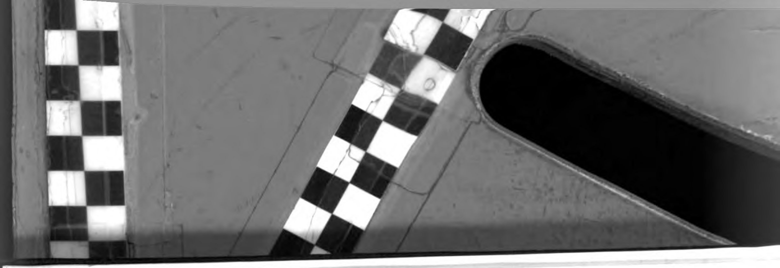

THE EFFECT OF DIFFERENT PHOSPHATE CARRIERS AND LIME ON THE YIELD AND PHOSPHORUS CONTENT OF ALFALFA, BEANS, AND WHEAT

by

HUGH W.alter HOUGH

A THESIS

Submitted to the School of Graduate Studies of
Michigan State College of Agriculture and
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of the requirements for the degree

of

DOCTOR OF PHILOSOPHY

Department of Soil Science

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The writer is grateful to the Soils and Fertilizer Research Branch, Division of Agricultural Relations, Tennessee Valley Authority, Knoxville, Tennessee, for the supply of experimental phosphate materials used in this study.

THE EFFECT OF DIFFERENT PHOSPHATE CARRIERS AND LIME ON THE YIELD AND PHOSPHORUS CONTENT OF ALFALFA, BEANS, AND WHEAT

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An Abstract

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Approved ______________________________

ABSTRACT

Rock phosphate, dicalcium phosphate, fused tricalcium phosphate, potassium metaphosphate, calcium metaphosphate, and superphosphate were added to Miami sandy loam in greenhouse pots. Applications were made at two levels on limed and unlimed soil. Alfalfa, white pea beans, and wheat were used as the test crops.

For alfalfa, these treatments, ranked from the highest to the lowest according to yields and total phosphorus removed in forage, were superphosphate, potassium metaphosphate, dicalcium phosphate, calcium metaphosphate, fused tricalcium phosphate, rock phosphate, and no treatment. Except where the alfalfa was treated with potassium metaphosphate and rock phosphate, lime (pH 7.2-7.5) caused lower yields for the first cutting and higher yields for the third cutting.

Bean and wheat yields on the limed soil ranked as follows: potassium metaphosphate, superphosphate, calcium metaphosphate, dicalcium phosphate, fused tricalcium phosphate, rock phosphate, and no treatment. The treatments which were unlimed gave more favorable results for fused tricalcium phosphate and calcium metaphosphate.

For all crops the concentration of phosphorus, in the part of the plant taken for yield, had no correlation with yield. This might not have been true for potassium metaphosphate which consistently produced the highest concentration of phosphorus in alfalfa and bean tissue but those data were not correlated separately with yields.

In the field, white pea beans were grown with 80 lbs. per acre total P_2O_5 supplied by each of the aforementioned carriers plus concentrated superphosphate. There were no significant differences in yield as affected by the differences in source of phosphate. The effects of the 0, 1.5, and 3 tons of lime per acre were more consistent but still were not statistically significant though the 1.5 ton rate appeared to be the best.

Both greenhouse and field soil samples were extracted with Bray's Available extracting reagent as well as with Bray's Adsorbed extracting reagent at two dilutions (1:10 and 1:50). With alfalfa and beans the latter method seemed to give nearly equal results for both dilutions when the amounts of phosphorus extracted were correlated with yields (0.5 or higher). No significance was obtained for a similar correlation of test results with the yield of wheat grain.

A significant negative correlation was obtained between the pH of field plot soil and the concentration of soil phosphorus using Bray's adsorbed method with the 1:50 dilution.

The acid in the Bray's available extracting reagent extracted large amounts of phosphorus from the soil fertilized with rock phosphate thus being the cause of a poor correlation with crop yields.

Vita

Hugh Walter Hough

candidate for the degree of

Doctor of Philosophy

Dissertation: The effect of different phosphate carriers and lime on the yield and phosphorus content of alfalfa, beans, and wheat.

Outline of Studies:

Major subject: Soil Science

Minor subjects: Physical Chemistry
Farm Crops

Biographical Items:

Born, February 10, 1922, Hebron, Indiana

Undergraduate studies at Purdue University, 1940-1942, 1946-1947

Graduate studies: Purdue University, 1947-1948; Michigan State College, 1949-1953

Experience: Member of Army of the United States 1942-1945; Faculty Sponsor in Purdue Men's Dormitory System, 1946-1947; Graduate Assistant, Purdue University, Agronomy Dept., 1947-1948; Instructor in Soil Science, Michigan State College, 1949-1953.

Member: American Society of Agronomy,
Soil Science Society of America
Sigma Xi

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THE EFFECT OF DIFFERENT PHOSPHATE CARRIERS AND LIME ON THE YIELD AND PHOSPHORUS CONTENT OF ALFALFA, BEANS, AND WHEAT

INTRODUCTION

The rapid increase in the amount of fertilizer distributed after World War II brought into sharp focus the limitations in the production of superphosphate. It was felt by many agronomists that the limited production of superphosphate might seriously affect fertilizer production and usage. This stimulated a re-examination of the efficiencies, properties, and possible supplies of all phosphate carriers.

Increased production of superphosphate was hampered by an increasingly short supply of sulphuric acid. Depletion of the sulphur stockpiles plus expansion of the chemical industries were the chief causes of the short supply of sulphuric acid for fertilizer production.

All industries using sulphuric acid examined the possibility of substituting other acids in their processes or of accomplishing either the elimination of the acid or the increasing of its efficiency. The alternatives available to the phosphate fertilizer industry for additional phosphate fertilizer production beyond that possible with the present supply of sulphuric acid may be listed as: (1) partial or complete substitution of nitric or phosphoric acid for sulphuric acid in the acidulation of phosphate rock; (2) production of metaphosphates; (3) production of defluorinated phosphates; (4) direct use of pulverized raw phosphate rock.

While some of these materials are not new to the agronomists, it seemed wise to test both the old and the new materials quite thoroughly with different crops, at various rates of application, and with different rates of lime application.

Present soil tests have been calibrated with field tests in which superphosphate has been the source of added phosphorus. It may be necessary to recalibrate these tests when other sources of phosphate fertilizer are used. For this reason it was felt that several different extracting procedures should be used on the soil samples taken in this study.

When the proper conditions for maximum response from the application of the materials used in this study are known, it may be possible to utilize them profitably to alleviate the phosphate fertilizer shortage.

REVIEW OF LITERATURE

Fried and MacKenzie (10) found that with rock phosphate, the higher the soil pH, the lower the relative amounts of fertilizer phosphorus to soil phosphorus is absorbed by plants. With superphosphate, soil pH did not influence this relative uptake. At pH 5.8, plant removal of phosphorus from superphosphate equalled or exceeded removal from rock phosphate even when the latter material was applied at rates which added four times as much P_2O_5.

In a greenhouse study of four Michigan soil types, Ripley (23) obtained higher yields of crops and higher phosphorus content of sap where superphosphate was applied at 100 pounds per acre than where treatments of finely ground rock phosphate as high as 1600 pounds per acre were applied.

Even when rock phosphate was applied at two to five times the P_2C_5 rate of superphosphate on various Indiana soils Wiancko and Conner (35) found that the returns were much greater from the superphosphate applications.

Whittaker, et al (34) found in the greenhouse that, for sudan grass and wheat, rock phosphate in general gave much lower crop response than the other phosphates and that response was less affected by varying placement. They also showed that tricalcium phosphate and especially dicalcium phosphate gave greatly reduced yields in a localized placement. Localization of the phosphate in a band placement or mixing with a limited proportion of the soil in the pot were

optimum placements for monocalcium phosphate, the principal phosphatic component of superphosphate.

In general, Jacob and Ross (15) found that fused rock phosphate and calcium metaphosphate were approximately equal to superphosphate as sources of phosphorus for the growth of plants on acid and neutral soils, but the results of a single series of experiments indicated that these materials, as well as the other types of water-insoluble phosphates, are not so effective as water-soluble phosphates (monocalcium phosphate and superphosphate) on alkaline soils.

Rich and Lutz (22) showed that in comparison to superphosphate at 100, rock phosphate applied in equivalent rates of P_2O_5 gave a relative yield of 92 for alfalfa and 84 for wheat. They also used corn, wheat, red clover-timothy, alfalfa, and pasture to test dicalcium phosphate and tricalcium phosphate against concentrated superphosphate. Their results showed that dicalcium phosphate was inferior to the concentrated superphosphate though superior to tricalcium phosphate for both the wheat and alfalfa. The wheat gave the lowest response of all crops tested with dicalcium and tricalcium phosphates.

On the calcareous soils of Idaho, Toevs and Baker (31) found rock phosphate unsatisfactory as a source of phosphorus for alfalfa and several other crops. They also showed fused tricalcium phosphate to be an unsatisfactory source of phosphorus on alkaline soils. For calcium metaphosphate they had inconsistent results, but in general found it to be inferior

to superphosphate and better than fused tricalcium phosphate.

According to Volk (32) superphosphate and calcium metaphosphate were the best phosphate fertilizers for oats and sorghum, fused rock phosphate was almost as good as the former two, and ordinary rock was decidedly inferior.

Brammel (3) growing oats in the field on Brookston silt loam in Michigan found that of the non-nitrogen bearing phosphates, superphosphate was highest in availability followed by dicalcium phosphate which was nearly equalled by fused tricalcium phosphate and calcium metaphosphate. He also found that differences in availability to the plant of phosphorus from the various phosphate carriers became progressively less pronounced during the growing season.

Stanford and Nelson (29) used dicalcium phosphate, alpha tricalcium phosphate, superphosphate, and calcium metaphosphate on three soils in Iowa for oats and alfalfa, and concluded that yields of dry matter at various stages of growth and grain yields at harvest gave no indication of a differential response to phosphate sources.

