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RESPONSE *of* CROPS *to* VARIOUS PHOSPHATE FERTILIZERS

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of the ALABAMA POLYTECHNIC INSTITUTE
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FOREWORD

"Response of Crops to Various Phosphate Fertilizers," a presentation of significant results from 38 years of research involving over 1,300 experiments by the Alabama Agricultural Experiment Station, was prepared by L. E. Ensminger, Associate Soil Chemist, who since joining the staff in late 1944 has been concerned with phosphorus research. In preparing this report, Dr. Ensminger has compiled the results of many workers of this Station.

Summarized are results of phosphorus experiments at the Main Station, Auburn, Alabama, carried on by R. Y. Bailey*, F. E. Bertram, E. F. Cauthen**, J. F. Duggar**, Franklin Fudge*, M. J. Funchess, W. H. Pierre*, F. W. Parker*, G. D. Scarseth*, D. G. Sturkie, J. W. Tidmore**, H. B. Tisdale, and G. W. Volk*.

Phosphorus response studies at the Experiment Fields reported herein were conducted by H. R. Benford*, F. E. Bertram, C. L. Breedlove*, J. W. Richardson, J. F. Segrest, Jr., J. R. Taylor*, R. W. Taylor*, and J. T. Williamson.

Phosphorus studies at the Substations were done by K. G. Baker, R. C. Christopher*, S. E. Gissendanner, Fred Stewart, and J. P. Wilson**.

Cooperative cotton, peanut, and pasture tests with farmers were conducted by E. L. Mayton, H. T. Rogers*, J. M. Scholl*, E. H. Stewart*, and J. T. Williamson. – *Editor.*

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RESPONSE *of* CROPS *to* VARIOUS PHOSPHATE FERTILIZERS

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MANY OF THE SOILS of Alabama are low in available phosphorous; consequently, phosphate fertilizers must be used to obtain satisfactory crop yields. Most of these soils were deficient in available phosphorous when first cleared; unless they have been given large applications of an available source of phosphorus during the period of cultivation, they have remained deficient in available phosphorus. As will be pointed out later, loss of phosphorus by erosion is one reason why rather large applications of phosphorus may be required over a period of years to build up an appreciable supply of phosphorus in soils. It should be pointed out in this connection that, since removal of phosphorus by the harvested portion of most crops is small, it should not preclude the possibility of considerable accumulation of applied phosphorus.

The importance of phosphorus in Alabama agriculture is shown by the volume of consumption. During the 1945-46 crop year, Alabama farmers spent approximately 11.5 million dollars for phosphorus in mixed fertilizers and as separate material. The State ranked third in the United States in consumption of phosphate fertilizers during that crop year, with a total of 91,630 tons of P_2O_5 being applied. The trend has been upward, as shown by an annual average of 55,306 tons of P_2O_5 used during the period 1935-44 *(6)*.

DESCRIPTION of MATERIALS

There are several kinds of phosphate materials available for distribution and there are others that may be placed on the market if found satisfactory as sources of phosphorus for plant growth. Sources on the market at present include such materials as raw rock phosphate, treated phosphate (superphosphate), and by-product phosphates. Solubility of these materials varies

* Author-compiler, see FOREWORD.

considerably; usually the more soluble the material, the more quickly its phosphorus is released for plant growth. However, the comparative availability of different sources of phosphorus may depend to a considerable extent on soil conditions and the crop being grown. The sources of phosphorus used in the experiments reported herein are briefly discussed with respect to preparation and properties.

ROCK PHOSPHATE. Rock phosphate occurs in natural deposits throughout the world. The ones of greatest commercial importance in the United States are located in Florida and Tennessee in the East, and in an area comprising Idaho, Montana, Utah, and Wyoming in the West. The principal constituent of the American phosphate rock is fluorapatite, which may be represented by the formula $Ca_{10}F_2(PO_4)_6$. Raw rock phosphate is not used extensively for direct application to the soil because of its insolubility. To be effective it must be finely ground. A good grade of rock phosphate will contain about 32 per cent total P_2O_5. Only a trace of this is water-soluble.

COLLOIDAL PHOSPHATE. The USDA Yearbook of Agriculture, Soils and Men, 1938 *(10)*, gives the following description of colloidal phosphate: " 'Colloidal phosphate' is a trade name applied to finely divided, comparatively low-grade rock phosphate or phosphatic clay. It is also designated 'waste pond phosphate' for the reason that in the hydraulic operation involved in mining rock phosphate in Florida a considerable quantity of fine phosphatic material, virtually colloidal from a mechanical standpoint, is washed into ponds and settles out. When removed, following drainage and evaporation of water, it contains a relatively high proportion of clay, so that the Colloidal phosphate usually contains only from 18 to 23 per cent of phosphoric acid. On account of the presence of so much foreign material, principally clay, Colloidal phosphate is considered to be unsatisfactory for treatment with sulfuric acid. The claim is made for this material and others of a similar nature that not only is the phosphoric acid more quickly available than that of mechanical ground rock phosphate, but also that the content of minor elements in Colloidal phosphate makes it superior to its close relative, rock phosphate. These claims, while highly interesting, have failed of substantiation in a number of states, particularly so when a comparison of such materials with superphosphate is taken into consideration." According to the above discussion, colloidal phosphate may be considered as rock phosphate diluted with colloidal material.

SUPERPHOSPHATE. Superphosphate (16 to 20 per cent available P_2O_5) is made by treating ground rock phosphate with sulfuric acid in about equal proportions by weight. In this process all of the sulfuric acid is consumed. This results in a mixture of more soluble phosphates and calcium sulfate (gypsum). Ordinary superphosphate usually contains 18 to 20 per cent available P_2O_5. Its P_2O_5 content depends largely on the grade of rock phosphate used. Practically all of the phosphorus in superphosphate is water-soluble. It is used as a source of phosphorus in mixed fertilizers as well as for direct application, and it ranks first among phosphatic materials in quantity consumed for fertilizer use.

TRIPLE SUPERPHOSPHATE. Triple superphosphate is made by treating rock phosphate with phosphoric acid instead of sulfuric acid. This results in a product higher in P_2O_5 than ordinary superphosphate. Triple superphosphate usually contains 42 to 52 per cent P_2O_5 and it may contain up to 10 per cent gypsum, depending upon method of manufacture. It is largely monocalcium phosphate, and most of the phosphorus is water-soluble. It should be pointed out here that the TVA triple superphosphate used in the experiments reported herein did not contain any appreciable amount of gypsum.

AMMO-PHOS A. Ammo-phos A is a trade name used to designate a grade of mono-ammonium phosphate used as a fertilizer material. It contains about 11 per cent N and 45 to 48 per cent P_2O_5. It is produced by partially neutralizing phosphoric acid with ammonia.

DI-AMMONIUM PHOSPHATE. Di-ammonium phosphate is made by adding ammonia in the proper proportion to a solution of mono-ammonium phosphate. The di-ammonium phosphate, being less soluble, separates as crystals. It contains about 21 per cent N and 53 per cent P_2O_5.

FUSED TRICALCIUM PHOSPHATE. Fused tricalcium phosphate is made by heating rock phosphate to the fusion point in the presence of water vapor and silica. This causes most of the fluorine to volatilize, resulting in the formation of a tricalcium phosphate containing about 30 per cent P_2O_5, most of which is soluble in ammonium citrate.

PRECIPITATED TRICALCIUM PHOSPHATE. Tricalcium phosphate may be formed by ammoniation of mono-calcium phosphate. It contains approximately 42 per cent total P_2O_5.

CALCIUM METAPHOSPHATE. Calcium metaphosphate is produced by bringing hot gaseous phosphorus in contact with phosphate rock at high temperature. After the mass melts, it is withdrawn from the furnace and allowed to cool. When ground it is ready for use as a fertilizer. It contains 62 per cent available P_2O_5 (soluble in ammonium citrate solution).

POTASSIUM METAPHOSPHATE. It is the potassium salt of metaphosphoric acid and contains about 60 per cent P_2O_5 and 40 per cent K_2O.

BASIC SLAG. Basic slag is produced as a by-product of the steel industry. Phosphorus occurs in some iron ores, and steel made from them is brittle unless the phosphorus is largely removed. In removing the phosphorus and other impurities, a blast of air is blown through the molten iron in a converter containing lime. The phosphorus oxidizes and unites with the lime. The resulting mass is lighter than iron and thus rises to the surface where it is drawn off, cooled, and ground to a certain fineness. Basic slag usually contains 8 to 10 per cent total P_2O_5, most of which is soluble in citric acid. Basic slag should not be confused with blast furnace slag which is calcium silicate.

RESULTS of EXPERIMENTS

The importance of phosphorus in Alabama agriculture was recognized years ago. Some of the experimental work reported in this bulletin was started as early as 1911.

Experiments of short and of long duration were conducted in order to test the immediate relative efficiencies of various sources of phosphorus, as well as relative efficiencies involving cumulative effects. Since the relative efficiency of sources may depend on conditions, a number of crops were tested at a large number of locations in the State. For convenience in discussing the results, the work reported herein is divided into experiments of long duration and of short duration dealing with crops other than pastures, and experiments with permanent pastures.

EXPERIMENTS OF LONG DURATION

STUDY OF SOURCES OF PHOSPHOROUS IN A ROTATION OF CORN AND COTTON WITH WINTER LEGUMES. In 1930 a sources-of-phosphorus study was started at the Tennessee Valley, Sand Mountain and

Wiregrass substations, and at the Prattville Experiment Field on Decatur, Hartsells, Norfolk, and Greenville soils, respectively. The different sources of phosphorus used in these tests were superphosphate, basic slag, triple superphosphate, precipitated tricalcium phosphate, Ammo-phos A, rock phosphate, and colloidal phosphate. The phosphorus was applied to the cotton and winter legumes. The rate per acre of P_2O_5 used, and yield data are given in Table 1. Response of corn to phosphates was rather low at all locations except the Sand Mountain Substation, and as a result the differences in yield for the various phosphates were rather small. In the case of cotton, there was a rather large response to phosphorus at the Tennessee Valley and Sand Mountain substations, while at the two other locations the response was rather low. Analysis of soil samples collected at the beginning of the experiment showed that the soils at the Tennessee Valley and Sand Mountain substations were lower in soluble phosphorus than the soils from the Wiregrass Substation and Prattville Field. Winter legumes responded well to phosphorus at all locations; however, the greatest response was obtained at the Tennessee Valley and Sand Mountain substations, as was in the case of cotton.

