AVAILABILITY OF PHOSPHORUS FROM CERTAIN PHOSPHATE FERTILIZERS WHEN APPLIED TO FIVE KANSAS SOILS

by

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INTRODUCTION

In recent years phosphatic fertilization of crop land has been a common practice in the eastern one half of the state. Crops grown on some calcareous soils in the western part of the state respond to phosphate application when sufficient soil moisture is available. Thus phosphatic fertilizers have become important in Kansas farm economy.

Along with increased use of phosphatic fertilizers, new technologies for their manufacture have occured. This has necessitated extensive research not only for finding the best and most economical methods of production but also for the laborious and time consuming job of testing the comparative value of the new products as they affect crop yields. Much of the latter research is carried out by land grant colleges. The research herein reported is of that nature.

Phosphatic fertilizers of varying degrees of water solubility were used in greenhouse pot cultures and in the laboratory to compare their abilities to furnish available phosphorus for plant uptake and to increase crop yields. This research was conducted in conjunction with field test plots, the results of which are not included in this report.

Soil-phosphorus relationships are very complex phenomena as is evident from the voluminous treatise of the subject in the literature. The ability of a soil to fix applied phosphorus in a form relatively unavailable for plant uptake has been appropriately termed "phosphorus fixation". Several theories have been proposed as to the possible reactions that can take place in the soil to cause phosphorus to be fixed. Because of the wide variation in the physical and chemical properties of soils, it becomes very important economically to be able to predict the availability of phosphorus after such is applied to the various soil types. In an effort to find out more on this subject five cropland soils from widely scattered areas in the eastern half of Kansas were used in the greenhouse and laboratory experiments.

Placement of fertilizers has been demonstrated to have significant importance in determining crop yields. Band placement generally is thought to be superior to broadcasting for the phosphate fertilizers of high water solubility. The reasoning behind this thinking is that when the fertilizer is concentrated in a small region it will not be fixed as fast by the soil and therefore will be available in larger amount for early plant uptake. Conclusive proof of this has not been demonstrated, however, for some Kansas soils.

Some new fertilizers have low water solubility of the phosphorus. There has been some doubt that banding these fertilizers is justified. It is possible that with low solubility it might be better to mix such with a large volume of soil so that more feeder roots could come in contact with the fertilizer. Each fertilizer used in this greenhouse experiment was applied both by banding with the seed and by mixing with the entire pot of soil.

REVIEW OF LITERATURE

Although no effort was made to determine the types of phosphorus fixation that occurred during the experiment, it was desired to have a fair understanding of what reactions might have occurred and what controlled them.

According to Burd (3) three types of complexes are responsible for fixing phosphorus in inorganic soils. These are: (1) calcium phosphate complexes, (2) kaolinitic type clay mineral adsorption of phosphorus and (3) hydrous oxides of iron and aluminum. Calcium phosphate complexes are relatively unimportant in acid soils, except possibly after heavy liming. Iron phosphate hydrolysis increases substantially above pH 3 while aluminum phosphate hydrolysis does not take place to a very large extent until a pH range of 5 to 6 is reached. This suggests that aluminum might have a greater effect than iron in fixing phosphorus in acid soils such as occur in eastern Kansas. Soils containing much kaolinite and similar type clay minerals might have phosphorus adsorbed by these minerals in relatively insoluble forms.

Metzger (15) sampled 13 profiles from various eastern Kansas soils ranging in pH from 5.0 to 7.0 and determined their phosphorus fixing capacity in the laboratory. The results showed a close relationship between total R_2O_3 and phosphorus fixing capacity of the soil. Total Fe_2O_3 and total Al_2O_3 considered separately provided similar evidence. Both dilute acid extractable and non-extractable forms of iron and aluminum fixed phosphorus. Soils containing the highest percentage of organic matter were found to contain a larger amount of their total Fe_2O_3 as dilute acid extractable. The organic matter was thought to cause reduction of iron so that it became more soluble and therefore fixed less phosphorus.

Using potentiometric titration methods, Swenson et al. (24) showed that maximum precipitation of basic iron phosphate and basic aluminum phosphate occurred in the pH range 2.5 to 3.5 and 3.5 to 4.0, respectively. In these pH ranges the $H_2PO_4^-$ ion is the form of phosphate most likely to react with iron and aluminum and precipitate out of solution.

Kittrick and Jackson (11) suggested that phosphorus fixation in soils follows the solubility product principle. They found after adding geothite to an iron phosphate suspension that soluble phosphorus content decreased from 10 to 1 ppm. Similar results occurred after adding kaolinite to an aluminum phosphate suspension, geothite to an aluminum phosphate suspension, and kaolinite to an iron phosphate suspension. Soil solution phosphate concentration was little affected by the addition of 1,000 pounds per acre of 0-20-0- fertilizer after 10 days. According to Kittrick and Jackson (11), the beneficial effect of phosphate fertilizers is due to the increased soil phosphate surface area once the fertilizer has reacted with the soil.

Perkins et al. (20) ground eight different aluminum silicate minerals for periods up to 21 weeks. This grinding was considered to yield products similar to those that might be formed by weathering under field conditions. By several types of analyses and despite the great differences in chemical composition, reaction, and mineral species, grinding produced a compound which was or closely resembled an alumina-silica gel. Since grinding yields a product that will react with and precipitate phosphorus, it is possible that the decomposition of soil clay minerals is responsible for a major part of phosphorus fixation.

Low and Black (12 and 13) found that kaolinite could be decomposed by concentrated phosphate solutions forming aluminum phosphate compounds and releasing silica. Their hypothesis was that phosphate ions in solution were exchanged for silicate ions in the outer layer of the clay lattice to such an extent that the clay lattice decomposed.

The phosphate ion has been demonstrated to exchange with hydroxyl ions at the edges of the clay lattice according to Dean and Rubins (9 and 10) and Rubins and Dean (22). They found that the phosphate ion could be replaced by or replace arsenate, fluoride, tartrate, and citrate ions on the anion exchange complex of clays. The data showed a correlation between anion exchange capacity and specific surface in clays.

Type of clay mineral most prevalent in the soil may have a bearing on how much phosphorus will be adsorbed. Data given by Perkins and King (19) and Coleman (4) show little difference between kaolinite and montmorillonite in their ability to fix phosphorus with the pH range of crop soils. This is contrary to the findings of some earlier work, however.

In the literature cited above there are good examples of how phosphorus might become fixed in the soil. There is also much contradiction in the literature as to the plant availability of these fixed forms of phosphorus. Dean and Rubins (8) showed that phosphorus adsorbed on kaolinite was readily available to barley plants. Phosphorus adsorbed on both montmorillonite and kaolinite clays was readily available to both oats and corn as demonstrated by Coleman (5). Availability of iron and aluminum phosphates to plants is not clearly shown. Dalton et al. (7) found in sand culture that freshly precipitated iron and aluminum phosphates were only 15 percent as effective as soluble phosphate for corn. Other investigations showed great variation from Dalton's findings, however. Truog (25) found pure aluminum phosphate nearly as effective as superphosphate for increasing yields of several types of plants.

Before turning from the subject of phosphorus fixation to the review of literature on comparisons of various phosphatic fertilizers on plant growth it is sufficient to say that soil-phosphate reactions still appear to be very complex phenomena. In view of the above it might be expected that fertilizers will react differently on different soils and that different fertilizers will react differently on the same soil. Also, it might be expected that a single fertilizer will react differently on the same soil from year to year, depending upon environmental conditions. Only by extensive experimental trials can safe predictions be made concerning the relative value of a fertilizer.

The review of literature along this line failed to show any previous comparisons of all the fertilizers used in the present research in the same experiment. Different reports did involve all of the fertilizers used however. Of particular interest were the comparisons of the slightly water soluble forms of nitraphosphate and ammoniated superphosphate with superphosphate which is quite soluble in water and has long been a standard phosphate fertilizer.

The manufacture of nitraphosphates has become of interest of late because of their potential economic method of production and because of the possible future shortage of sulfur needed for the production of the standard superphosphates. Nitric acid is substituted in part or in full for sulfuric and phosphoric acids used in the manufacture of superphosphates. The nitric acid serves a double purpose by rendering the phosphate soluble and by providing nitrogen. By increasing the proportion of phosphoric or sulfuric to nitric acid used, the water solubility can be varied from approximately 10 to 40 percent. Adding nitrogen by ammoniation of these products also lowers their solubility. Thus the most economically produced substances are the least water soluble.