Working with the same phosphate materials in Colorado, Olsen and Gardner (20) obtained increases in yield from the application of superphosphate and calcium metaphosphate for sugar beets and wheat.

Alway and Nesom (1) stated that for alfalfa both calcium metaphosphate and fused tricalcium phosphate would be as effective as superphosphate when well incorporated with the

soil in advance or at the time of planting the crop, at least on all but calcareous soils. They also showed that the benefit from top-dressing alfalfa with calcium metaphosphate was slight during the first season and much greater during the second season, in fact, nearly equal to superphosphate.

Sherwood, et al (25) used fused tricalcium phosphate, calcium metaphosphate, and concentrated superphosphate at equal total P_2O_5 rates on pasture and failed to obtain significant differences in yields. The phosphorus content of the herbage was virtually independent of yield.

On the alkaline or calcareous soils of Montana, Green (12) found both fused tricalcium phosphate and calcium metaphosphate to be much inferior to superphosphate for alfalfa, oats, and wheat.

Mooers (19) in Tennessee reported calcium metaphosphate as equal and fused tricalcium phosphate as somewhat inferior to superphosphate in field tests with potatoes, corn, wheat, millet, soybeans, and cowpeas.

For a wheat, corn, lespedeza rotation in Kentucky, Roberts, et al (24) reported fused tricalcium phosphate, calcium metaphosphate, and superphosphate as practically alike in their influence on yields.

Terman (30) in a greenhouse study with different particle sizes of fused tricalcium phosphate found that liming the soil decreased the effectiveness of its larger particles. In field tests, there were no significant differences in yields of corn and wheat from plots receiving triple superphosphate

or 6-mesh, 40-mesh, and 80-mesh fused tricalcium phosphate.

In a greenhouse experiment with annual yellow clover on a calcareous soil, Hinkle (14) reported that treble superphosphate produced yields significantly better than those produced with calcium metaphosphate. Using alfalfa on the same soil in the field he obtained no significant difference in yields as a result of using superphosphate, treble superphosphate, or calcium metaphosphate.

In field tests with various crops using superphosphate, calcium metaphosphate, and potassium metaphosphate, Chandler and Musgrave (7) found the yields resulting from the potassium metaphosphate treatments to be equal or slightly higher than those from the superphosphate treatments while calcium metaphosphate treatments gave equal or slightly lower yields than did superphosphate. The concentration of phosphorus in sudan grass tissue grown on plots treated with potassium metaphosphate was also equal or slightly higher than in that grown on plots treated with superphosphate.

Volkerding and Bradfield (33) studied the solubility of potassium and calcium metaphosphates in water and weak salt solutions. They reported that the presence of calcium carbonate greatly decreased the solubility of calcium metaphosphate but increased that of potassium metaphosphate.

Ensminger and Cope (8) working sixteen years with cotton on a Norfolk fine sandy loam report that dilute acid-soluble phosphorus was highest in the soil on the limed plots (pH 6.5)

and lowest in that on the unlimed plots (pH 6.0). Soils fertilized with tricalcium phosphate contained more dilute acid-soluble phosphorus than did soils fertilized with superphosphate. The neutral 0.5 N NH_4F solution extracted more phosphorus from soil which had received superphosphate than it did from soil treated with tricalcium phosphate.

Bowers (2) found the best correlations between alfalfa yields and soil phosphorus tests when he used the Bray and Kurtz method (6) for the total adsorbed plus acid soluble fraction.

When plotting Baule percentage yields against soil test results as advocated by Bray (4, 5), Smith and Cook (26) obtained their best results with a 1:50 extraction ratio of Bray and Kurtz's (6) adsorbed phosphorus method for wheat grown on various soils in the greenhouse. (Correlation coefficient r = -0.6603).

Long and Seatz (17) correlated the results of several different phosphorus extractants against the yields of unphosphated plots and expressed them as percentage yields of the phosphated plots. They obtained low and nonsignificant r values.

EXPERIMENTAL

Materials

The phosphate carriers used in this study were raw rock phosphate, dicalcium phosphate, fused tricalcium phosphate, potassium metaphosphate, calcium metaphosphate, superphosphate, and concentrated superphosphate.

The rock phosphate used in the greenhouse experiments was pulverized raw rock. For the experiments carried on in the field, the finely ground Florida phosphate rock sold as Aero-Phos was obtained from the American Cyanamid Company. The Aero-Phos has a guaranteed available phosphoric acid content of three per cent and a guaranteed total phosphoric acid content of thirty-three per cent.

The twenty per cent superphosphate used in both the greenhouse and field studies was obtained from the Lansing plant of the Davison Chemical Corporation. This product was not granulated. Pulverized raw rock phosphate, dicalcium phosphate, potassium metaphosphate, and calcium metaphosphate were provided in five pound lots and the dicalcium phosphate, fused tricalcium phosphate, potassium metaphosphate, calcium metaphosphate, and concentrated superphosphate was provided in two hundred pound lots by the Tennessee Valley Authority.

The characteristics of the various phosphate materials supplied by the Tennessee Valley Authority are listed in Table I.

Table 1. Characteristics of Phosphate fertilizer materials supplied by Tennessee Valley Authority*

Phosphate Material	Place used	Identity		Particle size, U.S. screen	Chemical Analysis, %						
		T.V.A. material No.	T.V.A. Lab. No.		P_2O_5			CaO	K_2O	CO_2	F
					Total	Available	Water Soluble				
Pulverized Raw Rock Phosphate	Grnhse	32	11,735	-100	32.2	--	-	47.2	--	-	3.50
Dicalcium Phosphate	Grnhse	19	8,878	-12	47.6	46.0	0.2	40.2	--	-	--
	Field	19	8,878	-12	47.6	46.0	0.2	40.2	--	-	0.02
Fused Tricalcium phosphate	Grnhse	79	18,550	-40	29.4	--	-	40.8	--	-	0.29
	Field	79	18,550	-40	29.4	--	-	40.8	--	-	0.29
Potassium Metaphosphate (conditioned with limestone)	Grnhse	20	7,050	-40	46.8	--	-	5.4	31.8	1.8	--
	Field	100	23,970	-40	49.9	49.7	-	7.4	33.3	2.4	--
Calcium Metaphosphate (conditioned with limestone)	Grnhse	14	64,665	-12	63.6	62.9	-	26.6	--	0.9	--
	Field	48	16,354	-40	61.4	60.9	-	28.0	--	2.4	--
Concentrated Superphosphate	Field	46	11,304	-4	49.8	47.6	45.5	23.0	--	-	--

*Courtesy of Mr. T. P. Hignett, Chief, Development Section, Division of Chemical Engineering.

In the case of the rock phosphate, fused tricalcium phosphate and potassium metaphosphate, the percentage of total P_2O_5 was used in determining the amount of material to add for the different application levels. However, with the other phosphate materials, application rates were based on available P_2O_5.

The rates of P_2O_5 applied in the greenhouse were suggested in the following way. The ten-year rotation studies being conducted at the Ferden farm by the Soil Science Department included two rates of fertilization with 4-16-8 fertilizer--400 pounds and 1000 pounds respectively per five year rotation. It was decided that the test crops (alfalfa, beans, and wheat) chosen from these rotations would show more distinct differences in the greenhouse if the 1000 pound rate of 4-16-8 or 160 pound rate of P_2O_5 were to be used. However, the 160 pound rate of P_2O_5 required only 500 pounds per acre of rock phosphate which is about one-third the amount recommended in some states. On this basis and the somewhat low solubility of some of the other phosphate carriers it was decided that the higher P_2O_5 rate should be 480 pounds per acre.

Due to the proportion of K_2O in potassium metaphosphate, it was necessary to think in terms of a 4-16-11 rather than in terms of a 4-16-8 for these experiments.

The nitrogen and K_2O portions of the 4-16-11 were supplied on beans and wheat in the greenhouse as a liquid mixture of potassium nitrate and potassium chloride except in the

case of the potassium metaphosphate treatment where the nitrogen was applied as an aqueous solution of ammonium nitrate. The alfalfa seed was inoculated with an approved inoculant and received no added nitrogen. However, the K_2O for the alfalfa was supplied in a similar manner by an aqueous solution of potassium chloride. The nitrogen and K_2O for the beans in the field were supplied by solid ammonium nitrate and solid muriate of potash respectively.

In the greenhouse cultures, precipitated calcium carbonate was used in place of limestone at the rate of two tons per acre. In the field experiment limestone meal was applied at one and one-half, and three tons per acre.

Methods

The fertilization and planting techniques will be discussed for each crop separately.

The moisture equivalent was determined on the soil used in the greenhouse so that the soil could be watered to or near that point with distilled water.

All plant material grown in the greenhouse was harvested with tinsnips, oven dried from twelve to twenty-four hours, and ground with a Wiley mill. Before the wheat was ground it was carefully threshed so that the grain could be kept separate from the straw and chaff. One gram of the dry, ground plant material was weighed out of each sample for wet ashing with a mixture of nitric, perchloric, and sulfuric acids.

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The ash was taken up in warm approximately tenth normal hydrochloric acid, filtered and washed with the same warm acid, and brought up to a volume of 100 milliliters when cool. A ten milliliter aliquot was in turn taken for the determination of phosphorus as the phosphovanado-molybdivanado-molybdate phosphoric acid complex according to the adaptation for biological materials proposed by Koenig and Johnson (16). The color was measured at one hour with a Lumetron colorimeter whose blue filter has its maximum transmittancy at 420 mu. The dilution factor was 250.

After the final harvest of crops in the greenhouse a 200 to 300 gram sample of soil was composited from seven or eight different places in the upper one-third of the pot where the lime and fertilizer had originally been mixed with the soil. After being air dried each soil sample was gently crushed with a rolling pin and then passed through a two millimeter sieve to remove rocks and roots.

The pH of the soil sample was measured with a line operated Macbeth pH meter. These samples were also used for the soil tests.

Smith (26) working with tomatoes and wheat in the greenhouse found the following extracting solutions and soil solution ratios of Bray and Kurtz (6) to be quite promising when the amount of phosphorus removed was compared to the plant growth response: (1) adsorbed phosphorus extracting reagent used at a ratio of ten milliliters to one gram of

soil; (2) acid-soluble and adsorbed phosphorus extracting reagent used at a ratio of ten milliliters to one gram of soil; and (3) adsorbed phosphorus extracting reagent used at a ratio of fifty milliliters to one gram of soil.

