A COMPARISON OF COARSE, MEDIUM AND FINE PARTICLES OF ROCK PHOSPHATE WITH SUPERPHOSPHATE ON THE GROWTH AND CHEMICAL COMPOSITION OF SEVEN LEGUMES

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INTRODUCTION

Finely ground rock phosphate has been applied to low phosphate soils for many years to increase the production of soil building crops, such as sweet clover and alfalfa. This material is less expensive than superphosphate per pound of phosphorus applied. However, larger quantities per acre are usually required and the applications are made at less frequent intervals than is normally practiced when superphosphate is used to increase crop yields on low phosphate soils.

Rock phosphate for direct application to the soil has been ground so that most of the material will pass a 200 mesh sieve. Some material is ground so that a high percentage passes through a 300 mesh sieve. During World World II some rock phosphate was used for direct application that was ground for use by the manufacturer of superphosphate. Only 50 to 60 percent of this material passed a 200 mesh sieve. Since it is less expensive to produce a coarser product some companies have inquired whether rock phosphate for direct application which contains a higher percentage of coarser material might be just as effective for soil improvement as rock phosphate containing a higher percentage of fine material.

This study was conducted to obtain information on the growth of seven legumes when fertilized at different rates per acre and using sand, silt, and clay fractions of rock phosphate as compared with superphosphate.

REVIEW OF LITERATURE

Wills (18) in his review of literature, states that the earliest work done on the degree of fineness of rock phosphate was that of Lupton in Alabama. In this work, consistently higher yields of seed cotton were secured from floats used in conjuction with cottonseed meal as compared with acid phosphate.

McCool (12) states that, when a value of 100 was used for the feeding power of plants on superphosphate, Bauer found that some crops showed relatively low feeding power on raw rock phosphate, notably red clover, wheat, oats, corn, timothy and soybeans. Those showing relatively high feeding power were rape, alfalfa, rye, buckwheat, redtop, red sorrel, and sweet clover. He further states that raw rock phosphate is most effective when used on soils which are low in lime. In support of this statement, he refers to Mooers statement that the Tennessee Agricultural Experiment station has repeatedly found the rock phosphate could be used with profit in various parts of the state especially where no liming was done.

Conner and Adams (5) studied the availability of rock phosphate, using four particle size groups equivalent to sand, very fine sand, silt and clay in pot tests with radishes, barley, corn, and wheat. A commercial grind containing 26.8 percent clay and a reground sample containing 75.5 percent clay were also compared. They found that the clay separate had a somewhat higher availability than the reground phosphate and that the three coarser separates were of lower value in promoting increased growth of the crops studied than the commercial product. From this study they concluded that it would not pay to grind phosphate rock finer than the commercial grades used as a fertilizer. On the basis of monocalcium phosphate having a relative effectiveness of 100 percent, they found commercial rock phosphate to be 45.1 percent effective while the reground product had an effectiveness of 52.8 percent on the crops tested.

Thor (17) conducted a study of the availability and downward movement of phosphorus in soils of three Illinois corn belt farms to which liberal amounts of rock phosphate had been applied during the past 25-30 years. The downward movement of phosphorus was evident on all three farms but more so on the open textured soils where there was appreciable movement into the 8 to 16 and 16 to 24 inch depths. In the more compact soils there was a definite movement into the 7 to 14 inch depth, however, he feels that much of the phosphorus may have been carried downward mechanically by gravitational water.

In a series of greenhouse tests McCool (12) used a Gloucester loam, pH 5.20, Merrimac loam, pH 5.17 and Illinois black clay loam, pH 5.34. Corn, tomatoes, tobacco, rye grass, Japanese millet, white clover, and buckwheat were used in growth studies with these soils. Colloidal phosphate and Tennessee brown rock phosphate were imployed as sources phosphate. Colloidal phosphates are low in sand and silt and carry high percentages of colloids. The Tennessee rock phosphate is higher in sand and silt and much lower in the finer fractions. He concluded that in greenhouse or field tests colloidal phosphate and Tennessee brown rock phosphate did not differ as a source of P_2O_5.

Wills (18) used a Zaneis sandy loam having a pH 6.1, in a greenhouse test in an effort to determine the response of sweet clover, alfalfa, crimson clover, big hop clover, Ladino clover and Korean lespedeza to various amounts of coarse and finely ground rock phosphate. He found, in this experiment that alfalfa was able to feed on rock phosphate which was held on a 200 mesh sieve as efficiently as it did on the commercial product and that one material was as effective as another in increasing total nitrogen and phosphorus. There was little difference in the effectiveness of the coarse and finely ground rock phosphate in promoting increased growth of big hop clover. Both were less efficient than superphosphate in promoting increased growth and phosphorus content of the latter crop. The fine rock phosphate was more efficient in increasing the yield and total phosphorus content of crimson clover and the yield of Ladino clover, but both coarse and fine rock phosphate were equally effective in promoting the growth of Korean lespedeza. Higher yields of sweet clover were obtained from the coarse rock phosphate. The total phosphorus content of the sweet clover plants was similar for each of these materials.