Rogers (21) compiled and evaluated the data obtained from pilot studies involving both greenhouse and field experiments comparing various nitraphosphates with concentrated superphosphates and other standard dry mixed phosphate fertilizers. The experiments were carried out by several state experiment stations working in cooperation with the Tennessee Valley Authority.

Questions of interest to Rogers in evaluating nitraphosphates were: (1) importance of water solubility, (2) effect of particle size, (3) single versus multiple-nutrient-component granules.

On one year corn trials in several southeastern states nitraphosphate (17-22-0) containing 10 percent of its phosphorus as water soluble P_2O_5 gave similar yields as did nitraphosphate (12-32-0) containing 40 percent of it phosphorus as water soluble P_2O_5. Both products were about equal to concentrated superphosphate in increasing yields. Two commercial grade dry mixed fertilizers containing ammoniated superphosphate were also used in these experiments. Their phosphorus contents were 25 and 50 percent water soluble. No significant yield differences were obtained due to the difference in water solubility of the two compounds.

Field trials with wheat were conducted in several southeastern states and in Nebraska and with oats in three southeastern states and in Iowa. Two year results (1949-1950) showed that with one exception the various nitraphosphates increased yields about like concentrated superphosphate. The nitraphosphate (12-32-0) which contained 40 percent of its P_2O_5 as water soluble caused slightly smaller yields than the other fertilizers. No explanation was given.

Very limited trials in Nebraska and Iowa on alkaline soils or soils extremely deficient in phosphorus showed that the low water soluble forms of nitraphosphates tended to produce lower yield increases than concentrated superphosphate.

Particle size of the nitraphosphate was found to affect crop yield. Material coarser than -12 mesh consistently produced poorer yields increases of corn, wheat, and oats. There also was limited evidence that material finer than + 50 mesh gave poorer results.

Greenhouse experiments conducted by Martin et al. (14) involved six California soils all low in phosphorus but representing a wide range in geographical location, parent material, pH, profile development, and chemical soil conditions responsible for phosphorus fixation. Romaine lettuce was used as the test crop. Phosphorus was supplied at rates of 50, 100, 200, and 400 pounds of P_2O_5 per acre. Two ammoniated superphosphates were compared with ordinary superphosphate. The percents of P_2O_5 soluble in water was 30, 67, and 95 respectively for the three forms of phosphate. Nitrogen and K_2O was supplied at 300 and 100 pounds per acre respectively.

On four acid soils (pH 5.4 to 5.9) the difference in water solubility of phosphate fertilizers failed to cause any difference in the weight of lettuce produced. With one of these soils (Aiken clay loam) the 50 and 100 pound rates were ineffective, illustrating the high phosphate fixing capacity of this soil.

Results with the two calcareous soils showed that the highly ammoniated superphosphate (least water soluble) was substantially inferior to ordinary superphosphate.

Working with 12 Nebraska soils, Olson et al. (17) conducted greenhouse experiments from 1953 to 1955 for the purpose of measuring the relative effectiveness of various phosphate fertilizers. Oats were grown first, followed by sweetclover to test for residual effects. Fertilizers were supplied at rates varying from 20 to 45 pounds of P_2O_5 and 80 pounds of N per acre. Radioactive phosphorus was used. Placement methods used were: (1) banding with the seed, (2) broadcasting on the surface, and (3) mixing throughout the pot.

Ammonium phosphate and concentrated superphosphate supplied more phosphate to the plants than did fertilizers of lower water solubility, particularly in the early growth stages. Near crop maturity the least soluble forms of phosphate were nearly equal to the most soluble forms on acid soils but not on calcareous soils. There was little residual effect of any of the fertilizers on the second crop with acid soils. The calcareous soils showed some residual fertilizer effect, however.

The data for placement methods showed very little differences for any of the five fertilizers used when broadcast on the surface or mixed throughout the soil. However, for band placement the plants adsorbed nearly twice as much phosphate from ammonium phosphate and superphosphate as from the other three less soluble forms (nitraphosphate, ammoniated phosphate and Rhenanian phosphate). Olson stressed that efficiency of fertilizers should be measured by using the best placement method for each particular fertilizer (17).

Webb (26) used field trials to evaluate the effectiveness of several T.V.A. nitraphosphates and concentrated superphosphate as starter fertilizers for corn on Iowa soils. The results for two seasons were in close agreement and showed that the overall effectiveness of the different fertilizers was largely a function of their degree of water solubility. Superphosphate gave the highest yields at 7 of 9 locations while the least water soluble form of nitraphosphate consistently gave the lowest yields.

A five year study was made by Bennett et al. (1) using 18 phosphate carriers on the highly calcareous Houston black clay in Texas. The soil was contained in frames 6 inches deep to simulate field conditions. Cowpeas and alfalfa were grown in rotation on one series of frames while wheat and sudan grass was rotated on an alternate series of frames.

The more soluble forms of phosphate gave significant yield increases but the comparatively insoluble forms had little effect. The percent of phosphorus in the plant tissue did not vary significantly regardless of the source of phosphate. Sodium pyrophosphate and monoammonium phosphate gave slightly higher average yields than either ordinary or concentrated superphosphate.

Greenhouse and field studies were made by Owen et al. (18) to determine the effect of the interaction between particle size and water solubility of various 12-12-12 mixed fertilizers. Solubility of phosphorus was adjusted from 2 to 90 percent by varying the ratio of ammonium phosphate to dicalcium phosphate. Three mesh sizes were used. Michigan Hillsdale sandy loam was adjusted to three pH values (5.5, 6.5, and 7.5) by liming three weeks in advance of adding 500 pounds per acre of the various fertilizers.

Variation in water solubility of the added phosphate failed to cause a significant difference in dry weight yield of wheat plants. However, the percentage of plant phosphorus derived from added fertilizer was proportional to the degree of water solubility and the particle sizes of the fertilizers. Phosphorus uptake from the 4-6 mesh sizes was directly proportional to water solubility. Degree of water solubility had little effect for particle sizes of 60 mesh, however. More phosphorus adsorption occurred at pH 5.5 than at the higher values.

A comprehensive series of field tests was conducted by Olsen et al. (16) in Colorado, Arizona, and Idaho to compare the relative effectiveness of different phosphatic fertilizers on calcareous soils. The fertilizers were tagged with radioactive phosphorus for evaluating percentage uptake from the fertilizers. The results showed that slightly water soluble materials were inferior to materials such as superphosphate, monocalcium phosphate, and monoammonium phosphate insofar as supplying phosphorus to the crops. Final crop yields were less affected, however, and many times only insignificant differences existed between the various fertilizers.

Band placement was superior to rotiller placement for the more soluble forms of fertilizers in a dry year. In a relative wet year band placement caused only limited early growth response after which time rotiller placement was equally effective for all fertilizers.

MATERIALS AND METHODS

Soils Used

Surface soils used in the greenhouse and laboratory experiments were taken from the fields in the fall of 1955. Four of the soils were taken from college experimental farms and the fifth soil was taken from the farm of a cooperating farmer. Pertinent information about the soils is given in Table 1.

The soils were collected from fields which were known to respond to phosphate fertilization even though there was considerable variation in their content of available phosphorus. In order to get fair representation of eastern Kansas soils they were taken from widely scattered locations. Natural soil fertility, soil parent material, and mean annual rainfall varied with the soils.

Fertilizers Used

Five phosphate fertilizers were used in the greenhouse experiment. A sixth (diammonium phosphate) was added in the laboratory experiment. The diammonium and monoammonium phosphates were pure forms while the rest of the fertilizers were commercial grade. Ammonium nitrate was used for adjusting the nitrogen level of the various treatments in the greenhouse. Table 2 lists the pertinent information about the fertilizers used. Considerable variation existed in their degree of water solubility.

The fertilizers for individual pot treatments were weighed to the nearest milligram on an analytical balance. These materials were not ground, but rather used directly as they were manufactured. This meant that for the coarse materials there were only a few individual particles applied to each pot.

Table 1. General characterization of soils used in experiments.

Soil type	Soil sampling location	County	pH	Lime requirement*	Previous crop	Previous phosphate fertilizer	Available phosphorus**
				(Lbs./A.)		(Lbs. P_2O_5/A.)	(Lbs./A.)
Unidentified silty clay loam	Howard Strout's farm, Wilsey	Morris	5.95	2000	wheat	25-30	30.2
Clark loam	Hutchinson exp. field	Reno	6.0	4500	wheat	25	31.3
Tabler clay loam	Canton exp. field	McPherson	5.3	3000	wheat	25-30	29.6
Grundy silty clay loam	Corn Belt exp. field, Powhattan	Brown	6.1	3000	wheat	40	12.5
Parsons silt loam	Mound Valley exp. sta.	Labette	5.4	5000	wheat	30	6.2

* Determined according to the method of Woodruff (27).
** Determined by a modified method of Bray and Kurtz (2).