The three extracting methods listed above were used on samples of soil from each pot in the greenhouse and on duplicate samples from each sub-plot in the field. The one to ten extracting ratio was achieved by using three grams of soil and thirty milliliters of extracting solution, and the one to fifty ratio was obtained with three grams of soil and 150 milliliters of extracting reagent.

A ten milliliter aliquot or when necessary a 5 or a 2 milliliter aliquot of the extractant was taken for phosphorus determination as molybdenum blue using 1, 2, 4 aminonapthol sulfonic acid for a reducing agent as suggested by Fiske and Subbarow (9).

The difference between the amount of phosphorus removed by the adsorbed phosphorus extractant and the amount removed by the acid-soluble and adsorbed phosphorus extractant was determined for each soil sample and was described as the acid-soluble fraction. This value was desired because of its similarity to that determined by the Spurway (28) reserve extraction.

Plant yield and composition data as well as the soil test data for phosphorus were subjected to analysis of variance. The analysis of variance outline applicable to the alfalfa, beans, and wheat experiments performed in the greenhouse is shown in Table 2.

Table 2. Analysis of Variance, greenhouse data

Source		df	Sum of Squares	Mean Square	F
Total		77			
Replications		2			
Treatments		12			
Cks vs P	1				
Rate of P_2O_5	1				
Carriers	5				
Carriers x rate	5				
Error A		24			
Lime (subplots)		1			
Lime x Treatments		12			
Lime x Carriers	5				
Rate x Lime	1				
Cks vs P x Lime	1				
Carriers x Rate x lime	5				
Error B		26			

The analysis of variance outline applicable to the bean experiment performed in the field is shown in Table 3.

Table 3. Analysis of Variance, field data

Source		df	Sum of Squares	Mean Square	F
Total		71			
Replications		2			
Treatments		7			
Cks vs P	1				
Within P	6				
Error A		14			
Lime (subplots)		2			
Lime vs no lime	1				
Rates of lime	1				
Lime x Treatments		14			
Error B		32			

Soils

Miami sandy loam used in the greenhouse for this study was obtained in Clinton County, Michigan, from the east half of the northwest one fourth of the southeast quarter of Section 21, Range 2 West, Township 6 North.

The bean plots were located on the same farm but in the southeast quarter of the northeast quarter of the southwest quarter of Section 21, Range 2 West, Township 6 North. The soils mapped in the area of the plots by Dr. E. P. Whiteside were Miami sandy loam, B slope, also Miami sandy loam, C slope, Conover sandy loam, B slope, and Brookston silt loam, A slope.

The Miami sandy loam had an AP layer of 0-8 inches of sandy loam; an A_2 layer of 8-10 inches of light sandy loam; a B_1 layer of 10-15 inches of heavy sandy loam; a B_2 layer of 15-30 inches of clay loam; and a C layer of loam at 30 inches.

The Conover silt loam had an AP layer of 0-8 inches of sandy loam; an A_2 layer of 8-19 inches of medium sandy loam; a B layer of 19-28 inches of clay loam; and a C layer of heavy loam.

The Brookston silt loam had an AP layer of 0-9 inches of silt loam; a G_1 layer of 9-15 inches of silty clay loam; a G_2 layer of 15-26 inches of clay loam; a G_3 layer of 26-44 inches of silty clay loam; and a G_4 layer of clay loam beyond 44 inches.

The areas involved for each can readily be seen in Figure 1.

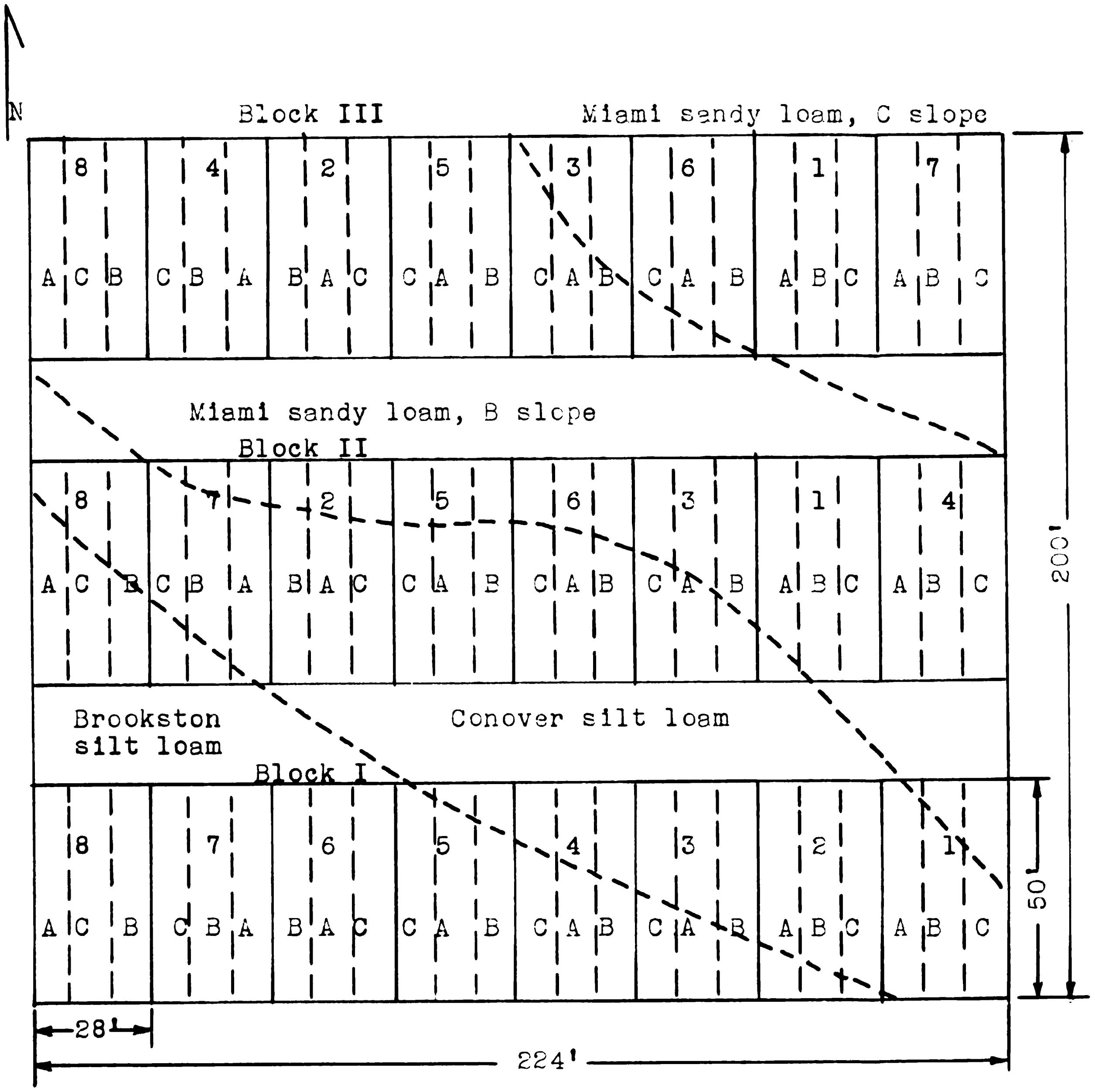


Figure 1. Field outline and soil type map. Phosphate carrier vs. lime levels, bean experiment.

EXPERIMENTAL RESULTS

Greenhouse

Alfalfa

In this experiment with alfalfa there were two rates of phosphorus used with zero and two tons of lime. The pots were filled two-thirds full of soil and then phosphate fertilizer was mixed into the remaining soil before placing in the upper third of the pot. When lime was required, precipitated calcium carbonate was thoroughly stirred into the upper three-inch layer of the soil. Nitrogen and potassium were added in solution after the pot was filled with soil. The pots were brought to moisture equivalent and allowed to stand one month before they were again moistened and planted. The inoculated alfalfa seed was scattered in a 1/2-inch deep depression formed by pressing the rim of a flower pot into the soil. The soil was then firmed over the seed with the hands.

Three harvests were made, each taken at the full bloom stage. All treatments were run in triplicate and the yields are reported in Table 4.

Yields

All phosphate carriers applied at the rate of 160 pounds of P_2O_5 produced an increase where no lime was applied. Superphosphate gave the highest yields, almost double those of the check. The cultures treated with rock phosphate,

Table 4. Alfalfa yields as affected by several phosphorus carriers applied at two rates of P_2O_5 to limed and unlimed soil. (Miami sandy loam in pot cultures) (Grams per pot*)

Cutting	Check	Rock phosphate	Dicalcium phosphate	Fused Tri calcium phosphate	Potassium Meta-phosphate	Calcium Meta-phosphate	Superphosphate
160 Pounds P_2O_5 per Acre: No Lime							
1	6.2	13.4	17.3	18.3	17.2	16.6	18.8
2	12.9	18.9	16.4	16.0	12.3	15.1	18.7
3	12.1	15.6	15.1	14.3	11.9	13.8	21.7
Total	31.2	47.9	48.8	48.6	41.4	45.5	59.2
160 Pounds P_2O_5 per Acre: 2 Tons Lime							
1	4.9	7.8	14.3	15.4	19.8	17.2	17.9
2	13.8	16.3	17.7	14.1	17.6	15.5	18.3
3	14.9	13.3	18.1	17.8	15.1	16.1	23.2
Total	33.6	37.4	50.1	47.3	52.5	48.8	59.4
480 Pounds P_2O_5 per Acre: No Lime							
1	6.2	15.7	19.2	19.8	21.8	23.2	22.7
2	12.9	16.7	17.1	15.7	16.8	18.2	19.8
3	12.1	16.6	16.3	15.7	14.1	14.8	23.6
Total	31.2	49.0	52.6	51.2	52.7	56.2	66.1
480 Pounds P_2O_5 per Acre: 2 Tons Lime							
1	4.9	10.5	16.9	15.1	22.0	17.9	20.8
2	13.8	15.2	17.1	16.2	17.6	15.9	19.2
3	14.9	13.0	16.0	18.2	16.4	16.0	25.5
Total	33.6	38.7	50.0	49.5	56.0	49.8	65.5

*Mean of 3 replications.

dicalcium phosphate, and fused tricalcium phosphate yielded about the same amount, approximately 1-1/2 times the yield of the check. The calcium metaphosphate treatment resulted in yields slightly less than did the three previously mentioned treatments. The wheat treated with potassium metaphosphate yielded about 1-1/3 times as much as did that which was unfertilized. The results show, that on this unlimed Miami soil, there was little difference between rock phosphate, dicalcium phosphate, and fused tricalcium phosphate as a source of phosphorus for alfalfa at 160 pounds of P_2O_5 per acre.

