining near the pellet site decreased in the order  $\text{Ca}^{++}$ , Check,  $\text{Mg}^{++}$ ,  $\text{K}^+$ ,  $\text{NH}_4^+$  for the Firdale soil (Figure 15). Saturation of the Firdale soil with calcium resulted in approximately the same distribution of phosphorus as in the untreated soil. This would be expected as the Firdale soil had a high exchangeable calcium content prior to treatment. The fraction of added phosphorus found at various distances from the phosphorus pellet also indicates that phosphorus movement was much greater when the soils were treated with Na, K or  $\text{NH}_4$  than when treated with Ca or Mg or not treated (Figure 17). The greater movement of phosphorus observed for the soils treated with Na, K or  $\text{NH}_4$  is to be expected. Sodium, potassium or ammonium would not form insoluble reaction products with the added phosphorus and thus a greater movement of phosphorus would result.

A greater movement of phosphorus occurred in the Mg saturated soil

TABLE IX EFFECT OF EXCHANGEABLE CATION ON THE MOVEMENT OF PHOSPHORUS FROM MONOAMMONIUM PHOSPHATE

FIRDALE CLAY LOAM																		
Distance (cm)	Check			NH <sub>4</sub>			Na			K			Mg			Ca		
	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.
0.00-0.64	2036	44.09	17.57	409	18.87	5.66	713	25.80	4.69	503	21.76	6.96	1811	33.22	7.03	1311	45.76	18.33
0.64-0.95	917	19.86	18.85	337	15.54	11.10	477	17.26	7.47	374	16.18	12.35	1201	22.03	11.12	678	23.66	22.59
0.95-1.27	569	12.32	22.71	325	14.99	20.79	402	14.54	12.22	257	11.12	16.46	723	13.26	12.99	292	10.19	18.88
1.27-1.59	363	7.86	23.97	232	10.70	24.54	314	11.36	15.80	258	11.16	27.35	559	10.25	16.62	145	5.06	15.52
1.59-1.91	172	3.72	16.89	241	11.12	37.91	231	8.36	17.28	234	10.12	36.88	383	7.03	16.93	85	3.00	13.52
1.91-2.22	139	3.01		208	9.59		206	7.45	21.57	206	8.91		304	5.58	18.81	50	1.75	11.15
2.22-2.54	126	2.73		161	7.43		151	5.46	20.98	190	8.22		201	3.69	16.50	85	3.00	
2.54-3.18	109	2.36		87	4.01		91	3.29		143	6.19		114	2.09		95	3.32	
3.18-3.81	78	1.69		95	4.38		95	3.44		82	3.55		84	1.54		74	2.58	
3.81-4.45	109	2.36		73	3.37		84	3.04		65	2.81		71	1.30		50	1.75	

TABLE IX (Continued)

Distance (cm)	LAKELAND I SILT LOAM																	
	Check			NH <sub>4</sub>			Na			K			Mg			Ca		
	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.
0.00-0.64	8658	73.79	45.63	3851	59.77	28.11	791	26.54	8.39	1859	49.76	17.54	689	43.94	21.51	5816	76.04	55.35
0.64-0.95	2072	17.66	26.03	1285	19.94	22.35	580	19.46	14.67	691	18.50	15.54	198	12.63	14.74	1148	15.01	26.03
0.95-1.27	386	3.29	9.41	532	8.26	17.96	373	12.52	18.31	268	7.17	11.70	85	5.42	12.28	1118	1.54	5.19
1.27-1.59	162	1.38	6.54	229	3.55	12.79	368	12.34	29.89	228	6.10	16.47	92	5.87	21.97	89	1.16	6.48
1.59-1.91	117	1.00	7.02	117	1.82	9.72	238	7.99	28.75	190	5.09	20.41	83	5.29	29.50	664	0.84	6.94
1.91-2.22	64	0.55	5.37	78	1.21	9.07	181	6.07		122	3.27	18.34	84	5.36		89	1.16	
2.22-2.54	73	0.62		91	1.41		183	6.14		102	2.73		86	5.48		88	1.15	
2.54-3.18	68	0.58		94	1.46		125	4.19		105	2.81		85	5.42		59	0.77	
3.18-3.81	69	0.59		98	1.52		71	2.38		87	2.33		90	5.74		90	1.18	
3.81-4.45	65	0.55		68	1.06		70	2.35		84	2.25		76	4.85		88	1.15	

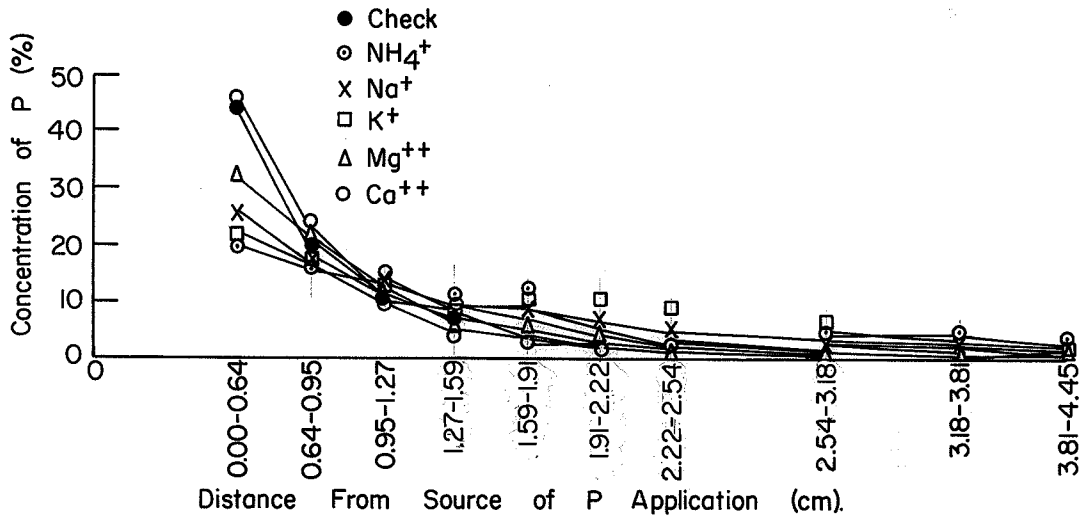


FIGURE 15 The Effect of Exchangeable Cation on the Concentration of Fertilizer Phosphorus at Various Distances from the Site of Phosphorus Application in the Firdale Soil.

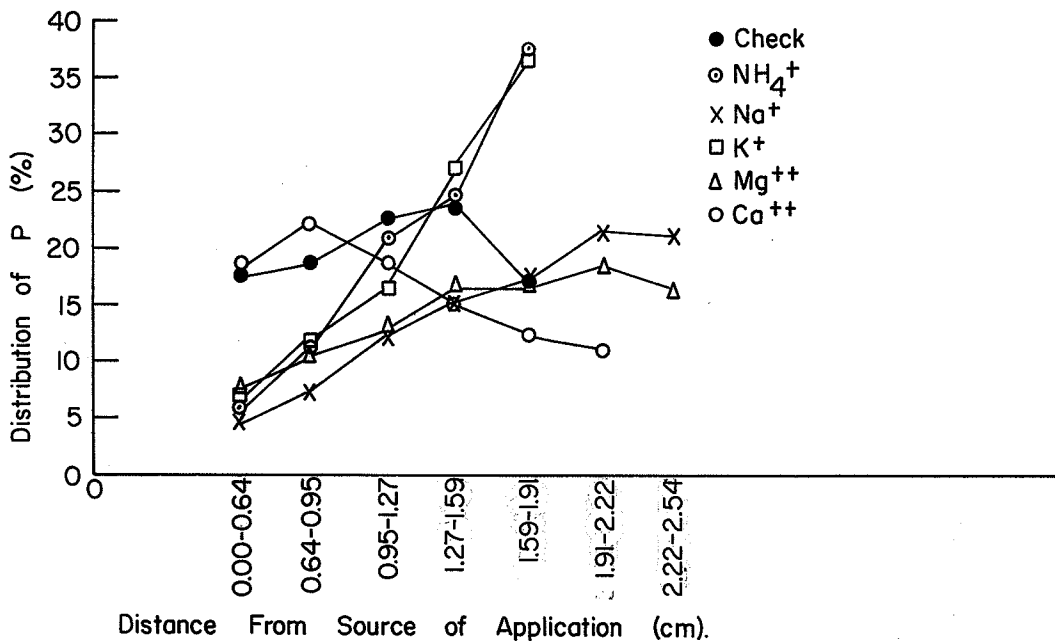


FIGURE 16 The Effect of Exchangeable Cation on the Distribution of Fertilizer Phosphorus at Various Distances from the Site of Phosphorus Application in the Firdale Soil.

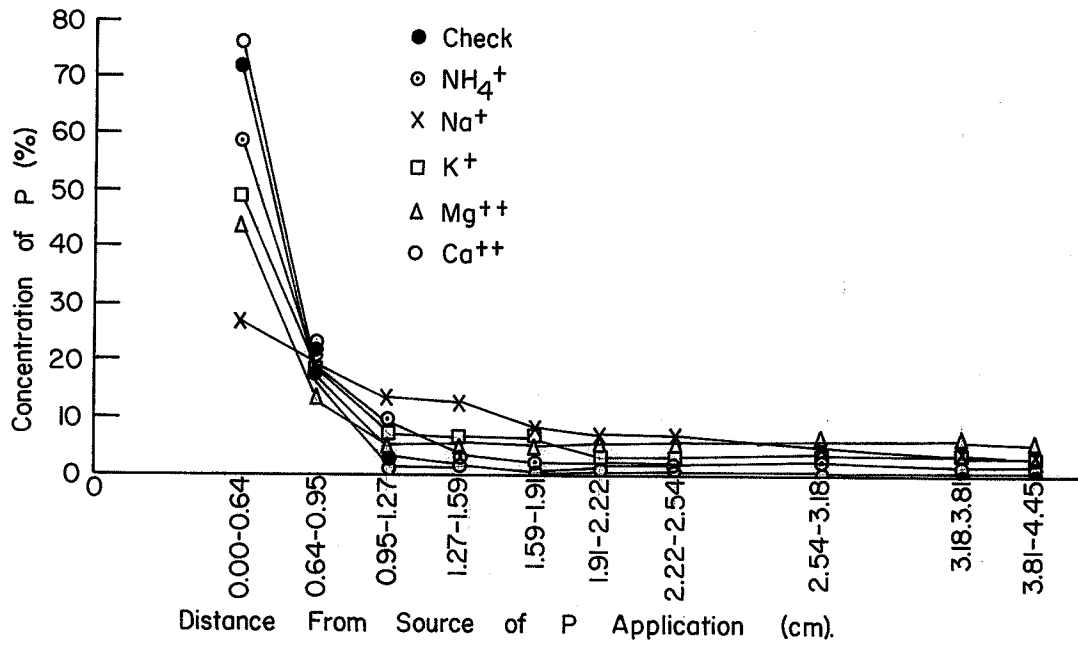


FIGURE 17 The Effect of Exchangeable Cation on the Concentration of Fertilizer Phosphorus at Various Distances from the Site of Phosphorus Application in the Lakeland I Soil