Table 2. General characterization of phosphate fertilizers used in experiments.*

Fertilizer	Manufacturer's guaranteed analysis	Total P_2O_5 contents**	Water soluble P_2O_5 content***	Portions of total P_2O_5 water soluble
		(%)	(%)	(%)
Superphosphate	0-42-0	41.9	28.7	68.5
Ammonium phosphate	16-20-0	22.1	15.4	69.7
Ammoniated superphosphate	16-20-0	20.0	10.4	52.0
Nitraphosphate	51-15-0	14.8	1.8	12.2
Diammonium phosphate	21-53.8-0	--	100	100
Monoammonium phosphate	12.1-61.6-0	--	100	100

*As listed in the Kansas State fertilizer handbook, 1955 edition.

**As measured by digestion in a mixture of HCl and HNO_3.

***Measured by placing one g. of fertilizer on filter paper and leaching with successive small portions of H_2O until filtrate measured 250 ml.

Laboratory Experiment

A laboratory experiment was designed to measure the phosphorus fixing ability of the soils when supplied with the various phosphate fertilizers. The fertilizers were added at the rate of 50 ppm. of phosphorus to 200 g. of air dry soil contained in 500 ml. Erlenmeyer flasks. Duplicate trials were established. Water was then added at a 1 to 1 soil to solution ratio. The flasks were stoppered and shaken for several hours on an end-over-end shaker. It was believed that this procedure caused an equilibrium to be established in the mixture.

The samples were filtered through Buchner funnels with suction using a fine phosphorus free paper. The soil was then replaced in the Erlenmeyer flasks and water was again added to keep a 1 to 1 soil to solution ratio. The filtrate volume was measured in order to tell how much water was left in the soil after filtering. Water soluble phosphorus was determined in the filtrate by a modified method of Bray and Kurtz (2). Ammonium molybdate-HCl-boric acid reagent[1] was added to the filtrate at the ratio of 1 to 25. The molybdate blue color was developed with stannous chloride reducing reagent[2] by adding three or four drops from a dropper.

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1 Prepared by dissolving 100 g. of ammonium molybdate in 850 ml. of H_2O. After filtering and cooling this soln. was mixed slowly into a second soln. containing 1,700 ml. of conc. HCl and 160 ml. of H_2O. One hundred and 10 g. of reagent grade boric acid was added to the final soln.

2 Prepared by dissolving 1.25 g. of $SnCl_2.2H_2O$ in 5 ml. of conc. HCl and heated slightly to dissolve. This soln. was diluted to 50 ml., filtered, and kept in a dark dropper bottle. It was made up fresh every 2 weeks.

The intensity of the color was measured by a photoelectric photometer using a 660 mu. filter 15 minutes after the stannous chloride had been added. The ppm. of phosphorus in the filtrate was then determined from a standard phosphorus curve using KH_2PO_4 as the source of phosphorus.

The above procedure was repeated on the soil samples until essentially no more phosphorus could be detected in the filtrate or until further extractions seemed unnecessary. This required from four to seven extractions depending on the soil. The additive amounts of phosphorus actually removed by the successive extractions was taken to be the water soluble phosphorus in the soil sample. The amount extracted from untreated samples was subtracted from the total water soluble amount. This gave the ppm. remaining out of the original 50 ppm. which was not fixed by the soil as water insoluble. The percent recovery was calculated.

"Available phosphorus" content was determined on the soil samples after the water extractions had been completed. A modified method of Bray and Kurtz (2) also was used to make this analysis.

The samples were air dried, finely ground, and thoroughly mixed[1]. Duplicate 1 g. samples were taken from the larger 200 g. samples and placed in 250 ml. Erlenmeyer flasks. Fifty ml. of a solution 0.03 N in NH_4F and 0.025 N in HCl was added. The

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1 The previous filtering processes caused fractionation of the soil particles on the Buchner funnel. In order to take a represenative 1 g. sample from the original 200 g. it was deemed necessary to grind and thoroughly mix the samples.

mixture was immediately placed on an end-over-end shaker for 1 minute and filtered through a fine phosphorus free paper in long necked glass funnels. Two ml. of the ammonium molybdate-HCl-boric acid solution was added to the filtrate and mixed briefly. Then 2 ml. of sulfonic acid[1] was added as the reducing reagent to develpp the molybdate blue color. After 15 minutes the color intensity was determined on the photoelectric photometer.

The sum of phosphorus extracted by water and NH_4F-HCl was taken to be the available phosphorus in the samples. The amount of added phosphorus that was recovered as available was determined by subtracting the amount of available phosphorus contained in the untreated samples.

Greenhouse Experiment

Soils for the greenhouse experiment were screened through 1/4 inch hail screen, thoroughly mixed, and air dried. One gallon earthenware pots containing 3,500 g. of soil each were used. The pots were spaced approximately three inches apart on the greenhouse bench.

Fertilizers were applied at the rate of 50 pounds per acre of available P_2O_5[2]. All treatments including the check were supplied with 50 pounds of nitrogen per acre. Each of the five

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1 Prepared by grinding and dry mixing 2.5 g. of 1-amino-2-naphthol-sulfonic acid, 5 g. of Na_2SO_3, and 146.25 g. of $Na_2S_2O_5$. Four g. of the powder mixture was dissolved in 25 ml. of H_2O and allowed to stand several hours before using. The soln. was made up fresh in 3 weeks or as needed.

2 Calculated on basis of 2,000,000 pounds of soil per acre.

fertilizers was applied by two methods, (1) banded with the seed and (2) mixed thoroughly throughout the soil mass. Thus 11 treatments including one check were used for each of the five soils and each treatment was replicated four times, constituting 220 pots in all.

Oats were planted during the first week of December, 1955. The method of planting involved removal of approximately 1 inch of soil from the pot, placement of the seed and fertilizer on the surface, and then replacement of the layer of soil. Mixed placement of fertilizer was carried out just prior to planting.

The plants were thinned to 15 per pot during the first week after emergence. Distilled water was supplied daily or as was needed to promote good soil moisture conditions. The plants were allowed to head and ripen before being harvested during the last week of May, 1956. Grain and straw were harvested separately.

Shortly after the oat crop was removed millet was planted in the pots without further addition of fertilizer. This crop was planted to test the residual effect of the fertilizers. Only the surface of the soil was disturbed while planting the millet so as to not disturb the band of fertilizer. The plants were thinned to 15 per pot during early growth stage. Approximately three weeks after planting, 100 pounds of nitrogen per acre as NH_4NO_3 was applied in solution to each cultures.

The millet was allowed to head and ripen before being harvested in August. Grain and straw again were harvested separately.

Analysis of Plant Material

The plant material was dried in a forced air drying oven at 100° C. for a period in excess of 24 hours. The dry weight of this material was recorded prior to its preparation for chemical analysis of phosphorus content. Each sample was analyzed sepparately.

The material was finely ground and thoroughly mixed so that a represenative sample could be taken. Single samples of 0.1 g. (for grain) and 0.2 g. (for straw) were weighed to the nearest milligram on an analytical balance and placed in small crucibles. Two ml. of ethyl alcohol containing 1 g. of $Mg(NO_3)_2 \cdot 6H_2O$ per 2.5 ml. was added to each sample and ignited. The samples were ashed for 2 hours at 570° C. in the muffle furnace.

After cooling, the ash was taken up in 5 ml. of 2 N HCl, then filtered and washed through a fine phosphorus free paper into volumetric flasks[1]. The filtrate was neutralized in the presence of phenolphthalein indicator by use of dilute NaOH. The flasks were brought to volume and emptied into 125 ml. Erlenmeyer flasks. One ml. of ammonium molybdate-H_2SO_4 reagent[2] was added per 25 ml. of solution. After briefly mixing, 1 ml. of sulfonic acid

1 One hundred ml. volumetric flasks were used for oat grain, millet grain, and millet straw. The 50 ml. size was used for oat straw. Some specific samples required different dilutions than these in order to give a reading on the scale of the photometer. In such cases new samples had to be taken.