Bartholomew (3) grew eleven crops common to the southern states in quartz cultures with various phosphate treatments in an effort to determine their ability to use rock phosphate as a source of phosphorus for plant growth. Analyses were made on the plants to determine if there was any relationship between the calcium and phosphorus content and their feeding power for rock phosphate as a source of phosphorus. His results show that cotton, cowpeas, soybeans, seradella, beggarweed, lespedeza, bur clover, rice and velvet beans made very little growth when phosphorus was supplied as rock phosphate. On the other hand, vetch made about one-third and sweet clover about three-fourths as much growth from rock phosphate as compared with superphosphate. He found no relationship between the calcium-phosphorus ratio of the plant and its ability to feed upon rock phosphate. The author concluded that other factors than calcium content seem to play an important part in determining the ability of a plant to utilize rock phosphate as a source of phosphorus.

Jones (11) in a study to determine to what extent KCl, $(NH_4)_2$ SO_4 and $CaCO_3$ influence the availability of phosphorus in rock phosphate, variously fertilized a Crosby silt loam with a pH 5.0 and seeded it to rye. He found that the pH or lime content of the soil influenced the availability of phosphorus more than did any other single factor studied. At a pH 5.0, 2 35 percent as much phosphorus was taken up by rye plants as at a pH 6.5. When ammonium sulfate and potassium chloride were mixed with rock phosphate and added to the soil, the uptake of phosphorus by rye was increased 285 percent over the uptake of phosphorus when rock phosphate alone was added. It was concluded by the author that the addition of KCl and $(NH_4)_2$ SO_4 along with rock phosphate to a soil of pH 5 may be a method of obtaining a better use of phosphorus in this form.

McGeorge and Breazeale (13) report that is has been shown repeatedly that phosphate rock is of little or no value as a phosphate fertilizer on calcareous soils, while on non-calcareous types it has often given returns almost equal to superphosphate. This latter is especially true for high organic soils, where carbon dioxide production is at a maximum. Under such conditions the authors offer the following reaction:

$$Ca_3PO_4 + 4H_2CO_3 ==== Ca\ H_4(PO_4)_2 + 2Ca(HCO_3)_2$$

On the other hand, they report that it has been found that if lime is added along with rock phosphate, the availability even in acid soils is greatly reduced as measured by crop response.

Ford (8) studying a group of soils found that the availability of superphosphate varies with the capacity of soils to fix phosphates in relatively insoluble and unavailable forms. On this basis, the author divided the soils studied into two groups. The first group with a low capacity to fix phosphorus included the DeKalb, Decatur, and Memphis silt loams. The second group with a high capacity to fix phosphorus in this respect included the Tilsit silt loam and two other silt loams one of which was derived from Waverly shale and one from Eastern Coal Basin shale. He also found that the use of lime reduced the rate of solution of rock phosphate in all of the soils. This reduction was found to be greater in the first group of soils with a low capacity to fix phosphorus in relatively insoluble forms than in the second group of soils with a high capacity in this respect. He reports that the use of lime did not seem to increase the availability of the native phosphates in six Kentucky soils. He concluded that the fixation of phosphates in soils occurs largely in the fine clay fraction, although he found that appreciable amounts were also fixed in coarse clay and silt fractions.

Burd and Martin (4) studied the behavior of phosphates in soils and found that different soils will have a different phosphate in concentration depending in each instance on the on the concentration of their solutes and the reactions of their solutions, and that the phosphate concentration of the solution in a given soil will fluctuate in accord with the concentration of other solutes and changes in reaction. They explain that any diminution of the concentration of solutes in the soil solution which will reduce the active mass of cations tending to form relatively insoluble phosphates, or which diminish the buffer effect of the solution, should tend to increase the phosphate concentration.

Wolkoff (19) carried out a laboratory investigation of many different soil types in an effort to determine the relative availability of the phosphorus in rock phosphate and acid phosphate in soils. Three different rock phosphates, five slags, ground apatite, iron phosphate, aluminum phosphate, steamed bone meal and acid and double acid phosphates were used as sources of phosphorus. Samples of a mineral or peat soil were treated with each of the phosphorus fertilizers and allowed to stand for one week at room temperature. Each mixture was extracted with 0.2N nitric acid and a phosphorus determination made on the extract. From this study the author found that phosphorus added in the form of phosphatic fertilizers reacts with some substance in the soil very rapidly, the reaction being practically completed the first day in these experiments. Peat was an exception to this in that it did not depress the recovery of phosphorus under the same conditions.

Jones (11) secured increased yields of rye from peat, but he found that it did not materially influence the uptake of potassium or phosphorus when rock phosphate was the source of phosphorus.

