THE FERTILIZING VALUE OF SOME PHOSPHATIC SHALES FROM EASTERN KANSAS

by

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INTRODUCTION

The recent work of the Kansas Geological Survey relative to certain outcrops of Pennsylvanian shales in eastern Kansas is responsible for this study. It has been known for several years that phosphatic nodules occur in some of these sedimentary rocks. Studies by the Kansas Geological Survey indicate that the shales contain a significant amount of phosphorus which is rather uniformly distributed throughout the deposits.

The United States has vast, usable deposits of phosphate-bearing rocks in Florida, Tennessee, Idaho, Wyoming, and Montana, but the cost of processing and shipping from these areas to areas of utilization in Kansas is high. If the relatively low grade phosphatic shales of eastern Kansas could give equally beneficial crop response at a lower cost to the farmer, another Kansas resource could be utilized and agriculture in adjacent areas would be benefited.

These shales also contain potassium, magnesium, and iron as well as several other elements that might prove beneficial in agricultural uses under certain soil conditions where these plant nutrients may be deficient. In general, the eastern one-third of Kansas is deficient in phosphorus as indicated by soil tests and crop response to applications of phosphate fertilizers. An additional supply added through the application of pulverized shale containing a significant amount of phosphoric acid should prove beneficial to crop production.

According to Runnels (7) the probable use of a particular shale as a fertilizer in eastern Kansas would depend upon the total as well as the available phosphoric acid content, the location of the shale deposit with reference to quarrying and transportation to adjacent areas of utilization, and the quantity of shale available. Several shale deposits with relatively lower phosphoric acid contents were included in this study since they are so readily accessible for quarrying operations.

Theoretically, the application of shale in large quantities of from two to four tons per acre to eastern Kansas soils should produce immediate results as well as long-time beneficial results. The available phosphoric acid and other soluble elements would be increased immediately. The degree of aggregation and the base exchange of the soil might be increased somewhat due to the large applications of colloidal clay material. The physical disintegration and the chemical decomposing action of weathering over a period of years should release additional phosphorus, iron, magnesium, potash, small amounts of nitrogen, and some of the trace elements.

REVIEW OF LITERATURE

During the summer of 1948, Mr. M. M. Runnels of Loring, Kansas, made an application of Eudora shale to soil planted to cabbage. The shale analyzed 0.19 per cent available phosphoric acid and was applied at the rate of two and one-half tons per acre. Mr. R. T. Runnels, Chief Chemist for the Kansas Geological Survey and a son of Mr. M. M. Runnels, reported an increase in yield of 1500 pounds of salable cabbage on the fertilized plots.

Runnels (7) stated that collophane and dahllite are the most common phosphate-bearing minerals of sedimentary rocks such as shales and limestones. Twenhofel (9) suggested that collophane has an organic origin since amorphous collophane is found in fossil bones. Dahllite is a crystalline, secondary mineral which usually occurs with collophane.

Runnels (7) found that only the bituminous shales or black shales contain enough phosphate to warrant consideration as phosphate fertilizer materials. The phosphorus found in the shales studied was concentrated in small concretions or nodules. Nodules of collophane, according to Twenhofel (9) are of rather frequent occurrence in certain dark-colored clays, shales, greensands, and similar deposits. They range from a few millimeters to 30 or more centimeters in diameter. The nodules are commonly black or brown in color due to the hydrocarbon content. Twenhofel (9) believed the origin of phosphatic nodules to be due to an abundance of decaying organic matter leading to the precipitation of the phosphate. Runnels (7) found that laboratory methods designed to concentrate the phosphate content of the shales were not successful due to the uniformity of hardness, specific gravity, and shape of the particles. For this reason the possibility of utilizing the shale without processing other than pulverizing must be considered.

Runnels (7) has tentatively identified the clay mineral making up these bituminous shales as illite. The name "illite" has been suggested by Grim (5) and others as a group name for the constituents of clay materials that are similar to the white micas. The general formula, $(OH)_4Ky(Al_4 \cdot Fe_4 \cdot Mg_6)Si_{8-y} \cdot Al_yO_{20}$, was advanced for illite with y varying from 1 to 1.5. Grim (4) suggested that the illite in the Pennsylvanian shales of Illinois formed after deposition from montmorillonite.

According to Moore, Frye, and Jewett (6) the exposed sedimentary rocks of the eastern third of Kansas are of the Paleozoic systems. The shales studied were deposited during the Pennsylvanian which in Kansas and Nebraska shows a transitional phase from the coal measures of the east to the limestone of the west. The system consists largely of shale, with a little sandstone and considerable limestone. Blackwelder (3) stated that the sea was more permanent west of the area within which the coal measures were being deposited, from Michigan and Indiana to Kansas and Oklahoma. The thickness of the fossiliferous shale and limestone with only occasional beds of coal and sandstone gives evidence of this. Brachiopods, crinoids, and other ordinary marine fossils are present in this area.

SOURCE AND PHOSPHORUS CONTENT OF SHALES USED

Moore, Frye, and Jewett (6) made a tabular description of the rock formations and their members which outcrop in Kansas. The description included most of the shales used in this study.

Representative samples of shale were taken from eastern Kansas outcrops by Mr. R. T. Runnels of the Kansas Geological Survey. These samples were used to make complete chemical analyses and a sample of each shale was sent to Kansas State College to be used in this investigation. The source and legal description of areas where phosphatic shales were sampled are given in Table 1.

Table 1. Legal description of localities where shale samples used as phosphate fertilizing materials were taken.*

Stratigraphic horizon	County	Location legal description
Muncie Creek shale	Wyandotte	sec. 12, T. 11 S., R. 24 E.
Quivera shale	Wyandotte	sec. 12, T. 11 S., R. 24 E.
Pleasanton shale	Labette	SE1/4 sec. 17, T. 32 S., R. 19 E.
Eudora shale	Franklin	SW1/4SW1/4 sec.6, T.17 S., R.19 E.

* From Runnels (7).

In making an analysis of the phosphoric acid contained in the shales, Runnels (7) used the citric acid-soluble phosphoric acid analyses as described in A.O.A.C. (2) for basic slag. After most of the shale treatments had been applied to the various tests carried out in the greenhouse and in the field, an analysis was made by the Kansas State College Control Laboratory. This analysis measured the content of available phosphoric acid by subtracting the citrate-insoluble phosphoric acid from the total phosphoric acid as outlined in A.O.A.C. (2) for fertilizer analyses. Since this measure of available phosphoric acid is the approved method for analyses of available phosphoric acid in fertilizers, it will be used in referring to the amounts of available phosphoric acid applied to the various treatments. Most of the treatments were made, however, using quantities calculated on the basis of citric acid-soluble phosphoric acid which was erroneously believed to be the correct measure of available phosphoric acid. The phosphoric acid content of the shales used in this investigation is given in Table 2.

Table 2. Per cent of phosphoric acid contained in the shales used in this investigation as phosphate fertilizers. Analyses were made according to methods described in A.O.A.C. (2).