2. Prepared by dissolving 25 g. of ammonium molybdate per l. of 9.6 N H_2SO_4.

reducing reagent[1] was added per 25 ml. of solution. The solution was again mixed briefly and let stand for 15 minutes. The intensity of the molybdate blue color developed was read on the photoelcetric photometer. Concentration of phosphorus (ppm.) was determined by reference to a standard phosphorus curve.

Statistical Methods

Statistical analyses were performed only on the data obtained from the greenhouse experiment. Analyses of variance and least significant differences (where appliable) were determined according to the methods of Snedecor (23). Analyses of variance was determined by considering each soil as a separate complete randomized experiment so as to make comparisons of the various fertilizer treatments on each soil. Yields of the oat and millet crops were analyzed singly and in combination.

The mean yields from four replication of each treatment on each of the five soils were utilized for determining an analysis of variance. Each soil was considered as an individual block of a randomized block design type of experiment. In this way the overall effects of the various fertilizers and methods of application were considered for five soils.

Analyses of variance were computed for grain yields, straw

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1. Prepared by grinding and dry mixing 2.5 g. of 1-amino-2-naphthol-sulfonic acid, 5 g. of Na_2SO_3, and 146.25 g. of $Na_2S_2O_5$. Four g. of the powder mixture was dissolve in 25 ml. of H_2O and allowed to stand several hours before using. The soln. was made up fresh in 3 weeks or as needed.

yields, grain plus straw yields, and total phosphorus uptakes for all of the above mentioned comparisons.

EXPERIMENTAL RESULTS AND DISCUSSION

Laboratory Experiment

Water Soluble Phosphorus. Tables 3 to 7, inclusive, list the amounts of phosphorus removed by successive water extractions of the soils after addition of 50 ppm. of phosphorus from the various fertilizers. Table 8 summarizes the total amounts of water soluble phosphorus extracted from all five soils.

The untreated samples were consistently low in water soluble phosphorus, containing considerably less than 1 ppm. in four of the five soils. The proportion of water soluble phosphorus in the various soils seemingly did not coincide with the amounts of available phosphorus (Table 9). This indicated that the native forms of phosphorus in the various soils were different, or at least present in different proportions. The forms of phosphorus naturally present in the soil might be indicative of the forms that added phosphorus could be expected to revert to. In other words, a soil which was originally low in water soluble phosphorus might be expected to release smaller amounts of added phosphorus when extracted with water than would a soil that was originally rather high in water soluble phosphorus. Such was not the case, however.

The Strouts' farm soil released the second greatest amount of water soluble phosphorus after addition of fertilizers even

Table 3. Phosphorus removed by successive water extractions of Strout farm soil after addition of 50 ppm. of P from the fertilizers indicated.

Fertilizer	Extraction number and P removed (ppm.)*.				
	1	2	3	4	Total
None	0	0	0	0	0
Superphosphate (0-42-0)	0.77	0.975	0.54	0.53	2.81
Ammonium phosphate (16-20-0)	0.725	0.935	0.55	0.54	2.75
Ammoniated superphosphate (16-20-0)	0.57	0.825	0.52	0.555	2.47
Nitraphosphate (15-15-0)	0.42	0.91	0.605	0.585	2.52
Diammonium phosphate (21-53.8-0)	0.91	0.98	0.63	0.59	3.11
Monoammonium phosphate (12.1-61.6-0)	1.05	1.02	0.62	0.585	3.28

* Average of duplicate samples.

Table 4. Phosphorus removed by successive water extractions of Clark soil after addition of 50 ppm. of P from fertilizers indicated.

Fertilizer	Extraction number and P removed (ppm.)*							
	1	2	3	4	5	6	7	Total
None	0.175	0.18	0.207	0.175	0.07	0.16	0.17	1.09
Superphosphate (0-42-0)	0.58	1.52	1.545	1.10	0.86	1.44	0.905	7.95
Ammonium phosphate (16-20-0)	0.615	1.39	1.55	1.52	0.945	1.835	1.04	8.86
Ammoniated superphosphate (16-20-0)	0.68	1.335	1.415	1.415	0.975	1.69	0.855	8.31
Nitraphosphate (15-15-0)	0.585	1.285	1.885	1.18	0.915	1.605	0.87	8.33
Diammonium phosphate (21-53.8-0)	0.935	1.545	1.635	1.13	0.915	1.465	0.685	8.31
Monoammonium phosphate (12.1-61.6-0)	1.055	1.68	1.52	1.365	0.945	1.52	0.855	8.94

* Average of duplicate samples.

Table 5. Phosphorus removed by successive water extractions of Tabler soil after addition of 50 ppm. of P from fertilizers indicated.

Fertilizer	Extraction number and P removed (ppm.)*.							
	1	2	3	4	5	6	7	Total
None	0	0.04	0.04	0.055	0.045	0.10	0	0.29
Superphosphate (0-42-0)	0.52	0.22	0.145	0.23	0.175	0.18	0.02	1.48
Ammonium phosphate (16-20-0)	0.355	0.165	0.185	0.235	0.225	0.205	0.045	1.42
Ammoniated superphosphate (16-20-0)	0.265	0.15	0.155	0.23	0.24	0.175	0.03	1.25
Nitraphosphate (15-15-0)	0.255	0.16	0.19	0.25	0.24	0.205	0.03	1.33
Diammonium phosphate (21-53.8-0)	0.525	0.285	0.145	0.17	0.18	0.16	0.03	1.49
Monoammonium phosphate (12.1-61.6-0)	0.535	0.20	0.125	0.15	0.16	0.18	0.02	1.37

* Average of duplicate samples.

Table 6. Phosphorus removed by successive water extraction of Grundy soil after addition of 50 ppm. of P from fertilizers indicated.

Fertilizer	Extraction number and P removed (ppm.)*.				
	1	2	3	4	Total
None	0	0.035	0.02	0	0.055
Superphosphate (0-42-0)	0.40	0.38	0.08	0	0.86
Ammonium phosphate (16-20-0)	0.365	0.34	0.12	0	0.825
Ammoniated superphosphate (16-20-0)	0.21	0.27	0.11	0	0.59
Nitraphosphate (15-15-0)	0.27	0.355	0.13	0	0.755
Diammonium phosphate (21-53.8-0)	0.405	0.36	0.085	0	0.85
Monoammonium phosphate (12.1-61.6-0)	0.485	0.33	0.13	0	0.945

* Average of duplicate samples.

Table 7. Phosphorus removed by successive water extractions of Parsons soil after addition of 50 ppm. of P from fertilizers indicated.

Fertilizer	Extraction number and P removed (ppm.)*.					
	1	2	3	4	5	Total
None	0.013	0.015	0.018	0.033	0.034	0.113
Superphosphate (0-42-0)	0.065	0.042	0.089	0.080	0.053	0.33
Ammonium phosphate (16-20-0)	0.043	0.080	0.074	0.063	0.060	0.32
Ammoniated superphosphate (16-20-0)	0.052	0.066	0.091	0.069	0.069	0.35
Nitraphosphate (15-15-0)	0.075	0.085	0.147	0.166	0.067	0.54
Diammonium phosphate (21-53.8-0)	0.061	0.040	0.141	0.069	0.071	0.335
Monoammonium phosphate (12.1-61.6-0)	0.055	0.060	0.084	0.137	0.058	0.39

* Average of duplicate samples.

Table 8. Water soluble phosphorus removed* from five soils after addition of various phosphatic fertilizers at the rate of 50 ppm. of P.

Fertilizer	Soil type and P removed**.									
	Strout farm		Clark		Tabler		Grundy		Parsons	
	(ppm.)	(%)	(ppm.)	(%)	(ppm.)	(%)	(ppm.)	(%)	(ppm.)	(%)
None	0	-	1.09	-	0.29	-	0.055	-	0.113	-
Superphosphate (0-42-0)	2.81	5.6	7.95	13.7	1.48	2.4	0.85	1.58	0.33	0.43
Ammonium phosphate (16-20-0)	2.75	5.5	8.86	15.5	1.42	2.3	0.83	1.52	0.32	0.41
Ammoniated superphosphate (16-20-0)	2.47	4.9	8.31	14.4	1.25	1.9	0.59	1.06	0.35	0.47
Nitraphosphate (15-15-0)	2.52	5.0	8.33	14.5	1.33	2,1	0.76	1.40	0.54	0.85
Diammonium phosphate (21-53.8-0)	3.11	6.2	8.31	14.4	1.49	2.4	0.85	1.58	0.335	0.44
Monoammonium phosphate (12.1-61.6-0)	3.28	6.6	8.94	15.7	1.37	2.2	0.95	1.78	0.39	0.55

* Sum of several extracts.
** Average of duplicate samples.

though it contained none before such treatment. Parsons soil contained twice as much water soluble phosphorus originally as did the Grundy. However, only about 1/3 to 2/3 as much was removed by water extraction from the Parsons soil as from the Grundy soil after fertilizers were added. From the evidence presented it apparently must be concluded that there was no relationship between the amount of water soluble phosphorus originally present in a soil and that which was present after addition of phosphatic fertilizer.