Wolkoff (19) found in his experiments that after phosphatic fertilizers are applied to the soil, the recovery of phosphorus from soil treated with double acid phosphate is no greater than the recovery from soil treated with ground rock phosphate, using 0.2 N nitric acid for the solvent in each case. He further states that the moisture content of the soil treated with phosphatic fertilizer is not a factor in modifying phosphorus recovery by 0.2 N nitric acid extraction, and that high temperature (40° C. in comparison with 20° C.) may decrease the availability of phosphorus in acid phosphate treated soil, but that it has no influence on rock phosphate treated soil. Phosphorus recovery was practically the same at temperatures of 0°C. to 20°C.

Cook (6) investigated the influence of hydrogen and calcium-saturated exchange material separated from bentonite, peat and mineral soils on the availability of rock phosphate to oats, corn, millet, and buckwheat grown in quartz cultures.

In addition, the influence of degree of base (calcium) saturation on the availability of native and applied soluble phosphates in thirteen Michigan soils were also studied. The author concluded from this study that; (a) the addition of hydrogen-saturated exchange material from bentonite and organic and inorganic soils greatly increased the availability of rock phosphate to crops like, oats, millet, and corn which otherwise do not feed well on it, as evidenced by increased yields and a higher phosphorus and lower calcium content of the plants, but calcium saturated exchange material from bentonite was not beneficial in this way; (b) hydrogen-saturated material from bentonite did not nearly so markedly effect the availability of rock phosphate to buckwheat which normally feeds well on rock phosphate; (c) in accordance with the law of mass action, hydrogen saturated exchange material greatly increased the availability of phosphate rock to crops low in calcium such as oats, corn and millet, but not generally, to crops high in calcium such as buckwheat; (d) increase in base saturation through the application of lime to seven soils resulted in significant increases in amounts of readily available soil phosphates and slight increases in two soils, and that, lime helped to preserve the availability of added soluble phosphate; (e) increasing additions of lime to five acid soils consistently lowered the power of these soils to fix added soluble phosphate in a difficulty soluble form; and (f) an increase in base saturation of soils lowers the immediate availability of rock phosphate to crops like corn and oats, but on the other hand, tends to keep native soi phosphates and those added as soluble salts in the form of calcium phosphate rather than in the less available basic iron phosphates.

McGeorge and Breazeale (12) contend that the influence of replaceable bases is largely indirect in that they control soil reaction which is intimately associated with phosphate solubility. They report that their observations on calcareous soils have led them to believe that the range of lowest phosphate solubility is between pH 8.0 and 8.5.

Heck (10) studied the relation of the base saturation of Miami silt loam and of Waipio soil (laterite) to the capacities of these soils to fix applied phosphorus in a difficulty available form. He concluded that a low degree of base saturation tends to give a soil a greater capacity for fixing phosphorus in a difficulty available form than if the soil is more fully saturated with bases. He attained a minimum phosphorus fixation at from 80 to 90 percent base saturation. The variation in phosphorus fixation that may be brought about by a change in base saturation of a soil does not usually exceed 20 to 30 percent.

Bauer (1) showed that leaching the soil increased the availability of rock phosphate to corn by removing the excess soluble calcium bicarbonate and other soluble calcium salts. These results, he states, are in accord with the laws of mass action and chemical equilibrium. He also found that ammonium nitrate had a marked influence on the solubility of rock phosphate to corn, due to its favorable effect on the solubility of calcium bicarbonate, and by producing an acid medium.

The author reports that sodium nitrate had no appreciable influence on the availability of rock phosphate and that 2.9 times as much soluble calcium was leached from the pots treated with rock phosphate and ammonium nitrate as compared with the sodium nitrate treated pots. The growth ratio of corn under the same conditions as 1:2.25, showing a rather definite relation between calcium leached out in solution and in plant growth. Leaching decreased the calcium and increased the nitrogen content of the plants.

Bauer (2) has concluded that the laws of mass action and chemical equilibrium offer a satisfactory basis for explaining the foraging power of plants for rock phosphate. According to these laws, the reaction making the phosphorus of rock phosphate available may be represented as follows:

$$Ca_3(PO_4)_2 + 2H_2CO_3 \rightleftharpoons Ca_2H_2(PO_4)_2 + CaH_2(CO_3)_2$$

Two soluble products are formed and the reaction can proceed only when both the soluble products are removed. If the soluble phosphate is removed more rapidly than the soluble calcium bicarbonate, an equilibrium will finally be established in which little or no phosphorus will be brought into solution. Bauer reasons that plants having a need for both the soluble products of the reaction should be good feeders, and the feeding power of plants low in calcium should be increased when grown on acid soils because of the soil capacity to take up basic materials. The use of increasing amounts of limestone reduces the availability of rock phosphate to plants low in calcium, and to those high in calcium when excessive amounts are used. He calls attention to the fact that on the basis of the reaction presented above, Truog has proposed a theory that plants containing a relatively high calcium oxide content should have a high feeding power and plants relatively low in calcium oxide content should have a relatively low feeding power for the phosphorus in rock phosphate.