The average yield increases of cotton, corn, and winter legumes at the four locations are given in Table 2. In relative terms the increases of cotton may be expressed as follows: superphosphate, 100; triple superphosphate, 90; basic slag, 88; precipitated tricalcium phosphate, 87; and rock phosphate, 49. The increases of corn expressed in a like manner are as follows: superphosphate, 100; basic slag, 110; triple superphosphate, 106; precipitate tricalcium phosphate, 105; and rock phosphate, 64. The winter legumes show the following relative increases: superphosphate, 100; basic slag, 89; precipitated tricalcium phosphate, 89; triple superphosphate, 89; and rock phosphate, 51. It is evident that the exact efficiency of the phosphates depends somewhat on the test crop. However, rock phosphate was low in all cases. The foregoing efficiencies were from the use of 48 pounds of P_2O_5 from each source of phosphorus. The use of 24 pounds of P_2O_5 shows relative efficiencies for cotton, corn, and legumes of 82, 80, and 67, respectively, as compared to 48 pounds of P_2O_5.

Colloidal phosphate, Ammo-phos A, and the double rate of rock phosphate (96 pounds P_2O_5) were not included in the test at the Sand Mountain Substation because of the lack of space.

TABLE 1. YIELD OF CROPS ON CHECK PLOTS AND INCREASED YIELDS OVER CALCULATED CHECK FROM VARIOUS SOURCES OF PHOSPHORUS IN A 2-YEAR ROTATION OF COTTON AND CORN WITH WINTER LEGUMES, 1930-1945

Plot no.	Source of phosphorus[1]	Amount per acre of P_2O_5 to cotton and to winter legumes	Yield increase per acre over calculated check: Tennessee Valley Substation			Sand Mountain Substation			Wiregrass Substation			Prattville Field		
			Seed cotton	Corn	Green wt. of winter legumes	Seed cotton	Corn	Green wt. of winter legumes	Seed cotton	Corn	Green wt. of winter legumes	Seed cotton	Corn	Green wt. of winter legumes
		Lb.	*Lb.*	*Bu.*	*Lb.*	*Lb.*	*Bu.*	*Lb.*	*Lb.*	*Bu.*	*Lb.*	*Lb.*	*Bu.*	*Lb.*
1	None (check)[2]	*0*	*1,025*	*28.2*	*1,870*	*875*	*15.3*	*1,201*	*1,178*	*24.7*	*4,947*	*1,469*	*32.7*	*6,007*
2	Basic slag	48	421	7.9	7,539	484	19.9	3,760	176	4.9	3,857	100	5.2	3,999
3	Superphosphate	48	460	5.7	8,279	546	16.9	3,745	213	4.9	2,839	114	7.0	5,571
4	Rock phosphate	48	172	3.5	3,548	383	12.8	3,549	50	1.6	869	44	4.1	2,408
5	None (check)[2]	*0*	*1,151*	*30.5*	*2,588*	*948*	*17.7*	*1,524*	*954*	*17.4*	*4,170*	*1,390*	*32.7*	*6,749*
6	Rock phosphate	96	320	6.1	5,585	--	--	--	100	3.4	1,377	88	4.9	3,066
7	Colloidal phos.	48	217	3.5	3,441	--	--	--	120	2.7	1,143	78	5.4	3,183
8	Ppt. trical. phos.	48	368	6.0	7,323	522	18.9	5,051	134	4.0	1,807	128	7.0	4,123
9	None (check)[2]	*0*	*1,051*	*26.9*	*1,928*	--	--	--	*883*	*15.4*	*3,719*	*1,305*	*29.9*	*5,920*
10	Triple superphosphate	48	390	6.0	7,483	517	18.9	4,897	117	3.7	1,526	174	7.7	4,275
11	Ammo-phos A	48	383	6.5	7,557	--	--	--	−87	3.5	1,088	−177	6.0	3,294
12	Superphosphate[3]	24	437	7.1	8,448	459	18.9	5,174	230	5.4	2,291	138	7.1	4,686
13	None (check)[2]	*0*	*1,145*	*29.7*	*2,443*	*1,107*	*22.3*	*2,138*	*976*	*18.3*	*4,421*	*1,350*	*33.1*	*6,830*
14	Superphosphate	48	392	6.4	7,452	489	15.9	4,236	179	4.7	2,776	181	7.1	5,916
15	Superphosphate[4]	24	428	6.2	7,423	481	22.4	5,135	226	6.0	4,346	187	6.7	5,728
16	Superphosphate	24	350	5.2	4,602	489	14.2	3,081	155	3.1	2,341	101	5.1	3,675
17	None (check)[2]	*0*	*892*	*25.0*	*1,506*	*886*	*15.3*	*1,230*	*1,177*	*23.3*	*4,836*	*1,477*	*33.1*	*6,208*

[1] In addition to phosphorous, cotton received 36 pounds of nitrogen and 24 pounds of potash per acre at all locations except at the Tennessee Valley Substation, where nitrogen was discontinued in 1937. Winter legumes received the above rates of P_2O_5 beginning in 1935 at the Tennessee Valley and Sand Mountain Substations, and in 1936 at Wiregrass Substation and Prattville Experiment Field. Corn received 600 pounds per acre of an 0-5-2 from 1930-34 at the Tennessee Valley and Sand Mountain Substations and Prattville Field, and from 1930-35 at the Wiregrass Substation but received no fertilizer after these dates.

[2] Check yields (in italic) are total yields per acre; all others are calculated increases over check (based on assumed uniform soil variation between check plots).

[3] In addition to superphosphate, rock phosphate applied at the rate of 2,000 pounds per acre in 1930, 1936, and 1942.

[4] In addition to superphosphate, basic slag applied at the rate of 2,000 pounds per acre in 1930, 1936, and 1942.

TABLE 2. AVERAGE INCREASED YIELDS OF SEED COTTON BY 4-YEAR PERIODS AND AVERAGE INCREASED YIELDS OF SEED COTTON, CORN, AND WINTER LEGUMES, 1930 TO 1945 (Summary of Data Reported in Table 1)

Source of phosphorus	Amount of P_2O_5 per acre to cotton and to winter legumes	Average increased yields per acre of seed cotton by 4-year periods				Average yields per acre 1930-45			Relative efficiency of phosphates (48 lb. P_2O_5 as superphosphate = 100)		
		1930-33	1934-37	1938-41	1942-45	Seed cotton	Corn	Green wt. of winter legumes	Cotton	Corn	Legumes
	Lb.	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Bu.*	*Lb.*			
TENNESSEE VALLEY, SAND MOUNTAIN, AND WIREGRASS SUBSTATIONS AND PRATTVILLE EXPERIMENT FIELD											
Basic slag	48	92	225	438	421	294	9.5	4,789	88	110	94
Superphosphate	48	150	248	472	463	333	8.6	5,101	100	100	100
Rock phosphate	48	48	100	232	268	162	5.5	2,593	49	64	51
Ppt. tricalcium phos.	48	125	222	397	407	288	9.0	4,551	87	105	89
Triple superphosphate	48	169	232	406	392	300	9.1	4,545	90	106	89
Superphosphate[1]	24	163	230	422	449	316	9.6	5,150	95	106	101
Superphosphate[2]	24	162	236	465	461	331	10.3	5,658	99	120	111
Superphosphate	24	101	188	385	420	273	6.9	3,425	82	80	67
TENNESSEE VALLEY AND WIREGRASS SUBSTATIONS AND PRATTVILLE EXPERIMENT FIELD											
Superphosphate	48	130	187	356	324	256	6.0	5,471	100	100	100
Rock phosphate	48	37	60	126	131	89	3.1	2,275	35	52	42
Rock phosphate	96	92	135	223	227	169	4.8	3,344	66	80	61
Colloidal phosphate	48	41	117	190	207	138	3.9	2,589	54	65	47
Ammo-phos A	48	115	80	102	−138	40	5.3	3,980	16	88	73
Superphosphate	24	87	149	285	288	202	4.5	3,539	79	75	67

[1] In addition to superphosphate, rock phosphate applied at the rate of 2,000 pounds per acre in 1930, 1936, and 1942.

[2] In addition to superphosphate, basic slag applied at the rate of 2,000 pounds per acre in 1930, 1936, and 1942.

As reported in Table 2, these phosphates show the following relative efficiencies for cotton at the three locations: superphosphate, 100; colloidal phosphate, 54; double rate of rock phosphate, 66; rock phosphate, 35; and Ammo-phos A, 16. For corn the relative increases are in the following order: superphosphate, 100; Ammo-phos A, 88; double rate of rock phosphate, 80; colloidal phosphate, 65; rock phosphate, 52. The order of efficiency for winter legumes is the same as for corn. The double rate of rock phosphate, which is about equivalent in cost to 48 pounds of P_2O_5 from superphosphate, did not give as large an increase in yields as superphosphate. Colloidal phosphate produced greater yields than the same amount of P_2O_5 in the form of rock phosphate. However, colloidal phosphate did not give as large increases in yields as 24 pounds of P_2O_5 from superphosphate, which would be about equivalent in cost to the colloidal phosphate.

It has been suggested that the relative efficiency of the insoluble phosphates may increase with successive applications. Increased yields of seed cotton from 1930 to 1945 by 4-year periods are reported in Table 2. These data show that there is a tendency for the relative efficiency of the insoluble phosphates to increase with time. However, with time the actual increases in yield show a wider spread between superphosphate and the insoluble phosphates. Studies in Alabama *(5, 9, 11)* have shown that considerable added phosphorus may be lost by erosion. Such loss of phosphorus would tend to prevent a cumulative effect of added phosphates.

Certain plots received 24 pounds of P_2O_5 as superphosphate plus periodic applications of rock phosphate or basic slag. As indicated by data in Table 2, the addition of 2,000 pounds of rock phosphate or basic slag every 6 years increased the yields of cotton, corn, and winter legumes appreciably. The addition of basic slag gave somewhat higher yields than did the addition of rock phosphate.