During the first extraction of the Strouts' farm soil (Table 3), nitraphosphate and ammoniated superphosphate yielded considerably less phosphorus than did the others. During the same extraction the completely water soluble fertilizers (diammonium and monoammonium phosphates) yielded the greatest amounts. After successive extractions the differences due to the fertilizers became less apparent until at the fourth extraction there was no appreciable difference at all.

These data for this particular soil suggest that the reaction of the insoluble fertilizer phosphorus with the soil was relatively slow (in comparison with other soils). After the reaction had taken place, however, the reverted form of fertilizer phosphorus seemed to be moderately susceptible to water extraction.

Clark soil (Table 4) was outstanding not only because it originally contained a relatively large amount of water soluble phosphorus but also because it released a large amount from the added fertilizers. It appeared that reaction of each fertilizer with the soil was rather rapid since even during the first extraction the effect of the different fertilizers was not very noticeable. As with the Strouts' farm soil, completely water soluble forms of phosphate (monoammonium phosphate and diammonium phosphate) released the most phosphorus during the first extraction.

Even during the seventh extraction considerable water soluble phosphorus was released by each fertilizer. From the evidence presented, it appeared that the forms of phosphate used with this soil had little final effect upon the amount that was extracted by water.

Fertilizers applied to the Tabler soil reacted similar to the way they did with the Strouts' farm soil. During the first water extraction the least water soluble forms of phosphate yielded the least amount of phosphorus while the most soluble forms yielded the most. After the initial extraction the differences were much less noticable. This soil released only small amounts of phosphorus during each extraction. During the seventh extraction there was definite indications that nearly all of the water soluble phosphorus was removed from the samples irrespective of the fertilizer that had been applied.

Grundy soil, like the Tabler and Strouts' farm soils, yielded less water soluble phosphorus during the first extraction from the least water soluble forms of added phosphate. Water soluble phosphorus was completely removed in three extractions. Evidently this soil had the ability to convert added phosphorus quite rapidly to a water insoluble form.

Applied to the Parsons soil, nitraphosphate (the least water soluble form used) released more phosphorus in each extraction except the fifth and last. This was a complete reversal from the way it had reacted with three other soils. There were only small variation among the remaining fertilizers in the first extraction and in the total amount of phosphorus in five extracts. Only very small amounts of phosphorus were removed by each extract by comparison to the other soils. Each successive extraction removed about the same amount of phosphorus as the preceding one, even in the case of the fifth extraction.

It appeared that added phosphate reverted to different forms in the cases of Parsons and Grundy soils. Like the Grundy soil, however, the Parsons soil reacted quickly with added phosphate to convert it to a form relatively, though not nearly so completely, water insoluble.

The proportions of phosphorus recovered as water soluble phosphorus are listed in Table 8. It was evident that the water solubility of added phosphate was far less important than the type of soil in determining the percent of phosphorus that could be removed by water extraction. From the data presented it was not definitely apparent whether any one fertilizer was superior to any other for the entire group of soils. There was some evidence that certain fertilizers may have been superior to others in the case of individual soils, however.

Of special significance was the extreme variation in the percent recovery among the soil types. The recovery from the Parsons soil averaged only about 0.5 percent while the Clark soil released approximately 15 percent.

Available Phosphorus. The amounts and percentages of recovery of available phosphorus[1] for the various soils after removal of water soluble phosphorus are presented in Table 9. As stated before there was no relationship between amounts of water soluble phosphorus and available phosphorus extracted from the various soils where fertilizer was not applied.

The percentage recovery as available phosphorus was influenced more by soil type than by the degree of water solubility of added phosphate. Differences due to the various fertilizers were relatively insignificant for the group of five soils as a whole. Nitraphosphate was noticeably superior to the other fertilizers with the Parsons soil. Ammoniated superphosphate was relatively inferior to the other fertilizers on the Clark and Tabler soils. Ammonium phosphate did not perform as well as other phosphates in the case of the Strouts' farm soil. No logical explanation of this pattern of behavior was apparent. There was considerably less variation among soil types insofar as recovery of available phosphorus was concerned than was true for extraction of water soluble phosphorus, however. Even so recovery ranged from approximately 16 percent with Parsons soil to over 45 percent with Clark soil.

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1 Sum of several water extracts plus NH_4F-HCl extract.

Table 9. Available phosphorus removed* from five soils after addition of various phosphatic fertilizers at the rate of 50 ppm. of P.

Fertilizer	Soil type and P removed**.									
	Strout farm		Clark		Tabler		Grundy		Parsons	
	(ppm.)	(%)	(ppm.)	(%)	(ppm.)	(%)	(ppm.)	(%)	(ppm.)	(%)
None	15.1	-	15.67	-	14.8	-	6.26	-	3.11	-
Superphosphate (0-42-0)	30.01	29.8	39.83	48.3	29.6	32.0	18.85	25.2	11.78	17.3
Ammonium phosphate (16-20-0)	28.25	26.3	39.49	47.6	31.2	35.1	21.13	29.7	11.57	16.9
Ammoniated superphosphate (16-20-0)	31.47	32.7	35.19	39.0	27.6	27.5	18.99	25.5	11.30	16.4
Nitraphosphate (15-15-0)	32.72	35.2	38.96	46.6	29.9	32.3	19.96	27.4	12.34	18.5
Diammonium phosphate (21-53.8-0)	33.31	36.4	43.06	54.8	29.9	32.6	18.85	25.2	10.41	14.6
Monoammonium phosphate (12.1-61.6-0)	34.08	38.0	39.57	47.8	28.7	30.0	18.95	25.4	10.46	14.7

* Sum of several water extracts plus NH_4F-HCl extract.
** Average of duplicate samples.

Greenhouse Experiment

Oat Crop. Various yield data for the oat crop are listed in Tables 10 to 13, inclusive. Only with Parsons soil were significant variations in grain yields (Table 10) produced as a result of application of phosphatic fertilizer. With this soil there also were significant variations as a result of application of different fertilizers and as a result of the placement methods. Nitraphosphate, banded ammoniated superphosphate, and mixed monoammonium phosphate were least effective of the fertilized treatments.

Straw yields (Table 11) varied significantly only in the cases of Tabler and Parsons soils. With these soils, only the controls produced inferior results.

Combined yields of grain plus straw are presented in Table 12. Significant effects were noted only in the case of Parsons soil. Differences due to placement were not significant.

The effects of various fertilizers or placement methods on plant uptake of phosphorus (Table 13) were significant with three of the five soils. Nitraphosphate, particularly when banded, was inferior to the other forms on the Clark soil. Superphosphate when mixed with the soil and ammoniated superphosphate when banded did not significantly increase the uptake of phosphorus on Tabler soil. Banded ammonium phosphate was superior to banded ammoniated superphosphate with this soil, however.

Phosphate applied from any source approximately doubled the phosphorus yield on Parsons soil. This fact further substantiated

Table 10. Oat grain yields obtained from greenhouse experiment with five soils fertilized with various phosphate carriers (50 lbs./A. of available P_2O_5) applied as indicated.

Treatment	Placement method	Soil type and yields in g./pot. Strout farm	Clark	Tabler	Grundy	Parsons	Average of five soils
No phosphate		7.35	6.05	4.56	6.49	2.52	5.39
Superphosphate (0-42-0)	Banded	8.86	5.48	4.64	6.16	4.79	5.99
	Mixed	6.54	6.21	5.69	7.46	4.61	6.10
Ammonium phosphate (16-20-0)	Banded	7.56	6.40	4.99	5.75	4.39	5.82
	Mixed	7.38	6.65	5.48	6.02	4.53	6.01
Ammoniated superphosphate (16-20-0)	Banded	5.58	6.68	4.56	7.04	3.16	5.40
	Mixed	7.52	7.32	4.54	6.03	4.03	5.89
Nitraphosphate (15-15-0)	Banded	6.88	5.49	5.61	6.57	3.30	5.57
	Mixed	7.69	6.11	5.72	7.63	3.35	6.10
Monoammonium phosphate (12.1-61.6-0)	Banded	7.62	5.59	5.73	6.51	4.65	6.02
	Mixed	6.95	5.89	6.56	7.50	3.64	6.11
L.S.D. at P = 0.05		N.S.	N.S.	N.S.	N.S.	0.58	N.S.
L.S.D. at P = 0.01		N.S.	N.S.	N.S.	N.S.	0.78	N.S.