Shale	Total phosphoric acid.*	Citric acid-soluble phosphoric acid.*	Available phosphoric acid.**
Muncie Creek	1.07	0.73	0.26
Quivera	1.64	1.34	0.56
Pleasanton	3.20	2.80	0.49
Eudora	0.81	0.79	0.19

* Analyses by Runnels (7).
** Analyses by the Kansas State College Control Laboratory.

EXPERIMENTAL METHODS

The purpose of the study carried out by the author at Kansas State College was to determine under greenhouse and field conditions, the added crop response due to application of phosphatic shales to soils known to be deficient in phosphorus. The soils used in the investigation consisted of Parsons silt loam from Neosho County and Geary silt loam from Riley County. The tests were carried out using alfalfa and wheat since they are the major crops requiring phosphate fertilizer treatment in eastern Kansas. A comparison of kinds and amounts of shale treatments was made with plots receiving no phosphate treatment as well as plots receiving applications of superphosphate and rock phosphate. No attempt was made to measure the possible benefits due to other elements contained in the shales.

Agronomy Farm Plot Tests with Phosphatic Shales

Field tests were conducted at the Kansas State College Agronomy Farm with wheat planted October 2, 1948. Thirty plots were used. The pulverized shale and rock phosphate were applied to the surface seedbed of the respective plots just prior to seeding and incorporated into the upper three to four inches with a disc harrow. Superphosphate was applied at the time of seeding with a conventional fertilizer drill. A spring top-dressing of ammonium nitrate equivalent to 50 pounds per acre of available nitrogen was made to all plots on March 28, 1949.

The plots which were to receive fertilizer treatment were picked at random. Four treatments and one check which did not receive a phosphate treatment were replicated six times. The fertilizer treatments and amounts applied are given in Table 3.

Greenhouse Jar Tests with Phosphatic Shales

The major part of this study was carried out with alfalfa and wheat grown on soil which was contained in glazed clay jars. These tests were conducted in the agronomy department greenhouse at Kansas State College during the winter and spring of 1948-49. The photoperiod during the time the plants were grown was not controlled. Only one cutting of alfalfa was grown after the greenhouse was whitewashed on May 23, 1949 to eliminate the intense rays of the sun during the summer months. The jars were moved at random regularly to avoid error due to differential light effects. All of the jar treatments were replicated four times.

One-gallon jars were used as soil containers in an experiment with shale treatments applied to Parsons silt loam soil from the F. E. Davidson farm in Neosho County. Alfalfa was grown on the soil from the Davidson farm. In the other experiment using alfalfa, one-gallon jars containing Geary silt loam soil from the Kansas State College Agronomy Farm were used. The greenhouse test with shale treatments made to Parsons silt loam soil growing wheat utilized one-half gallon jars. The Parsons silt loam soil used with the shale test on wheat was obtained from the Southeast Kansas Experiment Field at Thayer. The jars were cleaned and four thousand grams of air dry soil were added to each one-gallon jar. Two thousand grams of air dry soil were used in the one-half gallon jars.

Before the soil was added to the jars, it was thoroughly mixed with the respective fertilizer treatments by tabling on a large sheet of heavy paper. Rock phosphate and pulverized shales were added by adding mono-calcium phosphate in solution with a pipette. All of the Neosho County soil was treated with potassium chloride at the rate of 60 pounds of available potash per acre.

The Geary silt loam soil was not treated with potassium since it previously has not indicated a deficiency of this element. Nitrogen was added to all of the jars in the form of ammonium nitrate at the rate of 50 pounds of elemental nitrogen per acre. Both potassium chloride and ammonium nitrate were placed in solution and added with a pipette in the same manner as mono-calcium phosphate.

Phosphatic Shales Applied to Parsons Silt Loam Soil Growing Alfalfa. Forty plants of Kansas Common selection number 176 were taken from the alfalfa nursery on November 18, 1948. These mature plants were transplanted in jars containing Parsons silt loam soil. The soil was packed firmly around the roots and enough distilled water was added to bring the moisture content of the soil in each jar up to approximately three-fourths of the moisture equivalent which was determined in the laboratory to be 16.4 per cent. All of the plants had been propagated vegetatively from a single parent plant during the winter of 1947-48 and transplanted in the field during the spring of 1948. The main reason for using these mature plants was to obtain faster results. Also, the error due to individual differences in plants should have been less with plants propagated vegetatively from one individual. Nine fertilizer treatments and a check, which did not receive a phosphate fertilizer treatment, were included in this test. Each treatment and the check were replicated four times. The amount and kind of fertilizer material used in the treatments is given in Table 4.

The Parsons silt loam soil which was used in this test had a pH of 4.7. Calcium carbonate applied at the rate of four tons per acre was added to two shale treatments to compare the crop response due to heavy applications of both shale and lime.

Phosphatic Shales Applied to Geary Silt Loam Soil Growing Alfalfa. The first cutting of the alfalfa grown on the Parsons silt loam soil was used to make vegetative cuttings for the greenhouse fertilizer test using Geary silt loam soil. When the cuttings had roots about one-fourth to one-half inch long, they were transplanted in jars containing the Geary silt loam soil. The soil had been given the respective fertilizer treatments and enough distilled water had been added to bring the moisture content of the soil in each jar up to approximately one-half the moisture equivalent which previously had been determined in the laboratory to be 24 per cent. The pulverized shale used in this investigation would pass through a number 20 sieve having 0.0331 inch openings. The coarsely ground Eudora shale would pass through a number 10 sieve having 0.0787 inch openings. It was desired to determine what, if any, would be the effect of fineness of grinding on the availability of phosphorus in the shale. Twelve plants were transplanted in each jar. These were later thinned to eight plants in order to prevent crowding and yet obtain complete and efficient utilization of nutrients. Phosphate fertilizer treatments were made to the Geary silt loam soil growing alfalfa under greenhouse conditions according to Table 12.

Phosphatic Shales Applied to Parsons Silt Loam Soil Growing Wheat. The fertilizer test using wheat grown on Parsons silt loam soil from the Southeast Kansas Experiment Field had formerly been designed for alfalfa, however after the loss of some of the transplanted cuttings due to "damping off", the test was redesigned for wheat. The wheat was planted one-half inch deep with 15 seeds to each jar. These were later thinned to six plants. The fertilizer treatments made to the Parsons silt loam soil planted to wheat are listed in Table 24.

Reward, a spring wheat variety, was used as a crop for this test since there was not enough time left for winter wheat to grow and mature under greenhouse conditions. The wheat was planted on February 22, 1949. In this test a comparison was desired between shales, mono-calcium phosphate, and rock phosphate, when all of the treatments received an equal amount of available phosphoric acid.

Methods of Laboratory Analysis for Measuring Phosphorus Content of Plant Material

After the plant material had been oven dried at a temperature of 75 degrees Centigrade and weighed, it was ground in a Wiley mill. The phosphorus extraction was made by the wet digestion method for destroying organic matter with perchloric, nitric, and sulfuric acids as outlined by Piper (8).

When the digest was cold, it was transferred and diluted to volume in a 100 milliliter volumetric flask by the addition of distilled water. Two milliliters of the 100 milliliter extract were removed by a pipette and placed in a 50 milliliter volumetric flask and diluted to volume. Twenty milliliters of the resulting solution were used for colorimetric phosphorus determinations using an adaptation of the method outlined by Arnold and Kurtz (1).