STUDY OF SOURCES OF PHOSPHORUS IN A ROTATION OF CORN AND COTTON WITHOUT WINTER LEGUMES. A source-of-phosphorus test was started in 1930 at the Tennessee Valley, Sand Mountain and Wiregrass substations, and at the Monroeville and Alexandria experiment fields using corn and cotton in rotation as test crops. The sources of phosphorus (superphosphate, basic slag, triple superphosphate, precipitated tricalcium phosphate, Ammo-phos

TABLE 3. INCREASED YIELDS FROM VARIOUS SOURCES OF PHOSPHORUS OVER CALCULATED CHECK PLOT YIELDS IN A 2-YEAR ROTATION OF COTTON AND CORN, 1930-45

Plot no.	Source of phosphorus[1]	Amount of P_2O_5 per acre to cotton	Yield increase per acre over calculated check[2]									
			Tenn. Valley Substation		Sand Mountain Substation		Wiregrass Substation		Monroeville Field		Alexandria Field	
			Seed cotton	Corn	Seed cotton	Corn	Seed cotton	Corn	Seed cotton	Corn	Seed cotton	Corn
		Lb.	*Lb.*	*Bu.*	*Lb.*	*Bu.*	*Lb.*	*Bu.*	*Lb.*	*Bu.*	*Lb.*	*Bu.*
1	None (check)[2]	*0*	*828*	*31.9*	*831*	*28.1*	*1,141*	*22.9*	*858*	*31.2*	*732*	*31.4*
2	Basic slag	48	387	7.1	452	9.1	115	2.3	227	2.1	343	2.5
3	Superphosphate	48	455	7.0	485	7.9	123	1.8	320	2.0	441	3.2
4	Rock phosphate	48	204	2.1	390	7.7	23	1.8	148	0.9	215	2.9
5	None (check)[2]	*0*	*973*	*31.5*	*779*	*27.6*	*1,104*	*21.5*	*867*	*29.0*	*863*	*36.5*
6	Rock phosphate	96	328	4.8	–	–	73	1.8	170	2.2	407	3.0
7	Colloidal phosphate	48	233	3.2	–	–	110	1.9	136	1.6	–	–
8	Ppt. tricalcium phos.	48	382	5.4	494	8.4	136	3.5	221	1.8	–	–
9	None (check)[2]	*0*	*861*	*30.1*	–	–	*1,079*	*23.1*	*872*	*29.5*	–	–
10	Triple superphosphate	48	399	4.7	563	8.8	142	1.4	189	1.6	–	–
11	Ammo-phos A	48	340	3.0	–	–	−217	−2.4	−6	1.5	329	1.7
12	Superphosphate[3]	24	433	4.9	567	9.3	146	−1.9	288	1.0	440	2.6
13	None (check)[2]	*0*	*978*	*32.3*	*724*	*25.7*	*1,139*	*22.9*	*906*	*29.7*	*835*	*35.0*
14	Superphosphate	48	426	4.4	528	9.3	147	0.4	330	1.1	404	2.1
15	Superphosphate[4]	24	458	5.7	575	12.3	160	2.4	305	0.8	387	2.8
16	Superphosphate	24	378	5.0	500	7.9	88	0.7	291	2.3	328	2.1
17	None (check)[2]	*0*	*805*	*28.3*	*698*	*25.2*	*1,155*	*24.0*	*789*	*29.8*	*678*	*30.0*

[1] Cotton received 600 pounds per acre of 6-10-4 from 1930 to 1934, inclusive, and 600 pounds of 6-8-4 thereafter at all locations except at the Wiregrass Substation where the fertilizer was changed to a 6-8-4 in 1936. Corn received 600 pounds per acre of 6-5-2 from 1930 to 1934 and 36 pounds of nitrogen only thereafter at all locations except at the Wiregrass Substation where the fertilizer was changed to 36 pounds of nitrogen only in 1936.

[2] Check yields (in *italic*) are total yields per acre; all others are calculated increases over check (based on assumed uniform soil variation between check plots).

[3] In addition to superphosphate, rock phosphate applied at the rate of 2,000 pounds per acre in 1930, 1936, and 1942.

[4] In addition to superphosphate, basic slag applied at the rate of 2,000 pounds per acre in 1930, 1936, and 1942.

A, rock phosphate, and colloidal phosphate) were the same as those used in the study previously discussed.

Yield data for each of the five locations are presented in Table 3. The response of cotton to phosphorus was rather large at all locations except at the Wiregrass Substation. In most cases corn gave little response to phosphorus and as a result is not a very satisfactory crop to use in evaluating sources of phosphorus.

Since each source of phosphorus was not tested at every location, Table 4 has been divided into two sections so that comparisons may be made between phosphates tested at the same places. The relative efficiencies of materials tested at five locations are as follows for cotton: superphosphate, 100; basic slag, 83; and rock phosphate, 58. A half rate of superphosphate (24 pounds P_2O_5) gave 87 per cent as large an increase in yield as 48 pounds of P_2O_5 from the same source. The use of a ton of rock phosphate or basic slag every 6 years in addition to the half rate of superphosphate increased the yield of seed cotton by 56 and 58 pounds, respectively. The relative efficiencies of sources tested at the Tennessee Valley and Wiregrass substations and at the Monroeville Field are: superphosphate, 100; double rate of rock phosphate, 61; colloidal phosphate, 51; rock phosphate, 40; and Ammo-phos A, 22. The double rate of rock phosphate did not increase the yield of cotton as much as superphosphate. Colloidal phosphate (48 pounds P_2O_5) did not produce as large an increase in yield as superphosphate applied at the rate of 24 pounds of P_2O_5 per acre. According to these data, the insoluble phosphates did not increase the yield of cotton as much as superphosphate when applied on an approximately equal cost basis.

The cotton yields by 4-year periods are given in Table 4. As was the case for the rotation with legumes, the efficiency of the insoluble phosphates tends to increase with time. The actual spread between superphosphate and the insoluble phosphates, however, becomes larger with time.

LIME PHOSPHATE EXPERIMENT. In 1922 an experiment was started to test the value of basic slag, superphosphate, and two rates of rock phosphate with and without lime. This experiment was conducted at Atmore, Prattville, Cusseta, Sylacauga, and Hackleburg on Greenville, Red Bay, Cecil, Decatur, and Atwood soils, respectively. The phosphates were applied at the rate of 600 pounds per acre with a second rate of rock phosphate ap-

TABLE 4. AVERAGE INCREASED YIELDS OF SEED COTTON BY 4-YEAR PERIODS AND AVERAGE INCREASED YIELDS OF SEED COTTON AND CORN, 1930-45 (Summary of Data Reported in Table 3)

Source of phosphorus	P_2O_5 per acre applied to cotton	Average increased yield per acre of seed cotton by 4-year periods				Average yields per acre, 1930-45		Relative efficiency (48 lb. P_2O_5 as superphosphate = 100)	
		1930-33	1934-37	1938-41	1942-45	Seed cotton	Corn	Cotton	Corn
	Lb.	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Bu.*		
TENNESSEE VALLEY, SAND MOUNTAIN AND WIREGRASS SUBSTATIONS AND MONROEVILLE AND ALEXANDRIA EXPERIMENT FIELDS									
Basic slag	48	118	233	397	465	303	4.6	83	102
Superphosphate	48	210	293	454	504	365	4.5	100	100
Rock phosphate	48	97	159	235	352	211	3.1	58	69
Superphosphate[1]	24	232	295	462	504	373	4.0	102	89
Superphosphate[2]	24	220	276	489	517	375	4.8	103	107
Superphosphate	24	162	230	407	468	317	3.6	87	80
TENNESSEE VALLEY AND WIREGRASS SUBSTATIONS AND MONROEVILLE EXPERIMENT FIELD									
Superphosphate	48	259	251	367	352	307	3.6	100	100
Rock phosphate	48	88	77	138	190	123	1.6	40	44
Rock phosphate	96	135	157	206	253	188	2.9	61	81
Colloidal phosphate	48	76	118	188	245	157	2.2	51	61
Ammo-phos A	48	123	77	163	—162	67	1.0	22	28
Superphosphate	24	161	170	324	355	252	2.7	82	75

[1] In addition to superphosphate, rock phosphate applied at the rate of 2,000 pounds per acre in 1930, 1936, and 1942.
[2] In addition to superphosphate, basic slag applied at the rate of 2,000 pounds per acre in 1930, 1936, and 1942.

TABLE 5. RESPONSE OF CROPS TO PHOSPHATE WITH AND WITHOUT LIME AT ATMORE, PRATTVILLE, CUSSETA, SYLACAUGA, AND HACKLEBURG, 1923-30

Source of phosphorus[1]	Lime per acre applied in fall 1922	P_2O_5 per acre applied annually[2]	Weighted yield averages per acre of 5 locations from 1923-30[3]				Increases in yield per acre due to phosphorus			
			Cotton, 23 years	Oats, 13 years	Summer legumes, 20 years	Corn, 26 years	Cotton	Oats	Summer legumes	Corn
	Lb.	*Lb.*	*Lb.*	*Bu.*	*Lb.*	*Bu.*	*Lb.*	*Bu.*	*Lb.*	*Bu.*
None	0	0	584	27.2	4,166	14.6	--	--	--	--
Basic slag	0	96	829	35.6	5,254	19.4	245	8.4	1,088	4.8
Superphosphate	0	96	880	33.2	4,454	18.0	296	6.0	288	3.6
Rock phosphate	0	192	736	30.5	4,160	15.7	152	3.3	—4	1.1
Rock phosphate	0	768	774	31.6	4,279	19.1	190	4.4	113	4.5
None	4000	0	654	26.6	5,261	19.6	--	--	--	--
Basic slag	4000	96	879	33.7	6,402	20.2	225	7.1	1,141	0.6
Superphosphate	4000	96	914	35.7	6,524	20.4	260	9.1	1,263	0.8
Rock phosphate	4000	192	763	31.4	5,806	18.9	109	4.8	545	—0.7
Rock phosphate	4000	768	777	29.4	6,036	18.0	123	2.8	775	—1.6

[1] Each plot received 200 pounds of sodium nitrate (½N to oats and ½N in drill to cotton) and 100 pounds of muriate of potash (⅔ to winter legume preceding cotton and ⅓ in drill to cotton).

[2] Two-thirds of phosphorus to winter legume preceding cotton and ⅓ in drill to cotton.

[3] Weighted averages based on number of crops harvested; experiment did not run the full time at all locations.

plied at 2,400 pounds per acre. Yields and treatments for this experiment are reported in Table 5. The increased yields of cotton were in the following decreasing order for the phosphates with and without lime: superphosphate, basic slag, high rate of rock phosphate, and rock phosphate. For oats the positions of superphosphate and basic slag were reversed. In the case of summer legumes without lime, basic slag gave the best results, while with lime superphosphate resulted in slightly higher yields than those from slag. Differences between treatments for corn were small, especially for the limed plots.

At these five locations an exceptionally high rate of rock phosphate failed to produce as much cotton as 600 pounds of superphosphate. Slag also gave somewhat lower yields than superphosphate.

ROCK PHOSPHATE VS. SUPERPHOSPHATE, AUBURN. An experiment designed to evaluate superphosphate and rock phosphate for production of cotton was located on a Chesterfield soil. The experiment was begun in 1920 and was continued through 1931. The phosphates were applied annually at the rate of 320 pounds per acre, which means that twice as much P_2O_5 in the form of rock phosphate was used as was applied in the form of superphosphate. Results of the experiment are presented in Table 6.

TABLE 6. RESPONSE OF COTTON TO ROCK PHOSPHATE AND SUPERPHOSPHATE, MAIN STATION, 1920-31

Source of phosphorus[1]	Phosphate applied per acre	Average yield per acre of seed cotton 1920-31	Increase per acre due to phosphorus	Relative efficiency
	Lb.	*Lb.*	*Lb.*	
None	0	597	--	--
Superphosphate	320	894	297	100
Rock phosphate	320	851	254	85

[1] In addition to phosphate each plot received 160 pounds per acre of kainit containing 12.5 per cent K_2O and 100 pounds per acre of sodium nitrate from 1920-23, inclusive, and 160 pounds per acre thereafter.