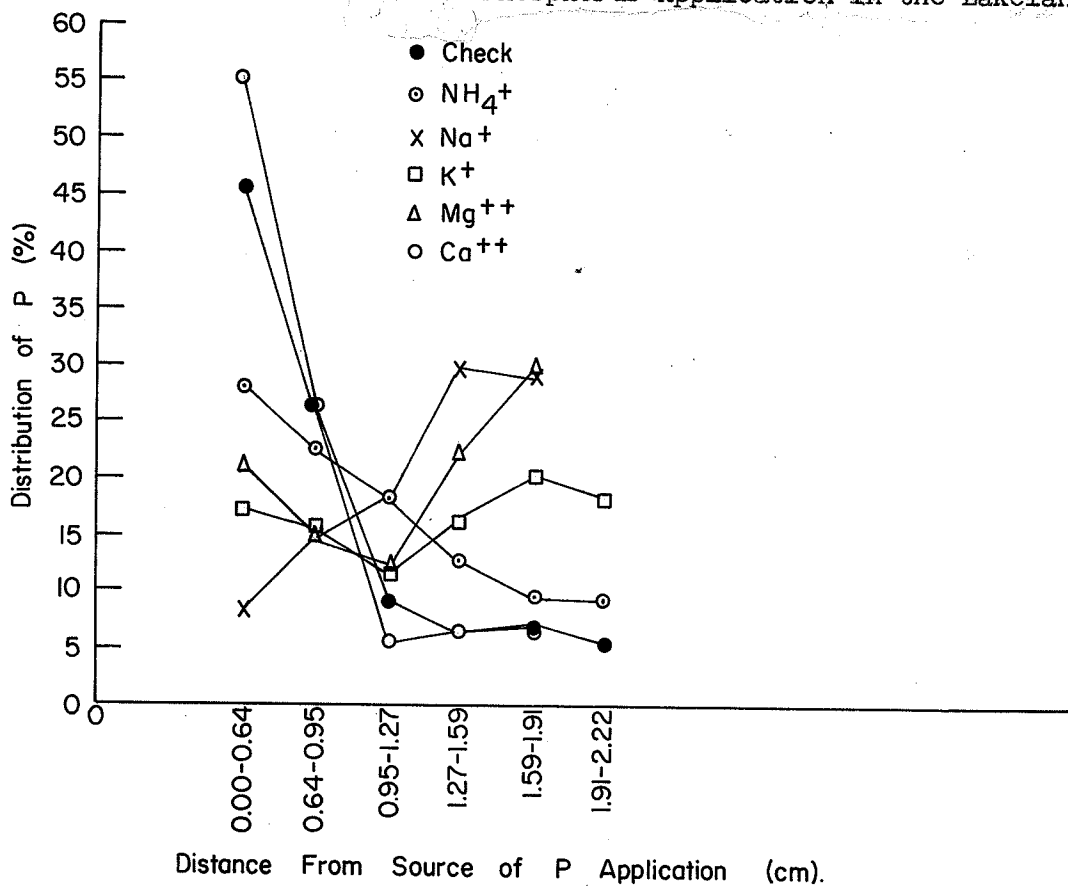


FIGURE 18 The Effect of Exchangeable Cation on the Distribution of Fertilizer Phosphorus at Various Distances from the Site of Phosphorus Application in the Lakeland I Soil.



than in the Ca saturated and untreated soil. This is probably due to the formation of  $\text{MgHPO}_4 \cdot 3\text{H}_2\text{O}$  in the Mg saturated soil and  $\text{CaHPO}_4 \cdot 2\text{H}_2\text{O}$  in the untreated and calcium saturated soil (41). Since  $\text{MgHPO}_4 \cdot 3\text{H}_2\text{O}$  is more soluble than  $\text{CaHPO}_4 \cdot 2\text{H}_2\text{O}$  a greater movement of phosphorus would be expected in the Mg saturated soil (41). The results obtained when the calcareous Lakeland I soil was saturated with various cations are shown in Figures 17 and 18. The results obtained are similar to that obtained for the Firdale soil. Saturation of the Lakeland soil with Na,  $\text{NH}_4$ , K or Mg increased the movement of phosphorus while saturation of the soil with Ca decreased phosphorus movement.

#### SOLUBILITY AND RATE OF PHOSPHORUS MOVEMENT STUDIES

The previous studies have shown that phosphorus added as a pellet to soils moved more readily in noncalcareous soils than in calcareous soils. The reasons for the difference in movement could be many. However, the rate at which phosphorus moved from the pellet and the solubility of the reaction products formed could be two of the main reasons why phosphorus moved more readily in the noncalcareous soils than in the calcareous soils.

If phosphorus added to noncalcareous soils formed more soluble reaction products than phosphorus added to calcareous soils, then a greater movement of phosphorus would be expected in the noncalcareous soils. Also, if the movement of added phosphorus was more rapid in the first two or three days in the noncalcareous soils than in calcareous soils, then phosphorus would distribute itself at a greater distance from the site of application. Experiments were conducted to determine:

- (1) the solubility of added phosphorus in calcareous and noncalcareous soils.

(2) the rate of phosphorus movement in calcareous and noncalcareous soils.

#### Solubility Studies

0.1000 gram monoammonium phosphate was added as a pellet to soils in cartons as previously described. A slice of soil, 1.91 cm., by 1.91 cm, was removed from the pellet site, air-dried and ground. A 10 gram sample was placed into 100ml. distilled water and equilibrated with shaking for twenty-four hours at room temperature. The pH of the suspension was measured and the suspension filtered. The calcium and magnesium contents of the filtrates were determined by use of EDTA (49). The phosphorus content of the filtrates was determined colorimetrically (16). The coordinates for the solubility diagram were then calculated as follows:

The pH of the systems studied remained between pH 5 to 9, thus the total phosphorus concentration,  $[P_T] = [H_2PO_4^-] + [HPO_4^{=}] + [MHPO_4]$  (1) where  $H_2PO_4^-$  and  $HPO_4^{=}$  are phosphate ions in solution and  $MHPO_4$  a soluble complex of calcium or magnesium with  $HPO_4^{=}$  (5, 48). The dissociation constant,  $K_d$ , of the  $CaHPO_4$  and  $MgHPO_4$  complex has been found to be  $1.75 \times 10^{-3}$  (5, 35) and  $1.24 \times 10^{-3}$  (48), respectively. A mean value of  $1.50 \times 10^{-3}$  was used when both calcium and magnesium were present in solution. Substitution of activities for concentrations,

$$\frac{(M^{2+})(HPO_4^{=})}{K_d} \text{ for } [MHPO_4] \text{ and } \frac{(H^+)(HPO_4^{=})}{K_2} \text{ for } [H_2PO_4^-]$$

in equation (1) results in the following expression:

$$[P_T] = (HPO_4^{=}) \left( \frac{M^{2+}}{K_d} + \frac{H^+}{f^- K_2} + \frac{1}{f^{2-}} \right) \quad (2)$$

where  $(M^{2+})$  represents calcium plus magnesium,  $f^-$  the activity coefficient of the  $H_2PO_4^-$  ion,  $f^{2-}$  the activity coefficient of the  $HPO_4^{2-}$  ion,  $K_2$  the second dissociation constant of phosphoric acid, the brackets concentrations and the parentheses activities. The total calcium plus magnesium in solution,

$$[M_T^{2+}] = [M^{2+}] + [MHPO_4] \quad (3)$$

where  $M^{2+}$  represents the concentration of calcium plus magnesium in solution and  $MHPO_4$  the soluble complex of calcium or magnesium with  $HPO_4^{2-}$ .

Thus,

$$[M_T^{2+}] = \frac{(M^{2+})}{f^{2+}} + \frac{(M^{2+})(HPO_4^{2-})}{K_d} \quad (4)$$

$$\text{and } (M^{2+}) = \frac{[M_T^{2+}]}{\left(\frac{1}{f^{2+}} + \frac{(HPO_4^{2-})}{K_d}\right)} \quad (5)$$

where  $f^{2+}$  represents the activity coefficient of calcium and/or magnesium. Substitution of the expression derived for  $(M^{2+})$  in equation (5) into equation (2) results in the following quadratic equation by which the  $HPO_4^{2-}$  ion activity was calculated.

$$\begin{aligned} & (HPO_4^{2-})^2 \left\{ (H^+)f^{2-} + f^-K_2 \right\} + (HPO_4^{2-}) \left\{ -[P_T]f^-K_2f^{2-} + [M_T^{2+}]f^-K_2f^{2-} + \right. \\ & \left. \frac{K_d}{f^{2+}} \left\{ (H^+)f^{2-} + f^-K_2 \right\} - \frac{[P_T]K_d f^-K_2 f^{2-}}{f^{2+}} \right\} = 0 \quad (6) \end{aligned}$$

The calcium or magnesium ion activity was obtained from the following quadratic equation derived by substituting the expression for  $(HPO_4^{2-})$  derived from equation (2) into equation (5).

$$\begin{aligned}
 & (M^{2+})^2 (f^{-K_2} f^{2-}) + (M^{2+}) (H^+) K_d f^{2-} + K_d f^{2-} + [P_T] f^{2+} f^{-K_2} f^{2-} - [M_T^{2+}] f^{2+} f^{-K_2} f^{2-} \\
 & - [M_T^{2+}] (f^{2+} (H^+) K_d f^{2-} + f^{2+} K_d f^{-K_2}) = 0 \quad (7)
 \end{aligned}$$

The activity coefficients,  $f$ , were calculated from the Debye-Huckel equation,  $\log_{10} f = \frac{-Az^2 \sqrt{u}}{1 + Bai \sqrt{u}}$  (34). The ionic strength,  $u$ , was

calculated from the expression:

$$u = \frac{1}{2} \sum C_i z_i^2 \quad (34).$$

The ionic activities were calculated by a series of successive approximations, first assuming no association of ions in solution and then correcting for complexing until a constant value for the ion activity was obtained. The values for  $pCa$ ,  $pMg$ , and  $pHPO_4$  were then calculated by taking the negative logarithm of the ion activities. The values for  $pH_2PO_4$  were obtained from the expression

$$pH_2PO_4 = pHPO_4 - pK_2 + pH$$

where  $pK_2$  represents the second dissociation constant of phosphoric acid.

The solubility of the added phosphates was calculated by two methods. First, using  $pH$  and calcium and  $H_2PO_4^-$  ion activities for the calculation of the phosphate and lime potentials, and second, using the magnesium ion activity rather than the calcium ion activity for the calculation of the lime and phosphate potentials. The two methods of calculation are designated as Ca-P and Mg-P, respectively.

The  $pH$  of the filtrates obtained from the phosphorus treated calcareous soils were usually lower than those of the filtrates obtained from the phosphorus treated noncalcareous soils (Table X). The concentration of calcium or magnesium in the filtrates obtained from the calcareous soils was usually higher than in the filtrates obtained from the

TABLE X IONIC CONCENTRATIONS AND ACTIVITIES, AND LIME AND PHOSPHATE POTENTIALS  
OBTAINED BY EQUILIBRATING SOILS WITH MONOAMMONIUM PHOSPHATE.

Soil	pH	[Ca] x10 <sup>3</sup> M	[Mg] x10 <sup>3</sup> M	[P] x10 <sup>3</sup> M	$\frac{1}{2}pCa$	$\frac{1}{2}pMg$	pH <sub>2</sub> PO <sub>4</sub>	pH- $\frac{1}{2}Ca$	pH- $\frac{1}{2}pMg$	pH <sub>2</sub> PO <sub>4</sub> + $\frac{1}{2}$ $\frac{1}{2}pCa^{4+}$	pH <sub>2</sub> PO <sub>4</sub> + $\frac{1}{2}$ $\frac{1}{2}pMg$
Stockton II	7.28	.173	.193	.031	1.92	1.89	4.94	5.36	5.39	6.86	6.83
Wellwood	5.88	.205	.315	.282	1.88	1.79	3.60	4.00	4.09	5.48	5.39
Lakeland I	8.08	.420	2.01	.239	1.77	1.43	4.93	6.31	6.65	6.70	6.36
Stockton I	7.10	.050	.590	.210	2.20	1.66	4.04	4.90	5.44	6.24	5.70
Lakeland II	6.35	.890	.810	.250	1.59	1.61	3.74	4.76	4.74	5.33	5.35
Pine Ridge	6.35	.620	.390	.096	1.65	1.76	4.14	4.70	4.59	5.79	5.90
Tarno	6.38	.855	1.40	.294	1.61	1.50	3.70	4.77	4.88	5.31	5.20
Plum Ridge	5.93	.680	.780	.092	1.64	1.61	4.11	4.29	4.32	5.75	5.72
Firdale	6.68	.475	.315	.226	1.76	1.70 <sup>8</sup>	3.84	4.92	4.88	5.60	5.64
St. Norbert	7.88	.355	.535	.266	1.79	1.70	4.54	6.09	6.18	6.33	6.24

noncalcareous soils. The amounts of phosphorus remaining in solution were small for all samples, particularly the Stockton II, Pine Ridge and Plum Ridge soils. The quantity of magnesium in solution was greater than the quantity of calcium in solution for all soils except the Firdale, Pine Ridge and Lakeland II soils.

The solubility of the added phosphorus was between that of dicalcium phosphate dihydrate and octocalcium phosphate for the noncalcareous St. Norbert and the calcareous Lakeland I soils (Figure 19). The solubility of the added phosphorus was between that of octocalcium phosphate and hydroxyapatite for the noncalcareous Stockton II, Stockton I and Firdale soils and the calcareous Lakeland II and Tarno soils. The phosphorus solubility values for the noncalcareous Wellwood soil and the calcareous Plum Ridge soil were below the solubility of hydroxyapatite.

It appears from this study that the solubility of phosphorus added to calcareous and noncalcareous soils was approximately equal after three weeks incubation. The solubility of phosphorus in all soils was very low, approximating that of octocalcium phosphate or hydroxyapatite. Phosphorus added to Manitoba soils usually remains more soluble than shown in this study (39, 40). The soils used in this investigation, however, were all very low in  $\text{NaHCO}_3$  extractable phosphorus (Table II). Thus, the small amount of phosphorus added to these soils may not have been sufficient to produce a relatively soluble phosphorus compound.