Analyses were made on the plant material from each replicate. Due to the small size of wheat grain samples, it was necessary to grind this material with a mortar and pestle. Phosphorus content was not measured on the wheat grown on the agronomy farm field plots and the fourth cutting of alfalfa grown on Parsons silt loam soil in the greenhouse.

EXPERIMENTAL RESULTS AND DISCUSSION

Agronomy Farm Plot Tests with Phosphatic Shales

Results from the wheat plots located on the Kansas State College Agronomy Farm did not show a significant response to applications of phosphate fertilizers when an analysis of variance of the yield data was made. However, as indicated in Table 3, there is a suggestion that treble-superphosphate, rock phosphate, and Muncie Creek shale gave an increased response in yield over the plots which received no phosphate fertilizer treatment and the Pleasanton shale treatments.

The shale fertilizer study with wheat grown in field plots on the agronomy farm was conducted on Geary silt loam soil which is not as deficient in phosphorus as some of the other soils on the agronomy farm. The results shown in Table 7 indicate that

Table 3. Yield of wheat in bushels per acre and the rate of application of different phosphatic fertilizer materials on the wheat plots located on the Kansas State College Agronomy Farm, 1948-49.

Treatment	Rate of application of fertilizer material in pounds per acre: Total material added	Rate of application of fertilizer material in pounds per acre: Available P_2O_5	Yield of grain in bushels per acre*
Pleasanton shale	4,000	20	34.25
Muncie Creek shale	6,350	18	37.10
Rock phosphate	2,500	50	37.80
Treble-super phosphate	110	50	37.93
No treatment	--	--	35.41

* Average of six replicate treatments which were 1/1452 of an acre in size.

this particular area of the agronomy farm is not deficient enough in phosphorus to warrant its use for a fertilizer study of this kind.

Tests with Phosphatic Shales Conducted in the Greenhouse

Alfalfa and wheat were grown in jars containing soil which had been treated with different phosphatic fertilizer materials. The alfalfa cuttings were made when the crop had matured to the one-tenth of full bloom stage. The wheat was cut when the grain was in the hard dough stage and allowed to finish ripening before threshing by hand in the laboratory.

Phosphatic Shales Applied to Parsons Silt Loam Soil Growing Alfalfa. The experiment with alfalfa grown on Parsons silt loam treated with the various phosphate fertilizing materials was designed to compare the fertilizing value of Pleasanton shale, Muncie Creek shale, and Eudora shale with mono-calcium phosphate, rock phosphate, and a check which did not receive a phosphate fertilizer treatment. A comparison of heavy applications of four tons per acre was made with relatively smaller applications of shale.

Five cuttings of alfalfa were made from the alfalfa grown in jars containing Parsons silt loam soil. The first cutting was not used for yield or phosphorus analysis since a large part of this growth was made from stored root reserves. Each jar contained only one plant which was obtained from a root stock. This resulted in large differences within treatments due to individual variations in the population. Several plants died during the season and the resulting missing data were taken into consideration when making a statistical analysis of variance. Chemical analysis of the plant material for phosphorus content was made on the second, third, and fifth cuttings. Each treatment was replicated four times and the average of the four replicates was reported in the tables giving yield per jar, per cent phosphorus in hay, and the phosphorus content of hay in grams per jar.

Table 4 shows the data obtained for the second alfalfa cutting. Applications of 1,786 pounds per acre of Pleasanton shale and 2,500 pounds per acre of rock phosphate gave the two highest yields respectively. Both were significantly greater at the 5 per cent level of significance (Table 5) than the no-treatment yield, the 6,849 pound per acre application of Muncie Creek shale yield, and the 100 pound per acre application of mono-calcium phosphate yield. The yields received from applications of 8,000 pounds per acre of Eudora shale and 8,000 pounds per acre of Muncie Creek shale plus lime ranked third and fourth respectively and were significantly greater than the mono-calcium phosphate treatment or the 6,849 pound per acre treatment of Muncie Creek shale.

Table 4. Yield and phosphorus content of the second cutting of alfalfa grown on Parsons silt loam soil treated with different phosphatic fertilizer materials in the greenhouse.

Treatment	Rate of application of fertilizer material in pounds per acre: Total material added	Rate of application of fertilizer material in pounds per acre: Available P_2O_5	Yield of hay in grams per jar	Per cent phosphorus in hay
Pleasanton shale	1,786	9	3.72*	0.433
Muncie Creek shale	6,849	18	2.41	0.553**
Muncie Creek shale	8,000	21	2.85	0.538**
Eudora shale	8,000	15	3.61	0.460
Pleasanton shale	8,000	39	3.32	0.444
Muncie Creek shale[1]	8,000	21	3.49	0.458
Pleasanton shale[1]	8,000	39	3.12	0.456
Mono-calcium phosphate	100	50	2.44	0.514*
Rock phosphate	2,500	50	3.66*	0.540**
No treatment	--	--	2.69	0.442

* Differs significantly from the untreated culture at the 5 per cent level of significance.

** Differs significantly from the untreated culture at the 1 per cent level of significance.

1 Received an additional treatment consisting of calcium carbonate applied at the rate of 8,000 pounds per acre.

Table 5. Analysis of variance values obtained using yield data for the second cutting of alfalfa grown on Parsons silt loam soil in the greenhouse study of the fertilizer value of certain phosphatic shales.

Factor	Variance	Calculated F value	F value needed for significance 5% level	F value needed for significance 1% level	Least significant difference 5% level	Least significant difference 1% level
Between treatments	0.93	2.58*	2.25	3.30	0.94	---
Within treatments	0.36					

* Differences significant at 5 per cent level.

The average per cent phosphorus in the second cutting of alfalfa grown on Parsons silt loam soil was determined and the results were found to be highly significant when treated statistically as indicated in Table 6. Using the least significant difference for probabilities of 1 per cent, three treatments were found to have resulted in a significantly greater per cent phos-

Table 6. Analysis of variance values obtained using per cent phosphorus content data for the second cutting of alfalfa grown on Parsons silt loam soil in the greenhouse study of the fertilizer value of certain phosphatic shales.

Factor	Variance	Calculated F value	F value needed for significance 5% level	F value needed for significance 1% level	Least significant difference 5% level	Least significant difference 1% level
Between treatments	0.0082	4.32**	2.25	3.30	0.068	0.092
Within treatments	0.0019					

** Differences significant at 1 per cent level.

phorus content than the plant material from the soil which did not have a phosphate fertilizer application. These three treatments consisted of the 6,849 pound per acre application of Muncie Creek shale, the 2,500 pound per acre application of rock phosphate, and the 8,000 pound per acre application of Muncie Creek shale. These same treatments were significantly greater at the 5 per cent level for the per cent phosphorus content of the hay than any of the other seven treatments in the test. The mono-calcium phosphate treatment was significantly greater than the non-treated culture at the 5 per cent level.

An analysis of variance of the average phosphorus content in grams was not made on the data from the individual cuttings of alfalfa grown on Parsons silt loam soil. The analysis of variance of the seasonal phosphate content in grams for the total of the second, third, and fifth cuttings revealed that the differences between treatments were insignificant.