Superphosphate resulted in an average increase of 297 pounds per acre of seed cotton as compared to a 254-pound average increase from rock phosphate. Thus, rock phosphate had a relative efficiency of 85 in the 12-year experiment.

FERTILIZER ROTATION EXPERIMENT. Fertilizer rotation experiments, started in 1916, were located on a Hartsells soil near Albertville and on a Greenville soil near Jackson. Yield data

TABLE 7. RESPONSE OF COTTON AND CORN TO PHOSPHATES IN AN EXPERIMENT ON HARTSELLS AND GREENVILLE SOILS

Treatments[1]			Average yields and increased yields per acre							
			Albertville[2], average 1920-26		Jackson[3], average 1916-29		Weighted average of two locations			
							Seed cotton		Corn	
Source of phosphorus	Phosphate per acre	Lime per acre	Seed cotton	Corn	Seed cotton	Corn	Average yields	Increase	Average yields	Increase
	Lb.	*Lb.*	*Lb.*	*Bu.*	*Lb.*	*Bu.*	*Lb.*	*Lb.*	*Bu.*	*Bu.*
None	0	0	223	21.8	498	19.2	406	--	20.0	--
Superphosphate (16% P_2O_5)	240	0	494	25.5	736	22.3	655	249	23.4	3.4
Basic slag (16% P_2O_5)	240	0	515	29.5	728	22.7	657	251	25.0	5.0
Rock phosphate	480	0	392	27.5	709	22.2	603	197	24.0	4.0
Superphosphate	240	4,000	602	29.2	875	24.1	784	378	25.8	5.8
Basic slag	240	4,000	573	27.0	837	22.9	749	343	24.3	4.3
Rock phosphate	480	4,000	592	32.0	737	21.5	689	283	25.0	5.0

[1] All plots received 100 pounds of sodium nitrate and 50 pounds of muriate of potash.
[2] Hartsells soil.
[3] Greenville soil.

TABLE 8. RESPONSE OF CROPS TO SUPERPHOSPHATE AND ROCK PHOSPHATE IN CULLARS ROTATION, MAIN STATION

Plot No.	Source of phosphorus[1]	Total P_2O_5 per acre applied from 1911-31	Average yields per acre, 1911-31				Average yields per acre, 1932-47			
			Seed cotton 19 yr. av.	Corn 17-yr. av.	Oats 15-yr. av.	Vetch, gr. wt. 4-yr. av.	Seed cotton 15-yr. av.	Corn 16-yr. av.	Oats 16-yr. av.	Vetch, gr. wt. 16-yr. av.
		Lb.	*Lb.*	*Bu.*	*Bu.*	*Lb.*	*Lb.*	*Bu.*	*Bu.*	*Lb.*
2	None	0	772	38.8	36.1	2,410	473	27.7	29.3	764
3	Superphosphate	914	1,243	49.2	48.6	7,369	995	45.2	46.8	2,856
5	Rock phosphate	3,656	1,161	46.1	50.8	9,088	1,169	51.3	51.5	7,385

[1] Two-thirds of phosphorus was applied to cotton and ⅓ to corn. From 1911-23 corn received 790 pounds per acre of dried blood and 532 pounds of kainit (12.5% K_2O); cotton, 900 pounds of dried blood and 614 pounds of kainit; and oats, 468 pounds of sodium nitrate and 510 pounds of kainit. From 1924-31 corn received 700 pounds of sodium nitrate and 132 pounds of muriate of potash; cotton, 800 pounds of sodium nitrate and 282 pounds of muriate of potash; and oats, 468 pounds of sodium nitrate. From 1932 on corn, cotton, and oats received 240 pounds of sodium nitrate.

from the Albertville test for the first 4 years were lost by fire. According to the data in Table 7, the average cotton yields for the two areas show that 240 pounds per acre of slag (16 per cent P_2O_5) produced as much cotton as 240 pounds of superphosphate on the unlimed plots. However, on the limed plots superphosphate was superior to basic slag. An application of 480 pounds of rock phosphate (four times as much P_2O_5) did not increase the yield of cotton as much as superphosphate on either the limed or unlimed plots. There was little response of corn to phosphorus; consequently, differences in yields due to sources were small.

ROCK PHOSPHATE VS. SUPERPHOSPHATE, CULLARS ROTATION. The Cullars rotation on Norfolk loamy sand was started in 1911. One objective of the experiment was to study the value of superphosphate and rock phosphate for the production of crops in a rotation. These plots were converted to a residual phosphorus study after 21 years of phosphate applications. The yields obtained from the different phosphates are given in Table 8. The yield data from 1911-31 show that superphosphate produced a little more cotton and corn than rock phosphate but less oats and vetch. It should be pointed out, however, that the rock phosphate applied contained 4 times as much total P_2O_5 as the superphosphate.

In 1932 the phosphate treatments on plots 3 and 5 were discontinued in order to study residual phosphorus. The average yields from 1932 to 1947 for all crops grown were higher where rock phosphate had been applied than where superphosphate had been used. In Figure 1 the cotton yields are plotted by years for the residual period. This graph shows that there was not much difference in value of the two phosphates the first 9 years; however, rock phosphate resulted in consistently higher

TABLE 9. SOLUBLE AND TOTAL PHOSPHORUS CONTENT OF SOILS OF PLOTS, CULLARS ROTATION, MAIN STATION (Samples collected June 3, 1947)

Plot No.	Source of phosphorus	Total P_2O_5 applied from 1911-31	Dilute acid soluble[1] P_2O_5	NH_4F soluble[2] P_2O_5	Total P_2O_5
		Lb.	*p.p.m.*	*p.p.m.*	*p.p.m.*
2	None	0	9	23	249
3	Superphosphate	914	18	40	322
5	Rock phosphate	3,656	265	71	721

[1] Two gm. of soil extracted with 200 ml. of .002N H_2SO_4 buffered pH 3.0 with ammonium sulfate.

[2] Two gm. of soil extracted with 100 ml. of neutral 0.5N NH_4F.

yields than superphosphate the last 7 years. The total and soluble phosphorus contents of samples taken in June, 1947, are given in Table 9. It is evident from these data that the high rate of rock phosphate caused a greater accumulation of total phosphorus as well as soluble phosphorus than superphosphate. The superphosphate plot contained little more total or soluble phosphorus

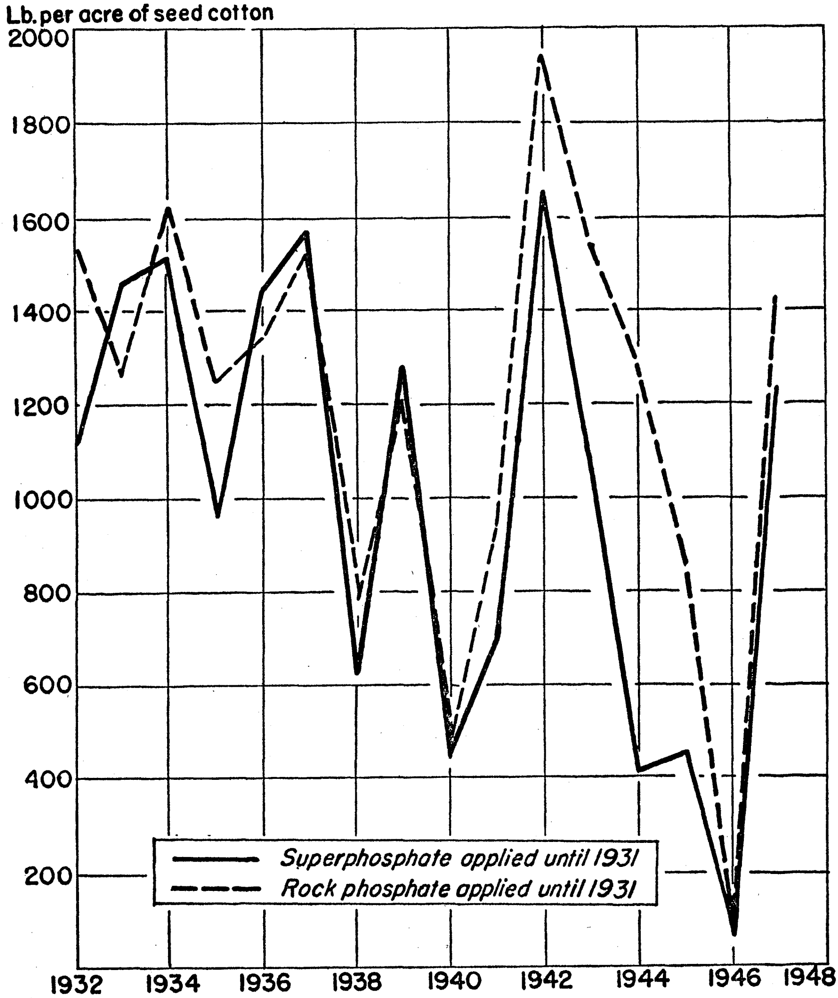

FIGURE 1. The effect of residual phosphate on the yield of cotton grown in Cullars rotation at Auburn. The superphosphate plots received a total of 914 pounds per acre of P_2O_5 from 1911 to 1931. The rock phosphate plots received a total of 3,656 pounds per acre of P_2O_5 during the same period.

than the check plot. The fact that most of the added phosphorus had been removed from the superphosphate plot by crops and erosion helps to explain the lower yields from superphosphate in the later years of the residual study.

EXPERIMENTS OF SHORT DURATION

SUPERPHOSPHATE, COLLOIDAL PHOSPHATE, AND BASIC SLAG FOR PEANUTS. A fertilizer experiment with peanuts was conducted at 50 locations in 1938 and 1939. The number of locations by soil groups are as follows: Norfolk, 38; Greenville, 10; and Lufkin, 2. The yield data for the sources of phosphorus treatments in this experiment are given in Table 10. The rate

TABLE 10. AVERAGE YIELDS AND INCREASES OBTAINED FROM FERTILIZER EXPERIMENTS WITH PEANUTS AT 50 LOCATIONS, 1938-39

Treatment	Phosphate applied per acre	Average yields per acre from 50 locations	
		Marketable nuts	Increase
	Lb.	*Lb.*	*Lb.*
None	0	998	--
Basic slag[1]	300	1,167	169
Basic slag	300	1,151	153
Colloidal phosphate	300	1,094	96
Superphosphate	150	1,180	182
Superphosphate[1]	150	1,164	166

[1] Received 25 pounds muriate of potash.

of P_2O_5 applied per acre according to source was: superphosphate, 24 pounds; basic slag, 24 pounds; and colloidal phosphate, 54 pounds. Yield increases in the 2-year period averaged 182, 153, and 96 pounds per acre of peanuts, respectively. At 1949 prices for these phosphates, the rate of P_2O_5 used in this experiment would be about the same in cost. Based on these data, it is obvious that superphosphate would be the most economical of the three phosphates for production of peanuts. Basic slag and superphosphate were tested when applied with 25 pounds of muriate of potash. Addition of potash to basic slag increased the yield 16 pounds over basic slag alone, while addition of 25 pounds of potash to superphosphate decreased the yield 16 pounds over superphosphate alone.