When the soil was limed at the rate of two tons per acre, wheat yields were slightly increased. The yield as affected by rock phosphate was considerably reduced by the applications of lime. Dicalcium phosphate, fused tricalcium phosphate, potassium metaphosphate, and calcium metaphosphate all resulted in essentially the same yields, smaller than those which resulted from the application of superphosphate.

Lime did not change the response which wheat made to superphosphate, dicalcium, or fused tricalcium phosphate. The phosphate source should not be rock phosphate when this soil has been limed, according to the indications of this experiment. The metaphosphates, however, showed much improvement where the soil was limed.

When the P_2O_5 rate of application was increased to 480 pounds per acre in an unlimed soil, the wheat treated with rock phosphate, dicalcium phosphate, and fused tricalcium phosphate yielded four to eight per cent more than where the lower rate was applied. The higher rates of potassium metaphosphate, calcium metaphosphate and superphosphate caused much greater increases in yields. It is interesting to note that 480 pounds of potassium metaphosphate resulted in the same increase in yield as the 160 pound rate with two tons of lime. These results would seem to indicate that increasing the phosphate rate per acre would only be advisable for potassium metaphosphate, calcium metaphosphate, and superphosphate. Comparing the two rates of phosphate when limed, rock phosphate, dicalcium phosphate, fused tricalcium phosphate, and calcium metaphosphate gave no significant increase in yield. Only potassium metaphosphate and superphosphate gave a significant increase in yield for an increase in the rate of phosphate applied.

It has long been recognized that superphosphate is adapted to soils with a wide pH range. The results of this experiment tend to indicate that potassium metaphosphate and calcium metaphosphate may also be used in soils where there is a liberal supply of calcium or at least a fairly high reaction. Potassium metaphosphate was the only material studied which increased the yield at the higher rate of phosphate application when the soil was limed. This experiment does not give a complete picture of the lime rate and

phosphorus rate for potassium metaphosphate. Further studies with this material are necessary.

In general, for the lower rate of phosphate the yields of the unlimed cultures were higher at the beginning and gradually decreased with the later cuttings. On the limed cultures the first cutting yields were lowest with yields tending to increase with successive cuttings, except for those treated with the potassium metaphosphate and calcium metaphosphate where there was a slight decrease from the first to last cuttings.

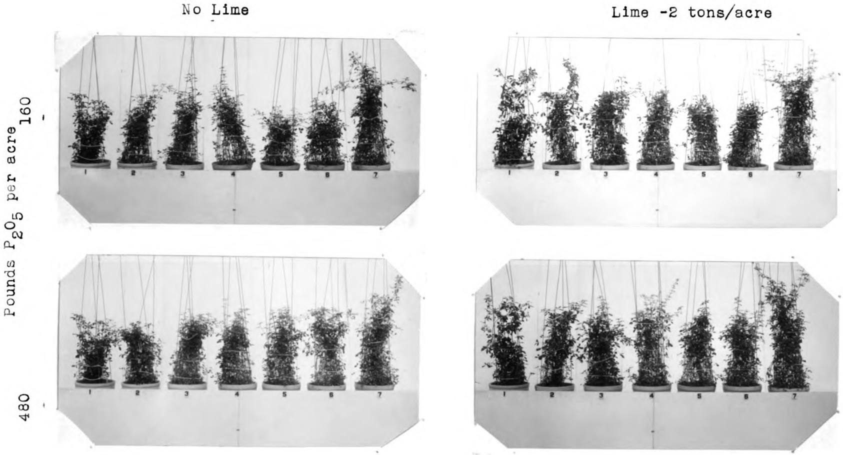
Plate 1 shows the general appearance of the plants just before the third cutting.

phosphorus rate for potassium metaphosphate. Further studies with this material are necessary.

In general, for the lower rate of phosphate the yields of the unlimed cultures were higher at the beginning and gradually decreased with the later cuttings. On the limed cultures the first cutting yields were lowest with yields tending to increase with successive cuttings, except for those treated with the potassium metaphosphate and calcium metaphosphate where there was a slight decrease from the first to last cuttings.

Plate I shows the general appearance of the plants just before the third cutting.

Plate 1. The Effect on the Growth of Alfalfa of Different Phosphate Carriers at Two Rates, With and Without Lime.



1-Check, 2-Rock Phosphate, 3-Dicalcium Phosphate, 4-Fused Tricalcium Phosphate, 5- Potassium Metaphosphate, 6-Calcium Metaphosphate, 7-Superphosphate.

Composition

For a more complete definition of the plant response characteristics of these phosphate materials it was decided to analyse the plant material. The concentration of phosphorus in the plant tissue is reported in Table 5. At the 160 pound rate of P_2O_5, where no lime was applied, the highest concentration of phosphorus in the tissue was found in the plants treated with potassium metaphosphate. The next highest was found in those treated with tricalcium phosphate. Then in decreasing order so far as phosphorus composition was concerned came the plants treated with calcium metaphosphate, superphosphate, dicalcium phosphate, and rock phosphate. The untreated plants contained the least phosphorus. When lime was added, the phosphorus concentration was lowered in plants grown in untreated soil and those treated with dicalcium and fused tricalcium. With all other materials at the lower rate of application, lime additions resulted in an increase in concentration of phosphorus in the plants. The increase was slight in the case of rock phosphate. The most marked increase occurred with potassium metaphosphate.

When the phosphate rate was increased to 480 pounds per acre, the phosphorus concentration in the plant tissue was markedly increased. Rock phosphate application resulted in the smallest increase in concentration of the phospherus in the tissue. When lime was applied with the 480 pound

treatment, the concentration of phosphorus found in the tissues was decreased in all cases except where potassium metaphosphate was applied. Lime at the high rates of calcium phosphate application consistently decreased the concentration of phosphorus in the tissue, while at lower rates of phosphate, lime increased the concentration of phosphorus in the tissue in several instances. Potassium metaphosphate in this study caused a direct increase in concentration of phosphorus in the plant tissue where lime was applied and where phosphate was increased. It behaved so differently from the other carriers that more study on this material will be necessary.

The weighted mean figures in Table 5 were obtained by dividing the total phosphorus in all tissue removed from the culture by the weight of all tissue removed, thus giving the average concentration of phosphorus.

To get the amount of phosphorus supplied by the soil and the fertilizer, it is necessary to multiply one factor by the other. This has been done in Table 6 where the total amount of phosphorus removed in alfalfa tops is reported. The phosphorus removed by these plants came from either the soil or the phosphate material applied to the soil. In this case the same soil was used for all treatments. It if is assumed that the soil has a relatively uniform phosphorus supplying power, then the variation in amounts removed will be strongly influenced by the kind of carrier applied since

Table 5. Phosphorus content of alfalfa as affected by several phosphorus carriers applied at two rates of P_2O_5 to limed and unlimed soil. (Miami sandy loam in pot cultures) (Milligrams P per gram of oven dry tissue*)

Cutting	Check	Rock phosphate	Dicalcium phosphate	Fused Tricalcium phosphate	Potassium Metaphosphate	Calcium Metaphosphate	Superphosphate
			160 Pounds P_2O_5 per Acre: No Lime				
1	1.23	1.20	1.43	1.51	1.39	1.68	1.47
2	1.21	1.49	1.49	2.21	2.65	1.56	2.49
3	0.74	0.69	1.08	1.28	1.72	1.17	0.58
Weighted mean	1.03	1.15	1.34	1.68	1.86	1.49	1.47
			160 Pounds P_2O_5 per Acre: 2 Tons Lime				
1	1.34	1.39	1.15	1.01	1.72	1.26	1.65
2	1.16	1.71	1.71	1.73	3.28	1.93	2.59
3	0.62	0.47	0.88	1.32	2.09	2.08	0.83
Weighted mean	0.95	1.20	1.25	1.34	2.35	1.74	1.62
			480 Pounds P_2O_5 per Acre: No Lime				
1	1.23	1.37	1.60	1.93	1.98	1.43	2.71
2	1.21	1.23	2.16	3.15	3.83	2.34	3.56
3	0.74	1.16	1.91	1.85	2.32	3.57	1.30
Weighted mean	1.03	1.25	1.88	2.28	2.66	2.29	2.46
			480 Pounds P_2O_5 per Acre: 2 Tons Lime				
1	1.34	1.23	1.54	1.84	1.80	1.52	1.73
2	1.16	1.43	1.78	1.90	3.58	2.40	3.83
3	0.62	0.51	0.98	1.13	4.25	2.65	1.72
Weighted mean	0.95	1.07	1.44	1.60	3.08	2.16	2.34

*Mean of 3 replicates.