Tables 7, 8, and 9 give the data for yield and per cent phosphorus content for the third, fourth, and fifth cuttings of alfalfa. The individual plant differences within treatments were so great that a significant difference between treatments was not found when an analysis of variance was applied to the data.

In comparing the seasonal yield of alfalfa grown on Parsons silt loam soil shown in Table 10, four treatments gave significantly (5% level, Table 11) greater yields than the treatment of 6,849 pounds per acre of Muncie Creek shale which gave the lowest yield of all treatments including the no-treatment yield. These

Table 7. Yield and phosphorus content of the third cutting of alfalfa grown on Parsons silt loam soil treated with different phosphatic fertilizer materials in the greenhouse.

Treatment	Rate of application of fertilizer material in pounds per acre: Total material added	Rate of application of fertilizer material in pounds per acre: Available P_2O_5	Yield of hay in grams per jar	Per cent phosphorus content of hay
Pleasanton shale	1,786	9	5.52	0.210
Muncie Creek shale	6,849	18	4.35	0.256
Muncie Creek shale	8,000	21	6.31	0.238
Eudora shale	8,000	15	5.83	0.225
Pleasanton shale	8,000	39	6.02	0.232
Muncie Creek shale[1]	8,000	21	7.16	0.230
Pleasanton shale[1]	8,000	39	6.64	0.243
Mono-calcium phosphate	100	50	5.04	0.248
Rock phosphate	2,500	50	7.08	0.262
No treatment	--	--	6.36	0.212

[1]Received an additional treatment consisting of calcium carbonate applied at the rate of 8,000 pounds per acre.

Table 8. Yield in grams for the fourth cutting of alfalfa grown on Parsons silt loam soil treated with different phosphatic fertilizer materials in the greenhouse.

Treatment	Rate of application of fertilizer material in pounds per acre: Total material added	Rate of application of fertilizer material in pounds per acre: Available P_2O_5	Yield of hay in grams per jar
Pleasanton shale	1,786	9	7.78
Muncie Creek shale	6,849	18	5.63
Muncie Creek shale	8,000	21	7.01
Eudora shale	8,000	15	8.38
Pleasanton shale	8,000	39	9.56
Muncie Creek shale[1]	8,000	21	8.60
Pleasanton shale[1]	8,000	39	9.08
Mono-calcium phosphate	100	50	7.45
Rock phosphate	2,500	50	8.80
No treatment	--	--	8.05

[1]Received an additional treatment consisting of calcium carbonate applied at the rate of 8,000 pounds per acre.

Table 9. Yield and phosphorus content of the fifth cutting of alfalfa grown on Parsons silt loam soil treated with different phosphatic fertilizer materials in the greenhouse.

Treatment	Rate of application of fertilizer material in pounds per acre: Total material added	Rate of application of fertilizer material in pounds per acre: Available P_2O_5	Yield of hay in grams per jar	Per cent phosphorus content of hay
Pleasanton shale	1,786	9	4.68	0.172
Muncie Creek shale	6,849	18	3.58	0.234
Muncie Creek shale	8,000	21	3.74	0.226
Eudora shale	8,000	15	4.12	0.198
Pleasanton shale	8,000	39	4.72	0.196
Muncie Creek shale[1]	8,000	21	4.90	0.201
Pleasanton shale[1]	8,000	39	4.68	0.192
Mono-calcium phosphate	100	50	3.31	0.218
Rock phosphate	2,500	50	4.44	0.273
No treatment	--	--	3.82	0.184

[1] Received an additional treatment consisting of calcium carbonate applied at the rate of 8,000 pounds per acre.

Table 10. Seasonal yield and phosphorus content for the second, third, fourth, and fifth cuttings of alfalfa grown on Parsons silt loam soil treated with different phosphatic fertilizer materials in the greenhouse.

Treatment	Rate of application of fertilizer material in pounds per acre		Yield of hay in grams per jar	Phosphorus content of hay		Per cent of available P_2O_5 recovered
	Total material added	Available P_2O_5		Per cent	Grams per jar	
Pleasanton shale	1,786	9	21.70	0.272	0.03541	38.17
Muncie Creek shale	6,849	18	15.97	0.348	0.03286	2.93
Muncie Creek shale	8,000	21	19.91	0.334	0.03965	39.48
Eudora shale	8,000	15	21.94	0.294	0.03774	40.76
Pleasanton shale	8,000	39	23.61	0.291	0.03735	15.98
Muncie Creek shale[1]	8,000	21	24.15	0.296	0.04214	53.11
Pleasanton shale[1]	8,000	39	23.52	0.297	0.03893	19.15
Mono-calcium phosphate	100	50	18.24	0.327	0.03231	--
Rock phosphate	2,500	50	23.98	0.358	0.04099	40.28
No treatment	--	--	20.92	0.279	0.03240	--

[1] Received an additional treatment consisting of calcium carbonate applied at the rate of 8,000 pounds per acre.

four treatments were the 2,500 pound per acre application of rock phosphate, the 8,000 pound per acre application of Muncie Creek shale plus lime, the 8,000 pound per acre application of Pleasanton shale, and the 8,000 pound per acre application of Pleasanton shale plus lime.

Table 11. Analysis of variance values obtained by using seasonal yield data for the second, third, fourth, and fifth cuttings of alfalfa grown on Parsons silt loam soil in the greenhouse study of the fertilizer value of phosphatic shales.

Factor	Variance	Calculated F value	F value needed for significance: 5% level	F value needed for significance: 1% level	Least significant difference: 5% level	Least significant difference: 1% level
Between treatments	24.94	2.84*	2.32	--	6.37	--
Within treatments	8.77					

* Differences significant at the 5% level.

An analysis of variance was made on the seasonal per cent phosphorus content of hay and the seasonal phosphorus content in grams per jar. The seasonal phosphorus content data was found to be insignificant as to differences between treatments.

The per cent of available phosphoric acid recovered by the plants was measured. To obtain this value, the phosphorus content of the hay in grams per jar for the non-treated soil was subtracted from the phosphorus content of the hay in grams for the treated jars. This gave the additional phosphorus which was taken up by the plant due to the application of phosphate fertilizer.

The above value was divided by the weight of available phosphorus added to the soil in the fertilizer application and multiplied by 100 to obtain a figure representing the per cent of available phosphoric acid recovered.

Table 10 shows that from 2.93 to 53.11 per cent of the available phosphoric acid that was added in the different shale treatments was recovered by the alfalfa plants as compared to 40.3 per cent recovery from rock phosphate and no recovery from mono-calcium phosphate. This indicates that the available phosphoric acid in Pleasanton, Muncie Creek, and Eudora shale is available to plants and compares favorably to rock phosphate as to availability of phosphoric acid to alfalfa grown on Parsons silt loam soil.

Phosphatic Shales Applied to Geary Silt Loam Soil Growing Alfalfa. Three cuttings of alfalfa were made from the test using Geary silt loam soil treated with different phosphate fertilizer materials.