SUPERPHOSPHATE, ROCK PHOSPHATE, AND BASIC SLAG FOR COTTON AND CORN. Several cooperative tests were carried on from 1920-22 to study the value of three sources of phosphorus for

TABLE 11. RESPONSE OF COTTON AND CORN TO SOURCES OF PHOSPHORUS, 1920-22

Fertilizers[1]		Cotton yields per acre, Av. eight locations		Corn yields per acre, Av. three locations	
Sources of phosphorus	Phosphate added per acre	Seed cotton	Increase	Corn	Increase
	Lb.	*Lb.*	*Lb.*	*Bu.*	*Bu.*
None	0	885	--	32.5	--
Superphosphate, 16% P_2O_5	240	1,023	138	29.9	—2.6
Basic slag, 16% P_2O_5	240	969	84	33.3	0.8
Rock phosphate	480	1,001	116	32.3	—0.2

[1] All plots received 200 pounds per acre of cottonseed meal and 200 pounds of kainit, which contained 12.5 per cent potash.

production of cotton and corn. The data for these tests are given in Table 11. The average increases in yield of seed cotton for the phosphates at eight locations were as follows: superphosphate, 138 pounds; rock phosphate, 116 pounds; and basic slag, 84 pounds. The order of response was probably influenced to a considerable extent by the quantity of P_2O_5 supplied by each source. Basic slag, superphosphate, and rock phosphate were applied at rates equivalent to 38, 38, and 152 pounds of P_2O_5 per acre, respectively. In these tests superphosphate was superior to basic slag and rock phosphate, even though the amount of P_2O_5 in the rock phosphate was four times greater than that of the superphosphate.

There was no response of corn to phosphorus. This is in line with data from experiments presented earlier in the report.

SUPERPHOSPHATE VS. BASIC SLAG FOR COTTON. Since superphosphate and basic slag are used in large quantities in the State, they have been tested at a number of locations for production of cotton. Results obtained from these two materials are given in Table 12. Where superphosphate and basic slag were used with ammonium sulfate as the source of nitrogen, superphosphate produced 914 pounds per acre of seed cotton and basic slag 852 pounds. These are averages obtained from 222 experiments conducted from 1927 to 1931. The data presented by soil groups show that in most cases superphosphate was superior to basic slag.

Presented also in Table 12 are data from 106 experiments comparing superphosphate and basic slag when used with sodium nitrate as the source of nitrogen. The average yield from super-

TABLE 12. YIELD OF COTTON IN POUNDS PER ACRE FROM SUPERPHOSPHATE AND BASIC SLAG

Source of phosphorus[1]	Average yield of seed cotton, pounds per acre, by soil groups								General average
	Clarksville soil group	Decatur soil group	Holston soil group	Hartsells soil group	Cecil soil group	Oktibbeha soil group	Greenville soil group	Norfolk soil group	
				COOPERATIVE TESTS, 1927-31					
	10 expt.	*32 expt.*	*21 expt.*	*36 expt.*	*17 expt.*	*15 expt.*	*34 expt.*	*57 expt.*	*222 expt.*
Superphosphate[2]	932	804	999	1,036	892	791	936	891	914
Basic Slag[2]	787	739	970	926	800	796	872	855	852
				COOPERATIVE TESTS, 1926-30					
	7 expt.	*19 expt.*	*8 expt.*	*18 expt.*	*3 expt.*	*9 expt.*	*19 expt.*	*23 expt.*	*106 expt.*
None[3]	434	721	914	852	899	599	815	773	762
Superphosphate[3]	937	899	1,112	1,003	951	676	932	928	930
Basic Slag[3]	751	789	1,072	904	890	709	892	869	859

[1] Phosphates applied at rate of 64 pounds P_2O_5 per acre; all plots received 25 pounds K_2O as muriate of potash.
[2] Received ammonium sulfate at rate of 30 pounds per acre of N.
[3] Received sodium nitrate at rate of 30 pounds per acre of N.

phosphate was 930 pounds per acre of seed cotton as compared with 859 pounds from basic slag. This is a difference of 71 pounds in favor of superphosphate. The difference in yield when the phosphates were used with ammonium sulfate was 62 pounds. These differences indicate that the source of nitrogen had little effect on the efficiency of these phosphates.

PHOSPHATES PRODUCED BY TENNESSEE VALLEY AUTHORITY. The Alabama Agricultural Experiment Station has cooperated with the Tennessee Valley Authority in testing new sources of phosphorus under field conditions. The data obtained as a result of this work are reported in Tables 13, 14, and 15. In most cases superphosphate has been used as the standard of comparison.

Work reported by Bartholomew *(1)* in 1935 showed that the availability of several rock phosphates was correlated with their fluorine content. Studies in the laboratories of the United States Department of Agriculture indicated the conditions under which rock phosphate could be defluorinated and the effect of defluorination on availability. Curtis *et al (3)* and Elmore *et al (4)* developed a process of defluorination for the purpose of producing a product to be used as a fertilizer. Since the cost of the products depends on the degree of defluorination, it became necessary to determine under field conditions the effect of degree of defluorination on availability to plants. The degree of fineness of the quenched material also is an important factor in connection with availability.

The Alabama Station has tested fused tricalcium phosphates of varying degrees of defluorination and fineness, as well as other phosphates that the Tennessee Valley Authority has produced. Data in Tables 13 and 14 show that within limits the availability of fused tricalcium phosphate increases with increasing fineness and decreasing fluorine content. These and other data from states in the Tennessee Valley area indicate that the efficiency of fused tricalcium phosphate does not increase with decreasing fluorine content below 0.4 per cent fluorine or with increasing fineness beyond 40 mesh.

Average yields of the superphosphate plots at the three locations listed in Table 13 are as follows: vetch, 8,453 pounds; oats, 45.8 bushels; and sorghum, 44,267 pounds. Average yields of plots treated with fused tricalcium phosphate of less than 0.4 per cent fluorine and finer than 40 mesh are: vetch, 7,099 pounds; oats, 41.8 bushels; and sorghum, 38,917 pounds. The fused tri-

TABLE 13. RESULTS OF TESTS WITH FUSED TRICALCIUM PHOSPHATE, CALCIUM METAPHOSPHATE, AND SUPERPHOSPHATE AT THREE LOCATIONS, 1941-42

Plot no.	Phosphorus[1]			Yields per acre								
	Source	Fineness all through	Fluorine in fused rock	Alexandria Field			Prattville Field			Monroeville Field		
				Green weight		Oats	Green weight		Oats	Vetch 1941	Sorghum 1941	Vetch 1942
				Vetch	Sorghum		Vetch	Sorghum				
		Mesh	*Pct.*	*Lb.*	*Lb.*	*Bu.*	*Lb.*	*Lb.*	*Bu.*	*Lb.*	*Lb.*	*Lb.*
1	None	--	--	7,507	56,000	26.3	2,820	28,650	36.4	2,070	17,850	5,910
2	Fused tricalcium phos.	6	1.29	7,384	55,800	25.2	3,470	37,150	40.0	1,815	17,900	4,590
3	Fused tricalcium phos.	10	1.22	8,389	57,500	32.4	3,550	35,700	42.1	1,960	18,350	6,110
4	Fused tricalcium phos.	40	1.36	8,860	61,700	29.3	3,640	35,200	43.5	1,805	18,850	6,520
5	Fused tricalcium phos.	80	1.30	9,247	66,100	30.9	4,740	39,450	41.3	2,520	19,150	7,985
6	Fused tricalcium phos.	6	0.98	8,137	61,600	29.9	3,050	32,300	36.7	1,685	18,800	6,015
7	Fused tricalcium phos.	10	1.03	8,338	62,300	29.4	2,760	30,750	32.6	1,585	17,360	6,035
8	Fused tricalcium phos.	40	0.92	8,621	59,800	30.1	3,530	26,850	35.6	1,990	18,300	6,175
9	Fused tricalcium phos.	80	0.99	8,381	57,100	29.9	4,750	34,900	40.3	2,145	19,750	7,075
10	Fused tricalcium phos.	6	0.10	8,586	58,800	31.8	3,150	31,950	43.1	2,440	19,256	8,320
11	Fused tricalcium phos.	10	0.10	8,910	58,300	29.2	3,510	31,600	45.6	2,126	19,800	8,150
12	Fused tricalcium phos.	40	0.10	9,522	60,800	34.1	5,310	34,600	49.4	2,010	20,500	9,745
13	Fused tricalcium phos.	80	0.13	9,465	63,800	26.9	7,470	33,100	56.8	3,560	20,700	9,710
14	Calcium metaphos.	20	--	9,627	63,900	32.4	8,420	37,950	58.8	2,615	19,000	10,085
15	Calcium metaphos.	35	--	9,678	63,000	30.7	10,240	41,000	65.4	2,315	19,550	9,235
16	Calcium metaphos.	60	--	10,250	67,300	34.8	12,560	43,750	58.7	2,775	19,900	12,155
17	Calcium metaphos.[2]	60	--	11,076	69,600	37.5	11,650	42,950	58.2	2,400	20,500	11,180
18	Superphosphate[2]	--	--	10,427	70,500	36.6	11,270	45,700	55.1	2,355	20,600	9,760

[1] The following fertilizers applied to vetch and sorghum: 48 pounds P_2O_5 and 25 pounds K_2O to each crop; 36 pounds of nitrogen as sodium nitrate to sorghum; 50 pounds per acre of gypsum applied to all plots except 17 and 18. Fertilizer for oats: 36 pounds of nitrogen as sodium nitrate applied as top dressing in March.

[2] No gypsum.