Although the solubility of phosphorus was approximately equal in both the calcareous and noncalcareous soils after incubation for three weeks, it is possible that the solubility of phosphorus might have been different in these soils the first two or three days after the phosphorus was added. This, however, was not investigated and therefore a clear

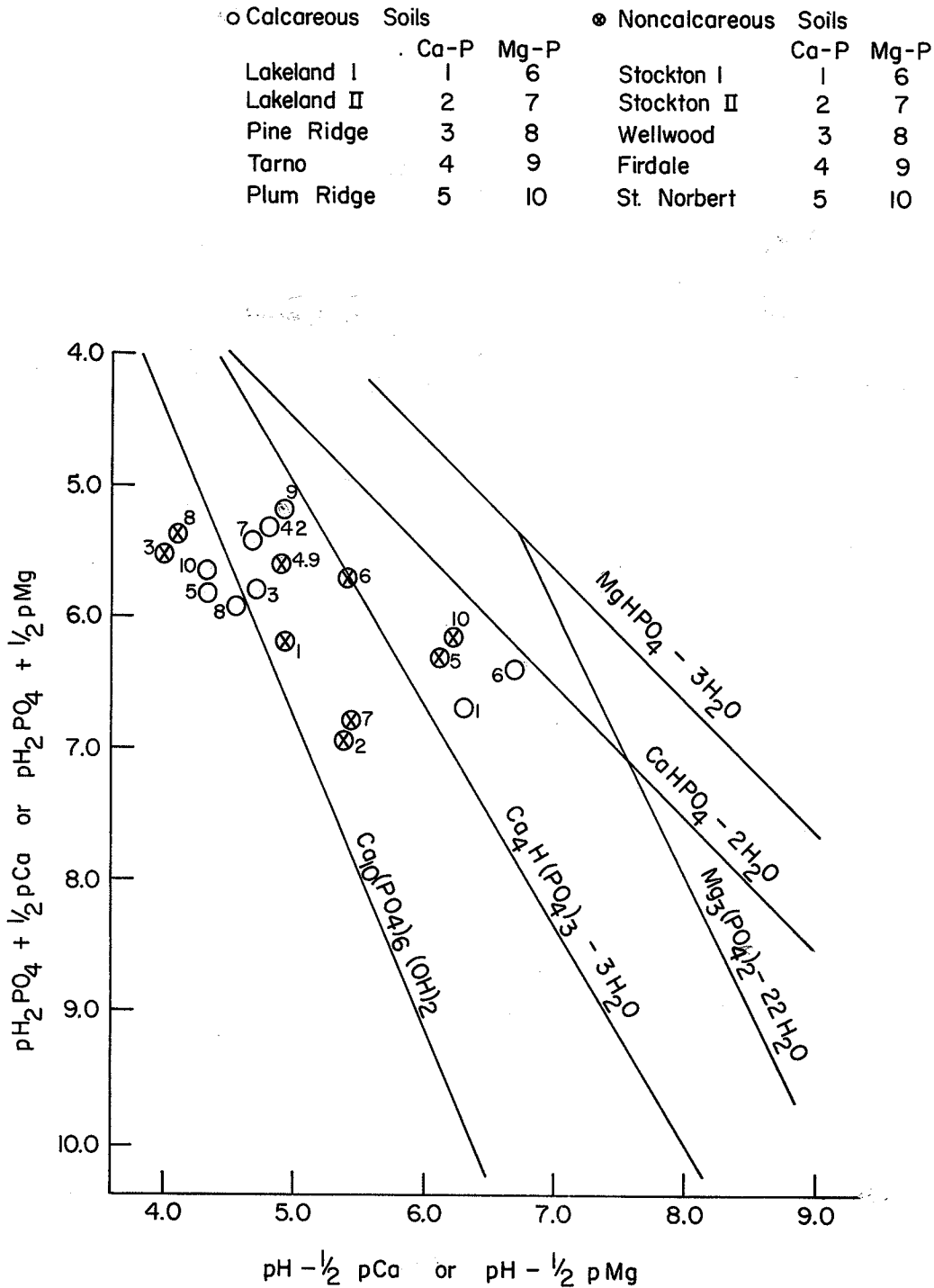


FIGURE 19 The Solubility of Phosphorus in Soils Treated With Monoammonium Phosphate.

conclusion on the relative solubility of added phosphorus in calcareous and noncalcareous soils could not be drawn.

#### Rate of Phosphorus Movement Studies.

Three calcareous and three noncalcareous soils were selected for this study. Monoammonium phosphate was added to the soils in paper cartons as described previously. A sufficient number of cartons were prepared so that the movement of phosphorus could be measured at 0.5, 1, 2, 3, 5, 7, 9, 12, 16 and 21 days after the application of the P<sup>32</sup> "tagged" monoammonium phosphate.

The results of the experiment are presented in Tables XI to XX, and Figures 20 to 39, inclusive. The movement of phosphorus from monoammonium phosphate was greater in the noncalcareous soils than in the calcareous soils after 0.5 day of incubation (Table XI and Figures 20 and 21). This indicates that the movement of phosphorus in noncalcareous soils is more rapid than in calcareous soils. The data obtained when samples were taken at later dates also show a greater phosphorus movement in the noncalcareous soils than in the calcareous soils. The movement of phosphorus in both calcareous and noncalcareous soils occurred mostly in the first twelve hours after the phosphorus was added. There was small but noticeable redistributions of phosphorus around the pellet site for 2 to 3 days after the phosphorus fertilizer was added. The distribution of phosphorus around the pellet site remained relatively constant after three days. These results indicate that phosphorus fertilizers added to soils wetted to field capacity would dissolve and move away from the pellet site very quickly.

The greater movement of phosphorus in noncalcareous soils as compared to calcareous soils can possibly be explained on the basis of a



TABLE XI MOVEMENT OF PHOSPHORUS FROM THE SITE OF MONOAMMONIUM PHOSPHATE PLACEMENT AFTER 0.5 DAY.

Distance (cm)	FIRDALE			STOCKTON I			WELLWOOD		
	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.
0.00 - 0.64	45722	49.86	20.94	7064	42.83	14.79	40807	52.70	23.41
0.64 - 0.95	25528	27.84	27.86	4927	29.88	24.59	22809	29.46	31.18
0.95 - 1.27	13130	14.32	27.82	2386	14.47	23.12	9553	12.34	25.35
1.27 - 1.59	4726	5.15	16.57	1117	6.77	17.90	3225	4.17	14.16
1.59 - 1.91	800	0.87	4.17	449	2.72	10.70	563	0.73	3.68
1.91 - 2.22	362	0.39	2.64	175	1.06	5.84	124	0.16	1.13
2.22 - 2.54	376	0.41		69	0.42	3.06	89	0.11	1.08
2.54 - 3.18	316	0.34		100	0.61		87	0.11	
3.18 - 3.81	375	0.41		100	0.61		83	0.11	
3.81 - 4.45	363	0.40		105	0.64		86	0.11	

TABLE XI (Continued)

Distance (cm)	LAKELAND I			PLUM RIDGE			LAKELAND II		
	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.
0.00 - 0.64	54484	55.43	24.68	27427	73.53	49.39	61344	56.63	26.70
0.64 - 0.95	26596	27.06	28.71	6206	16.64	26.63	31536	29.11	32.72
0.95 - 1.27	11311	11.51	23.70	1423	3.81	11.85	10338	9.54	20.82
1.27 - 1.59	2826	2.87	9.80	408	1.09	5.62	2781	2.57	9.27
1.59 - 1.91	1056	1.07	5.44	317	0.85	6.50	9989	0.91	4.90
1.91 - 2.22	561	0.57	4.05	285	0.76		448	0.41	3.11
2.22 - 2.54	379	0.39	3.63	329	0.88		270	0.25	2.48
2.54 - 3.18	361	0.37		308	0.83		401	0.37	
3.18 - 3.81	365	0.37		285	0.76		113	0.10	
3.81 - 4.45	363	0.37		314	0.84		98	0.09	

TABLE XII MOVEMENT OF PHOSPHORUS FROM THE SITE OF MONOAMMONIUM PHOSPHATE PLACEMENT AFTER 1 DAY

Distance (cm)	FIRDALE			STOCKTON I			WELLWOOD		
	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.
0.00 - 0.64	35552	44.29	15.58	8849	38.66	11.88	45115	50.20	21.80
0.64 - 0.95	23384	29.13	24.41	6843	29.89	21.90	28176	31.35	32.44
0.95 - 1.27	12560	15.65	25.46	3469	15.15	21.55	11115	12.37	24.84
1.27 - 1.59	5659	7.05	18.98	1762	7.70	18.11	3949	4.39	14.60
1.59 - 1.91	2163	2.69	10.79	823	3.60	12.58	541	0.60	2.98
1.91 - 2.22	446	0.56	3.11	337	1.47	7.21	165	0.18	1.27
2.22 - 2.54	181	0.23	1.68	238	1.04	6.76	202	0.22	2.06
2.54 - 3.18	118	0.15		200	0.87		188	0.21	
3.18 - 3.81	119	0.15		165	0.72		195	0.22	
3.81 - 4.45	93	0.12		206	0.90		222	0.25	

TABLE XII (Continued)

Distance (cm)	LAKELAND I			PLUM RIDGE			LAKELAND II		
	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.
0.00 - 0.64	102339	72.15	45.19	26406	62.70	39.20	77538	75.17	45.91
0.64 - 0.95	28884	20.36	30.40	13751	32.65	48.66	16367	15.87	23.10
0.95 - 1.27	8842	6.23	18.06	1022	2.43	7.02	6768	6.56	18.54
1.27 - 1.59	1091	0.77	3.69	249	0.59	2.83	868	0.84	3.93
1.59 - 1.91	172	0.12	0.86	135	0.32	2.28	503	0.49	3.39
1.91 - 2.22	119	0.08	0.84	113	0.27		262	0.25	2.47
2.22 - 2.54	103	0.07	0.96	107	0.25		212	0.21	2.65
2.54 - 3.18	77	0.05		99	0.24		211	0.21	
3.18 - 3.81	108	0.08		171	0.41		212	0.21	
3.81 - 4.45	110	0.08		59	0.15		204	0.20	

TABLE XIII MOVEMENT OF PHOSPHORUS FROM THE SITE OF MONOAMMONIUM PHOSPHATE PLACEMENT AFTER 2 DAYS

Distance (cm)	FIRDALE			STOCKTON I			WELLWOOD		
	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.
0.00 - 0.64	26813	43.11	15.02	12297	43.01	15.07	28634	43.68	14.99
0.64 - 0.95	18262	29.36	24.38	8973	31.38	26.20	19108	29.15	23.84
0.95 - 1.27	10251	16.48	26.56	4292	15.01	24.33	10158	15.49	24.60
1.27 - 1.59	3717	5.98	15.94	1691	5.91	15.86	4920	7.50	19.71
1.59 - 1.91	2024	3.25	12.91	624	2.18	8.70	1508	2.30	8.99
1.91 - 2.22	322	0.52	2.87	316	1.11	6.17	694	1.06	5.79
2.22 - 2.54	196	0.32	2.32	142	0.50	3.68	188	0.29	2.08
2.54 - 3.18	209	0.34		82	0.29		136	0.21	
3.18 - 3.81	202	0.32		129	0.45		130	0.20	
3.81 - 4.45	199	0.32		48	0.17		83	0.13	

TABLE XIII (Continued)

Distance (cm)	LAKELAND I			PLUM RIDGE			LAKELAND II		
	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.
0.00 - 0.64	83516	74.61	49.92	45521	77.00	50.25	50462	46.44	21.25
0.64 - 0.95	21152	18.90	30.13	9219	15.59	24.25	43089	39.66	43.25
0.95 - 1.27	5438	4.86	15.04	2935	4.96	14.99	11647	10.72	22.70
1.27 - 1.59	760	0.68	3.48	625	1.06	5.28	2019	1.86	6.51
1.59 - 1.91	212	0.19	1.44	192	0.32	2.41	734	0.68	3.52
1.91 - 2.22	235	0.21		160	0.27	2.81	220	0.20	1.48
2.22 - 2.54	165	0.15		160	0.27		145	0.13	1.29
2.54 - 3.18	158	0.14		102	0.17		137	0.13	
3.18 - 3.81	154	0.14		108	0.18		132	0.12	
3.81 - 4.45	152	0.14		99	0.17		65	0.06	