The analysis of variance of the yield data for the first cutting of alfalfa grown on Geary silt loam soil proved that the differences between treatments were significant (5% level) as shown in Table 13. A significant response in yield was made with the application of 100 pounds per acre of mono-calcium phosphate. Table 12 shows that none of the shale treatments or the rock phosphate which was applied at the same rate of available phosphoric acid as the mono-calcium phosphate gave significant increases in yield. However, in all cases except the treatment

Table 12. Yield and phosphorus content of the first cutting of alfalfa grown on Geary silt loam soil treated with different phosphatic fertilizer materials in the greenhouse.

Treatment	Rate of application of fertilizer material in pounds per acre: Total material added	Rate of application of fertilizer material in pounds per acre: Available P_2O_5	Yield of hay in grams per jar	Phosphorus content of hay: Per cent	Phosphorus content of hay: Grams per jar
Pleasanton shale	1,786	9	4.72	0.106	0.00500
Eudora shale	6,309	12	4.93	0.111	0.00548
Pleasanton shale	8,000	39	5.38	0.120	0.00642
Eudora shale	8,000	15	5.24	0.104	0.00546
Quivera shale	8,000	45	5.14	0.117	0.00604
Muncie Creek shale	8,000	21	5.10	0.117	0.00598
Eudora shale-coarse	8,000	15	5.57	0.108	0.00600
Mono-calcium phosphate	100	50	6.33*	0.127	0.00806**
Rock phosphate	2,500	50	5.40	0.150**	0.00813**
No treatment	--	--	4.86	0.119	0.00578

* Differs significantly from the untreated culture at the 5 per cent level of significance.

** Differs significantly from the untreated culture at the 1 per cent level of significance.

Table 13. Analysis of variance values obtained using yield data for the first cutting of alfalfa grown on Geary silt loam soil in the greenhouse study of the fertilizer value of certain phosphatic shales.

Factor	Variance	Calculated F value	F value needed for significance 5% level	1% level	Least significant difference 5% level	1% level
Between treatments	0.833	2.41*	2.22	3.08	0.85	--
Within treatments	0.345					

* Differences significant at the 5% level.

receiving 1,786 pounds per acre of Pleasanton shale, an increase in yield over the plants on the non-treated soil was obtained.

Table 14. Analysis of variance values obtained by using per cent phosphorus content data for the first cutting of alfalfa grown on Geary silt loam soil in the greenhouse study of the fertilizer value of certain phosphatic shales.

Factor	Variance	Calculated F value	F value needed for significance 5% level	1% level	Least significant difference 5% level	1% level
Between treatments	0.000722	16.79*	2.22	3.06	0.009	0.013
Within treatments	0.000043					

* Differences significant at the 1 per cent level.

Table 14 shows that the results from the analysis of variance on the per cent phosphorus content of hay for the first cutting of alfalfa were highly significant. The plant material from the rock phosphate treatments gave a significantly greater per cent phosphorus content over all other treatments. The plant material from the mono-calcium phosphate treatment ranked second in per cent phosphorus content to rock phosphate and was significantly higher than the plant material from all of the shale treatments except Pleasanton shale applied at the rate of 8,000 pounds per acre. A highly significant F value was obtained from the analysis of variance of the phosphorus content in grams.

The plant material from the mono-calcium phosphate and rock phosphate treatments had a significantly (1 per cent level) greater content of phosphorus than all other treatments. Alfalfa grown on soil treated with Pleasanton shale at the rate of 8,000 pounds per acre had a significantly (5 per cent level) greater phosphorus content than did the plant material from the treatment of Pleasanton shale applied at the rate of 1,786 pounds per acre.

The analysis of variance of the yield data from the second cutting of alfalfa grown on Geary silt loam soil showed no significance between treatments. Table 16 shows the lowest yield for the second cutting to be on the soil which did not have a phosphate fertilizer treatment. This would indicate that all of the phosphate fertilizer materials were giving some response. However, none of the differences in yield were large enough to be statistically significant.

Table 15. Analysis of variance values obtained by using the phosphorus content in grams for the first cutting of alfalfa grown on Geary silt loam soil in the greenhouse study of the fertilizer value of certain phosphatic shales.

Factor	Variance	Calculated F value	F value needed for significance		Least significant difference	
			5% level	1% level	5% level	1% level
Between treatments	0.0000044550	7.38**	2.22	3.08	0.00112	0.00151
Within treatments	0.0000006029					

** Differences significant at the 1% level.

Table 16. Yield and phosphorus content of the second cutting of alfalfa grown on Geary silt loam soil treated with different phosphatic fertilizer materials in the greenhouse.

Treatment	Rate of application of fertilizer material in pounds per acre		Yield of hay in grams per jar	Phosphorus content of hay	
	Total material added	Available P_2O_5		Per cent	Grams per jar
Pleasanton shale	1,786	9	4.98	0.170	0.00848
Eudora shale	6,329	12	4.76	0.168	0.00802
Pleasanton shale	8,000	39	4.56	0.192	0.00874
Eudora shale	8,000	15	4.60	0.168	0.00772
Quivera shale	8,000	45	4.41	0.190	0.00836
Muncie Creek shale	8,000	21	4.62	0.173	0.00800
Eudora shale--coarse	8,000	15	4.62	0.190	0.00879
Mono-calcium phosphate	100	50	4.41	0.213	0.00938
Rock phosphate	2,500	50	4.61	0.250*	0.01156*
No treatment	--	--	3.70	0.206	0.00763

* Differs significantly from the untreated cultures at the 1 per cent level of significance.

Table 17. Analysis of variance values obtained by using per cent phosphorus content data for the second cutting of alfalfa grown on Geary silt loam soil in the greenhouse study of the fertilizer value of certain phosphatic shales.

Factor	Variance	Calculated F value	F value needed for significance: 5% level	F value needed for significance: 1% level	Least significant difference: 5% level	Least significant difference: 1% level
Between treatments	0.0026667	80.08*	2.22	3.08	0.008	0.011
Within treatments	0.0000333					

* Differences significant at the 1% level.

The plant material from the rock phosphate treatment had a significantly (1% level, Table 17) greater percentage of phosphorus than any of the other treatments and the nontreated culture. Plant material from the mono-calcium phosphate treatments ranked second in phosphorus percentage and contained significantly (1% level) more phosphorus than any of the other treatments with the exception of the plant material from the soil which did not receive an application of phosphate fertilizer. As will be noted in Table 16, the shale treatments produced plants having a significantly lower phosphorus percentage than the plant material grown on soil which did not have a phosphate fertilizer application.

The content of phosphorus in grams for the alfalfa grown on Geary silt loam soil treated with rock phosphate was significantly

Table 18. Analysis of variance values obtained by using the data for the phosphorus content in grams of the second cutting of alfalfa grown on Geary silt loam soil in the greenhouse study of the fertilizer value of certain phosphatic shales.

Factor	Variance	Calculated F value	F value needed for significance: 5% level	F value needed for significance: 1% level	Least significant difference: 5% level	Least significant difference: 1% level
Between treatments	0.0000052812	5.05*	2.22	3.08	0.00148	0.00199
Within treatments	0.0000010455					

* Differences significant at the 1 per cent level.