Mattson, according to Scarseth and Tidmore (15), has shown that the phosphate ion was absorbed to a considerable extent by a number of soil colloids. He noted that the most absorption occurred where the silica-sesquioxide ratio was the smallest. Scarseth and Tidmore (15) report that the acidity of the soil, particularly the degree of calcium saturation, is of great significance in the fixation of phosphates. While the nature and extent of fixation is not well understood, they state that it is generally accepted that the colloidal fraction is the principal seat of fixation. These authors also found that the amount of available phosphate in soil colloids varied directly with the silica-sesquioxide ratio of the colloid and that the phosphate fixing capacity of the colloid varied inversly with the silica-sesquioxide ratio. They also found that rock phosphate was 20% less available in the presence of gray colloids and was slightly more available than monocalcium phosphate in the presence of red colloids.

Harper and Daniel (9) conducted a study of the chemical composition of 66 samples of Andropogon furcatus and scopariious from typical native pastures, hay meadows, and virgin soils and 62 soils from 37 counties in Oklahoma. They found a slight positive correlation between total calcium in the plants and the exchangeable calcium in high calcium soils.

No data were obtained to indicate whether plants growing in soil low in exchangeable calcium would also be low in this element. They also found a slight positive correlation between the total phosphorus in the grass and the easily soluble phosphorus in soils, when the grasses were grown on soils high in easily soluble phosphorus. A slight negative correlation occurred when the plants were collected from soils containing less than 10 p.p.m. of available phosphorus. The authors concluded that there was no simple relation between the total quantity of any one element and the availability of that element in the soil.

Daniel (7) in a review of literature on the chemical composition of a large number of grasses and legumes, found that Greenhill and Page had studied the nitrogen and phosphorus content of pastures and found that phosphorus consistently showed a highly positive correlation with the nitrogen content of plants.

Daniel (7) found that legumes have a low nitrogen-calcium and a high calcium-phosphorus ratio while the grasses have a high nitrogen-phosphorus, a low calcium- phosphorus and a low nitrogen-calcium ratio. A very poor correlation was found between the calcium and phosphorus content of the grass. These elements showed a negative correlation in mature legumes.

EXPERIMENTAL PROCEDURE

This study was undertaken in an effort to determine to what extent different legumes could utilize rock phosphate particles of varying sizes which had been separated from a commercial sample of rock phosphate.

In this experiment a Fitzhugh fine sandy loam with a pH of 5.7, was placed in glazed porcelain pots and the following treatments were made. A basic treatment of one ton of limestone containing a mixture of 1000 grams of 60 mesh limestone, 50 grams of potassium sulfate, 50 grams of magnesium carbonate and 1 gram of borax was prepared. The above mixture was added at the ratio of 10.5 grams to one quart of air dry soil and the mass shaken thoroughly in a gallon jar. The remaining soil required to fill the pot was spread out on a large card board and the soil containing the fertilizer was thoroughly mixed with it and returned to the pot.

The phosphate treatments and crops planted were as follows: rock phosphate from Wales, Tennessee was separated into three fractions; sand, silt, and clay, by dispersing a 900 gram sample of the rock phosphate in a mechanical dispersing machine used for physical soil analysis. After dispersing the sample, the suspension was passed through a 300 mesh sieve which retained the sand fraction. The suspension which passed through the sieve was transferred to large glass bottles and diluted with water. The silt was removed from the clay by allowing it to settle, which was calculated as 77 minutes for

10 cm. of height in the container (14). The clay in the surface layer was then siphoned into a glass bottle and flocculated by adding calcium chloride to make the concentration of that salt in the solution 250 parts per million. Most of the excess water was then siphoned off and the clay suspension was transferred to a two-liter Erlenmyer flask. When the flask had been filled, a sample of clay suspension was drawn out with a pipette and placed in an oven dry, weighed porcelain evaporating dish and the excess water evaporated. From these weights the amount of clay in suspension in each flask was calculated. This procedure was continued until 100 grams of each separate was obtained.

Analysis of the sand, silt, and clay showed that they contained 27.50, 25.65, and 29.50 percent of total P_2O_5, respectively. On the basis of these values, the amount in grams of each separate equivalent to the amount of P_2O_5 in pounds per acre was calculated. The clays were added in suspension and the quantity of dry material calculated in terms of milliliters equivalent to each application of P_2O_5.

Two sizes of pots were used in this experiment and all treatments were duplicated. Alfalfa and sweet clover were planted in the smaller pots and Ladino clover, big hop clover, Hubam sweet clover and Tifton sweet clover were planted in the larger pots. The phosphate treatments were mixed with the top two inches of soil in the pots planted to alfalfa, sweet clover, Ladino and big hop clover, and with the top four inches of soil in the pots seeded to Hubam, sweet clover, Tifton sweet clover, and Hairy vetch.