TABLE XIV MOVEMENT OF PHOSPHORUS FROM THE SITE OF MONOAMMONIUM PHOSPHATE PLACEMENT AFTER 3 DAYS

Distance (cm)	FIRDALE			STOCKTON I			WELLWOOD		
	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.
0.00 - 0.64	13095	45.36	15.74	8146	32.25	8.08	20914	38.89	11.00
0.64 - 0.95	8413	29.14	24.09	7265	28.77	17.17	14264	26.52	17.87
0.95 - 1.27	3962	13.73	22.03	4311	17.07	19.78	8784	16.33	21.37
1.27 - 1.59	1654	5.73	15.21	2679	10.61	20.34	5867	10.91	23.61
1.59 - 1.91	837	2.90	11.45	1310	5.19	14.79	2301	4.28	13.77
1.91 - 2.22	353	1.22	6.76	699	2.77	11.05	1067	1.98	8.94
2.22 - 2.54	186	0.64	4.72	420	1.66	8.80	310	0.58	3.45
2.54 - 3.18	106	0.37		176	0.70		126	0.23	
3.18 - 3.81	133	0.46		130	0.51		75	0.14	
3.81 - 4.45	128	0.44		120	0.48		73	0.14	

TABLE XIV (Continued)

Distance (cm)	LAKELAND I			PLUM RIDGE			LAKELAND II		
	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.
0.00 - 0.64	92502	70.99	43.24	64981	74.11	45.35	72923	60.66	34.95
0.64 - 0.95	27002	20.72	30.08	15479	17.65	25.74	36376	30.26	38.88
0.95 - 1.27	8060	6.19	17.43	4824	5.50	15.57	8596	7.15	17.83
1.27 - 1.59	1616	1.24	5.78	1378	1.57	7.36	1379	1.15	4.73
1.59 - 1.91	375	0.29	2.00	374	0.43	2.97	287	0.24	1.47
1.91 - 2.22	197	0.15	1.47	205	0.23	2.28	138	0.11	0.99
2.22 - 2.54	139	0.11		71	0.08	0.80	122	0.10	1.16
2.43 - 3.18	144	0.11		123	0.14		140	0.12	
3.18 - 3.81	133	0.10		117	0.13		132	0.11	
3.81 - 4.45	132	0.10		130	0.15		116	0.09	



TABLE XV MOVEMENT OF PHOSPHORUS FROM THE SITE OF MONOAMMONIUM PHOSPHATE PLACEMENT AFTER 5 DAYS

Distance (cm)	FIRDALE			STOCKTON I			WELLWOOD		
	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.
0.00 - 0.64	9757	38.63	11.81	12901	39.32	10.16	18362	45.34	14.84
0.64 - 0.95	7746	30.67	22.34	8181	24.93	15.35	9684	23.91	18.65
0.95 - 1.27	3801	15.05	21.28	4959	15.11	18.06	6956	17.18	26.01
1.27 - 1.59	2105	8.33	19.50	3159	9.63	19.04	3176	7.84	19.65
1.59 - 1.91	959	3.80	13.21	1625	4.95	14.57	1423	3.52	13.09
1.91 - 2.22	371	1.47	7.15	899	2.74	11.28	380	0.94	4.89
2.22 - 2.54	184	0.73	4.71	693	2.11	11.54	168	0.41	2.87
2.54 - 3.18	99	0.39		179	0.55		123	0.30	
3.18 - 3.81	108	0.43		93	0.28		101	0.25	
3.81 - 4.45	136	0.54		124	0.38		121	0.30	

TABLE XV (Continued)

Distance (cm)	LAKELAND I			PLUM RIDGE			LAKELAND II		
	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.
0.00 - 0.64	51724	47.12	20.57	39982	68.89	37.61	68179	61.43	31.92
0.64 - 0.95	40890	37.25	38.76	12215	21.05	27.38	28555	25.73	31.86
0.95 - 1.27	11857	10.80	21.82	3164	5.45	13.77	10817	9.75	23.43
1.27 - 1.59	3018	2.75	9.19	1570	2.71	11.30	2468	2.22	8.84
1.59 - 1.91	1141	1.04	5.17	331	0.57	3.54	362	0.33	1.93
1.91 - 2.22	532	0.48	3.37	257	0.44	3.85	85	0.08	0.63
2.22 - 2.54	133	0.12	1.12	128	0.22	2.54	139	0.13	1.38
2.54 - 3.18	151	0.14		97	0.17		125	0.11	
3.18 - 3.81	184	0.17		112	0.19		111	0.10	
3.81 - 4.45	141	0.13		179	0.31		143	0.13	

TABLE XVI MOVEMENT OF PHOSPHORUS FROM THE SITE OF MONOAMMONIUM PHOSPHATE PLACEMENT AFTER 7 DAYS.

Distance (cm)	FIRDALE			STOCKTON I			WELLWOOD		
	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.
0.00 - 0.64	6846	37.15	10.31	12948	39.63	10.65	23060	38.75	10.70
0.64 - 0.95	4866	26.41	17.46	8520	26.08	16.71	15879	26.69	17.56
0.95 - 1.27	2780	15.09	19.37	4686	14.34	17.84	9219	15.49	19.79
1.27 - 1.59	1478	8.02	17.04	2557	7.83	16.11	5872	9.87	20.85
1.59 - 1.91	864	4.69	14.81	1744	5.34	16.34	2844	4.78	15.02
1.91 - 2.22	446	2.42	10.70	1071	3.28	14.04	1416	2.38	10.47
2.22 - 2.54	324	1.76	10.31	478	1.46	8.31	573	0.96	5.62
2.54 - 3.18	305	1.66		318	0.97		261	0.44	
3.18 - 3.81	266	1.44		141	0.43		188	0.32	
3.81 - 4.45	253	1.37		208	0.64		192	0.32	

TABLE XVI (Continued)

Distance (cm)	LAKELAND I			PLUM RIDGE			LAKELAND II		
	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.
0.00 - 0.64	76497	70.43	42.10	65787	78.96	50.40	89129	69.67	43.43
0.64 - 0.95	22245	20.48	29.18	11446	13.74	20.90	31764	24.83	36.88
0.95 - 1.27	6042	5.56	15.38	3456	4.15	12.25	4738	3.70	10.68
1.27 - 1.59	1856	1.71	7.82	1051	1.26	6.16	759	0.59	2.83
1.59 - 1.91	434	0.40	2.72	373	0.45	3.25	335	0.26	1.86
1.91 - 2.22	320	0.29	2.81	300	0.36	3.66	278	0.22	2.16
2.22 - 2.54	299	0.28		208	0.25	3.37	210	0.16	2.16
2.54 - 3.18	318	0.29		253	0.30		191	0.15	
3.18 - 3.81	313	0.29		208	0.25		212	0.17	
3.81 - 4.45	287	0.26		240	0.29		220	0.17	

TABLE XVII MOVEMENT OF PHOSPHORUS FROM THE SITE OF MONOAMMONIUM PHOSPHATE PLACEMENT AFTER 9 DAYS.

Distance (cm)	FIRDALE			STOCKTON I			WELLWOOD		
	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.
0.00 - 0.64	13559	44.44	13.81	12741	39.99	10.42	13386	36.54	9.01
0.64 - 0.95	8076	26.47	19.60	8308	26.08	16.20	9124	24.90	14.64
0.95 - 1.27	3673	12.04	17.30	4213	13.22	15.94	5508	15.03	17.15
1.27 - 1.59	2678	8.78	20.87	2651	8.32	16.60	4028	10.99	20.75
1.59 - 1.91	1311	4.30	15.20	1718	5.39	16.00	2344	6.40	17.96
1.91 - 2.22	510	1.67	8.28	1093	3.43	14.25	1345	3.67	14.43
2.22 - 2.54	230	0.75	4.95	613	1.92	10.60	426	1.16	6.06
2.54 - 3.18	124	0.41		300	0.94		195	0.53	
3.18 - 3.81	192	0.63		151	0.47		151	0.41	
3.81 - 4.45	158	0.52		72	0.23		129	0.35	

TABLE XVII (Continued)

Distance (cm)	LAKELAND I			PLUM RIDGE			LAKELAND II		
	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.
0.00 - 0.64	99228	69.03	40.41	65035	74.03	47.81	61124	73.44	45.24
0.64 - 0.95	32066	22.31	31.12	16297	18.55	28.55	15985	19.21	28.20
0.95 - 1.27	8410	5.85	15.84	4185	4.76	14.23	4015	4.82	13.75
1.27 - 1.59	2693	1.87	8.39	996	1.13	5.60	1065	1.28	6.03
1.59 - 1.91	592	0.41	2.74	266	0.30	2.23	244	0.29	2.06
1.91 - 2.22	230	0.16	1.49	135	0.15	1.58	143	0.17	1.69
2.22 - 2.54	207	0.14		159	0.18		194	0.23	3.04
2.54 - 3.18	120	0.08		221	0.25		157	0.19	
3.18 - 3.81	112	0.08		279	0.32		150	0.18	
3.81 - 4.45	83	0.06		277	0.32		148	0.18	

TABLE XVIII MOVEMENT OF PHOSPHORUS FROM THE SITE OF MONOAMMONIUM PHOSPHATE PLACEMENT AFTER 12 DAYS.

Distance (cm)	FIRDALE			STOCKTON I			WELLWOOD		
	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.
0.00 - 0.647	25709	51.17	19.68	13423	37.29	10.13	17468	36.17	9.43
0.64 - 0.95	13964	27.79	25.48	11099	30.83	19.96	14331	29.67	18.44
0.95 - 1.27	5652	11.25	20.02	4871	13.53	17.01	6825	14.13	17.05
1.27 - 1.59	2489	4.95	14.59	2689	7.47	15.53	4303	8.91	17.78
1.59 - 1.91	1415	2.82	12.33	1608	4.47	13.81	2727	5.65	16.76
1.91 - 2.22	502	1.00	6.12	1043	2.90	12.54	1383	2.86	11.90
2.22 - 2.54	110	0.22	1.78	690	1.92	11.01	756	1.57	8.63
2.54 - 3.18	136	0.27		332	0.92		193	0.40	
3.18 - 3.81	138	0.27		125	0.35		148	0.31	
3.81 - 4.45	131	0.26		118	0.33		161	0.33	

TABLE XVIII B(Continued)

Distance (cm)	LAKELAND I			PLUM RIDGE			LAKELAND II		
	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.
0.00 - 0.64	81764	73.71	44.86	30124	48.23	23.10	26115	69.57	36.90
0.64 - 0.95	19536	17.61	25.54	25312	40.53	46.25	7154	19.06	24.09
0.95 - 1.27	6239	5.62	15.83	4300	6.88	15.25	2404	6.46	15.71
1.27 - 1.59	2050	1.85	8.61	1765	2.83	10.36	1028	2.74	11.12
1.59 - 1.91	511	0.46	3.19	391	0.63	3.41	377	1.00	6.06
1.91 - 2.22	225	0.20	1.97	133	0.21	1.63	118	0.31	2.66
2.22 - 2.54	138	0.12		140	0.22		116	0.31	3.46
2.54 - 3.18	148	0.13		69	0.11		72	0.19	
3.18 - 3.81	152	0.14		114	0.18		67	0.18	
3.81 - 4.45	169	0.15		109	0.17		86	0.23	



TABLE XIX MOVEMENT OF PHOSPHORUS FROM THE SITE OF MONOAMMONIUM PHOSPHATE PLACEMENT AFTER 16 DAYS.