(1 per cent level, Table 18) greater than all other treatments. The mono-calcium phosphate treatment produced plants which gave a significant (5 per cent level) response in phosphorus content over the plants grown with Eudora shale applied at the rate of 8,000 pounds per acre and the check which was not treated with a phosphate fertilizer. The smallest content of phosphorus in grams was received from plants grown on the nontreated soil.

An analysis of variance of the yield data shown in Table 20 for the third cutting of alfalfa revealed that the differences between treatments were just significant at the 5 per cent level. Five treatments gave significantly greater yields of alfalfa than the soil which was not fertilized. These treatments consisted of Pleasanton shale applied at the rate of 8,000 pounds per acre, Eudora shale applied at the rate of 8,000 pounds per acre. Eudora shale applied at the rate of 6,329 pounds per acre, and rock phosphate applied at the rate of 2,500 pounds per acre. The Eudora shale treatment, which ranked second, was coarsely ground. This suggests that fineness of grinding is not a factor in the availability of phosphorus in the shales. Table 19 shows the yield from the soil which had not been treated to be the lowest which would again indicate that a response in the yield of alfalfa was obtained by addition of mono-calcium phosphate and rock phosphate as well as the phosphatic shales.

Table 19. Yield and phosphorus content of the third cutting of alfalfa grown on Geary silt loam soil treated with different phosphatic fertilizer materials in the greenhouse.

Treatment	Rate of application of fertilizer material in pounds per acre		Yield of hay in grams per jar	Phosphorus content of hay	
	Total material added	Available P_2O_5		Per cent	Grams per jar
Pleasanton shale	1,786	9	2.84	0.229	0.00649
Eudora shale	6,329	12	2.98*	0.271	0.00804**
Pleasanton shale	8,000	39	3.20*	0.235	0.00754**
Eudora shale	8,000	15	3.08*	0.254	0.00782**
Quivera shale	8,000	45	2.76	0.238	0.00656
Muncie Creek shale	8,000	21	2.84	0.251	0.00710
Eudora shale--coarse	8,000	15	3.14*	0.241	0.00756**
Mono-calcium phosphate	100	50	2.78	0.277	0.00768**
Rock phosphate	2,500	50	2.96*	0.344**	0.01020**
No treatment	--	--	2.48	0.258	0.00637

* Differs significantly from the untreated culture at the 5 per cent level of significance.

** Differs significantly from the untreated culture at the 1 per cent level of significance.

Table 20. Analysis of variance values obtained by using yield data for the third cutting of alfalfa grown on Geary silt loam soil in the greenhouse study of the fertilizer value of certain phosphatic shales.

Factor	Variance	Calculated F value	F value needed for significance: 5% level	1% level	Least significant difference: 5% level	1% level
Between treatments	0.18111	2.21*	2.22	3.08	0.41	
Within treatments	0.08200					

* Differences significant at the 5 per cent level.

Table 21. Analysis of variance values obtained by using per cent phosphorus content data for the third cutting of alfalfa grown on Geary silt loam soil in the greenhouse study of the fertilizer value of certain phosphatic shales.

Factor	Variance	Calculated F value	F value needed for significance: 5% level	1% level	Least significant difference: 5% level	1% level
Between treatments	0.00444	22.20*	2.22	3.08	0.020	0.028
Within treatments	0.00020					

* Differences significant at the 1 per cent level.

The third cutting of plant material from Geary silt loam treated with rock phosphate had a significantly (1 per cent level, Table 21) greater phosphorus percentage than any of the plant material from other phosphate treatments. The alfalfa grown on soil treated with mono-calcium phosphate ranked second and had a significantly (5 per cent level) greater phosphorus percentage than the alfalfa from any of the other treatments with the exception of Eudora shale applied at the rate of 6,329 pounds per acre and the soil which did not have a phosphate fertilizer treatment. The plant material from the Eudora shale treatment and from the non-treated soil in turn gave significantly (5 per cent level) greater phosphorus percentages when compared to the plant material from the Pleasanton shale treatment applied at the rate of 1,786 pounds per acre.

The analysis of variance of the data for phosphorus content in grams for the third cutting of alfalfa is shown in Table 22. The differences between treatments were highly significant. Alfalfa grown on soil treated with rock phosphate took up significantly (1 per cent level) more phosphorus than the alfalfa grown on the other treatments. As indicated in Table 19, five treatments had significantly (1 per cent level) greater contents of phosphorus than did the no-treatment plant material. The plant material from the Eudora shale treatment applied at the rate of 6,329 pounds per acre had a significantly (1 per cent level) greater phosphorus content than the plant material from treatments of Muncie Creek shale applied at the rate of 8,000 pounds per acre, Quivera shale applied at the rate of 8,000 pounds per acre, Pleasanton shale applied at the rate of 1,786 pounds per acre, and the soil which did not receive a phosphate fertilizer treatment.
As shown in Table 19, the Quivera shale, Pleasanton shale, and the no-treatment plant material were significantly lower in phosphorus content than the plant material from all the other treatments.

Table 22. Analysis of variance values obtained by using the data for the phosphorus content in grams of the third cutting of alfalfa grown on Geary silt loam soil in the greenhouse study of the fertilizer value of certain phosphatic shales.

Factor	Variance	Calculated F value	F value needed for significance		Least significant difference	
			5% level	1% level	5% level	1% level
Between treatments	0.0000048822	18.95*	2.22	3.06	0.00073	0.00099
Within treatments	0.0000002577					

* Differences significant at the 1 per cent level.

Table 23. Seasonal yield and phosphorus content for the first, second, and third cuttings of alfalfa grown on Geary silt loam soil treated with different phosphatic fertilizer materials in the greenhouse.

Treatment	Rate of application of fertilizer material in pounds per acre: Total material added	Rate of application of fertilizer material in pounds per acre: Available P_2O_5	Yield of hay in grams per jar	Phosphorus content of hay: Per cent	Phosphorus content of hay: Grams per jar	Per cent of available P_2O_5 recovered
Pleasanton shale	1,786	9	12.54	0.168	0.01997	2.29
Eudora shale	6,329	12	12.67	0.183	0.02154	16.79
Pleasanton shale	8,000	39	13.14	0.182	0.02270	8.58
Eudora shale	8,000	15	12.98	0.175	0.02100	9.31
Quivera shale	8,000	45	12.31	0.182	0.02096	3.00
Muncie Creek shale	8,000	21	12.56	0.180	0.02108	7.09
Eudora shale[1]	8,000	15	13.33	0.180	0.02235	19.54
Mono-calcium phosphate	100	50	13.52	0.206	0.02512	12.24
Rock phosphate	2,500	50	12.61	0.248	0.02989	23.14
No treatment	--	--	11.04	0.194	0.01978	--

[1] Coarsely ground material which will pass through a number 10 sieve.

Table 23 gives the seasonal data for the first, second, and third cuttings of alfalfa grown on Geary silt loam. An analysis of variance was not made with this data since each individual cutting was thoroughly treated statistically.

The seasonal yield data suggest that an increase in yield over the no-treatment in every case followed applications of phosphatic fertilizers. The seasonal phosphorus percentage of the hay shows definite increases for the hay grown on soil treated with rock phosphate. Mono-calcium phosphate treated soil produced hay which had a slightly greater phosphorus percentage than the no-treatment plant material. The data for each cutting show that the shale treatments produced hay which analyzed a lower percentage phosphorus than the no-treatment hay. This suggests that the increased growth due to application of shale may have been due to the action of some element other than phosphorus contained in the shales. Relatively large quantities of phosphorus were taken up by the plant material grown on the soil treated with rock phosphate. However, the yield of this same plant material was not increased in the same proportion.