Superphosphate was also applied to each crop so that yield data and plant composition could be compared with similar data obtained from the various rock phosphate treatments. The control pots recieved the basic fertilizer treatment but no phosphate was applied.

The various rates of phosphate fertilization and the equivalent amounts in grams for each crop are shown in table 1.

Table 1. Application Rates of Sand, Silt, and Clay Fractions of Rock Phosphate With the Equivalent Amount in Grams of Each Separate for Each Crop.*

Pounds Per Acre	Grams Rock Phosphate Per Pot and Fraction			Super-Phosphate
	Sand	Silt	Clay	
Alfalfa				
500	3.04	2.64	2.83	1.56
1000	6.08	5.28	5.66	--
Evergreen Sweet Clover				
500	3.04	2.64	2.83	1.56
Ladino Clover				
500	3.04	2.64	2.83	1.56
1000	6.08	5.28	5.66	--
1500	9.12	7.92	8.49	--
Big Hop Clover				
500	3.04	2.64	2.83	1.56
1000	6.08	5.28	5.66	--
1500	9.12	7.92	8.49	--
Hubam Sweet Clover				
500	3.04	2.64	2.83	1.56
Tifton Sweet Clover				
500	3.04	2.64	2.83	1.56
Hairy Vetch				
500	3.04	2.64	2.83	1.56
1000	6.08	5.28	5.66	--

*All plantings had two check pots which recieved no phosphate fertilizer.

EXPERIMENTAL RESULTS

Data on the effect of rock phosphate of varying particle size on the growth, total nitrogen and phosphorus content of alfalfa are presented in table 2. The rates of application for the three particle sizes were 500 and 1000 pounds per acre. Both rates gave large increases in yield over the control pots. However, both rates for sand, silt, and clay applications were less effective in increasing yields than superphosphate. Both rates of all three fractions were about equal to superphosphate in increasing the total nitrogen content of alfalfa. Rock phosphate was slightly more effective in increasing the total phosphorus content of the plants than superphosphate. It will be observed from the data in table 2 that the silt size fraction of rock phosphate applied at 1000 pounds per acre was most effective in promoting growth. However, the method of applying the clay fraction may have been responsible for the relatively low utilization of the phosphorus in this material.

Distilled water was used to keep the soil in each pot at optimum moisture content throughout the experiment.

The plants were harvested during the blooming stage by cutting about one-fourth inch above the soil line. The plant material was placed in an oven and dried at 105° C. and then weighed to obtain an oven dry forage weight. The plant material was ground in a small Wiley mill and analyzed for total nitrogen and total phosphorus. The Kjeldahl method was used in determining the nitrogen content of the forage and total phosphorus was determined as recommended by Shelton and Harper (17).

Table 2. Yield and Percent of Nitrogen and Phosphorus of Alfalfa From Duplicate Treatments of Sand, Silt, and Clay Fractions of Rock Phosphate as Compared With Superphosphate.

Pot No.	Fraction	Pounds Per Acre	Yields (Gms)	Nitrogen %	Phosphorus %
1		None	.58	3.59	.068
9		None	.75	2.62	.109
2	Sand	500	6.72	2.08	.086
10	Sand	500	5.73	1.88	.080
3	Silt	500	9.85	2.09	.118
11	Silt	500	9.50	1.63	.099
4	Clay	500	2.19	2.18	.082
12	Clay	500	3.11	1.92	.071
6	Sand	1000	11.93	2.02	.102
14	Sand	1000	5.96	2.02	.099
7	Silt	1000	13.91	1.96	.133
15	Silt	1000	17.95	2.14	.181
8	Clay	1000	5.52	2.06	.077
16	Clay	1000	7.40	1.36	.077
5	Super-phosphate	300	14.51	2.03	.089
13	Super-phosphate	300	24.85	2.08	.103

Data on the effect of rock phosphate of various particle sizes on the growth of Evergreen Sweet clover are presented in table 3. Only one rate of application was made since previous studies have shown that sweet clover can utilize rock phosphate effectively when applied at the rate of 500 pounds per acre. It will be observed that very little difference in yield was obtained from the coarse medium and fine rock phosphate. The yield of sweet clover from an application of superphosphate which would cost about $5.10 per acre ~~were~~ was less than from the rock phosphate application which would cost about $6.00 per acre. The rock phosphate treatments increased the phosphorus content of sweet clover about 46 percent. The sweet clover produced on soil fertilized with superphosphate contained less total nitrogen than sweet clover grown on unfertilized soil.

Table 3. Yield and Percent of Nitrogen and Phosphorus in Evergreen Sweet Clover From Duplicate Treatments of Sand, Silt and Clay Fractions of Rock Phosphate as Compared With Superphosphate.