Distance (cm)	FIRDALE			STOCKTON I			WELLWOOD		
	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.
0.00 - 0.64	20221	41.35	13.29	14514	37.80	9.68	10738	30.90	7.10
0.64 - 0.95	16416	33.57	25.72	11280	29.38	17.92	9636	27.73	15.19
0.95 - 1.27	6152	12.58	18.71	4637	12.08	14.30	6181	17.79	18.92
1.27 - 1.59	2619	5.36	13.18	3154	8.21	16.09	3495	10.06	17.70
1.59 - 1.91	1741	3.56	13.03	2028	5.28	15.39	2267	6.52	17.07
1.91 - 2.22	997	2.04	10.45	1287	3.35	13.67	970	2.79	10.23
2.22 - 2.54	404	0.83	5.62	919	2.39	12.95	986	2.84	13.79
2.54 - 3.18	152	0.31		357	0.93		318	0.92	
3.18 - 3.81	70	0.14		87	0.23		53	0.15	
3.81 - 4.45	126	0.26		135	0.35		1108	0.31	

TABLE XIX (Continued)

Distance (cm)	LAKELAND I			PLUM RIDGE			LAKELAND II		
	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.
0.00 - 0.64	64223	55.84	23.19	34027	55.25	24.25	58255	58.73	28.97
0.64 - 0.95	31356	27.26	26.97	18172	29.51	30.86	29478	29.72	34.93
0.95 - 1.27	9272	8.06	15.48	5221	8.48	17.21	6561	6.61	15.09
1.27 - 1.59	3810	3.31	10.53	2258	3.67	12.32	3288	3.31	12.51
1.59 - 1.91	3683	3.20	15.13	1001	1.63	8.12	717	0.72	4.06
1.91 - 2.22	1057	0.92	6.08	432	0.70	4.91	315	0.32	2.50
2.22 - 2.54	343	0.30	2.62	155	0.25	2.34	184	0.19	1.93
2.54 - 3.18	487	0.42		122	0.20		133	0.13	
3.18 - 3.81	595	0.52		62	0.10		123	0.12	
3.81 - 4.45	204	0.18		137	0.22		141	0.14	

TABLE XX MOVEMENT OF PHOSPHORUS FROM THE SITE OF MONOAMMONIUM PHOSPHATE PLACEMENT AFTER 21 DAYS.

Distance (cm)	FIRDALE			STOCKTON I			WELLWOOD		
	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.
0.00 - 0.64	12242	41.89	11.88	10522	41.29	9.87	26510	38.95	10.48
0.64 - 0.95	7739	26.48	17.90	5423	21.28	12.13	17667	25.96	16.65
0.95 - 1.27	3999	13.68	17.96	3281	12.88	14.24	11178	16.42	20.45
1.27 - 1.59	2063	7.06	15.33	2333	9.16	16.75	6178	9.08	18.70
1.59 - 1.91	1545	5.29	17.07	1401	5.50	14.96	3820	5.61	17.19
1.91 - 2.22	872	2.98	13.49	1073	4.21	16.04	1489	2.19	9.38
2.22 - 2.54	311	1.06	6.38	807	3.17	16.01	856	1.26	7.15
2.54 - 3.18	170	0.58		397	1.56		159	0.23	
3.18 - 3.81	135	0.46		138	0.54		108	0.16	
3.81 - 4.45	147	0.50		108	0.42		95	0.14	

TABLE XX (Continued)

Distance (cm)	LAKELAND I			PLUM RIDGE			LAKELAND II		
	ccpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.	cpm	% Conc.	% Distr.
0.00 - 0.64	83227	70.44	36.16	49737	79.74	50.37	80456	68.52	38.45
0.64 - 0.95	19413	16.43	20.10	8270	13.26	19.96	26519	22.58	30.21
0.95 - 1.27	8991	7.61	18.07	2774	4.45	13.00	6905	5.88	15.27
1.27 - 1.59	3857	3.26	12.83	923	1.48	7.16	2357	2.01	8.62
1.59 - 1.91	1620	1.37	8.01	438	0.70	5.05	857	0.73	4.66
1.91 - 2.22	505	0.43	3.50	96	0.15	1.55	2207	0.18	1.58
2.22 - 2.54	144	0.12	1.32	136	0.22	2.91	120	0.10	1.21
2.54 - 3.18	129	0.11							
3.18 - 3.81	117	0.10							
3.81 - 4.45	73	0.12							

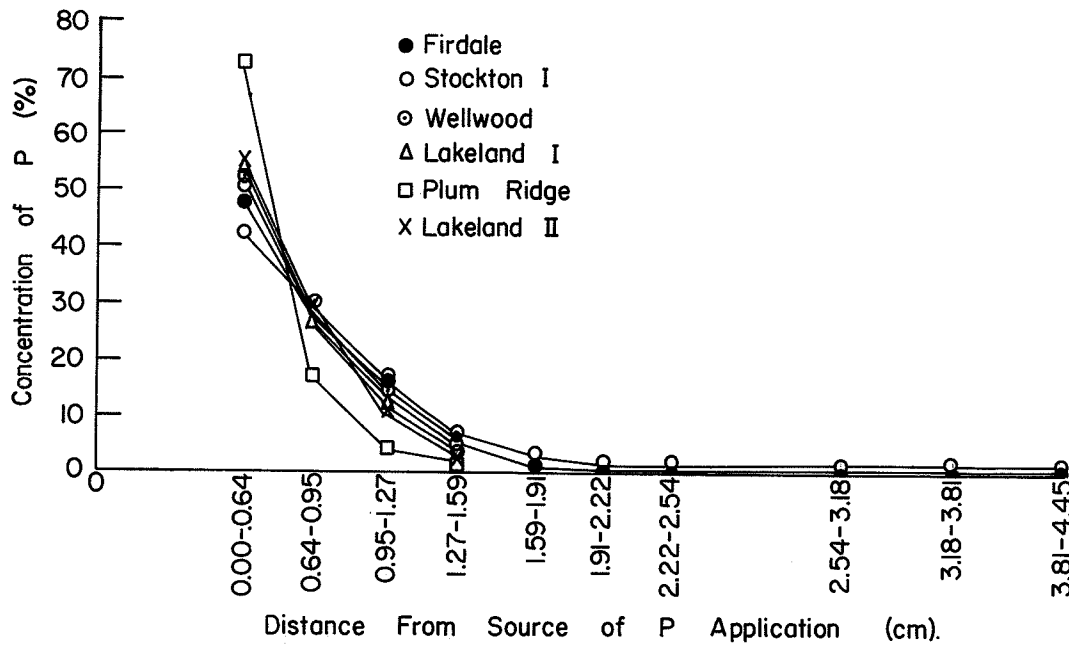


FIGURE 20 Concentration of Fertilizer Phosphorus at Various Distances from the Site of Phosphorus Application after 0.5 Day.

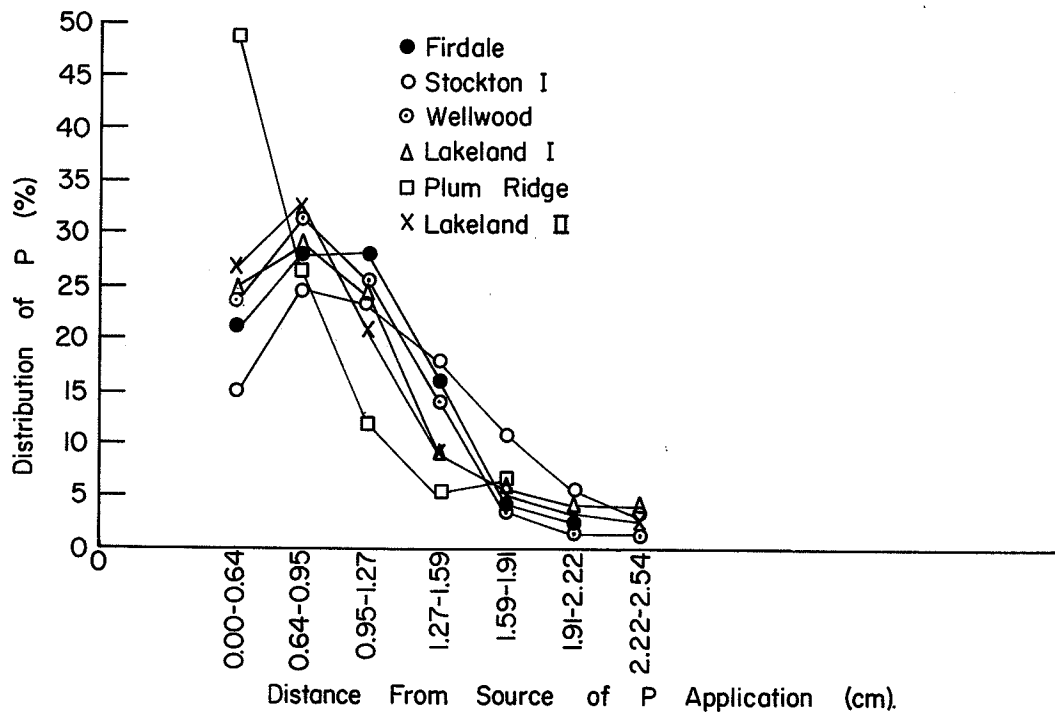


FIGURE 21 Distribution of Fertilizer Phosphorus at Various Distances from the Site of Phosphorus Application after 0.5 Day.

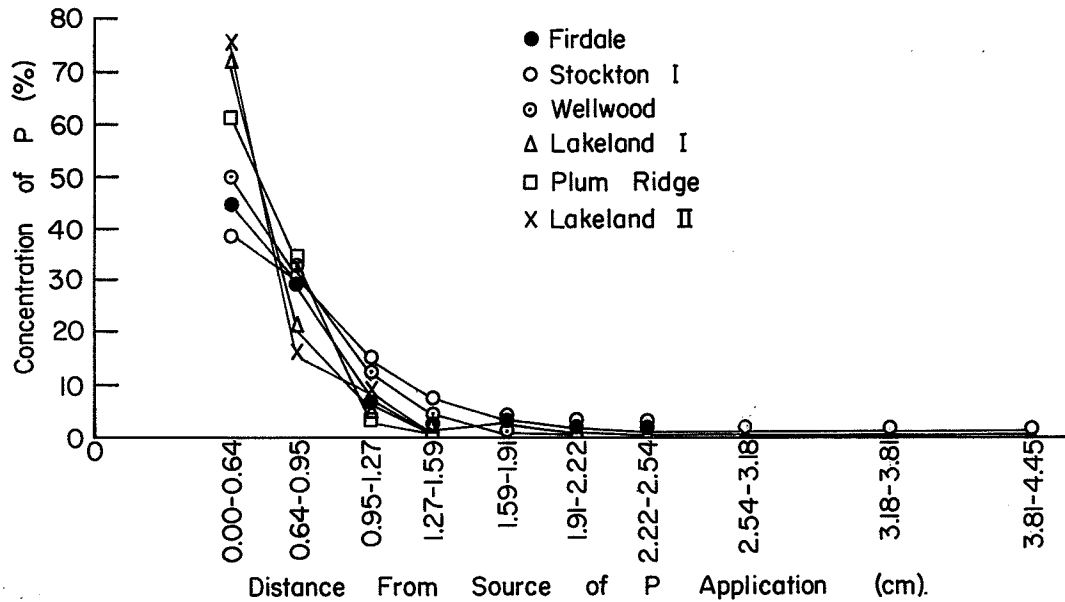


FIGURE 22 Concentration of Fertilizer Phosphorus at Various Distances from the Site of Phosphorus Application after 1 Day.

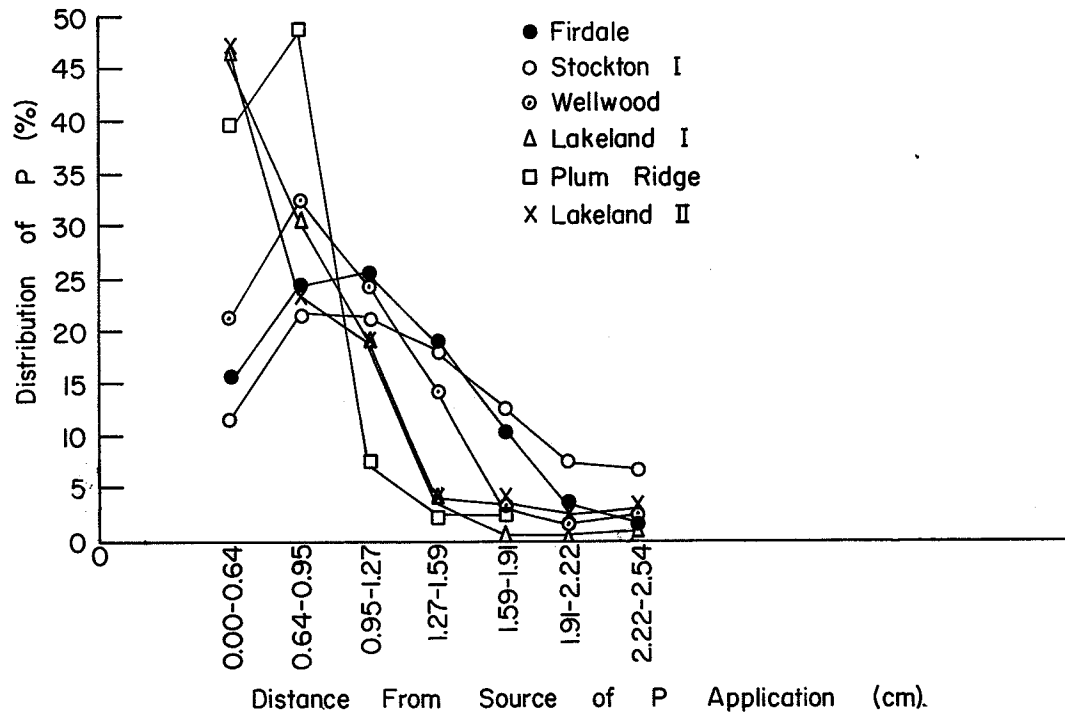


FIGURE 23 Distribution of Fertilizer Phosphorus at Various Distances from the Site of Phosphorus Application after 1 Day.