The seasonal data shown in Table 23 indicate that all the phosphate fertilizer treatments resulted in a greater phosphorus content in grams per jar for the plant material than was contained by the hay grown on soil which did not receive a phosphate fertilizer treatment. The increased growth and yield of the shale treatments account for this since their phosphorus percentage was in most cases lower than the percentage phosphorus of the hay grown on soil which received no treatment.

Table 23 shows that from 2.29 to 19.54 per cent of the available phosphoric acid that was added by the different shale treatments was recovered by three cuttings of alfalfa grown on Geary silt loam. Eudora shale compared favorably with rock phosphate which indicated a high per cent recovery by alfalfa. The other shales used in this test were somewhat lower having plant material which recovered from 2.29 to 9.30 per cent of the available phosphoric acid. Mono-calcium phosphate treated soil produced alfalfa which recovered 12.24 per cent of the available phosphoric acid.

Phosphatic Shales Applied to Parsons Silt Loam Soil Growing Wheat. The wheat which was grown in the agronomy greenhouse was harvested 87 days after it was planted. Pictures were taken one month prior to harvest to illustrate the marked response that was given to wheat grown on soil treated with mono-calcium phosphate. This test was designed to study the results when equal amounts of available phosphoric acid were added to each treatment.

The grain yield of wheat from the soil treated with mono-calcium phosphate as shown in Table 24 was significantly (1 per cent level) greater than any other treatment. During the growing period, the wheat planted in soil treated with mono-calcium phosphate could be easily identified because of its darker green color and more vigorous growth. Figures 1 and 2 of Plate I and Figs. 1 and 2 of Plate II illustrate the favorable response of wheat grown on soil treated with mono-calcium phosphate compared

EXPLANATION OF PLATE I

Fig. 1. Illustration of the number I replicate for each treatment used in the greenhouse study with wheat grown on Parsons silt loam soil treated with different phosphatic fertilizer materials. The treatments may be identified by reading the cod number on the jar. The individual jar treatments and code legend from left to right are: Pleasanton shale (T-1), Muncie Creek shale (T-2), Eudora shale--finely ground (T-3), Quivera shale (T-4), Eudora shale--coarsely ground (T-5), mono-calcium phosphate (T-6), rock phosphate (T-7), and the check which did not have a phosphate fertilizer treatment (T-8).

Fig. 2. Illustration of the number II replicate for each treatment used in the greenhouse study with wheat grown on Parsons silt loam soil treated with different phosphatic fertilizer materials. The treatments may be identified by reading the code number on the jar. The individual jar treatments and code legend from left to right are: Pleasanton shale (T-1), Muncie Creek shale (T-2), Eudora shale--finely ground (T-3), Quivera shale (T-4), Eudora shale--coarsely ground (T-5), mono-calcium phosphate (T-6), rock phosphate (T-7), and the check which did not have a phosphate fertilizer treatment (T-8).

PLATE I

Fig. 1

Fig. 2

EXPLANATION OF PLATE II

Fig. 1. Illustration of the number III replicate for each treatment used in the greenhouse study with wheat grown on Parsons silt loam soil treated with different phosphatic fertilizer materials. The treatments may be identified by reading the code number on the jar. The individual jar treatments and code legend from left to right are: Pleasanton shale (T-1), Muncie Creek shale (T-2), Eudora shale--finely ground (T-3), Quivera shale (T-4), Eudora shale--coarsely ground (T-5), mono-calcium phosphate (T-6), rock phosphate (T-7), and the check which did not have a phosphate fertilizer treatment (T-8).

Fig. 2. Illustration of the number IV replicate for each treatment used in the greenhouse study with wheat grown on Parsons silt loam soil treated with different phosphatic fertilizer materials. The treatments may be identified by reading the code number on the jar. The individual jar treatments and code legend from left to right are: Pleasanton shale (T-1), Muncie Creek shale (T-2), Eudora shale--finely ground (T-3), Quivera shale (T-4), Eudora shale--coarsely ground (T-5), mono-calcium phosphate (T-6), rock phosphate (T-7), and the check which did not have a phosphate fertilizer treatment (T-8).

PLATE II

Fig. 1

Fig. 2

Table 24. Yield and phosphorus content of the spring wheat crop which was grown on Parsons silt loam soil treated with different phosphatic fertilizer materials in the greenhouse.

Treatment	Rate of application of fertilizer material in pounds per acre: Total material added	Rate of application of fertilizer material in pounds per acre: Available P_2O_5	Yield of grain in grams	Yield of straw in grams	Phosphorus content of grain: Per cent	Phosphorus content of grain: Grams per jar	Per cent of available P_2O_5 recovered
Pleasanton shale	10,204	50	1.0964	1.69	0.486	0.00526	5.30
Muncie Creek shale	19,231	50	0.8734	1.58	0.627*	0.00545	4.17
Eudora shale[1]	26,316	50	0.7957	1.35	0.629*	0.00500	2.11
Quivera shale	8,929	50	0.8060	1.29	0.536	0.00431	--
Eudora shale[2]	26,316	50	0.7663	1.71	0.549	0.00419	--
Mono-calcium phosphate	100	50	1.6940*	1.94	0.414	0.00702	11.37
Rock phosphate	2,500	50	1.1108	1.58	0.523	0.00590	6.23
No treatment	--	--	0.8853	1.45	0.516	0.00454	--

* Differs significantly from the untreated culture at the 1 per cent level of significance.

1 Finely ground shale which will pass through a number 20 sieve.

2 Coarsely ground shale which will pass through a number 10 sieve.

Table 25. Analysis of variance values obtained using yield data for the grain yield of spring wheat grown on Parsons silt loam soil in the greenhouse study of the fertilizer value of certain phosphatic shales.

Factor	Variance	Calculated F value	F value needed for significance		Least significant difference	
			5% level	1% level	5% level	1% level
Between treatments	0.381	6.05*	2.43	3.50	0.3663	0.4964
Within treatments	0.063					

* Difference significant at the 1 per cent level.

to treatments of rock phosphate and shales which were applied at the same rate of available phosphoric acid per acre.

An analysis of variance of the phosphorus percentage of the wheat grain proved that the difference between treatments was highly significant as shown in Table 26. The grain from the finely ground Eudora shale and the Muncie Creek shale gave significantly (1 per cent level) greater phosphorus percentages than any of the other treatments with the exception of the Eudora shale which was coarsely ground. As indicated in Table 24 the phosphorus percentage of the grain, in general, is inversely proportional to the yield. There is a suggestion in Table 24 that a direct relationship exists between yield and grams of phosphorus taken up by the grain. An analysis of variance of the data for phosphorus content of the grain in grams proved that the differences between treatments were statistically insignificant.

Table 26. Analysis of variance values obtained using the data for per cent phosphorus content of grain of spring wheat grown on Parsons silt loam soil in the greenhouse study of the fertilizer value of certain phosphatic shales.