Pot No.	Fraction	Pounds Per Acre	Yields (Gms)	Nitrogen %	Phosphorus %
17		None	0.93	2.08	.090
22		None	0.97	2.49	.059
18	Sand	500	36.00	2.04	.102
23	Sand	500	33.69	2.04	.116
19	Silt	500	40.46	1.91	.124
24	Silt	500	32.82	2.12	.122
20	Clay	500	33.67	1.50	.080
25	Clay	500	43.43	2.12	.112
21	Super-phosphate	300	29.64	1.46	.075
26	Super-phosphate	300	31.74	1.88	.076

Data on the comparative yields and percent of total nitrogen and phosphorus in Ladino clover grown in soil fertilized with three rates of rock phosphate applied as sand, silt and clay fractions are presented in table 4. In the 500 pound application, the silt and clay fractions were similar in promoting increased growth and the total nitrogen and phosphorus content of the fertilized Ladino clover plants were also similar. The yields from both of these fractions were considerably larger than those produced from the sand fraction, however, the nitrogen and phosphorus content of the plants from the sand applications compared favorably with the silt and clay fractions. All of the fractions in the 500 pound per acre applications produced a much lower yield of Ladino clover than that obtained from superphosphate.

Large increases in yield were obtained from all fractions of rock phosphate when the application rate was increased to 1000 pounds per acre. The total nitrogen content of the plants and total phosphorus recovery were also increased. The clay fraction seemed to be as effective or slightly more effective than sand and silt in increasing the yield of Ladino clover, whereas, the silt fraction was slightly more effective in increasing the total phosphorus content of the forage. The increase in total phosphorus from the silt fraction was 83.1 percent greater than the amount recovered by Ladino clover from the superphosphate application.

When the rate of fertilization was increased to 1500 pounds per acre considerably larger yields were obtained from the silt and clay fractions while little or no increase in yield was obtained from the sand fraction over the 1000 pound per acre application. The data show that the clay fraction in this case was very definitely much more effective in increasing yields than either of the two other fractions. It was also much more effective in this respect than was superphosphate. The silt fraction was slightly more effective in increasing the total phosphorus content of the plants than the clay fraction. The total phosphorus in the plants fertilized with the silt fraction was 71.5 percent greater than the plants fertilized with superphosphate.

Table 4. Yield and Percent of Nitrogen and Phosphorus in Ladino Clover From Varied Amounts of Sand, Silt and Clay Fractions of Rock Phosphate as Compared With Superphosphate.

Pot No.	Fraction	Pounds Per Acre	Yields (Gms)	Nitrogen %	Phosphorus %
27		None	1.08	4.20	.105
38		None	1.53	3.03	.082
28	Sand	500	2.26	2.10	.125
39	Sand	500	1.36	1.45	.096
29	Silt	500	4.74	3.33	.109
40	Silt	500	4.20	2.05	.124
30	Clay	500	4.05	1.98	.082
41	Clay	500	1.79*	1.86	.070
32	Sand	1000	14.34	2.70	.167
43	Sand	1000	5.85	2.60	.123
33	Silt	1000	21.37	2.34	.197
44	Silt	1000	20.87	2.16	.171
34	Clay	1000	18.72	2.36	.144
45	Clay	1000	22.18	2.30	.163
35	Sand	1500	16.12	2.44	.168
46	Sand	1500	9.49	2.66	.174
36	Silt	1500	24.29	2.43	.173
47	Silt	1500	22.94	2.34	.185
37	Clay	1500	28.04	2.41	.170
48	Clay	1500	25.57	2.42	.162
31	Superphosphate	300	20.54	2.35	.130
42	Superphosphate	300	20.37	2.19	.125

*The low yield of this pot was probably due to failure to mix the clay suspension thoroughly with the soil.

The comparative yields and the results of total phosphorus and nitrogen determinations on big hop clover are given in table 5.

Moderate increases were obtained from the 500 pound per acre applications of sand, silt, and clay fractions of the rock phosphate. The largest increase in yield in this series was obtained in soil fertilized with the clay fraction. The largest increase in total phosphorus in the plant was obtained from the sand applications, however, the clay fraction compared very closely to the sand in this respect. The total growth produced was very low consequently, the differences in chemical composition are relatively unimportant.

In the 1000 pound per acre application, slight increases in yield were obtained with the sand and silt fractions. The clay fractions produced very large increases in yields over the 500 pound applications. The clays were also more effective in increasing the total phosphorus content of big hop clover. The total amount of phosphorus in the plants fertilized with the clay was larger than the amount in plants fertilized with superphosphate. The yields from the application of clay also compared well with that from the superphosphated pots.
In the 1500 pound per acre applications, only slight increases were obtained over the unphosphated soil. The problem of mixing, the retardation of early growth by damping off fungi, and spraying with parathion to control insects may have affected the growth. The total phosphorus content of these plants were as great or greater than that obtained in plants

from the control pots and compared closely with those from the superphosphated pots.