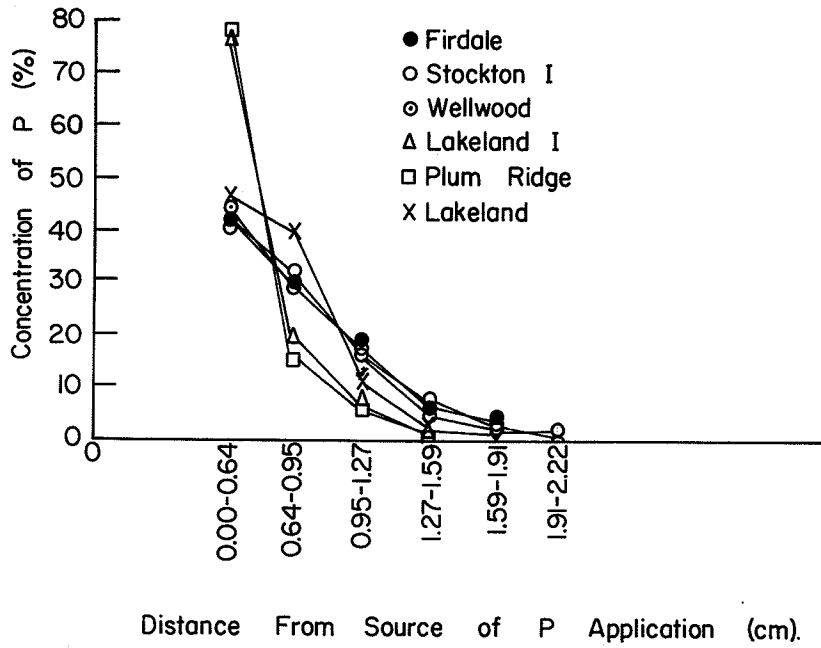


FIGURE 24. Concentration of Fertilizer Phosphorus at Various Distances from the Site of Phosphorus Application after 2 Days

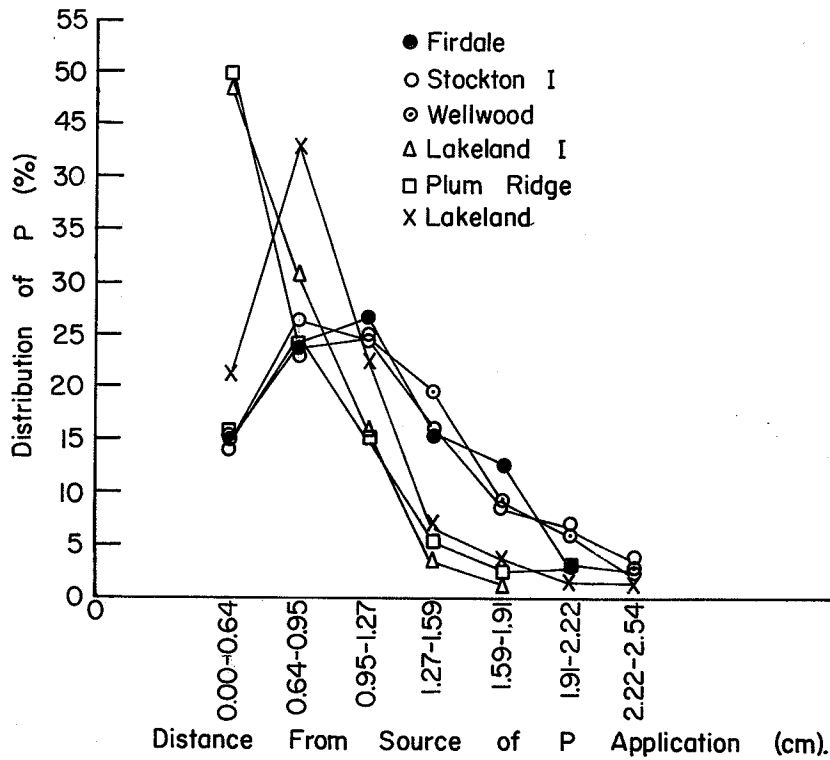


FIGURE 25 Distribution of Fertilizer Phosphorus at Various Distances from the Site of Phosphorus Application after 2 Days.

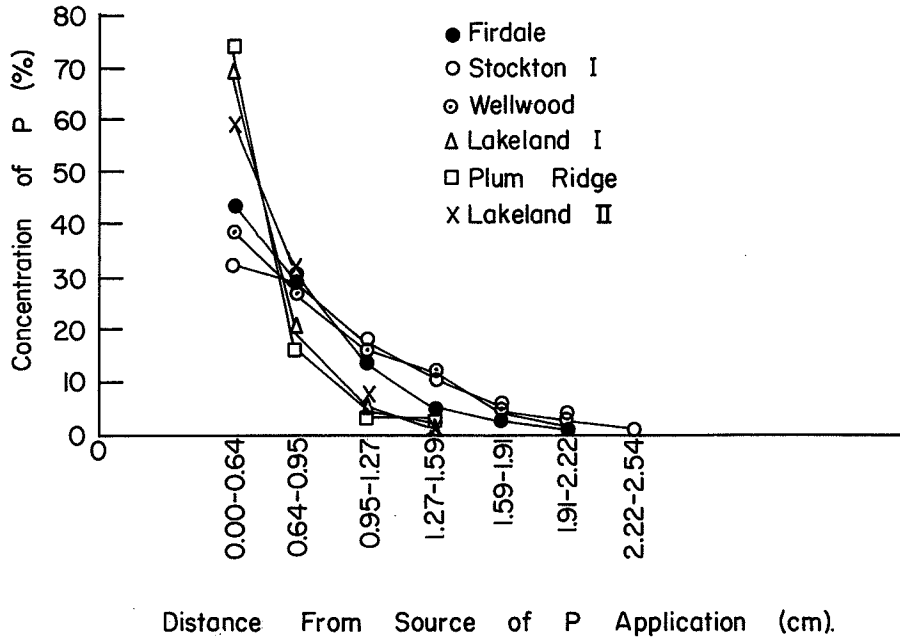


FIGURE 26 Concentration of Fertilizer Phosphorus at Various Distances from the Site of Phosphorus Application after 3 Days.

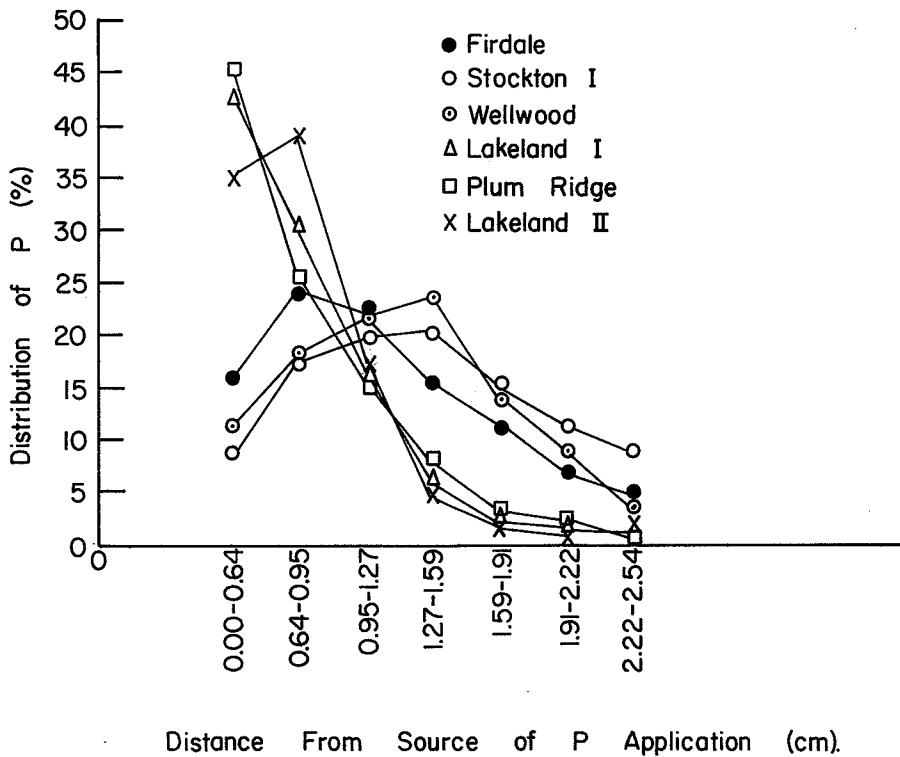


FIGURE 27 Distribution of Fertilizer Phosphorus at Various Distances from the Site of Phosphorus Application after 3 Days.



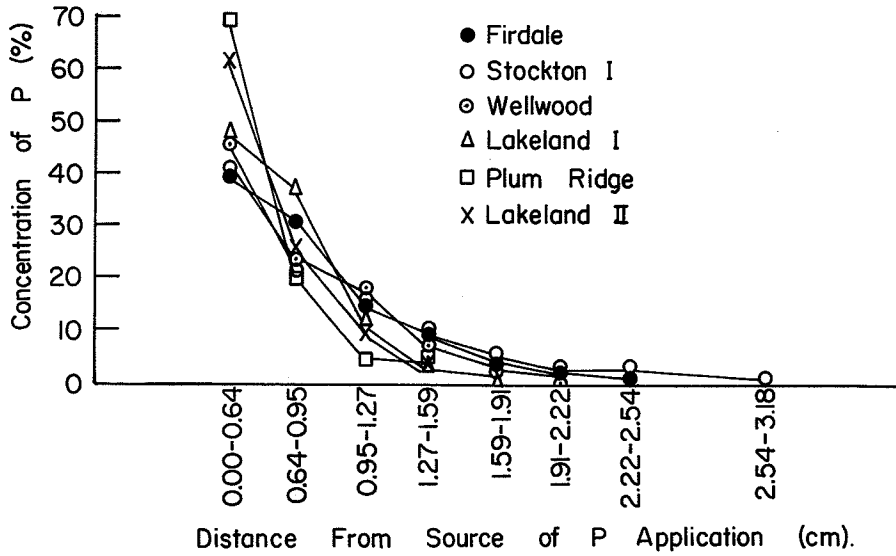


FIGURE 28 Concentration of Fertilizer Phosphorus at Various Distances from the Site of Phosphorus Application after 5 Days.

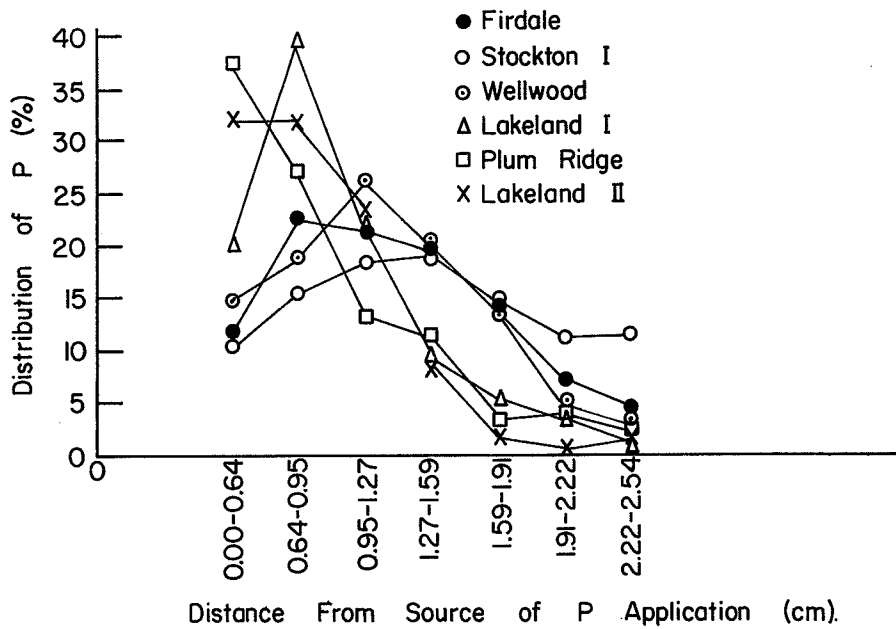


FIGURE 29 Distribution of Fertilizer Phosphorus at Various Distances from the Site of Phosphorus Application after 5 Days.