TABLE 14. RESPONSE OF CROPS TO FUSED TRICALCIUM PHOSPHATE, CALCIUM METAPHOSPHATE, AND SUPERPHOSPHATE

Plot no.	Phosphorus[1]			Green weight per acre, 1943			Green weight of sudan grass per acre, 1942			
	Source of phosphorus	Fluorine in fused rock	Fineness	Prattville	Monroeville Field		Sylacauga area	Prattville area	Monroeville Field	Av. 3 expt.
				Vetch	Vetch	Soybeans				
		Pct.	*Mesh*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*
1	No phosphate	-----	--------	11,880	14,335	18,721	6,570	5,505	13,600	8,558
2	Fused tricalcium phos.	0.55	— 60+ 80	11,430	27,130	18,914	6,690	6,548	14,100	9,113
3	Fused tricalcium phos.	0.55	— 80+100	12,360	27,230	19,493	6,660	7,590	14,300	9,517
4	Fused tricalcium phos.	0.55	—100+150	12,720	28,275	19,879	6,885	7,815	14,300	9,667
5	Fused tricalcium phos.	0.55	—150	12,675	28,290	18,721	7,050	5,873	14,300	9,074
6	Fused tricalcium phos.	0.36	— 60+ 80	12,420	27,260	16,984	7,050	6,143	14,750	9,314
7	Fused tricalcium phos.	0.36	— 80+100	11,070	26,615	18,914	6,990	6,255	14,400	9,215
8	Fused tricalcium phos.	0.36	—100+150	10,380	29,165	18,721	6,765	6,533	14,000	9,099
9	Fused tricalcium phos.	0.36	—150	10,930	28,260	16,791	6,615	6,270	14,400	9,095
10	Fused tricalcium phos.	0.20	— 60+ 80	9,810	28,595	18,142	6,495	6,383	14,250	9,043
11	Fused tricalcium phos.	0.20	— 80+100	9,720	25,855	17,177	5,760	6,495	14,500	8,918
12	Fused tricalcium phos.	0.20	—100+150	10,280	28,640	19,686	6,495	6,683	14,500	9,226
13	Fused tricalcium phos.	0.20	—150	10,580	29,020	20,265	6,435	5,715	14,650	8,933
14	Calcium metaphosphate	-----	— 60+ 80	11,880	28,605	18,528	7,395	6,135	15,100	9,543
15	Calcium metaphosphate[2]	-----	— 60+ 80	13,410	27,760	19,493	6,945	6,060	13,500	8,835
16	Superphosphate[3]	-----	--------	11,730	25,205	19,300	6,690	8,820	14,700	10,070

[1] Fertilizers applied to vetch (none to soybeans) as follows: All plots received 48 pounds P_2O_5 (calcium metaphosphate and superphosphate used on available basis and fused rock phosphate on total basis) and 25 pounds K_2O per acre; all plots except plots 15 and 16 received 50 pounds per acre of gypsum.

[2] No gypsum.

calcium phosphate plots received 50 pounds per acre of gypsum to eliminate sulfur as a variable. Average yields of the superphosphate plots for the experiments listed in Table 14 are: vetch, 18,467 pounds; and sudan grass, 10,070. For fused tricalcium phosphate containing less than 0.4 per cent fluorine and finer than 60 mesh, the yields are: vetch, 19,287 pounds; and sudan grass, 9,105.

According to the data in Table 15, the yields of cotton, corn, oats, winter legumes, and sudan grass were about the same from the use of fused tricalcium phosphate as from triple superphosphate. There was little or no relationship between the fineness of fused tricalcium phosphate and yields within the range of fineness tested in this experiment.

The data reported in Tables 13, 14, and 15 show that calcium metaphosphate was equal to superphosphate and triple superphosphate as a source of phosphorous. The data in Table 15 show that potassium metaphosphate resulted in yields of cotton, corn, oats, winter legumes, and sudan grass equal to or slightly higher than those produced by triple superphosphate.

TABLE 15. CALCULATED YIELDS[1] OF CROPS FROM FERTILIZERS CONTAINING PHOSPHATE OF DIFFERENT SOURCES AND FUSED TRICALCIUM PHOSPHATE OF DIFFERENT FINENESSES AT EIGHT LOCATIONS, 1944-46

Source of phosphorus[2]	Yields per acre				
	Seed cotton, 1944	Oats[3], 1945	Sudan grass hay, 1945	Winter legumes[4] (green wt.)	Corn, 1946
	Lb.	*Bu.*	*Lb.*	*Lb.*	*Bu.*
Triple superphosphate	1,120	34.9	3,206	17,145	42.5
Fused tricalcium phos., 6 mesh[5]	1,073	34.7	3,000	17,465	42.8
Fused tricalcium phos., 20 mesh[5]	1,089	32.7	3,095	17,693	43.4
Fused tricalcium phos., 20 mesh	1,109	37.0	3,207	17,853	42.0
Fused tricalcium phos., 40 mesh	1,096	34.2	3,089	18,438	42.8
Fused tricalcium phos., 80 mesh	1,095	33.4	3,181	18,559	43.9
Calcium metaphosphate	1,118	33.6	3,151	17,123	41.2
Potassium metaphosphate	1,167	35.6	3,120	17,891	42.5
None	1,074	28.0	2,624	11,733	35.7

[1] Based on an assumed uniform soil variation between check plots (triple superphosphate plots used as check plots).

[2] The crops received the following fertilizers: Cotton, 600 pounds 6-8-4; oats, 300 pounds 0-12-9 under and 36 pounds N about March 1; Sudan grass, 300 pounds 6-8-6 under and 36 pounds about June 20; vetch, 600 pounds 0-8-6; corn, 300 pounds 0-8-6. The sudan grass, vetch, and corn plots received gypsum at the rate of 50 pounds per acre.

[3] Average yield of seven experiments.

[4] Blue lupines used in one test, vetch on all others.

[5] Larger size particles screened out; all others fused rock phosphate ground to pass indicated screen.

EFFECT OF SUPPLEMENTS ON RESPONSE OF CROPS TO SOURCES OF PHOSPHORUS. Phosphorus in various forms may be equally available, but the materials may give different results when tested for growth of plants. Some phosphorus carriers may contain other essential elements in sufficient quantities to increase yields when applied to soils deficient in these particular elements. The data presented in Tables 16, 17, and 18 show that the efficiency of phosphates often changes as a result of the addition of supplements to the phosphorus carrier.

In Table 16 are given the relative efficiencies of several phosphates for cotton when used with ammonium sulfate as the source of nitrogen. The order of efficiencies are: superphosphate, 100; di-calcium phosphate, 99; triple superphosphate, 92; and tricalcium phosphate, 81. The sulfate supplied by the ammonium sulfate should be sufficient to supply the sulfur needed by the crops. It appears, therefore, that the relative response may be explained either on the basis of solubility differences or differences in calcium content. The low efficiency of tricalcium phosphate is probably due to its slow solubility. Phosphorus in

TABLE 16. RESPONSE OF COTTON TO SOURCES OF PHOSPHORUS AND SUPPLEMENTS AT 358 LOCATIONS, 1934-38

Plot no.	Fertilizers[1]		Yield of seed cotton per acre	Increase over no phosphorus plots, per acre	Relative efficiency (response to superphos. = 100)
	Source of nitrogen	Source of phosphorus and supplement			
			Lb.	*Lb.*	
1	$(NH_4)_2SO_4$	Superphosphate	982	254	------
2	$(NH_4)_2SO_4$	Tri-calcium phosphate	928	200	81
3	$(NH_4)_2SO_4$	Di-calcium phosphate	972	244	99
4	$(NH_4)_2SO_4$	None	727	------	------
5	$(NH_4)_2SO_4$	Triple superphosphate	956	227	92
6	$(NH_4)_2SO_4$	Triple superphos. + dolomite[2]	1,013	285	116
7	$(NH_4)_2SO_4$	Superphosphate	966	238	------
8	$NaNO_3$	Triple superphos. + dolomite[2]	997	269	109
9	$NaNO_3$	Triple superphosphate	997	269	109
10	$(NH_4)_2$[1]SO_4	None	728	------	------
11	$NaNO_3$	Triple superphos. + gypsum[3]	1,050	322	131
12	$(NH_4)_2SO_4$	Superphosphate + dolomite[2]	1,020	292	119
13	$(NH_4)_2SO_4$	Superphosphate	975	247	------
Average, plots 1, 7, 13			974	246	------

[1] Basis of 600 pounds 6-10-4 per acre. All potash from muriate. Monocalcium phosphate used in 1934 on all triple superhoshate plots.

[2] Dolomite (212 pounds per acre) sufficient to correct the acidity from ammonium sulfate.

[3] Gypsum (164 pounds per acre) equal to the amount supplied on the superphoshate plots.

TABLE 17. YIELD PER ACRE OF SEED COTTON FROM THREE SOURCES OF PHOSPHORUS WITH AND WITHOUT DOLOMITE, 1932-35

Fertilizer treatments[1]		Av. yield seed cotton per acre by soil groups				Av. all soil groups 199 expt.
Source of phosphorus	Dolomite[2] per acre	Clarksville soil group 41 expt.	Decatur soil group 40 expt.	Greenville soil group 34 expt.	Norfolk soil group 84 expt.	
	Lb.	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*
Superphosphate	0	800	995	926	952	925
Superphosphate	212	931	1,037	928	1,028	993
Superphosphate	1,050[3]	899	1,044	935	1,025	988
Di-ammonium phosphate	0	731	980	868	846	853
Di-ammonium phosphate	212	884	1,013	906	962	947
Di-ammonium phosphate[4]	212	888	1,014	920	1,000	966
Mono-ammonium phosphate	0	729	945	872	849	847
Mono-ammonium phosphate	212	882	1,025	950	978	963

[1] Fertilizers applied on basis of 600 pounds per acre of 6-10-4; nitrogen from ammonium sulfate for superphosphate plots and remainder of nitrogen from ammonium sulfate for ammonium phosphate plots; potash from muriate of potash.

[2] Mixed and applied with NPK.

[3] Dolomite broadcast in 1932 and none applied thereafter.

[4] Received 50 pounds per acre of gypsum.

superphosphate and triple superphosphate is mainly in the form of mono-calcium phosphate. Sixty pounds of P_2O_5 as superphosphate would supply 84 pounds of CaO, while the same amount of P_2O_5 from triple superphosphate would supply only 27 pounds of CaO. When enough dolomite was used with these two phosphates to correct the acidity of the ammonium sulfate, superphosphate produced 1,020 pounds per acre of seed cotton and triple superphosphate 1,013 pounds. Without dolomite superphosphate produced 974 pounds per acre of seed cotton and triple superphosphate 956 pounds.

The data in Table 16 show that when triple superphosphate was used with sodium nitrate as the source of nitrogen, it produced 997 pounds per acre of seed cotton. Triple superphosphate and sodium nitrate plus 164 pounds per acre of gypsum resulted in 1,050 pounds, or an increase of 53 pounds for the gypsum.