Table 5. Yield and Percent of Nitrogen and Phosphorus in Big Hop Clover From Application of Varied Amounts of Sand, Silt, and Clay Fractions of Rock Phosphate as Compared With Superphosphate.*

Pot No.	Fraction	Pounds Per Acre	Yields (Gms)	Nitrogen %	Phosphorus %
49		None	.87	1.04	.085
60		None	.78	2.11	.095
50	Sand	500	1.57	2.09	.156
61	Sand	500	.82	2.08	.133
51	Silt	500	1.77	2.17	.084
62	Silt	500	1.36	1.95	.102
52	Clay	500	1.45	2.47	.136
63	Clay	500	2.39	1.64	.095
54	Sand	1000	2.36	1.93	.087
65	Sand	1000	2.09	1.80	.078
55	Silt	1000	3.61	2.13	.092
66	Silt	1000	4.11	1.33	.084
56	Clay	1000	9.60	1.98	.130
67	Clay	1000	11.42	2.39	.140
57	Sand	1500	2.20	2.21	.102
68	Sand	1500	2.18	1.83	.091
58	Silt	1500	6.64	2.24	.130
69	Silt	1500	3.85	1.81	.122
59	Clay	1500	2.75	2.08	.084
70	Clay	1500	3.78	1.92	.096
53	Super-phosphate	300	11.65	2.01	.093
64	Super-phosphate	300	12.29	2.15	.099

*The growth of these plants was retarded by damping off in the early stages of their growth.

The data on yield and total nitrogen and phosphorus in Hubam sweet clover when fertilized with sand, silt, and clay fractions of commercial rock phosphate are given in table 6. Only one rate of application study was made. It will be noted that very little or no difference in yield was obtained from either the sand or silt applications, although the increases obtained from these fractions were large when compared with the yields from the unfertilized pots. A very significant increase, comparable to that obtained from the superphosphate application, was obtained from the clay application. The increase in total phosphorus was larger than for the sand and silt fractions and was only slightly lower than the increase obtained from plants fertilized with superphosphate. The increase in total nitrogen was higher than that obtained from superphosphate applications or from the control pots. It is quite evident that fineness of grinding is not an important factor in the utilization of rock phosphate by annual sweet clover.

Table 6. Yield and Percent of Nitrogen and Phosphorus in Hubam Sweet Clover From Sand, Silt, and Clay Fractions of Rock Phosphate as Compared with Superphosphate.

Pot No.	Fraction	Pound Per Acre	Yields (Gms)	Nitrogen %	Phosphorus %
71		None	1.34	2.18	.103
76		None	1.26	2.46	.097
72	Sand	500	9.85	2.78	.150
77	Sand	500	8.24	2.40	.116
73	Silt	500	0.95*	1.79	.111
78	Silt	500	8.08	2.44	.115
74	Clay	500	10.13	2.63	.166
79	Clay	500	12.08	2.41	.159
75	Superphosphate	500	9.65	1.92	.164
80	Superphosphate	500	13.24	2.96	.163

*No explanation can be given for the low yield of this pot.

Tifton annual sweet clover is a selection of this crop made by staff members of the Agricultural Experiment Station at Tifton, Georgia. Data on the effect of sand, silt, and clay fractions of rock phosphate, as compared with superphosphate, on this crop are presented in table 7.

It will be observed from these data that the silt gave largest increase in yield and that yields from the clay fraction were only slightly lower than those obtained from the silt fraction. The yields from these two fractions were both larger than that obtained from superphosphate. The clay fraction was most effective in increasing the total phosphorus of the plants while the superphosphate treated plants were about equal to the unfertilized pots in total phosphorus content. All of the rock phosphate fractions and the superphosphate treatment were about equal in increasing the total nitrogen content of the plants.

Table 7. Yield and Percent of Nitrogen and Phosphorus in Tifton Sweet Clover From Sand, Silt and Clay Fractions of Rock Phosphate as Compared With Superphosphate.

Pot No.	Fraction	Pound Per Acre	Yields (Gms)	Nitrogen %	Phosphorus %
81		None	1.10	2.14	.156
86		None	1.03	2.28	.092
82	Sand	500	10.43	2.39	.109
87	Sand	500	8.85	2.56	.130
83	Silt	500	13.34	2.40	.142
88	Silt	500	21.24	1.96	.106
84	Clay	500	14.53	2.36	.148
89	Clay	500	15.11	2.36	.136
85	Superphosphate	300	14.26	2.52	.141
90	Superphosphate	300	11.72	2.19	.098

Data on the yield and results of total nitrogen and phosphorus determinations on Hairy vetch are given in table 8. As indicated in the footnote at the end of the table, the growth of these plants was considerably retarded by two parathion sprays to control aphids.

In the 500 pound per acre application, the clay application was most effective in increasing yields of vetch, while the silt fraction was most effective in increasing the total phosphorus content of the plants.

In the 1000 pound per acre application, the clay fraction again was most effective in increasing the yields and in increasing the total phosphorus content of the plants. The largest yields were obtained from the superphosphate applications, however, the total phosphorus content of these plants were lower than that obtained in any of the rock phosphate applications.