Table 6. Total phosphorus removed in alfalfa tops as affected by several phosphorus carriers applied at two rates of P_2O_5 to limed and unlimed soil. (Miami sandy loam in pot cultures) (Milligrams P per pot*)

Cutting	Check	Rock phosphate	Dicalcium phosphate	Fused Tri calcium phosphate	Potassium Metaphosphate	Calcium Metaphosphate	Super phosphate
		160 Pounds P_2O_5 per Acre: No Lime					
1	7.63	16.08	24.74	28.13	23.91	27.89	27.64
2	15.61	28.16	24.44	35.36	32.60	23.56	46.56
3	8.95	10.76	16.31	18.30	20.47	16.15	12.59
Total	32.19	55.00	65.49	81.79	76.98	67.60	86.79
		160 Pounds P_2C_5 per Acre: 2 Tons Lime					
1	6.57	10.84	16.45	15.55	34.06	21.67	29.54
2	16.01	27.87	30.27	24.39	57.73	29.92	47.40
3	9.24	6.25	15.93	23.50	31.56	33.49	19.26
Total	31.82	44.96	62.65	63.44	123.35	85.08	96.20
		480 Pounds P_2O_5per Acre: No Lime					
1	7.63	21.51	30.72	38.21	43.16	33.18	61.52
2	15.61	20.54	36.94	49.46	64.34	42.59	70.49
3	8.95	19.26	31.13	29.05	32.71	52.84	30.68
Total	32.19	61.31	98.79	116.72	140.21	128.61	162.69
		480 Pounds P_2O_5 per Acre: 2 Tons Lime					
1	6.57	12.92	26.03	27.78	39.60	27.21	35.98
2	16.01	21.74	30.44	30.78	63.01	38.16	73.54
3	9.24	6.63	15.68	20.57	69.70	42.40	43.86
Total	31.82	41.29	72.15	79.15	172.31	107.77	153.38

*Mean of 3 replications

all were applied to supply the same quantities of P_2O_5. The outstanding values in Table 6 are for potassium metaphosphate which had a remarkable ability to supply the plants with phosphorus in a limed soil. Table 6 also shows that rock phosphate applied to soil which is limed fails to adequately supply phosphorus for the growing crop as evidenced by the low value for phosphorus removed where the 480 pound treatment was made with lime. The supplying power of fused tricalcium phosphate was also reduced when lime was applied to the soil.

Soil Tests

Rapid chemical soil tests are used in obtaining an indication of fertilizer needs of soil. These soil tests were calibrated against soils where no phosphorus, rock phosphate, or superphosphate was applied. It seemed desirable to evaluate several extracting methods against the phophate sources used in this experiment. The methods of sampling, preparation for extraction, and extracting are described on page 14. The results for these tests on the soils where alfalfa was grown are shown in Table 7. In all cases but one the extracting solutions removed more phosphorus from the soils which received the higher rate of phosphorus. An exception was found for the limed soil with high rate rock phosphate treatment and tested by the Bray adsorbed method with the ratio of one part soil to ten parts of extracting solution. In several instances the strong acid extracting reagent

Table 7. Mean* available phosphorus contents determined by different methods of chemical extraction of the variously treated soils after having been cropped with alfalfa. (P expressed in ppm.)

Phosphate Carriers	Rate	No Lime				2 Tons Lime			
	Pounds P_2O_5 per acre	Bray's Adsorbed + Acid Soluble	Bray's Adsorbed (1:10)	Acid Soluble by diff.	Bray's Adsorbed (1:50)	Bray's Adsorbed + Acid Soluble	Bray's Adsorbed (1:10)	Acid Soluble by diff.	Bray's Adsorbed (1:50)
Check	-	7.3	5.3	2.0	7.0	10.1	5.8	4.3	6.5
Rock Phosphate	160	35.9	7.3	28.6	10.5	53.0	5.0	48.0	8.5
	480	72.7	9.5	63.2	18.8	105.7	4.9	100.8	11.0
Dicalcium Phosphate	160	17.6	8.3	9.3	14.0	26.2	6.7	19.5	13.8
	480	69.3	35.3	34.0	60.0	93.2	16.8	76.4	43.3
Fused Tricalcium Phosphate	160	18.0	8.8	9.2	10.5	23.0	5.6	17.4	8.3
	480	42.1	17.2	24.9	25.4	74.8	12.2	62.6	19.1
Potassium Metaphosphate	160	19.8	10.8	9.0	16.2	30.1	10.3	19.8	16.3
	480	51.2	35.7	15.5	48.8	47.9	32.1	15.8	44.2
Calcium Metaphosphate	160	15.5	9.5	6.0	16.7	12.7	5.5	7.2	9.3
	480	39.0	25.2	13.8	37.9	26.4	14.6	11.8	23.8
Superphosphate	160	19.2	10.8	8.4	14.6	19.0	9.7	9.3	11.3
	480	63.3	37.9	25.4	50.0	94.8	35.7	59.1	72.5

*Mean of three replicates.

removed more phosphorus from limed, rock phosphate treated soil than from that treated with rock but not limed. This was especially true where the rock, dicalcium, and fused tricalcium phosphates were applied. However, the two adsorbed phosphorus methods resulted in the removal of less phosphorus from the limed soil. The highest phosphorus removal by the strong acid was from the soil treated with rock phosphate. Yields, however, were lower where rock was applied than where the phosphate was of any other form.

A simple correlation was run between the test results and the grams of dry tissue obtained per culture. The results failed to show a correlation between yield and soil test for the acid soluble phosphorus by difference extraction method. The adsorbed plus acid soluble phosphorus showed a correlation coefficient of .246 which is significant at the 5% level. Higher correlations were obtained for adsorbed phosphorus with either ratio. The 1-10 ratio correlation with yields was .639 and the 1-50 ratio correlation was .605, both significant at the 1% level.

BEANS

Pots were filled two-thirds full with Miami sandy loam. The phosphate materials and lime, each added separately to the remaining third, were stirred in thoroughly before being placed in the pot. Nitrogen and potash were then added in solution and additional moisture added to bring the soil to moisture equivalent. After this had dried until the soil was suitable for planting, a flower pot was used to create a depression in the soil about 1/2 inch deep. Twenty bean seeds were equally spaced in the depression and the soil pressed firmly against the seed. The pots were covered with paper and allowed to stand until the beans germinated and then were thinned to eight per pot. The cultures were watered with distilled water, the maximum amount added being sufficient to bring the soil moisture back to the moisture equivalent. The beans were allowed to grow until the blossom stage was reached, photographs were taken and the plants then cut off about 1/2-inch above the surface of the soil. The tissue was dried and ground as described in the "Methods" section of this study. Phosphorus was determined in the dry plant tissue. The results of these determinations along with the yield results are shown in Table 8.

Table 8. The effect of various phosphorus carriers applied at two rates of P_2O_5 to limed and unlimed soil, (Miami sandy loam in pot cultures) on the yield and phosphorus content of beans.

Phosphate Carriers	Pounds P_2O_5 per acre	Plant Yield per pot*		Phosphorus content**		Phosphorus Uptake (mgms/pot)***	
		No Lime	Lime	No Lime	Lime	No Lime	Lime
Check	-	2.9	3.3	0.89	0.92	2.58	3.04
Rock Phosphate	160	4.1	3.1	1.22	0.99	5.00	3.07
	480	4.0	3.8	1.27	0.76	5.08	2.89
Dicalcium Phosphate	160	7.3	4.1	1.52	1.02	11.10	4.18
	480	10.5	5.9	3.32	1.43	34.86	8.44
Fused Tricalcium Phosphate	160	7.8	3.3	1.43	0.88	11.15	2.90
	480	9.8	3.7	2.93	1.19	28.71	4.40
Potassium Metaphosphate	160	9.9	8.0	2.52	1.64	24.95	13.12
	480	12.7	11.8	5.69	3.85	72.26	45.43
Calcium Metaphosphate	160	9.3	4.6	1.49	1.00	13.86	4.60
	480	10.7	7.5	3.10	1.25	33.17	9.38
Superphosphate	160	9.1	7.6	1.09	0.82	9.92	6.23
	480	11.6	11.1	3.80	3.76	44.08	41.74

*Mean oven dry weight of three replicates expressed in grams.

**Mean phosphorus content of three replicates expressed in milligrams per gram of oven dry plant material.

***Obtained by multiplying the mean yield by the mean phosphorus content for the same treatment.

Yields

Except in the case of the cultures which were unlimed and treated with rock phosphate, increasing the rate of phosphorus applied increased the yield whether the soil was limed or not. Liming increased the yields of the check slightly but for all phosphate materials, at both rates, liming resulted in a decrease in yield. The smallest decreases as a result of lime however, were obtained where potassium metaphosphate and superphosphate fertilizers were applied at the higher rates. On the unlimed soil, the beans yielded better with the dicalcium phosphate than did the alfalfa but yielded less on the rock and the fused tricalcium phosphate. The relationship between yields of beans as affected by potassium metaphosphate, calcium metaphosphate, and superphosphate on the unlimed soil was essentially the same as for the alfalfa. On the limed soils, however, the potassium metaphosphate and superphosphate resulted in by far the highest bean yields. Most of the other materials were almost entirely ineffective where lime was applied.

Composition

The phosphorus concentration of the bean tissue was increased by lime where there was no phosphate applied. For all phosphate carriers, however, at both rates of P_2O_5 application, the phosphorus concentration in the tissue was decreased by lime. The smallest decrease was for the high rate of superphosphate but not significantly so.

The results for the total phosphorus content of bean plants were parallel to those of the phosphorus concentration in the tissue. The amount of phosphorus removed by the plants treated with potassium metaphosphate was greater than for any of the other materials including superphosphate. This was more a result of the high phosphorus concentration in the tissue than it was of the high yield.

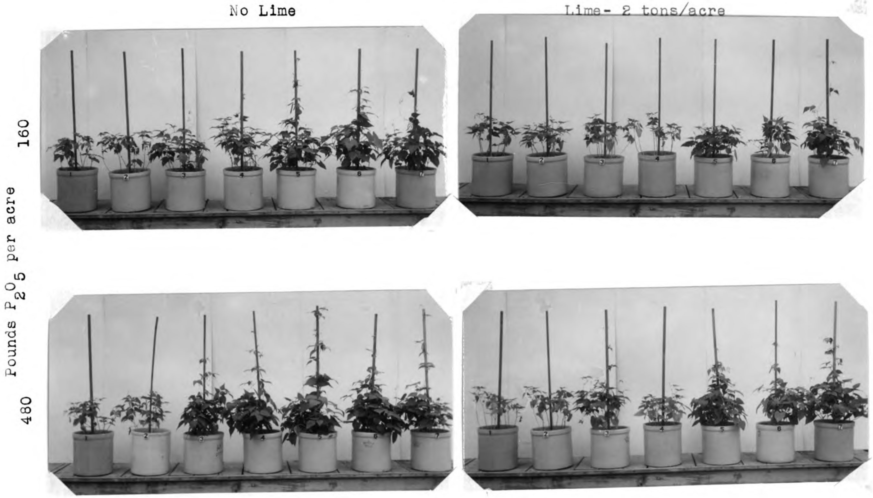
The general appearance and growth of the bean plants under the various conditions of this experiment can be seen in Plate 2.