Table 11. Oat straw yields obtained from greenhouse experiment with five soils fertilized with various phosphate carriers (50 lbs./A. of available P_2O_5) applied as indicated.

Treatment	Placement method	Soil type and yields in g./pot. Strout farm	Clark	Tabler	Grundy	Parsons	Average of five soils
No phosphate		19.30	19.20	15.86	16.05	9.03	15.94
Superphosphate (0-42-0)	Banded	20.3	20.10	18.45	17.80	13.00	17.93
	Mixed	21.55	19.55	17.85	17.25	12.35	17.71
Ammonium phosphate (16-20-0)	Banded	19.70	21.00	20.45	19.25	13.10	18.70
	Mixed	21.30	21.55	18.70	16.80	13.40	18.35
Ammoniated superphosphate (16-20-0)	Banded	19.50	20.10	19.30	15.85	11.50	17.25
	Mixed	19.60	20.70	20.70	18.45	12.30	18.35
Nitraphosphate (15-15-0)	Banded	19.25	19.10	18.90	17.10	12.40	17.35
	Mixed	21.00	20.25	16.45	17.40	11.70	17.36
Monoammonium phosphate (12.1-61.6-0)	Banded	22.25	19.25	17.40	15.75	13.00	17.53
	Mixed	20.90	19.50	19.20	18.50	11.90	18.00
L.S.D. at P = 0.05		N.S.	N.S.	2.80	N.S.	1.83	N.S.
L.S.D. at P = 0.01		N.S.	N.S.	N.S.	N.S.	2.46	N.S.

Table. 12. Oats plant yields (grain and straw) obtained from greenhouse experiment with five soils fertilized with various phosphate carriers (50 lbs./A. of available P_2O_5) applied as indicated.

Treatment	Placement method	Soil type and yields in g./pot.					
		Strout farm	Clark	Tabler	Grundy	Parsons	Average of five soils
No phosphate		26.65	25.25	20.42	22.54	11.82	21.34
Superphosphate (0-42-0)	Banded	29.16	25.58	23.09	23.96	17.79	23.92
	Mixed	28.09	25.76	23.54	24.71	16.96	23.81
Ammonium phosphate (16-20-0)	Banded	27.26	27.40	25.44	25.00	17.49	24.52
	Mixed	28.68	28.20	24.18	22.82	17.93	24.36
Ammoniated superphosphate (16-20-0)	Banded	25.08	26.78	23.86	22.89	14.66	22.65
	Mixed	27.12	28.02	25.24	24.48	16.33	24.24
Nitraphosphate (15-15-0)	Banded	26.13	24.59	24.51	23.67	15.70	22.92
	Mixed	28.69	26.36	22.17	25.03	15.05	23.46
Monoammonium phosphate (12.1-61.6-0)	Banded	29.87	24.84	23.13	22.26	17.65	23.55
	Mixed	27.85	25.39	25.76	26.00	15.54	24.11
L.S.D. at P = 0.05		N.S.	N.S.	N.S.	N.S.	2.18	1.67
L.S.D. at P = 0.01		N.S.	N.S.	N.S.	N.S.	2.93	N.S.

Table 13. Oat plant phosphorus yields (grain and straw) obtained from greenhouse experiment with five soils fertilized with various phosphate carriers (50 lbs./A. of available P_2O_5) applied as indicated.

Treatment	Placement method	Soil type and yields in mg./pot.					
		Strout farm	Clark	Tabler	Grundy	Parsons	Average of five soils
No phosphate		17.46	20.45	12.12	15.27	4.42	13.94
Superphosphate (0-42-0)	Banded	25.64	32.89	16.04	19.06	10.55	20.84
	Mixed	23.26	30.79	14.96	19.88	9.50	19.68
Ammonium phosphate (16-20-0)	Banded	20.72	30.95	16.95	20.98	10.37	19.99
	Mixed	21.47	32.21	17.04	18.24	9.93	19.78
Ammoniated superphosphate (16-20-0)	Banded	18.03	29.90	14.76	17.92	8.06	17.73
	Mixed	21.95	31.94	17.25	18.86	9.24	19.85
Nitraphosphate (15-15-0)	Banded	21.80	23.11	16.60	19.38	7.87	17.75
	Mixed	24.67	26.56	16.56	20.19	7.30	19.06
Monoammonium phosphate (12.1-61.6-0)	Banded	24.01	31.64	19.38	20.70	10.28	21.12
	Mixed	21.14	28.37	18.60	20.13	7.72	19.19
L.S.D. at P = 0.05		N.S.	5.72	3.78	N.S.	1.04	2.28
L.S.D. at P = 0.01		N.S.	7.70	N.S.	N.S.	1.40	3.04

the laboratory findings that this soil was very low in naturally available phosphorus. Highly water soluble forms of phosphate produced the greatest yields of phosphorus with this soil when banded with the seed. In contrast, banded ammoniated superphosphate yielded significantly less phosphorus than the same did when mixed with the soil.

For the average of five soils, phosphorus yields were significantly increased by each fertilizer when compared to that where phosphorus was not added. Banded ammoniated superphosphate and banded nitraphosphate were significantly inferior to the other treatments with respect to supplying phosphorus to plants.

Millet Crop. The residual effect of the various phosphate fertilizers supplied to the oat experiment were evaluated by growing a subsequent millet crop. Tables 14 to 17, inclusive, list the yields for this crop.

Significant variations among grain yields for the various treatments occurred with three soils (Table 14). Some fertilizer treatments did not increase the yield of millet. In fact, with Grundy soil nitraphosphate mixed with the soil yielded significantly less than the control while band placement of the same fertilizer produced the greatest yield of any treatment. This high yield might be explained due to the fact that this relatively insoluble phosphate was less likely fixed during the oat experiment when banded than were more soluble substances. No reasonable explanation can be postulated by the writer as to why the mixed nitraphosphate decreased the millet yield. There may have been the possibility that some foreign unobserved controlling

Table 14. Millet grain yields obtained from greenhouse experiment with five soils fertilized with various phosphate carriers* (50 lbs./A. of available P_2O_5) applied as indicated.

Treatment	Placement method	Soil type and yields in g./pot.					
		Strout farm	Clark	Tabler	Grundy	Parsons	Average of five soils
No phosphate		2.56	1.40	2.12	4.12	0.81	2.20
Superphosphate	Banded	2.28	1.97	2.12	2.87	1.74	2.20
(0-42-0)	Mixed	2.34	2.52	1.40	3.94	1.16	2.27
Ammonium phosphate	Banded	1.95	4.68	1.64	3.37	1.79	2.69
(16-20-0)	Mixed	2.62	4.94	2.40	3.86	1.67	3.10
Ammoniated superphosphate	Banded	2.49	4.34	2.63	3.76	1.62	2.97
(16-20-0)	Mixed	2.60	3.39	1.95	3.51	1.84	2.66
Nitraphosphate	Banded	2.31	3.26	3.10	4.81	1.83	3.06
(15-15-0)	Mixed	2.40	4.47	2.18	1.68	1.72	2.49
Monoammonium phosphate	Banded	2.72	1.65	1.54	3.97	1.62	2.30
(12.1-61.6-0)	Mixed	2.79	1.52	1.59	3.62	1.38	2.18
L.S.D. at P = 0.05		N.S.	1.34	N.S.	1.54	0.477	0.620
L.S.D. at P = 0.01		N.S.	1.80	N.S.	N.S.	0.638	0.838

* Residual from oat experiment.

Table 15. Millet straw yields obtained from greenhouse experiment with five soils fertilized with various phosphate carriers* (50 lbs./A. of available P_2O_5) applied as indicated.