Factor	Variance	Calculated F value	F value needed for significance: 5% level	F value needed for significance: 1% level	Least significant difference: 5% level	Least significant difference: 1% level
Between treatments	0.02000	9.62*	2.43	3.50	0.064	0.087
Within treatments	0.00208					

* Differences significant at the 1 per cent level.

An analysis of variance made for the yield of straw for the wheat grown in the greenhouse proved that the differences in straw yield were statistically insignificant. A study of the yield of straw and yield of grain in Table 24 will show that the two were closely correlated in this fertilizer test.

The per cent of available phosphoric acid recovered by the grain as shown in Table 24 was relatively high in the case of the mono-calcium phosphate applied to Parsons silt loam growing wheat. Three shale treatments indicate that some of the phosphoric acid was recovered and that the shale would compare to rock phosphate in per cent recovery of the available phosphoric acid.

SUMMARY

The object of this study was to determine the phosphatic fertilizing value of certain Pennsylvanian shales which outcrop in eastern Kansas. The shales used in the investigation contained from 0.19 to 0.56 per cent available phosphoric acid. The total phosphoric acid analyses range from 0.81 to 3.20 per cent for the same shales. These shales also contain small amounts of potassium, magnesium, and iron as well as several other elements that might prove beneficial in agricultural uses under certain soil conditions where these plant nutrients may be deficient.

The four shales studied in this investigation were Muncie Creek shale and Quivera shale from Wyandotte County, Pleasanton shale from Labette County, and Eudora shale from Franklin County. Pulverized samples of the shales were applied to soils which had previously indicated deficiencies of phosphorus in fertilizer experiments.

Tests using phosphatic shales as fertilizer materials were carried out in a greenhouse and on the Agronomy Department Farm during 1948-49. The agronomy farm test was designed to compare the effects of treble-superphosphate, rock phosphate, and shale applications on the yield of winter wheat. It supplemented the major part of the study conducted in the greenhouse which compared mono-calcium phosphate, rock phosphate, and shale treatments applied to soil contained in glazed clay jars. Alfalfa and wheat were grown in the studies. Soils used for the green-

house tests consisted of Parsons silt loam from Neosho County and Geary silt loam from Riley County. The response in yield was measured and the phosphorus content of the plant material was determined in the laboratory by chemical analysis.

Increases in the yield of wheat were received with the application of 6,850 pounds per acre of Muncie Creek shale, 2,500 pounds per acre of rock phosphate, and 110 pounds per acre of treble-superphosphate to the fertilizer plots located on the agronomy farm. However, none of the yield responses due to phosphate fertilizer application was statistically significant.

Four cuttings were made from the alfalfa grown in the greenhouse on Parsons silt loam soil. In this test only one rootstalk of alfalfa was contained in each jar. The large individual variations in the population gave results in yield which are not considered by the author to be reliable. However, yield differences for the second cutting and the total of the four cuttings proved significant at the 5 per cent level of significance when the data were treated statistically. Results of this test did indicate that the shale treatments along with mono-calcium phosphate and rock phosphate increased the phosphorus content of the plant material. This would suggest that the shale treatments were supplying additional phosphorus which was needed for the nutrition of alfalfa grown on Parsons silt loam soil.

Another test was conducted in the greenhouse using alfalfa grown on Geary silt loam soil. Mono-calcium phosphate gave a significantly (5 per cent level) greater yield than the nontreated soil for the first cutting. None of the treatments responded with significantly (5 per cent level) higher yields for the second cutting. The third cutting of alfalfa showed that three different treatments of Eudora shale applied at rates varying from 6,329 to 8,000 pounds per acre gave significant (5 per cent level) yield increases. Applications of 8,000 pounds per acre of Pleasanton shale and 2,500 pounds per acre of rock phosphate also gave significant increases. The failure of the shales to produce alfalfa giving yield increases until the third cutting indicates that the major amount of the element responsible for this additional yield on Geary silt loam soil was not soluble or available to the plant until after the second cutting was made.

With all three cuttings, only the hay from the rock phosphate treatment contained a significantly (1 per cent level) higher phosphorus percentage than the hay from the nonfertilized soil. In general, the shale treatments produced hay which was lower in phosphorus than the hay from the nonfertilized soil which would indicate that the response in yield due to shale treatments applied to Geary silt loam may be due to some element other than phosphorus contained in the shales.

The third cutting of alfalfa from the treatments which gave significant yield increases also removed significantly (1 per cent level) more phosphorus from the soil than did the hay from the nonfertilized soil. The mono-calcium phosphate treatment produced hay which did not give a significant yield increase but it removed significantly (1 per cent level) more phosphorus from the soil than the hay from the nonfertilized soil.

The phosphatic shales did not increase the yield of wheat grown on Parsons silt loam soil in the greenhouse. They were applied at the same rate of available phosphoric acid as monocalcium phosphate which gave a significant (1 per cent level) response in yield. This test indicated that the available phosphoric acid found in the shales by chemical analysis is not readily available to wheat plants or else some other element in the shale tends to overcome any beneficial effects that the additional phosphorus may have on the plant.

The pulverized shales used in this investigation were ground until the majority of the material would pass through a number 20 sieve. A coarsely ground sample of Eudora shale which would pass through a number 10 sieve was used as a treatment to determine the effect of fineness of grinding. There was no indication that the finer ground material would make the phosphorus more available to plants. This is probably due to the relatively soft and easily weathered nature of these sedimentary rocks.

The percentage of available phosphoric acid recovered by the plants grown in the greenhouse indicates that relatively large applications of four to five tons per acre of shale would compare with rock phosphate as a phosphate fertilizing material when used on legumes such as alfalfa. From 2.93 to 53.11 per cent of the available phosphoric acid that was added in the different shale treatments to Parsons silt loam growing alfalfa, was recovered as compared to 40.3 per cent recovery from rock phosphate and no recovery from mono-calcium phosphate. From 2.29 to 19.54 per cent of the available phosphoric acid that was added in the different shale treatments to Geary silt loam growing alfalfa, was recovered as compared to 23.14 per cent for rock phosphate and 12.24 per cent for mono-calcium phosphate.

All of the shales studied had about the same value as phosphate fertilizers with the exception of Quivera shale which did not compare with the other shales in tests conducted in the greenhouse. The small total phosphoric acid content of the shales would probably limit the length of time that the availability would persist. It is doubtful if much phosphate fertilizer value could be obtained beyond the second or third season after application of the shales.

The greenhouse test with wheat indicated that shales and rock phosphate should not be recommended for crops such as wheat due to the relatively low percentage of phosphoric acid recovered by the grain compared to that recovered from mono-calcium phosphate treated soil. This agrees with results previously obtained in Kansas with the use of rock phosphate as a phosphate fertilizer for soils growing wheat. Wheat grown on the soil treated with mono-calcium phosphate recovered 11.37 per cent of the available phosphoric acid added as compared to only 6.23 per cent recovery for the rock phosphate treatments. Two shale treatments produced grain which contained less phosphorus than the nontreated soil and the remaining shale treatments produced grain which recovered from 2.11 to 4.17 per cent of the available phosphoric acid.

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