Soil Tests

The results of soil tests after beans were very similar to those after alfalfa as indicated in Table 9. The correlation coefficients obtained between the soil test results and yield of beans for the various extracting solutions are as follows: adsorbed plus acid soluble was a positive .231, significant at the 5% level; acid soluble by difference was a negative .05 which is not significant; adsorbed 1:10 was a positive .788, significant at the 1% level; and adsorbed using the extracting ratio of 1:50 was a positive .732, significant at the 1% level. As was the case with the alfalfa, the results from the two adsorbed methods were not significantly different.

Plate 2. The Effect of Diss

Plate 2. The Effect of Different Phosphate Carriers at Two Rates, With and Without Lime on the Growth of Beans.



1-Check, 2-Rock phosphate, 3-Dicalcium phosphate, 4-Fused Tricalcium phosphate, 5-Potassium metaphosphate, c-Calcium metaphosphate, 7-Superphosphate.

Table 9. Mean* available phosphorus contents determined by different methods of chemical extraction of the variously treated soils after having been cropped with beans. (P expressed in ppm.)

Phosphate Carriers	Rate	No Lime							
	Pounds P_2O_5 per acre	Bray's Adsorbed + Acid Soluble	Bray's Adsorbed (1:10)	Acid Soluble by diff.	Bray's Adsorbed (1:50)	Bray's Adsorbed + Acid Soluble	Bray's Adsorbed (1:10)	Acid Soluble by diff.	Bray's Adsorbed (1:50)
Check	-	15.4	8.8	6.6	4.8	17.5	10.2	7.3	6.2
Rock Phosphate	160	61.3	11.7	49.6	7.5	56.5	9.2	47.3	5.3
	480	118.3	11.1	107.2	8.0	123.7	9.9	113.8	5.7
Dicalcium Phosphate	160	133.2	18.5	114.7	23.3	67.5	16.1	51.4	19.6
	480	92.5	39.6	52.9	43.1	78.3	21.3	57.0	32.5
Fused Tricalcium Phosphate	160	30.0	20.0	10.0	19.2	37.1	11.8	25.3	10.0
	480	81.2	37.8	43.4	42.5	103.0	18.3	84.7	19.6
Potassium Metaphosphate	160	35.8	24.9	10.9	25.4	41.7	24.0	17.7	21.3
	480	108.2	72.8	35.4	58.3	116.8	74.2	42.6	55.6
Calcium Metaphosphate	160	24.6	17.1	7.5	7.8	20.0	11.3	8.7	4.7
	480	42.5	26.3	16.2	14.7	32.9	17.7	15.2	10.2
Superphosphate	160	45.0	25.4	19.6	26.4	50.8	27.4	23.4	34.6
	480	96.7	60.2	36.5	49.6	112.7	67.4	45.3	68.3

*Mean of three replicates.

WHEAT

The pots for wheat were handled similarly to those for beans. Twenty five wheat seeds were placed in each pot and the soil firmed over them, and then covered with paper until the seeds had germinated. After the plants were past the danger of damping-off, they were thinned to 12 plants per culture. The wheat was kept watered with distilled water so the soil moisture was never greater than the moisture equivalent. The wheat plants were allowed to mature and harvested by cutting the heads off and keeping them separate and then cutting the straw 1/2-inch above the soil so as not to contaminate the samples with soil containing phosphorus. These materials were dried--the straw kept for grinding and the seed threshed and weighed and kept for analysis. The chaff was added to the straw and both were ground for analysis by the methods outlined in the "Methods" section of this study.

Yields

The yields of grain and straw are shown in Table 10. The yields of grain for all carriers at the 160 pounds per acre rate and not limed were essentially the same except for rock phosphate. The rock phosphate and check yields were about half those of other treatments. There was more variation in the straw and chaff weights. Added lime caused a decrease in all grain yields except where superphosphate was applied at the heavy rate. In the cases of the fused tricalcium phosphate, dicalcium phosphate, rock phosphate, and the

Table 10. Wheat yields as affected by several phosphorus carriers applied at two rates of P_2O_5 to limed and unlimed soil. (Miami sandy loam in pot cultures) (Grams per pot*)

Phosphate Carriers	No Lime			2 Tons Lime		
	Grain	Straw and Chaff	Total	Grain	Straw and Chaff	Total
Check	2.7	5.3	8.0	1.4	3.9	5.3
	160 Pounds P_2O_5 per Acre					
Rock Phosphate	2.3	5.4	7.7	1.5	4.7	6.2
Dicalcium Phosphate	5.0	9.4	14.4	2.7	6.8	9.5
Fused tricalcium phosphate	5.5	10.7	16.2	2.2	5.7	7.9
Potassium Metaphosphate	5.5	9.9	15.4	4.6	8.5	13.1
Calcium Metaphosphate	5.1	9.6	14.7	3.6	7.8	11.4
Superphosphate	5.0	11.7	16.7	4.2	9.5	13.7
	480 Pounds P_2O_5 per Acre					
Rock Phosphate	3.8	9.2	13.0	1.6	4.5	6.1
Dicalcium Phosphate	5.3	11.9	17.2	4.3	8.7	13.0
Fused tricalcium phosphate	5.3	10.9	16.2	2.8	6.7	9.5
Potassium Metaphosphate	6.0	14.3	20.3	5.2	10.7	15.9
Calcium Metaphosphate	5.5	15.1	20.6	4.8	9.9	14.7
Superphosphate	4.7	12.0	16.7	5.1	10.0	15.1

*Mean of 3 replicates

check, yields were greatly reduced by the lime. Relatively small decreases as a result of lime occurred where the potassium metaphosphate and the low rate of superphosphate were applied. The decrease was intermediate where the phosphate carrier was calcium metaphosphate. The weight of straw and chaff did not vary with treatment as much as did the weight of grain.

Increasing the rate of P_2O_5 application to 480 pounds per acre did not appreciably affect the yield for any material except potassium metaphosphate and rock phosphate. Liming the soil at the higher rate of phosphate application decreased the grain yield in all cases except where superphosphate was applied. The only difference brought about by the different rates of phosphate and added lime occurred where dicalcium phosphate was used, the depression in yield being less where the phosphate rate was greater. The yields were not significantly increased by the rock phosphate. At the higher rate of phosphate, straw and chaff yields were more variable where lime was applied than elsewhere in the experiment.

The general appearance in growth of the wheat plants at about heading time can be observed from Plate 3.

Composition

A comparison of the yield of wheat grain with the content of phosphorus in the grain and the straw is shown in Table 11. The concentration of phosphorus in the wheat grain

Plate 3. The Effect on the Growth of Wheat of Different Phosphate Carriers at Two Rates, With and Without Lime.

1-Check, 2-Rock phosphate, 3-Dicalcium phosphate, 4-Fused tricalcium phosphate, 5-Potassium metaphosphate, 6-Calcium metaphosphate, 7-Superphosphate.

Table 11. A comparison of the yield of wheat with the concentration of phosphorus in the grain and straw as affected by several phosphorus carriers applied at two rates of P_2O_5 to limed and unlimed soil. (Miami sandy loam in pot cultures*)

Phosphate Carriers	No Lime			2 Tons Lime		
	Yield (grams /pot)	Mgms P/gm of dry tissue Grain	Mgms P/gm of dry tissue Straw	Yield (grams /pot)	Mgms P/gm of dry tissue Grain	Mgms P/gm of dry tissue Straw
Check	2.7	3.28	0.20	1.4	3.43	0.30
160 Pounds P_2O_5 per acre						
Rock Phosphate	2.3	4.85	0.43	1.5	5.96	0.38
Dicalcium Phosphate	5.0	4.68	0.03	2.7	5.70	0.14
Fused Tricalcium Phosphate	5.5	4.49	0.45	2.2	5.58	0.32
Potassium Metaphosphate	5.5	5.53	0.47	4.6	3.85	0.48
Calcium Metaphosphate	5.1	5.28	0.41	3.6	5.87	0.77
Superphosphate	5.0	5.83	0.41	4.2	5.13	0.14
480 Pounds P_2O_5 per acre						
Rock Phosphate	3.8	4.76	0.24	1.6	5.37	0.47
Dicalcium Phosphate	5.3	6.53	0.60	4.3	4.49	0.58
Fused Tricalcium Phosphate	5.3	6.80	0.93	2.8	6.13	0.68
Potassium Metaphosphate	6.0	7.12	1.87	5.2	6.79	0.58
Calcium Metaphosphate	5.5	8.38	1.78	4.8	5.16	1.29
Superphosphate	4.7	7.47	1.68	5.1	6.80	0.52

* Mean of three replicates

was not significantly different as a result of the various phosphate materials at the rate of 160 pounds of P_2O_5 and unlimed. Where the soil was limed, all materials resulted in essentially the same content of phosphorus in the seed except for the potassium metaphosphate treatment which caused a decidedly lower concentration. The concentration of phosphorus in the straw was essentially the same for all materials except the dicalcium phosphate which caused a decrease in phosphorus in both limed and unlimed soil. The superphosphate treatment also resulted in a low concentration of phosphorus in the straw when applied at the 160 pound rate with lime. Where lime was added, the calcium metaphosphate caused a high phosphorus content in the straw and also in the seed. The behavior of potassium metaphosphate was different that it was in the alfalfa and the beans. On the other hand the calcium metaphosphate seemed to be a better source of phosphate for wheat than it was for alfalfa or beans.