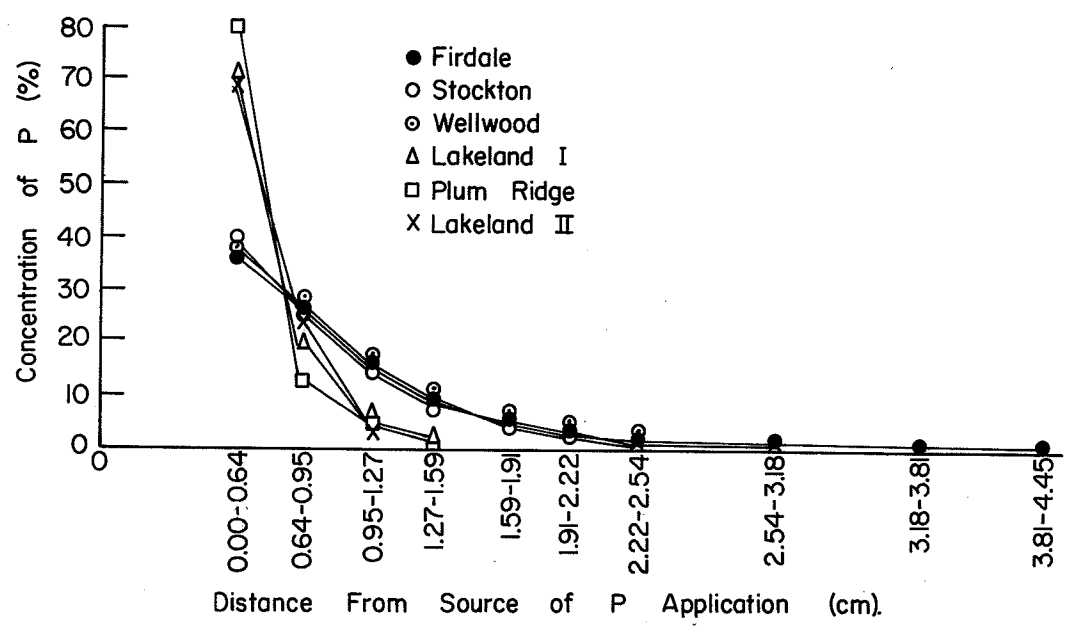


FIGURE 30 Concentration of Fertilizer Phosphorus at Various Distances from the Site of Phosphorus Application after 7 Days

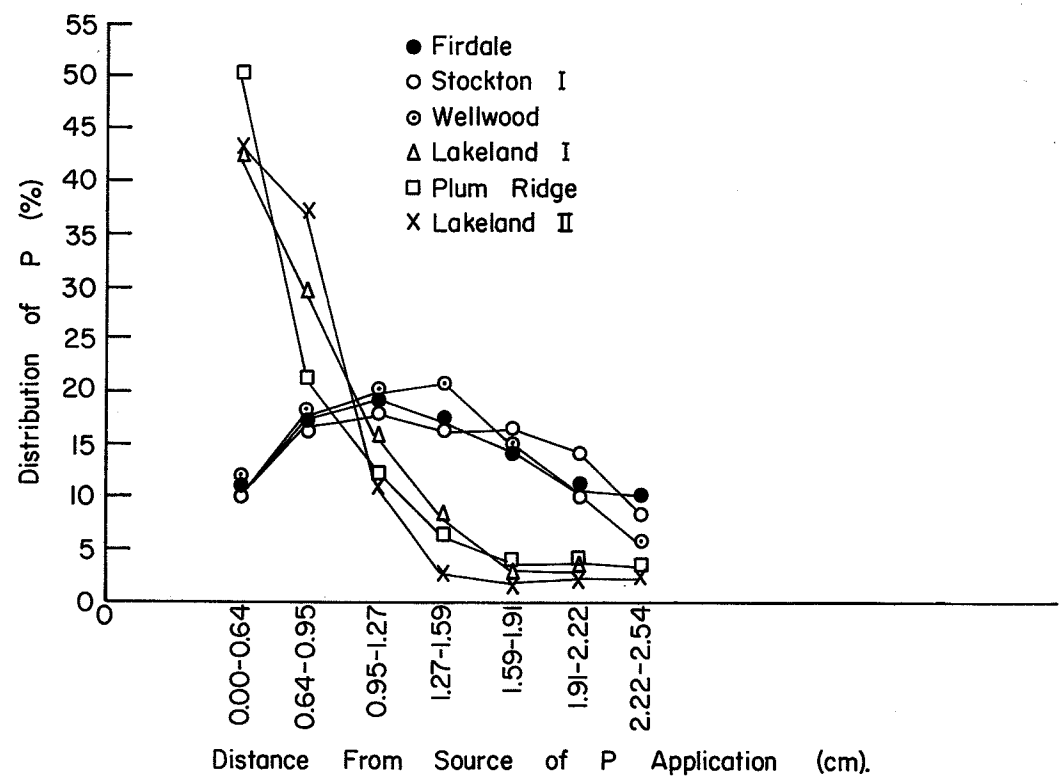


FIGURE 31 Distribution of Fertilizer Phosphorus at Various Distances from the Site of Phosphorus Application after 7 Days

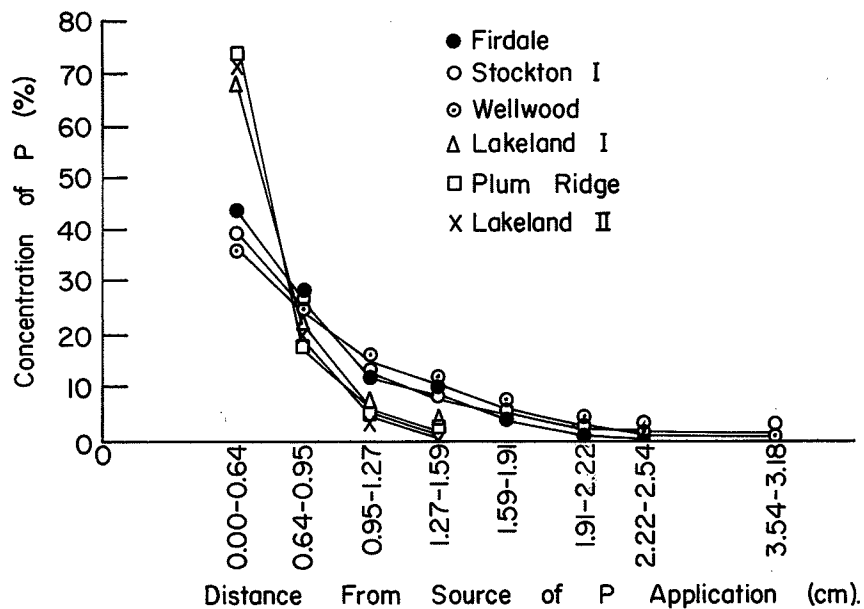


FIGURE 32 Concentration of Fertilizer Phosphorus at Various Distances from the Site of Phosphorus Application after 9 Days

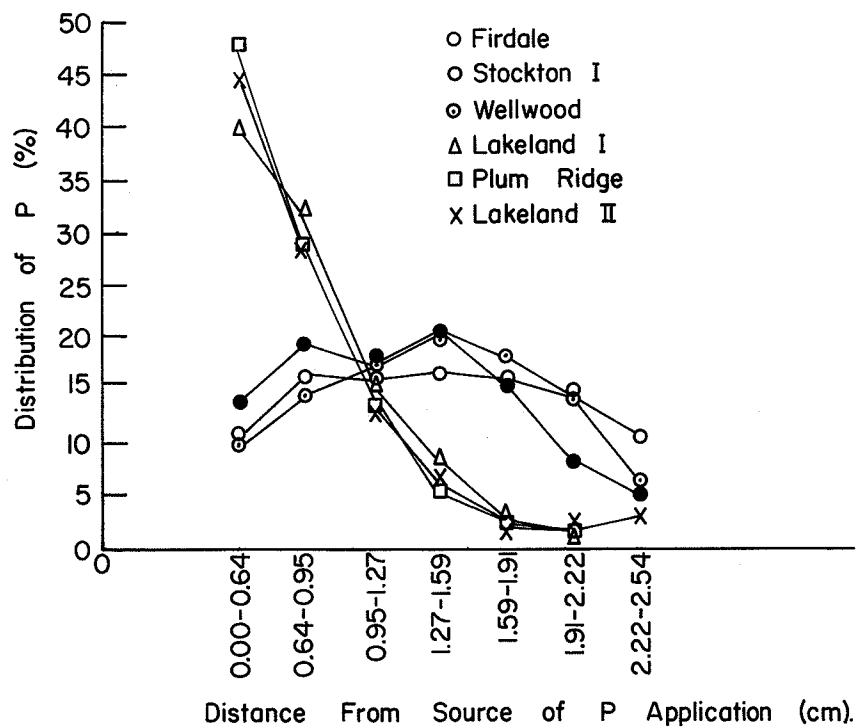


FIGURE 33 Distribution of Fertilizer Phosphorus at Various Distances from the Site of Phosphorus Application after 9 Days

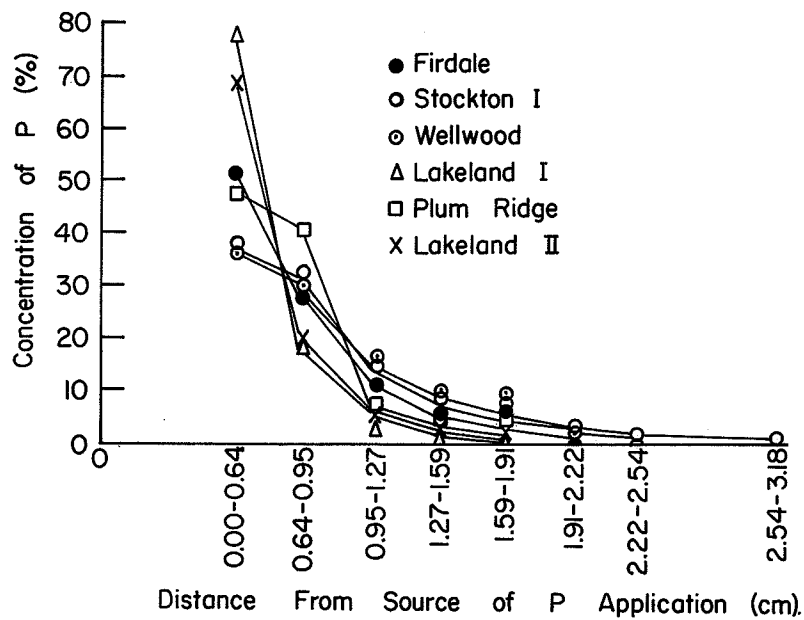


FIGURE 34 Concentration of Fertilizer Phosphorus at Various Distances from the Site of Phosphorus Application after 12 Days

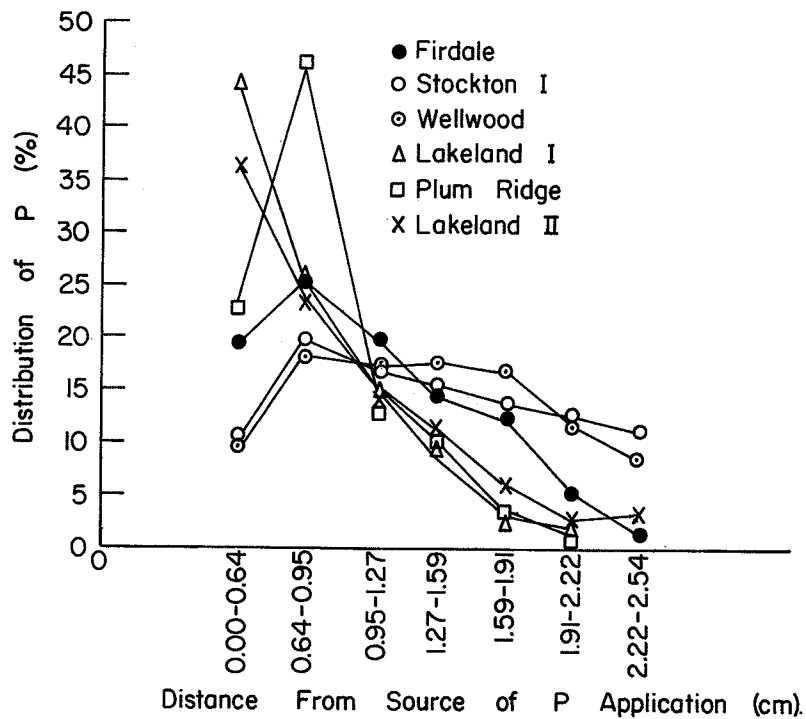


FIGURE 35 Distribution of Fertilizer Phosphorus at Various Distances from the Site of Phosphorus Application after 12 Days