Treatment	Placement method	Soil type and yields in g./pot.					
		Strout farm	Clark	Tabler	Grundy	Parsons	Average of five soils
No phosphate		6.09	5.90	5.51	6.18	2.28	5.19
Superphosphate (0-42-0)	Banded	5.28	6.58	5.32	6.01	3.39	5.32
	Mixed	5.01	6.94	5.06	6.43	3.19	5.33
Ammonium phosphate (16-20-0)	Banded	5.32	7.28	4.46	5.40	2.96	5.08
	Mixed	5.76	7.50	4.82	6.58	3.35	5.60
Ammoniated superphosphate (16-20-0)	Banded	5.52	7.30	5.08	6.40	2.66	5.39
	Mixed	6.33	6.78	4.73	6.47	3.32	5.53
Nitraphosphate (15-15-0)	Banded	5.70	7.09	5.63	6.61	3.20	5.65
	Mixed	5.70	7.26	5.23	4.20	3.67	5.21
Monoammonium phosphate (12.1-61.6-0)	Banded	5.79	6.29	4.52	5.72	3.01	5.07
	Mixed	6.14	6.46	5.37	6.07	3.22	5.45
L.S.D. at P = 0.05		N.S.	N.S.	N.S.	N.S.	0.555	N.S.
L.S.D. at P = 0.01		N.S.	N.S.	N.S.	N.S.	0.753	N.S.

* Residual from oat experiment.

Table 16. Millet plant yields (grain and straw) obtained from greenhouse experiment with five soils fertilized with various phosphate carriers* (50 lbs./A. of available P_2O_5) applied as indicated.

Treatment	Placement method	Soil type and yields in g./pot. Strout farm	Clark	Tabler	Grundy	Parsons	Average of five soils
No phosphate		8.65	7.30	7.63	10.30	3.09	7.39
Superphosphate (0-42-0)	Banded	7.56	8.55	7.44	8.88	5.13	7.51
	Mixed	7.35	9.46	6.46	10.37	4.35	7.60
Ammonium phosphate (16-20-0)	Banded	7.27	11.96	6.10	8.77	4.75	7.77
	Mixed	8.38	12.44	7.22	10.44	5.02	8.70
Ammoniated superphosphate (16-20-0)	Banded	8.01	11.64	7.71	10.16	4.28	8.36
	Mixed	8.93	10.17	6.68	9.98	5.16	8.18
Nitraphosphate (15-15-0)	Banded	8.01	10.35	8.73	11.42	5.03	8.71
	Mixed	8.10	11.73	7.41	5.88	5.39	7.70
Monoammonium phosphate (12.1-61.1-0)	Banded	8.51	7.94	6.06	9.69	4.63	7.37
	Mixed	8.93	7.98	6.96	9.69	4.60	7.63
L.S.D. at P = 0.05		N.S.	2.082	N.S.	2.80	1.09	N.S.
L.S.D. at P = 0.01		N.S.	2.750	N.S.	N.S.	0.81	N.S.

* Residual from oat experiment.

Table 17. Millet plant phosphorus yields (grain and straw) obtained from greenhouse experiment with five soils fertilized with various phosphate carriers* (50 lbs./A. of available P_2O_5) applied as indicated.

		Soil type and yields in mg./pot.					
Treatment	Placement method	Strout farm	Clark	Tabler	Grundy	Parsons	Average of five soils
No phosphate		9.38	21.37	7.98	12.33	2.66	10.74
Superphosphate (0-42-0)	Banded	9.31	21.28	7.68	11.40	4.88	10.91
	Mixed	8.96	24.47	7.12	14.47	4.19	11.84
Ammonium phosphate (16-20-0)	Banded	8.85	16.51	4.75	11.40	5.36	9.37
	Mixed	10.15	18.35	6.78	14.19	5.40	10.97
Ammoniated superphosphate (16-20-0)	Banded	9.38	14.48	7.08	13.44	5.14	9.90
	Mixed	9.80	16.08	6.66	12.34	5.82	10.14
Nitraphosphate (15-15-0)	Banded	9.88	13.88	8.54	16.92	6.53	11.15
	Mixed	10.14	17.90	7.03	7.04	6.15	9.65
Monoammonium phosphate (12.1-61.6-0)	Banded	10.48	20.33	5.50	14.14	5.91	11.27
	Mixed	11.23	27.57	7.90	14.07	4.56	13.07
L.S.D. at P = 0.05		N.S.	5.00	N.S.	N.S.	1.19	N.S.
L.S.D. at P = 0.01		N.S.	6.74	N.S.	N.S.	1.60	N.S.

* Residual from oat experiment.

factor was present.

Residual effect of the fertilizers was most pronounced with the Parsons soil insofar as it affected grain and straw yields. This soil also produced the least yields of grain and straw of any of the soils. Placement of fertilizer had significant influence on fertilizer behavior only with superphosphate. Band placement was superior to mixing with the entire soil volume.

Fertilizer placement did not produce significant variations in grain yields in the case of Clark soil. There was considerable variation among the fertilizers on this soil, however. Superphosphate and monoammonium phosphate produced the least grain yields.

Table 16 presents the total amount of grain plus straw harvested from the millet crop. Again only the Clark, Grundy and Parsons soils had significant variation in yields due to the added fertilizer treatments. What has been said about grain yields for these soils also applied to the total plant yield.

Phosphorus yields of the millet crop are listed in Table 17. Only Clark and Parsons soils had significant variations. With Clark soil, ammoniated superphosphate, both banded and mixed, and banded nitraphosphate yielded significantly less than the control. Again no satisfactory explanation can be offered for this behavior. Only monoammonium phosphate mixed with the soil significantly increased the phosphorus yield over the check.

Each fertilizer caused a significant phosphorus yield increase with the Parsons soil. Nitraphosphate was the most outstanding fertilizer with this soil. Placement of the fertilizers caused significant effect only with monoammonium phosphate. Band placement was the best. This was the opposite of its effect with Clark soil.

Sum of Two Crops. Tables 18 and 19 present yields for the combined oat and millet crops. Total plant yields (Table 18) varied significantly only in cases of Clark and Parsons soils. Ammonium phosphate, ammoniated superphosphate, and mixed nitraphosphate significantly increased yields over the no phosphate treatment with the Clark soil. Mixed nitraphosphate was superior to band placement of the same.

With the Parsons soil, total plant yields were quite significantly increased as a result of each fertilizer treatment. Mixed placement was the best for ammoniated superphosphate while banding was best for monoammonium phosphate.

Total plant phosphorus uptake (Table 19) varied significantly only with Clark and Parsons soils and for the average of all five soils. Nitraphosphate, ammoniated superphosphate, and banded ammonium phosphate did not significantly increase the phosphorus yield over the check with the Clark soil. This was of interest since only these same treatments (banded nitraphosphate excepted) increased the total plant yields over the check (Table 18). Superphosphate and monoammonium phosphate caused just the opposite effect.

All fertilized cultures of Parsons soil yielded approximately twice as much plant phosphorus as the control cultures. There were significant variations among the fertilizers and placement methods also. Banded monoammonium phosphate was definitely

Table 18. Total plant yields from oat and millet crops from greenhouse experiments with five soils fertilized with various phosphate carriers* (50 lbs./A. of available P_2O_5) applied as indicated.

Treatment	Placement method	Soil type and yields in g./pot.					
		Strout farm	Clark	Tabler	Grundy	Parsons	Average of five soils
No phosphate		35.30	32.55	28.05	32.84	14.91	28.73
Superphosphate (0-42-0)	Banded	36.72	34.13	30.53	32.84	22.92	31.43
	Mixed	35.44	35.22	30.00	35.08	21.31	31.41
Ammonium phosphate (16-20-0)	Banded	34.53	39.36	31.54	33.77	22.24	32.39
	Mixed	37.06	40.64	31.40	33.26	22.95	33.06
Ammoniated superphosphate (16-20-0)	Banded	33.09	38.42	31.57	33.05	18.94	31.01
	Mixed	36.05	38.19	31.92	34.46	21.49	32.42
Nitraphosphate (15-15-0)	Banded	34.14	34.94	33.24	35.09	20.73	31.63
	Mixed	36.79	38.09	29.50	30.91	20.44	31.16
Monoammonium phosphate (12.1-61.6-0)	Banded	38.38	32.78	29.19	31.95	22.28	30.92
	Mixed	36.78	33.37	32.72	35.69	20.14	31.74
L.S.D. at $P = 0.05$		N.S.	3.54	N.S.	N.S.	1.97	N.S.
L.S.D. at $P = 0.01$		N.S.	4.76	N.S.	N.S.	2.66	N.S.

* Applied only to oat experiment.