The phosphorus concentration in the straw and chaff essentially paralleled that of the grain at the 480 pound rate of P_2O_5 on unlimed soil. Furthermore, the phosphorus concentration in the grain, for all materials except the rock phosphate, was higher than where the materials were applied at the lower rate. Where the soil received rock phosphate the phosphorus concentration in the grain was increased by the application of lime. For other phosphate treatments the phosphorus content of the grain was decreased where the soil

was limed.

The total amount of phosphorus removed in wheat tops was calculated and recorded in Table 12. The highest amounts removed at both rates and at both levels of lime occurred with but one exception where the metaphosphates were applied. For all other materials liming caused a decrease in the amount of phosphorus removed from the soil.

Soil Tests

The soil tests following the growth of the wheat again point to the inadvisability of using the adsorbed plus acid soluble and the acid soluble by difference methods on treated soils with rock phosphate.

The amounts of phosphorus extracted by these various tests (Table 13) were intermediate between the amounts extracted following alfalfa and beans. The correlation coefficients between these tests and the yields of wheat grain obtained were not significant. They did, however, fall in the same relative order as those for the tests on the other cropped soils. The value for adsorbed plus acid soluble was a positive .041. That for the acid soluble by difference was a negative .026 and those for the adsorbed at both extraction ratios were a positive .12.

Table 12. Total phosphorus removed in wheat tops as affected by several phosphorus carriers applied at two rates of P_2O_5 to limed and unlimed soil. (Miami sandy loam in pot cultures) (Milligrams P per pot*)

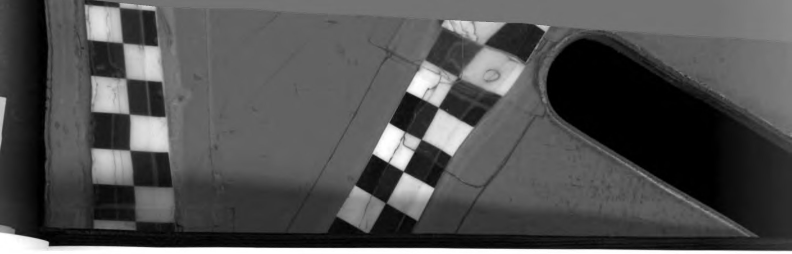
Phosphate Carriers	No Lime			2 Tons Lime		
	Grain	Straw and Chaff	Total	Grain	Straw and Chaff	Total
Check	8.86	1.06	9.92	4.80	1.17	5.97
	160 Pounds P_2O_5 per Acre					
Rock Phosphate	11.16	2.32	13.48	8.94	1.79	10.73
Dicalcium Phosphate	23.40	0.28	23.68	15.39	0.95	16.34
Fused Tricalcium Phosphate	24.70	4.82	29.52	12.28	1.82	14.10
Potassium Metaphosphate	30.42	4.65	35.07	17.71	4.08	21.79
Calcium Metaphosphate	26.93	3.94	30.87	21.13	6.01	27.14
Superphosphate	29.15	4.80	33.95	21.55	1.33	22.88
	480 Pounds P_2O_5 per Acre					
Rock Phosphate	18.09	2.21	20.30	8.59	2.12	10.71
Dicalcium Phosphate	34.61	7.14	41.75	19.31	5.05	24.36
Fused Tricalcium Phosphate	36.04	10.14	46.18	17.16	4.56	21.72
Potassium Metaphosphate	42.72	26.74	69.46	35.31	6.21	41.52
Calcium Metaphosphate	46.09	26.88	72.97	24.77	12.77	37.54
Superphosphate	35.11	20.16	55.27	34.68	5.20	39.88

*Mean of three replications

Table 13. Mean* available phosphorus contents determined by different methods of **chemical extraction** of the veriously treated soils after having been cropped with wheat. (P expressed in ppm.)

Phosphate Carriers	Rate	No Lime				2 Tons Lime			
	Pounds P_2O_5 per acre	Bray's Adsorbed + Acid Soluble	Bray's Adsorbed (1:10)	Acid Soluble by diff.	Bray's Adsorbed (1:50)	Bray's Adsorbed + Acid Soluble	Bray's Adsorbed (1:10)	Acid Soluble by diff.	Bray's Adsorbed (1:50)
Check	-	10.8	4.8	6.0	5.0	13.8	5.2	8.6	6.2
Rock Phosphate	160	69.0	7.5	61.5	10.0	78.0	6.3	71.7	9.3
	480	175.5	8.3	167.2	14.5	204.5	7.0	197.5	11.0
Dicalcium Phosphate	160	33.3	13.8	19.5	17.9	47.9	10.3	37.6	17.1
	480	133.3	32.3	101.0	43.3	123.3	19.4	103.9	40.0
Fused Tricalcium Phosphate	160	27.7	12.3	15.4	15.8	54.2	9.9	44.3	17.0
	480	62.5	42.2	20.3	55.8	109.8	15.6	94.2	32.5
Potassium Metaphosphate	160	39.1	24.2	14.9	30.4	55.4	31.0	24.4	45.0
	480	124.0	74.9	49.1	110.5	166.0	88.7	77.3	116.7
Calcium Metaphosphate	160	29.4	17.3	12.1	21.7	24.3	11.5	12.8	17.5
	480	75.7	49.2	26.5	61.7	55.8	29.0	26.8	41.7
Superphosphate	160	42.9	27.3	15.6	35.8	55.0	27.9	27.1	37.9
	480	129.5	70.7	68.8	95.0	167.7	84.7	83.0	108.3

*Mean of three replicates.



PHOSPHATE CARRIERS VERSUS LIME RATE

Beans

After seeing the results from the three crops (alfalfa, beans, and wheat) in the greenhouse, it was decided to try these various carriers in the field and compare them with 0, 1.5, and 3 tons of lime per acre with beans selected as the first crop. Three replicates were set up for the eight phosphate treatments and the lime treatments were put in as sub-plots. The soil was plowed, disked, and harrowed and after the plots were staked out nitrogen and potassium fertilizers were applied with a grain drill. The soil was then harrowed thoroughly and the separate phosphorus carriers were drilled in. Lime was then applied on the surface with an E-Z-Flow lime spreader and the soil was harrowed again before the beans were planted. The beans were planted in 28 inch rows, four rows per sub-plot. Harvests were taken from the two center rows. Precipitation seemed to be properly spaced providing adequate moisture for a good yield. The site selected was not as uniform as was desired, there being three soil types, Miami sandy loam (both B and C slopes), Conover sandy loam, and Brookston silt loam. The site selected had been used for a wheat-clover rotation, and clover was plowed down for this experiment.

Yields

The yields of beans in bushels per acre are given in Table 14. The yields from block to block varied a great deal, Ta

Ph
80

Ch

Ro

Di

F

Table 14. Bean yields as affected by three rates of lime applied to soils fertilized with several phosphorus carriers. (Field experiment in Miami sandy loam, Conover sandy loam, and Brookston silt loam soils)

Phosphate Carriers at 80 pounds P_2O_5 per acre	Lime (Tons per acre)	Block			Sum	Mean
		1	2	3		
Check	0	34.8	25.5	17.2	77.5	25.8
	1½	26.5	29.1	23.9	79.5	26.5
	3	33.3	18.2	17.7	69.2	23.1
Rock Phosphate	0	32.2	26.5	20.8	79.5	26.5
	1½	33.8	24.4	21.3	79.5	26.5
	3	28.6	22.4	20.3	71.3	23.8
Dicalcium Phosphate	0	25.0	28.1	13.5	66.6	22.2
	1½	29.1	25.5	18.2	72.8	24.3
	3	27.0	22.4	20.8	70.2	23.4
Fused Tricalcium Phosphate	0	22.9	23.9	19.8	66.6	22.2
	1½	26.0	23.4	26.5	75.9	25.3
	3	30.2	27.6	21.8	79.6	26.5
Potassium Metaphosphate	0	28.1	19.8	23.9	71.8	23.9
	1½	31.2	22.4	21.8	75.4	25.1
	3	25.0	23.9	24.4	73.3	24.4
Calcium Metaphosphate	0	23.9	22.9	18.2	65.0	21.7
	1½	26.5	25.0	19.8	71.3	23.8
	3	32.2	19.2	16.1	67.5	22.5
Superphosphate	0	25.5	21.8	15.6	62.9	21.0
	1½	26.0	27.0	19.2	72.2	24.1
	3	22.4	24.4	18.2	65.0	21.7
Concentrated Superphosphate	0	22.9	28.6	17.2	68.7	22.9
	1½	30.2	26.0	27.0	83.2	27.7
	3	21.8	25.0	25.0	71.8	23.9
Sum		665.1	583.0	488.2	1736.3	
Mean	23.3* 25.4 23.7	27.7	24.3	20.3		24.1

*Mean yields for 0, 1½, and 3 ton lime treatments respectively

and as a result the significance for replications was at the 1% level. Differences in yield caused by phosphate treatments showed no significance and only slight significance occurred for the lime treatments. In general, the highest yields were in block one, followed in order by blocks 2 and 3.

The data reported in Table 14 show that the yields which resulted from the 1.5 ton rate of lime were highest except in the case of rock phosphate and fused tricalcium phosphate. Keeping the variant yields of rock phosphate and fused tricalcium phosphate in mind, an examination of Table 15 shows that in blocks 2 and 3, where rock phosphate was applied, the unlimed and limed (1.5 tons) sub-plots had about the same pH. This parallels the similarity in yields. An examination of the pH values for blocks 1 and 3 for fused tricalcium phosphate and the 1.5 and 3 ton lime levels reveals a similar situation. This would tend to indicate that there is a strong relationship between the pH and the ability of the soil to supply phosphorus to the plants from the sources applied as well as from native soil phosphorus.