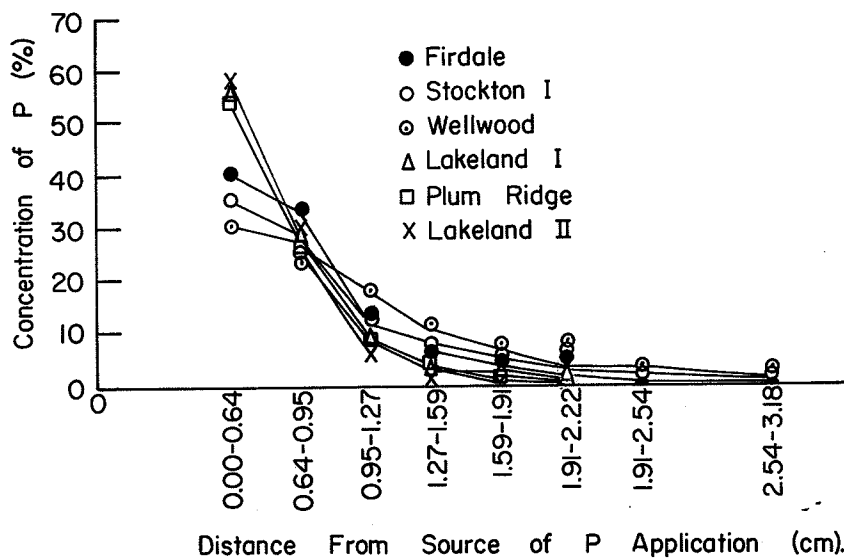


FIGURE 36 Concentration of Fertilizer Phosphorus at Various Distances from the Site of Phosphorus Application after 16 Days

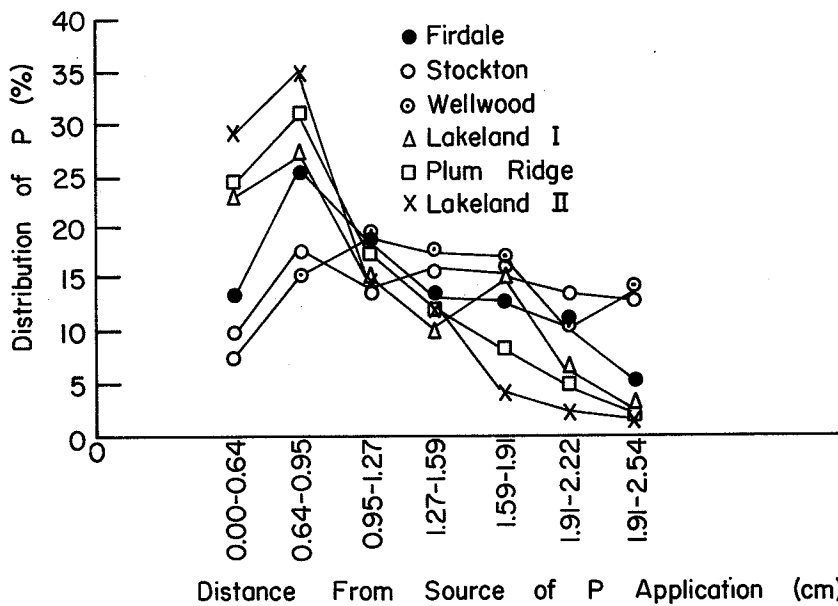


FIGURE 37 Distribution of Fertilizer Phosphorus at Various Distances from the Site of Phosphorus Application after 16 Days

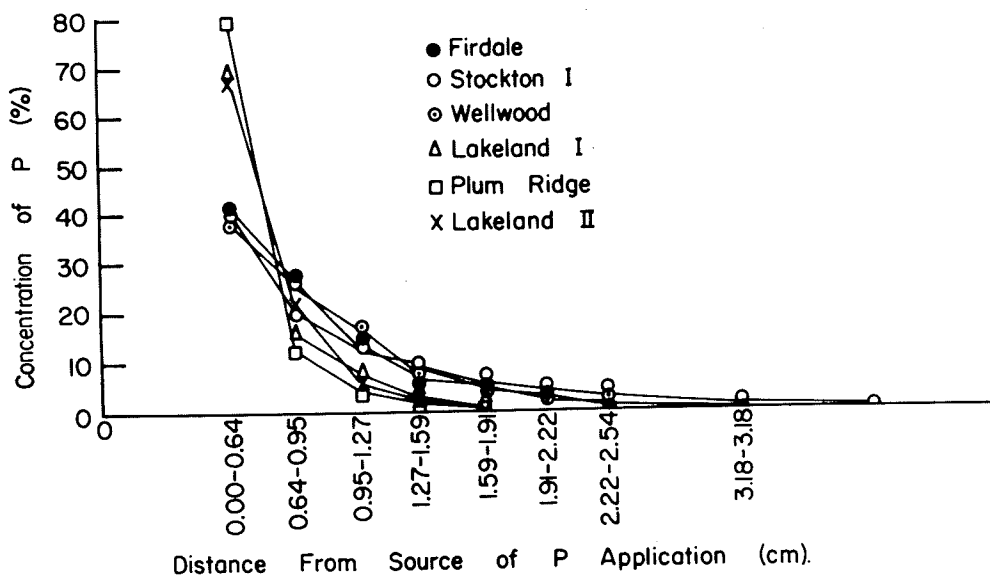


FIGURE 38 Concentration of Fertilizer Phosphorus at Various Distances from the Site of Phosphorus Application after 21 Days

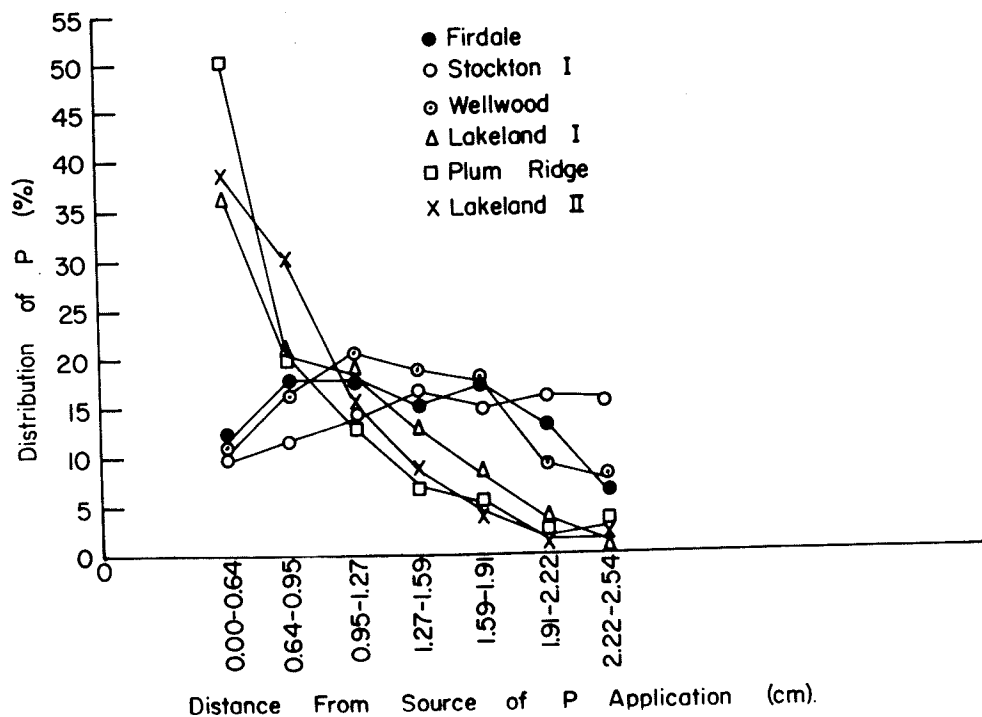


FIGURE 39 Distribution of Fertilizer Phosphorus at Various Distances from the Site of Phosphorus Application after 21 Days

more rapid movement of phosphorus in noncalcareous soils. Since the movement of phosphorus in noncalcareous soils was greater than the movement of phosphorus in calcareous soils after 0.5 day of incubation, the rate at which phosphorus moved must have been greater in noncalcareous soils than in calcareous soils. The solubility studies revealed that more calcium and/or magnesium was present in the soil solutions of calcareous soils than was present in the soil solutions of noncalcareous soils. The large amounts of calcium and/or magnesium in the soil solutions of calcareous soils probably restricted the movement of phosphorus.

The supply of calcium and/or magnesium immediately adjacent to the pellet in noncalcareous soils is lower than in calcareous soils. Thus, phosphorus added to noncalcareous soils would move farther from the pellet before it would be precipitated by calcium or magnesium. In calcareous soils, the large amounts of calcium and magnesium supplied from carbonates of calcium and magnesium, would precipitate the added phosphorus near the pellet site and thus restrict the movement of phosphorus.

## V CONCLUSIONS AND SUMMARY

The study of phosphorus movement has engaged the interest of many soil scientists. Many studies have been conducted by researchers in other countries, but there has been little or no work of this nature using Canadian soils. Also, the studies conducted have been limited to acid and noncalcareous soils. Since Manitoba contains large areas of calcareous soils, a study was initiated to study phosphorus movement in several calcareous and noncalcareous soils.

A method for studying the movement of phosphorus in soils was developed. The method was as follows: A phosphorus fertilizer "tagged" with  $P^{32}$  was applied to soils as a pellet. A 1.9l cm. slice of soil was then taken from the phosphorus fertilizer reaction zone and sectioned at 0.64, 0.95, 1.27, 1.59, 1.91, 2.22, 2.54, 3.18, 3.81 and 4.45 cms. from the site of fertilizer application. The sectioning was conducted using specially constructed steel rings of appropriate diameters. The samples were dried and one gram representative samples pressed into a briquet using a hydraulic press. The activity of each sample was then measured on an End Window Geiger Mueller Counter. The method was found to give a high reproducibility of count rate and could be used to measure the concentration of added phosphorus at various distances from the site of phosphorus application.

The movement of phosphorus from monoammonium phosphate was usually greater than that from diammonium phosphate in both calcareous and noncalcareous soils when the phosphorus fertilizers were added as a pellet. This observation was more noticeable in calcareous than in noncalcareous soils. Phosphorus movement was greater in the noncalcareous soils than in the



calcareous soils regardless of form of phosphorus added or method of fertilizer application. Phosphorus movement was greater in the coarse-textured soils than in the fine-textured soils when the phosphorus fertilizer was added in granular form to the surface of soil columns and leached with water. Soil texture had little or no effect on phosphorus movement when the fertilizer was added as a pellet.

The movement of phosphorus was slightly retarded in both a calcareous and noncalcareous soil when  $P^{32}$  "tagged" monoammonium phosphate was mixed with  $CaCl_2$ ,  $MgCl_2$ ,  $KCl$ ,  $NaCl$  and  $NH_4Cl$ . In soils saturated with  $Na$ ,  $K$ ,  $Ca$ ,  $Mg$ , or  $NH_4$ , phosphorus movement was greatest when  $Na$ ,  $K$  or  $NH_4$  was on the soil exchange complex. Saturation of the soils with  $Ca$  reduced phosphorus movement, whereas saturation of the soils with  $Mg$  increased phosphorus movement when compared to the untreated soil.

Solubility studies were conducted to determine the solubility of the reaction products formed in noncalcareous and calcareous soils when treated with a phosphorus fertilizer. The studies showed that the solubility of the added phosphorus was approximately the same in the soils investigated. This, therefore, indicated that the greater movement of phosphorus in noncalcareous soils as compared to calcareous soils was not due to a greater solubility of the added phosphorus in noncalcareous soils. The solubility studies, however, showed that the soil solutions of the calcareous soils contained greater amounts of calcium and magnesium than did the soil solutions of the noncalcareous soils.

The rate of phosphorus movement in both calcareous and noncalcareous soils was studied. Phosphorus was found to move at a greater rate in noncalcareous soils than in calcareous soils. Most likely, the large amounts of calcium and magnesium in the soil solutions of calcareous soils

precipitated the added phosphorus rapidly and very close to the pellet site. Thus the movement of phosphorus in calcareous soils was restricted more than in the noncalcareous soils which contained smaller amounts of calcium and magnesium in the soil solutions. Phosphorus added to the noncalcareous soils was able to move farther from the pellet before it was precipitated by calcium and/or magnesium.

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