Presented in Table 17 are the average yields of seed cotton from 199 experiments on four soil groups involving use of superphosphate, mono-ammonium phosphate, and di-ammonium phosphate with and without lime. Without lime the following average acre yields of seed cotton were obtained: superphosphate, 925 pounds; di-ammonium phosphate, 853; and mono-ammonium

TABLE 18. AVERAGE YIELDS OF SEED COTTON FROM COMPLETE FERTILIZERS WITH AND WITHOUT SULFATE

Fertilizer treatments[1]		Average yield of seed cotton per acre								Increase over 100% urea, av. of 420 expt.
Source of nitrogen	Gypsum per acre	Clarksville soil group 41 expt.	Decatur soil group 76 expt.	Holston soil group 27 expt.	Hartsells soil group 57 expt.	Cecil soil group 53 expt.	Greenville soil group 64 expt.	Norfolk soil group 102 expt.	All soil groups 420 expt.	
	Lb.	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*
100% urea	0	991	1,019	1,339	1,048	738	659	664	864	
100% urea	22.5	1,016	1,049	1,357	1,136	776	722	771	926	62
100% urea	45.0	1,037	1,055	1,379	1,157	787	753	778	941	77
100% urea	90.0	1,048	1,037	1,351	1,180	784	762	792	944	80
50% urea and 50% $(NH_4)_2SO_4$	0	1,047	1,051	1,396	1,210	812	772	801	961	97

[1] Fertilizer applied on basis of 600 pounds per acre of 6-8-6; fertilizers made from triple superphosphate, muriate of potash, nitrogen source as indicated above, and enough dolomite to make mixture nonacid-forming.

phosphate, 847. With 212 pounds of lime per acre, the average yields were: superphosphate, 993 pounds; mono-ammonium phosphate, 963; and di-ammonium phosphate, 947. Although the yields from superphosphate were highest in both cases, the addition of lime brought the yields closer together. Ammonium sulfate was used with the phosphates to bring the total nitrogen applied to 36 pounds per acre. Each plot, therefore, received a different quantity of sulfate supplement because of the varying nitrogen content of the phosphorus carriers. The di-ammonium phosphate received 62 pounds of ammonium sulfate as compared with 109 pounds for the mono-ammonium phosphate plots. Sixty-two pounds of ammonium sulfate evidently did not furnish sufficient sulfur for maximum yields, since the addition of 50 pounds of gypsum to di-ammonium phosphate increased the average yield of seed cotton 19 pounds. Di-ammonium and mono-ammonium phosphates produced 966 and 963 pounds of seed cotton, respectively, when each received about the same sulfur supplement.

RESPONSE OF COTTON TO GYPSUM. An experiment was started in 1939 to determine the response of cotton to sulfur under a wide range of conditions. This experiment was conducted from 1939 to 1943 at 420 locations involving a number of soil types. The fertilizer was applied at the rate of 600 pounds per acre of 6-8-6 made from triple superphosphate, urea, and muriate of potash. Results of this experiment are reported in Table 18. Addition of 22.5, 45, and 90 pounds per acre of gypsum to the fertilizer mixture increased cotton yields 62, 77, and 80 pounds, respectively. According to these data, ordinary superphosphate applied at 48 to 60 pounds of P_2O_5 per acre would supply more than enough sulfur for cotton.

RESPONSE OF CLOVER PASTURES TO SOURCES OF PHOSPHORUS

The development of a livestock industry in Alabama depends to a large extent on production of an adequate supply of feed. Many pastures will not produce a satisfactory quantity of good quality forage without fertilization. Since phosphorus is likely to be one of the deficient elements, use of the proper source of phosphorus is of considerable importance. A number of cooperative tests have been conducted over the State to evaluate sources of phosphorus for pasture production under a wide range of conditions. Clipping yields were obtained as a measure of the availability of the phosphates used.

TABLE 19. CLIPPING YIELDS FROM PASTURE FERTILIZER EXPERIMENTS IN NORTHERN ALABAMA, 1944

Treatment every 3 years[1]		Clipping yields per acre of green material					
Source of phosphorus, 144 pounds P_2O_5 per acre	Muriate of potash per acre	Craig farm Lauderdale County	Stafford farm Madison County	Thompson farm Limestone County	Braly farm Limestone County	Rosch farm Lauderdale County	Average of five locations
	Lb.	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*
None	0	4,376	5,105	8,481	4,918	3,959	5,368
Superphosphate	75	8,313	15,252	21,813	18,502	7,688	14,314
Colloidal phosphate[2]	75	9,190	7,439	11,626	16,063	6,438	10,151
Basic slag	75	11,563	19,876	13,375	20,938	6,943	14,539

[1] All plots except no fertilizer plots limed to pH 6.5.
[2] Received gypsum at rate of 100 pounds per acre.

TABLE 20. CLIPPING YIELDS FROM SIX PASTURE FERTILIZER EXPERIMENTS IN SOUTHEASTERN ALABAMA, 1942-44

Treatments[1] every 3 years			Clipping yields per acre of green material						
Source of phosphorus	Phosphate per acre	Muriate of potash per acre	Baxley farm, Coffee County, 2-yr. av.	Dees farm, new land, Dale County, 1 yr. result	Dees farm, old land, Dale County, 2-yr. av.	Hixon farm, Pike County, 2-yr. av.	Womack farm, Houston County, 1-yr. results	Wood farm, Henry County, 2-yr. av.	Average of 6 locations
	Lb.	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*
None	0	0	282	313	1,469	3,375	250	1,500	1,198
None	0	150	563	500	3,125	4,125	2,750	1,750	2,135
Superphosphate	900	150	4,313	7,063	8,907	12,813	7,188	11,313	8,599
Colloidal phosphate	1,620	150	2,032	4,688	3,063	6,313	5,188	719	3,667
Basic slag	2,000	150	3,282	4,625	4,969	10,094	4,375	6,344	5,615

[1] All plots except no fertilizer plots and basic slag plots received one ton of lime.

In Table 19 are given clipping yield data from pasture fertilizer experiments in northern Alabama in 1944. The averages of five locations are as follows: basic slag, 14,539 pounds per acre; superphosphate, 14,314; and colloidal phosphate, 10,151. According to field notes, most of the herbage was grass with very little clover. The phosphates were applied at the rate of 144 pounds per acre of P_2O_5, which means that the colloidal phosphate treatment would cost only about half as much as the superphosphate or basic slag.

The yield data reported in Table 20 show the response of six clover pastures in southeastern Alabama to superphosphate, colloidal phosphate, and basic slag when applied on an approximate cost basis. The average yields of six locations are 8,599, 5,615, and 3,667 pounds per acre for superphosphate, basic slag, and colloidal phosphate, respectively. The unphosphated plots averaged 2,135 pounds. Thus, 900 pounds of superphosphate was superior to 2,000 pounds of basic slag or 1,620 pounds of col-

TABLE 21. CLIPPING YIELDS SHOWING RESPONSE OF CLOVER PASTURES TO VARIOUS SOURCES OF PHOSPHORUS, FOUR LOCATIONS

Fertilizer treatments per acre[1]	Clipping yields per acre of green material				
	Gulf Coast Substation, 2-yr. av., 1944 and 1946	Moss Farm, Lamison, 5-yr. av., 1943-47	Sand Mountain Substation, 1-year results, 1941	Vail Farm, Armstrong, 1 yr., 1943	Av. of four locations
	Lb.	*Lb.*	*Lb.*	*Lb.*	*Lb.*
None	4,625		2,403	313	
LK		10,346			
LK and superphosphate	10,879	13,746	5,712	3,313	8,370
LK and Colloidal phosphate	3,976	11,211	2,816	375	4,537
K and basic slag	9,049	13,766	6,316		

[1] *Gulf Coast Substation:* L = 2,000 pounds of lime; K = 100 pounds of muriate of potash; superphosphate = 600 pounds; colloidal phosphate = 1,200 pounds; and basic slag = 2,400 pounds. Phosphorus and potash applied annually.

Moss Farm: L = 4,000 pounds of lime; K = 150 pounds of muriate of potash; superphosphate = 900 pounds; colloidal phosphate = 1,620 pounds; and basic slag = 2,000 pounds. Phoshorus and potash repeated every 3 years.

Sand Mountain Substation: L = 4,000 pounds of Lime; K = 75 pounds of muriate of potash; superphosphate = 600 pounds; colloidal phosphate = 516 pounds; and basic slag = 2,000 pounds. Phosphorus and potash applied every 3 years.

Vail Farm: L = 4,000 pounds of lime; K = 150 pounds of muriate of potash; superphosphate = 900 pounds; and colloidal phosphate = 1,620 pounds. Phosphorus and potash applied every 3 years.

TABLE 22. CLIPPING YIELDS SHOWING RESPONSE OF CLOVER PASTURES TO VARIOUS SOURCES OF PHOSPHORUS AND TO RATES OF COLLOIDAL PHOSPHATE, FOUR LOCATIONS

Fertilizer treatment per acre[1]	Clipping yields per acre of green material				
	Gulf Coast Sub-station, 2-yr. av., 1946-47	McCreary Farm, Brewton, 2-yr. av., 1946-47	Upper Coastal Plain Sub-station, 2-yr. av., 1946 and 1948	Piedmont Sub-station, 1 yr., 1947	Av. of four loca-tions
	Lb.	*Lb.*	*Lb.*	*Lb.*	*Lb.*
None			1,776	2,097	
LK and superphosphate	9,890	8,265	12,607	6,757	9,380
LK and colloidal phosphate	3,587	3,185	6,109	1,631	3,628
LK and double rate colloidal phosphate	2,603	5,067	7,271		
K and basic slag	6,886	8,432	9,561	7,223	8,025

[1] *Gulf Coast Substation and McCreary Farm:* L = 2,000 pounds of lime; K = 150 pounds of muriate of potash annually; superphosphate = 600 pounds; colloidal phosphate = 1,000 pounds; double rate of colloidal phosphate = 2,000 pounds; and basic slag = 1,000 pounds. Phosphorus applied every 2 years.

Upper Coastal Plain Substation: L = 3,000 pounds of lime; K = 100 pounds of muriate of potash; superphosphate = 800 pounds; colloidal phosphate = 1,500 pounds; double rate of colloidal phosphate = 3,000 pounds; and basic slag = 1,500 pounds. Phosphorus and potash applied every 2 years.

Piedmont Substation: L = 2,000 pounds of lime; K= 100 pounds of muriate of potash; superphosphate = 800 pounds; colloidal phosphate = 1,500 pounds; and basic slag = 1,500 pounds. Phosphorus and potash applied every 2 years.

loidal phosphate. The basic slag plots did not receive lime in these experiments, and the low yield from basic slag may have been due to inadequate lime.

In Table 21 are given the results from four other locations in the State, showing response of clover pastures to sources of phosphorus. Superphosphate produced an average 8,370 pounds of green material as compared with 4,537 pounds from colloidal phosphate. The two phosphates were applied on an approximately equal cost basis except at the Sand Mountain Substation. There was not much difference between the yields from superphosphate and colloidal phosphate on the Moss farm. This is to be expected, since the plot getting no phosphate yielded rather high. At the three locations where basic slag was used, it produced 9,710 pounds of herbage as compared with 10,112 from superphosphate.

The clipping yields in Table 22 show the response of clover pastures to three sources of phosphorus and to two rates of colloidal phosphate. The averages of four locations show clipping yields of 9,380, 8,025, and 3,628 pounds for superphosphate, basic slag, and colloidal phosphate, respectively, when applied on an approximately equal cost basis. At three locations a double rate of colloidal phosphate also was tested. The average yields for these locations are 10,321, 4,294, and 4,980 pounds per acre for superphosphate, single rate of colloidal phosphate, and double rate of colloidal phosphate, respectively. A rate of colloidal phosphate equivalent to twice the cost of superphosphate produced only half as much herbage as superphosphate.