The soils of each sub-plot were sampled by taking ten samples and compositing them from each sub-plot and then repeating the procedure so that there were duplicate composite samples for each of the 72 sub-plots. According to Reed and Rigney (21) this should give an accuracy of 6 ppm. for the phosphorus determinations. These samples were treated by analytical methods described earlier and the results of the different phosphorus extractions are shown on Table 16. The

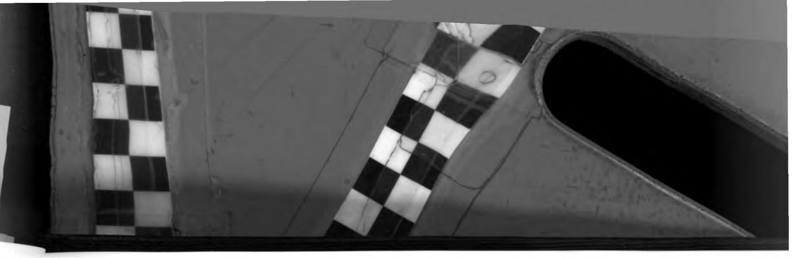


Table 15. pH values where three rates of lime were applied to soils fertilized with several phosphorus carriers. (Field experiment in Miami sandy loam, Conover sandy loam, and Brookston silt loam soils.)

Phosphate Carriers applied at 80 pounds P_2O_5 per acre.	Lime (Tons per acre)	Block			Mean based on H ion conc.
		1	2	3	
Check	0.0	6.5	5.7	5.2	5.5
	1.5	6.6	6.0	5.4	5.8
	3.0	6.7	6.1	5.7	6.0
Rock Phosphate	0.0	6.2	6.1	5.7	5.9
	1.5	6.5	5.9	5.8	6.0
	3.0	6.7	6.1	6.2	6.3
Dicalcium Phosphate	0.0	6.2	6.1	6.0	6.1
	1.5	6.5	6.0	5.8	6.0
	3.0	6.5	6.3	6.0	6.2
Fused Tricalcium Phosphate	0.0	6.1	5.7	5.5	5.7
	1.5	6.4	6.0	5.9	6.0
	3.0	6.3	6.4	5.9	6.1
Potassium Metaphosphate	0.0	6.2	6.1	6.1	6.1
	1.5	6.1	6.1	5.7	5.9
	3.0	6.4	6.2	6.0	6.2
Calcium Metaphosphate	0.0	6.0	6.0	5.3	5.6
	1.5	6.2	6.2	5.3	5.7
	3.0	6.2	6.0	5.7	5.9
Superphosphate	0.0	5.8	5.8	5.7	5.8
	1.5	6.1	5.9	5.6	5.8
	3.0	6.3	6.3	6.6	6.4
Concentrated Superphosphate	0.0	5.9	5.8	5.9	5.9
	1.5	6.0	6.0	5.9	6.0
	3.0	6.0	6.2	6.2	6.1

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Table 16. Mean* available phosphorus contents determined by different methods of chemical extraction of the variously treated soils after they had been cropped with beans. (P expressed in ppm.)

Phosphate Carriers at 80 pounds P_2O_5 per acre	Lime (Tons per acre)	Bray's Adsorbed + Acid Soluble	Bray's Adsorbed (1:10)	Acid Soluble by diff.	Bray's Adsorbed (1:50)
Check	0	28.6	14.4	14.2	20.9
	1½	25.4	14.0	11.4	24.5
	3	34.8	14.3	20.5	23.7
Rock Phosphate	0	30.5	10.1	20.4	16.0
	1½	35.7	11.6	24.1	19.2
	3	35.7	11.0	24.7	17.5
Dicalcium Phosphate	0	27.0	12.7	14.3	20.6
	1½	29.7	12.4	17.3	21.7
	3	26.6	11.7	14.9	19.8
Fused Tricalcium Phosphate	0	35.4	13.0	22.4	20.6
	1½	30.9	11.4	19.5	20.0
	3	26.4	11.4	15.0	20.6
Potassium Metaphosphate	0	22.6	12.5	10.1	19.0
	1½	19.5	11.4	8.1	16.0
	3	23.2	11.6	11.6	17.0
Calcium Metaphosphate	0	25.1	14.0	11.1	20.2
	1½	27.4	13.1	14.3	19.6
	3	24.7	12.9	11.8	18.5
Superphosphate	0	45.4	15.9	29.5	24.4
	1½	41.5	16.5	25.0	29.0
	3	36.2	17.3	18.9	27.1
Concentrated Superphosphate	0	31.3	14.8	16.5	26.5
	1½	30.7	12.6	18.1	22.1
	3	40.5	18.2	22.3	30.0

*Mean of three replications

results do not show any distinct pattern or offer any significant trends due to phosphorus treatment or to lime treatment.

Correlations

With so little variation in these data it was decided they should be correlated with both yield of beans and pH values obtained for each of the plots. Where the amount of phosphorus extracted by the various methods was correlated with the bean yields in the field, it was found that the Bray adsorbed plus acid soluble method gave a negative correlation of .109, which is not significant. The acid soluble by difference technique gave a positive correlation of .134, also not significant. For the adsorbed methods, however, there was a negative correlation of .553 which is significant at the 1% level for the 1-10 extracting ratio. The 1-50 extracting ratio gave a negative correlation of .502, significant at the 1% level. When the amount of phosphorus extracted from the soil was correlated with the pH of the samples involved, it was found that there was not a significant correlation for the acid soluble plus adsorbed method or the acid soluble by difference method. The adsorbed at the 1-10 extracting ratio and the 1-50 extracting ratio gave negative correlations which were significant at the 1% level. (See Table 17.)

Table 17. Correlation coefficients of correlations between yield and soil tests or between pH and soil tests.

Crop	df	Bray's Adsorbed + Acid Soluble	Bray's Adsorbed (1:10)	Acid Soluble by diff.	Bray's Adsorbed (1:50)
Alfalfa yields (pots)	77	0.248*	0.639**	0.000	0.605**
Wheat yields (pots)	77	0.041	0.128	-0.026	0.12
Bean yields (pots)	77	0.231*	0.788**	-0.205	0.732**
Bean yields (field)	71	-0.109	-0.553**	0.134	-0.502**

*Significant at the 5 per cent level.
**Significant at the 1 per cent level.

DISCUSSION AND SUMMARY

Rock phosphate supplied for alfalfa in the greenhouse resulted in about the same yield of dry plant material as did most carriers other than superphosphate. The concentration of phosphorus in the alfalfa plant tissue was somewhat lower and the total amount of phosphorus removed per acre was lower than where other forms of phosphate were applied at the rate of 160 pounds of P_2O_5 per acre without lime. Lime reduced the yield and slightly increased the concentration of phosphate in the plant tissue. The same was true for both beans and wheat. At the higher rate of application, plants treated with rock phosphate and without lime, yielded slightly more than where the low rate was used but the application of lime reduced the yield for all crops. The values for both the concentration of phosphorus in the plant tissue and the total amount of phosphorus removed by plants were reduced by the application of lime.

Under the conditions of this experiment, the yields of alfalfa treated with dicalcium phosphate at the 480 pound rate were increased slightly by lime. The higher rate of phosphorus was not particularly beneficial to alfalfa. With beans the yields were depressed at both rates of phosphate application when the soil was limed, but there was a positive response to the higher rate of phosphate application. The yield increase with wheat for additional phosphate was more pronounced on the limed than on the unlimed soil. The

concentration of phosphorus in alfalfa tissue, as affected by the dicalcium phosphate, decreased when lime was applied but there was a greater concentration of phosphorus in the tissue grown on the soil treated with heavier phosphate applications. While the concentration of phosphorus in the bean plants was greatly increased by increasing the rate of phosphate application on unlimed soil, it was markedly reduced by the application of lime. On wheat, however, lime application increased the concentration of phosphorus in the straw with dicalcium phosphate and also increased the concentration in the grain at the 160 pound level. Lime decreased both the concentration of phosphorus in the grain and in the straw at the 480 pound level of phosphate.

Increasing the rate of application of fused tricalcium phosphate had little effect on alfalfa yields while the addition of lime seemed to reduce yields slightly. However, increasing the rate of phosphate application was beneficial to bean yields on both the limed and unlimed cultures but lime did severely reduce the yields where fused tricalcium phosphate was used. This severe reduction in yield due to liming was also apparent in wheat treated with this form of phosphate.

Alfalfa yields were markedly increased by lime when fertilized with potassium metaphosphate, at both rates of phosphate application. There was a response to both rate of phosphate and lime with the bean crop, but the lime slightly reduced the yield. For wheat the situation was similar to that for beans.

Alfalfa fertilized with calcium metaphosphate gave a positive yield response at the 160 pound rate of P_2O_5 and to lime, but at the higher rate of phosphate application yield was reduced by liming. Lime inhibited the yield of beans at both levels of calcium metaphosphate. There was some increase in yield due to increase in rate of phosphate application.

Superphosphate with alfalfa produced positive yield responses for both rates of phosphorus and only a slight reduction in yield, if any, from the application of lime. There was a very slight reduction in yield of beans, at either level of phosphate application, when lime was applied and an increase for additional phosphorus applied. On wheat there was no increase in yield for additional phosphorus on the unlimed soils but some increase when limed.

For alfalfa there was generally a favorable response to phosphate rate and lime for potassium metaphosphate, calcium metaphosphate, and superphosphate. The two outstanding materials for beans were potassium metaphosphate and superphosphate, while for wheat potassium metaphosphate, calcium metaphosphate, and superphosphate were the leading materials, with fused tricalcium phosphate showing up favorably under certain conditions. The leading material for all crops was superphosphate. The potassium metaphosphate was of particular interest in encouraging high yields and producing plant material with a high phosphate content at the higher pH

levels with alfalfa, beans, and wheat. This was not found to be consistently true with the other phosphate carriers which agrees with Ripley (23).

In general, the adsorbed extraction method of Bray (6) gave the best results under the conditions of this experiment and phosphorus extractions correlated quite readily with yields, with a high correlation coefficient. A similar check of the field results gave a high coefficient when the adsorbed method was correlated with pH. The correlations obtained were somewhat different than those obtained by Bowers (2) in his study, but he used total adsorbed and total adsorbed plus acid soluble which are slightly different procedures for extracting.

There was not a significant difference between the results from the two extracting ratios. (See Table 17.) However, Smith and Cook (26) found the adsorbed 1-50 extracting ratio superior to the adsorbed 1-10 extracting ratio. Their method of correlating yield response with test results was somewhat different than that used here. They also used several soils in the greenhouse, while here only one soil was used in the greenhouse and three in the field.

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