Table 19. Total plant phosphorus yields from oat and millet crops from greenhouse experiments with five soils fertilized with various phosphate carriers* (50 lbs./A. of available P_2O_5) applied as indicated.

Treatment	Placement method	Soil type and yields in mg./pot. Strout farm	Clark	Tabler	Grundy	Parsons	Average of five soils
No phosphate		26.84	41.82	20.10	27.60	7.08	24.69
Superphosphate (0-42-0)	Banded	34.95	54.17	23.72	30.46	15.43	31.75
	Mixed	32.22	55.26	22.08	34.35	13.69	31.52
Ammonium phosphate (16-20-0)	Banded	29.57	47.46	21.70	32.38	15.73	29.37
	Mixed	31.62	50.56	23.82	32.43	15.33	30.75
Ammoniated superphosphate (16-20-0)	Banded	27.41	44.38	21.24	31.36	13.20	27.64
	Mixed	31.75	48.02	23.91	31.20	15.06	29.99
Nitraphosphate (15-15-0)	Banded	31.68	36.99	25.14	36.30	14.40	28.90
	Mixed	34.81	44.46	23.59	27.23	13.45	28.11
Monoammonium phosphate (12.1-61.6-0)	Banded	34.49	51.97	24.88	34.84	16.19	32.47
	Mixed	32.37	55.94	26.50	34.20	12.28	32.26
L.S.D. at P = 0.05		N.S.	7.43	N.S.	N.S.	1.385	3.68
L.S.D. at P = 0.01		N.S.	10.00	N.S.	N.S.	1.877	5.06

* Applied only to oat experiment.

superior to the same fertilizer mixed. These two treatments yielded, respectively, the greatest and least amounts of plant phosphorus among the various phosphate treatments. Also, banding was the best method for applying superphosphate but mixed placement was best for ammoniated superphosphate.

When considering the average of all five soils, banded ammoniated superphosphate and mixed nitraphosphate were the only two treatments that did not increase total phosphorus yields. Placement of fertilizer had no significant effect with any of the fertilizers. Monoammonium phosphate and superphosphate were the best sources for supplying phosphorus to the plants.

SUMMARY AND CONCLUSIONS

Phosphatic fertilizers of varying degrees of water solubility were tested in the laboratory to compare their abilities to supply water soluble phosphorus and available phosphorus after being applied to soil. These fertilizers were also used in a greenhouse experiment to compare their effects on plant growth. Two placement methods (banding with the seed and mixing with the entire soil) were used for each fertilizer. Residual effects were evaluated by growth of a millet crop after the harvest of an initial crop of oats. Grain yields, straw yields, total plant yields, and total phosphorus yields were determined and evaluated statistically for each crop alone and for the two combined. Five cropland soils from widely scattered areas in the eastern half of Kansas were utilized in the experiments.

Each soil was naturally low in water soluble phosphorus, ranging from none to slightly more than 1 ppm. After the fertilizers were added to the soils there was some variation in the amount of phosphorus that could be extracted by water. These differences occurred mostly during the first extraction. The sum of several successive extractions failed to show any marked differences in the amount of phosphorus removed as a result of initial variation in water solubility of the fertilizers. There were large variations attributable to soil types, however. Recovery of added phosphorus by water extraction varied from approximately 0.5 to 15 percent, depending on the soil type.

Variations in amounts of chemically available phosphorus extracted from the laboratory soil samples were small when comparing the various fertilizers. However, there was large variations among soil types.

Oat grain yields from the greenhouse experiment varied significantly only in the case of Parsons soil. Nitraphosphate, banded ammoniated superphosphate and mixed monoammonium phosphate were the least effective of all treatments. Oat plant phosphorus yields were significantly different in the case of three of the five soils. Various fertilizers did not behave the same on all soils, however. For the average of five soils, phosphorus yields were significantly increased by each fertilizer as compared to the control. Banded ammoniated superphosphate and banded nitraphosphate were inferior to the other treatment.

Residual effects of the fertilizers (as measured by millet yields) were significant with three soils. The variations were not consistent for any given treatment with all of the soils involved. In general, Parsons soil reflected greatest residual response. This soil contained the least naturally available phosphorus.

Phosphorus yields abtained with millet varied significantly with both Clark and Parsons soils. Ammoniated superphosphate and banded nitraphosphate actually yielded less phosphorus than the control in the case of Clark soil. No explanation of this was provided. With Parsons soil, each fertilized treatment yielded approximately twice as much phosphorus as the control.

Total plant yields and total plant phosphorus yields for the sum of two crops varied significantly in the cases of Clark and Parsons soils only. Band placement was superior to mixing for superphosphate and monoammonium phosphate with the Parsons soil while mixed placement was best for nitraphosphate. Yield data from the Clark soil were quite variable and provided no convincing evidence.

Of particular significance with reference to the greenhouse experiment was the fact that, for all practical purposes, only the Parsons and Clark soils (containing respectively the least and the most amounts of naturally occurring available phosphorus of the five soils) gave significant responses to the addition of phosphate fertilizers.

It must be concluded that this experiment failed to provide any convincing evidence that degree of water solubility of added phosphate materially influenced crop response.

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AVAILABILITY OF PHOSPHORUS FROM CERTAIN PHOSPHATE FERTILIZERS WHEN APPLIED TO FIVE KANSAS SOILS

by

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In recent years various phosphatic fertilizers have been introduced which have a wide range in degree of water solubility of phosphorus. The fertilizers used in this experiment and the percentages of their total P_2O_5 contents soluble in water were as follows: Concentrated superphosphate (68.5), commercial ammonium phosphate (69.7), ammoniated superphosphate (52), nitraphosphate (12.2), diammonium phosphate (100), and monoammonium phosphate (100). These fertilizers were evaluated in the laboratory insofar as ability to be removed by successive water extractions and subsequent NH_4F-HCl extraction after 50 ppm. of phosphorus from each had been applied to five different Kansas soils. The soils were collected from fields representing widely separated areas in the eastern half of the state.

A greenhouse pot culture experiment was designed to evaluate the same materials. The fertilizers were applied by two methods (banding with seed and mixing with entire pot of soil) at a rate equivalent to 50 pounds per acre of available P_2O_5. Initially an oat crop was grown and this was followed by a millet crop to test the residual effects of the fertilizers.

Grain yields, straw yields, total plant yields, and total plant phosphorus yields were determined for each crop separately and for the combined crops. Data from the greenhouse experiment were statistically analyzed.

Each soil was naturally low in water soluble phosphorus content, ranging from none to slightly more than 1 ppm. Only with the first water extraction was there noticeable variation in amount of phosphorus removed as the result of various fertilizer treatments. The least soluble forms of fertilizer phosphorus released the least amounts of phosphorus only in the cases of three of the five soils. However, the final amount extracted by water was about the same for a given soil regardless of the fertilizer added. Soil type had far greater effect than kind of fertilizer on controlling the amount of water soluble phosphorus removed from fertilized soil. Recovery of added phosphorus by water extraction ranged from approximately 0.5% to 15% for the various soil types.

Only small variation as to the amount of available phosphorus that could be extracted from any given soil existed for the various fertilizers. There was considerable variation due to soil type, however.

Oat grain yield response to fertilization was very small, being significantly increased only with one soil (the soil lowest in available phosphorus). On this soil nitraphosphate, banded ammoniated superphosphate and mixed placement of monoammonium phosphate were the least effective of all treatments. Oat plant phosphorus uptake varied significantly on three of the five soils but a given fertilizer did not behave the same on all soils. Considering the average of oat phosphorus yields from all five soils, each fertilizer treatment was significantly superior to the control. Banded ammoniated superphosphate and banded nitraphosphate were somewhat inferior to the other treatments.

Residual effects of the fertilizer treatments, as measured by effect upon yield of millet, were significant in cases of three soils. As before, the soil naturally lowest in chemically available phosphorus content responded most in this regard. Variations in millet yields as the result of fertilizer treatments were not consistent among the soil types.

Total plant material yields and total plant phosphorus yields for the sum of two crops varied significantly with two soils. These two soils contained respectively the least and the most naturally available soil phosphorus.

Because of the very slight yield response to added phosphate no clear cut evidence was obtained with regard to whether or not the degree of water solubility of phosphorus was related to crop response. Limited evidence was obtained that band placement was superior to mixing for fertilizers which contained most of the phosphorus in water soluble form. Also, some evidence was obtained that mixing with the soil was the best placement method for fertilizers which contained most of the phosphorus in forms which were not water soluble.