In the fall of 1947, two tests were established on lime land at the Black Belt Substation. One was designed to test the value of several sources of phosphorus and the other was designed to test the residual value of some phosphates. The two experiments were located within a few hundred feet of each other. The results of these tests are presented in Tables 23 and 24. Using 80 pounds of P_2O_5, the relative increases in yield from the phosphates listed in Table 23 are: superphosphate, 100; basic slag, 103; triple superphosphate, 94; calcium metaphosphate, 85; colloidal phosphate, 8; and rock phosphate, 1. Doubling the rate of colloidal phosphate had no appreciable effect on yields. The yield data reported in Table 24 show that 144 pounds of P_2O_5 from superphosphate increased the yield of herbage 8,185 pounds but that colloidal phosphate applications ranging from 288 to 1,152 pounds of P_2O_5 per acre had little or no effect on yields. The increased yield from 576 pounds of P_2O_5 applied as rock

TABLE 23. RESPONSE OF CLOVER TO VARIOUS SOURCES OF PHOSPHORUS ON LIME LAND, BLACK BELT SUBSTATION

Fertilizer treatment[1]		Green weight per acre, 1948	Increased yield due to phosphorus	Relative efficiency (superphosphate = 100)
Source of phosphorus	P_2O_5 applied per acre			
	Lb.	*Lb.*	*Lb.*	
None	0	480	--	--
Superphosphate	80	9,510	9,030	100
Triple superphosphate	80	8,935	8,455	94
Calcium metaphosphate	80	8,135	7,655	85
Basic slag	80	9,805	9,325	103
Rock phosphate	80	585	105	1
Colloidal phosphate	80	1,175	695	8
Colloidal phosphate	160	300	—180	—2

[1] All plots received 60 pounds of K_2O from muriate of potash.

TABLE 24. RESPONSE OF CLOVER TO HIGH RATES OF COLLOIDAL AND ROCK PHOSPHATES ON LIME LAND, BLACK BELT SUBSTATION

Fertilizer treatment[1]		Green weight per acre, 1948	Increased yield due to phosphorus	Relative efficiency (superphosphate = 100)
Source of phosphorus	P_2O_5 applied per acre			
	Lb.	*Lb.*	*Lb.*	
None	0	1,595	--	--
Superphosphate	144	9,780	8,185	100
Colloidal phosphate	288	2,865	1,270	16
Colloidal phosphate	576	1,730	135	2
Colloidal phosphate	1,152	2,260	665	8
Rock phosphate	576	2,345	750	9

[1] All plots to receive 90 pounds of K_2O from muriate of potash every 2 years.

phosphate was slight. One year's results on lime land show that colloidal and rock phosphates are inferior to the processed phosphates for the growth of clover pastures.

DISCUSSION

Results of studies presented herein show that different phosphates vary as to their efficiency for crop production. Relative values of these materials vary somewhat depending upon soil conditions and the crop grown. Some of the raw phosphates, such as rock and colloidal, were not satisfactory sources of phosphorus for the crops studied, but were relatively more efficient for cotton than they were for pastures.

Certain soil conditions may affect the response obtained from phosphates. The more insoluble phosphates are usually better sources of phosphorus for acid soils than for alkaline soils. Ammonium phosphates give relatively better response when applied to soils containing considerable calcium than when applied to light sandy soils low in calcium. This was especially evident in the experiments of long duration. The lack of sulfur may be another reason for the low response obtained from ammonium phosphates.

Since a number of variables affect the efficiency of phosphates, it is impossible to give ratings that will apply under all conditions. However, certain phosphates give consistently high response, while others are consistently low. For example, results of these studies show that the superphosphate plots always ranked at the top or near the top in yields. It appears that superphosphate would be a satisfactory source of phosphorus under a wide range of conditions.

From a practical standpoint, the best source of phosphorous for the farmer to use is the one that gives the greatest returns over cost of material. A cheap source of phosphorus may be 80 per cent as efficient for cotton as another and yet give a lower return over cost of material. At present the cost of an average application of superphosphate (48 pounds P_2O_5) would be about $1.60 more than the cheapest source of phosphorus. It is evident, therefore, that the efficiency of the cheap source must be very near that of superphosphate to be considered a satisfactory source of phosphorus.

It is often suggested that the cheaper insoluble phosphates may have a greater cumulative effect or residual value than processed phosphates. Results from experiments of long duration do not indicate any appreciable cumulative effect.

The data reported herein are in agreement with those obtained by other experiment stations. Salter and Barnes *(8)* working with Ohio soils found that, for both grain crops and clover on unlimed land, rock phosphate was 40 per cent as efficient as superphosphate. Under the same conditions basic slag showed an efficiency of 85 per cent for cereals and 140 per cent for clover. Efficiency of rock phosphate and basic slag decreased with liming. Noll and Irvin *(7)* studied the response of a number of crops to sources of phosphorus when grown on a Hagerstown silt loam in Pennsylvania. They found that on unlimed land with manure, basic slag and superphosphate yielded nearly alike and exceeded the yields from rock phosphate applied at twice the equivalent rate of P_2O_5. On limed land, rock phosphate gave lower yields than superphosphate when applied at two and three times the equivalent rate of P_2O_5. Indiana *(12)* results show that 715 pounds of superphosphate and 1,000 pounds of rock phosphate ($5.00 worth in each case) produced average annual crop increases of $5.19 for superphosphate and $2.80 for rock phosphate when each was used alone. When nitrogen and potash were applied, the increase was $8.11 for superphosphate and $3.61 for rock phosphate.

Results reported by Bauer *et al (2)* of the Illinois Station show that on limed land at five locations superphosphate produced greater increases in yield on the average than rock phosphate. On unlimed land at the same location, rock phosphate was more effective than superphosphate. In 1929, the Carthage and Lebanon fields were modified for the purpose of comparing superphosphate and rock phosphate. Rock phosphate was applied at the rate of 400 pounds in the drill with wheat, and 125 pounds was hill-dropped with corn. Superphosphate was applied at the rate of 200 pounds to wheat and 125 pounds to corn. The data at these two locations show that superphosphate produced larger increases at first but that the results have been somewhat similar in recent years.

SUMMARY

A number of studies have been conducted over a period of years by the Alabama Agricultural Experiment Station to test the relative value of different sources of phosphorus. The data obtained from these studies are reported in this publication. The relative yield values for the various phosphates given below are based on the increased yield from superphosphate as 100.

Results of the experiments of long duration may be summarized as follows:

1. Triple superphosphate showed relative yield increases of 91, 102, and 89 for cotton, corn, and winter legumes, respectively.

2. Using equivalent quantities of P_2O_5 (48 pounds) basic slag showed the following efficiencies: cotton, 85; corn, 114; and winter legumes, 94.

3. Relative values of yields from rock phosphate (48 pounds P_2O_5) on cotton, corn, and winter legumes were 54, 67, and 51, respectively. When used at double the P_2O_5 rate of superphosphate, the relative yield values of rock phosphate on cotton, corn, and legumes were 57, 43, and 61, respectively. Use of four times as much phosphorus from rock phosphate as from superphosphate did not increase the yields of cotton and corn as much as superphosphate.

4. The relative yield values of colloidal phosphate ranged from 47 for legumes to 65 for corn.

5. The relative yield values of tricalcium phosphate, which were similar to those of basic slag, were 87 for cotton, 109 for corn, and 89 for legumes.

6. Ammo-phos A was not a satisfactory material for cotton, corn, or winter legumes. On sandy soils it reduced the yield of cotton below check yields after several years of continued application. The relative efficiencies of Ammo-phos A were 26, 57, and 73 for cotton, corn, and legumes, respectively.

The following is a summary of the results of experiments of short duration:

1. Fertilizer experiments conducted at 50 locations show the following increases in yield of peanuts: superphosphate, 182 pounds per acre; basic slag, 153; and colloidal phosphate, 96.

2. Results of experiments conducted at eight locations show that superphosphate, rock phosphate, and basic slag increased the yield of seed cotton 138, 116, and 84 pounds per acre, respectively. Superphosphate and basic slag were applied at the rate of 240 pounds per acre, while rock phosphate was aplied at the rate of 480 pounds.

3. An average of 222 experiments shows that where ammonium sulfate was used as the source of nitrogen, 914 pounds of seed cotton was obtained from superphosphate, while the same amount of P_2O_5 from slag yielded 852 pounds. Where sodium nitrate was used as the source of nitrogen, 930 pounds was obtained from superphosphate and 859 pounds from slag.

4. Fused tricalcium phosphate of 40-mesh fineness or less and of less than 0.4 per cent fluorine content produced relative yield increases of 84, 72, 40, and 34 for vetch, oats, sorghum, and sudan grass, respectively. In another series of tests using triple superphosphate as the standard, fused tricalcium phosphate produced practically the same yields of cotton, corn, oats, winter legumes, and sudan grass as triple superphosphate.

5. Calcium and potassium metaphosphates were as effective as the superphosphate and triple superphosphate in increasing yields of most of the crops tested.

6. Results of 358 tests in which ammonium sulfate was used as the source of nitrogen show the following relative yield values of seed cotton, with that of superphosphate representing 100: triple superphosphate, 92; di-calcium phosphate, 99; and tricalcium phosphate, 81. The use of enough dolomite to correct acidity from ammonium sulfate gave relative yields of 119 for superphosphate and 109 for triple superphosphate. The addition of gypsum to triple superphosphate increased the yield of seed cotton 53 pounds.

7. Mono-ammonium and di-ammonium phosphates were about as satisfactory sources of phosphorus for cotton as superphosphate when used with dolomite. The use of gypsum and dolomite with di-ammonium phosphate increased the yield of seed cotton 19 pounds over dolomite alone.

8. Many Alabama soils responded to sulfur. An average of 420 experiments shows that 22.5, 45, and 90 pounds per acre of gypsum increased the yield of seed cotton 62, 77, and 80 pounds per acre respectively. Therefore, the response of certain crops to superphosphate may be due partially to the sulfate supplied by the phosphate.

The results from pasture experiments dealing with the value of various sources of phosphorus are briefly summarized:

1. Clipping yields from eight experiments on acid land show that colloidal phosphate produced less than half as much herbage as superphosphate when the two phosphates were applied on an equivalent cost basis.

2. In three experiments on acid land, colloidal phosphate applied at double the cost of superphosphate produced only 15 per cent as much herbage as superphosphate.

3. One year's results on lime land of the Black Belt showed that colloidal and rock phosphates produced little more herbage than the plots getting no phosphate. The plots receiving superphosphate produced a satisfactory growth of clover.

4. On acid land basic slag produced 88 per cent as much herbage as superphosphate. The slag plots were not limed; this may account for the lower response of slag in some cases.

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