Table 8. Yield and Percent of Nitrogen and Phosphorus in Hairy Vetch From Two Different Amounts of Sand, Silt, and Clay Fractions of Rock Phosphate as Compared With Superphosphate.*

Pot No.	Fraction	Pound Per Acre	Yields (Gms)	Nitrogen %	Phosphorus %
91		None	1.80	1.63	.110
99		None	1.73	1.58	.080
92	Sand	500	1.09	1.42	.118
100	Sand	500	1.03	1.62	.021
93	Silt	500	1.24	1.67	.124
101	Silt	500	1.18	2.16	.105
94	Clay	500	3.17	1.54	.106
102	Clay	500	2.66	1.58	.102
96	Sand	1000	1.43	1.46	.099
104	Sand	1000	1.47	1.26	.110
97	Silt	1000	1.69	1.54	.113
105	Silt	1000	1.15	1.34	.102
98	Clay	1000	4.56	1.47	.137
106	Clay	1000	2.02	1.28	.128
95	Superphosphate	300	6.57	1.50	.097
103	Superphosphate	300	6.56	1.51	.030

*Low yields were obtained due to injury from two parathion sprays applied to control aphids.

SUMMARY

Sand, silt, and clay fractions of rock phosphate were separated from a commercial sample of this material and added to a Fitzhugh fine sandy loam at different rates to study the effect of particle size and rate of application on the growth of seven legumes. The soil had a pH of 5.7, consequently, finely ground limestone was applied at the rate of one ton per acre, potassium sulfate and magnesium carbonate each were applied at the rate of 100 pounds per acre and borax was applied at the rate of 2 pounds per acre to make certain that phosphorus would be the first limiting factor in the growth of different legumes. The total phosphorus pentoxide content of the sand, silt, and clay fractions of rock phosphate was 27.50, 25.65, and 29.50 percent, respectively.

A 13.74 percent increased in yield of alfalfa was obtained from the silt fraction of rock phosphate applied at 500 pounds per acre. Yields from the superphosphate application were about 50 percent greater than this silt application. The yield of alfalfa from superphosphate fertilization was 19.05 percent greater than was produced from the silt fraction applied at 1000 pounds per acre. This fraction of rock phosphate was also more effective in increasing the total phosphorus content of the plants than was superphosphate.

Very little difference in the yield of Evergreen sweet clover was obtained when fertilized with the three fractions of rock phosphate. These yields were 25.61 percent higher than those produced on the superphosphate treated soil. The total nitrogen content of the plants fertilized with rock phosphate was higher than that of the plants fertilized with superphosphate.

Similar yields of Ladino clover were obtained from the three fractions of rock phosphate applied at 500 pounds rate per acre. However, when the rate of application was increased to 1000 pounds per acre, the clay gave the largest yield. These yields were about equal to that obtained from superphosphate fertilization. The total phosphorus content of rock phosphate fertilized plants was also higher than those fertilized with superphosphate. When the rate of application was increased to 1500 pounds per acre, the clay fraction gave the largest yields of the three fractions. The total phosphorus content of these plants were higher than those obtained from superphosphate. The yields from the application of the clay fraction were 31.0 percent greater than yields from application of superphosphate.

Although the growth of big hop clover was retarded by damping off fungi when the plants were small, the clay fraction gave slightly larger increases in yield than was obtained from the sand or silt fraction when applied at a 500 pound rate per acre. The total phosphorus content was also highest in the plants fertilized with the clay fraction of rock phosphate. At the 1000 pound rate per acre, the yields from the clay fraction of rock phosphate produced yields practically equivalent to the yields produced by superphosphate. The total phosphorus content of the plants fertilized with silt fraction was also practically equivalent to the total phosphorus content of the plants fertilized with superphosphate. In the 1500 pound per acre applications the yields were only slightly larger than those obtained from the 500 pound per acre application. The total phosphorus content of the plants in all the rock phosphorus applications were larger than in plants fertilized with superphosphate.

The clay applications of rock phosphate at the 500 pound rate per acre produced larger yields of Hubam sweet clover than sand or silt fractions. Slightly larger yields were obtained from pots treated with superphosphate. However, this crop can effectively utilize rock phosphate regardless of particle size. The increase in total phosphorus of plants fertilized with the clay fraction was slightly higher than that of plants fertilized with superphosphate.

Similar results were obtained with Tifton sweet clover. It is evident from the data obtained that particle size of rock phosphate is not a factor in the utilization of this material by Tifton sweet clover.

The yields of Hairy vetch in this study were very low. However, the largest increase in yield was obtained from the clay fraction in both the 500 and the 1000 pound rates per acre. In the 500 pound treatment, silt gave the largest increase in total phosphorus in the plants. Plants fertilized with 1000 pounds per acre of the clay fraction were highest in total phosphorus content.

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TYPIST PAGE

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