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The Comparative Values of Different Phosphates

University of Tennessee Agricultural Experiment Station

C. A. Mooers

THE UNIVERSITY OF TENNESSEE
AGRICULTURAL EXPERIMENT STATION
Knoxville

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Director and Agronomist

The experimental range

Corn was grown on the outer quarters and potatoes on the middle quarters, so that the two crops were grown on both limed and unlimed land

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INTRODUCTION

The question of the comparative values of different phosphates is of great practical importance in Tennessee because of the soil deficiency of phosphoric acid over large areas in all three grand divisions of the State. As might be expected, soils derived from different geologic formations differ in their need of phosphoric acid, and consequently in their response to phosphatic fertilizers. Two large areas in the State, one in the Central Basin and the other in western West Tennessee, give little or no response to phosphatic fertilizers. Other large areas, such as the Cumberland Plateau, the "Barrens" of the Highland Rim, and certain formations in East Tennessee, are characterized by soils greatly in need of phosphate. In these areas phosphate must be supplied in order to make farming profitable. Between the two extremes are all gradations.

The experiments reported in this bulletin were conducted for 10 years (1919-1928) near Crossville, in Cumberland County. The soil was a mellow, friable loam of the DeKalb series, and was derived from the decomposition of the sandstone rock which is characteristic of the Cumberland Plateau. The land had been cleared of forest growth only two years, and the soil was well supplied with organic matter, but decidedly deficient in both lime and phosphoric acid. The lay of the land was excellent, but there was some variation in the fertility of the plots, due largely to irregularities arising from the operation of clearing the land. The extent of these irregularities is well depicted in the yields obtained from the various check, or unphosphated, plots. In the comparison of the effects of the different phosphates, therefore, no great stress should be laid on the yields from any one plot, but the writer considers that the averages as reported for any series give reliable information.

EXPERIMENTAL

The plots used in this series were 1/20-acre each. One half of each plot was limed at the outset of the experiments with ground limestone at the rate of 2 tons per acre, and the crops from the limed and unlimed halves were harvested and weighed separately. The diagram shows the experimental range with the various plot treatments.

500 Slag	1
1713 R.P.	2
500 A.P.	3
0	4
400 Slag	5
224 T.C.	6
0	7
1371 R.P.	8
400 A.P.	9
0	10
300 Slag	11
168 T.C.	12
0	13
1028 R.P.	14
300 A.P.	15
0	16
200 Slag	17
	18
0	19
685 R.P.	20
200 A.P.	21
0	22
100 Slag	23
	24
0	25
343 R.P.	26
100 A.P.	27

Plot scheme

A systematic 3-year rotation of corn and potatoes, spring oats, and clover and grass was followed throughout the period. Corn and potatoes were grown the same year, the range being divided into two outer and two inner sections, or quarters. Corn was always grown on the two outer quarters and potatoes on the two inner, so that both crops were grown on limed as well as unlimed areas. The varieties used were such as are well adapted to the Plateau—Piedmont White Dent corn, Green Mountain potatoes, Rust-Proof oats, and for hay a mixture of red top, Timothy, and red clover, sown with the oats. In practically all instances excellent stands were obtained.

The yields reported are on the acre basis and are of marketable products, in a thoroughly cured condition. The weights of the corn, oats, and hay were obtained in the field and later corrected to an air-dry basis from the changes in weights of sub-samples that were dried out under cover. The potato yields, however, are of the total crop. A separation into the larger, or salable, portion and the smaller, or unsalable, would undoubtedly have given results even more favorable to the use of phosphate.

The Phosphates Used and their Analyses

The acid phosphate was the usual high-grade material, analyzing nearly 18 per cent of total phosphoric acid and 16 per cent of "available," as determined by the official method. The Duplex basic phosphate was a Thomas slag meal produced by the Tennessee Coal, Iron and Railway Company, of Birmingham, Alabama. It analyzed nearly 18 per cent of total phosphoric acid and 16 per cent "available," as determined by the Wagner method. The T. C. Co. phosphate was an experimental product manufactured by the Tennessee Chemical Company, of Nashville, and is not commercially available. It was a basic phosphate, analyzing nearly 24 per cent of total phosphoric acid. The rock phosphate was a good grade of Tennessee brown rock, analyzing 31.5 per cent of total phos-

TABLE 1—*Average yields per acre obtained from different phosphates in the 10-year period, 1919-1928, on DeKalb loam*

Kind of phosphate and annual rate of application*	Plot No.	Corn 4 crops				Potatoes 3 crops		Oats 3 crops				Clover & Grass 4 crops	
		Unlimed		Limed		Unlimed	Limed	Unlimed		Limed		Unlimed	Limed
		Grain	Stover	Grain	Stover			Grain	Straw	Grain	Straw	Hay	Hay
		Bu.	Tons	Bu.	Tons	Bu.	Bu.	Bu.	Tons	Bu.	Tons	Tons	Tons
Duplex basic phosphate 500 lbs.	1	47.9	1.25	50.0	1.30	98.7	90.2	25.2	.37	38.3	.41	1.52	1.32
Do 400 lbs.	5	40.3	1.03	50.9	1.27	102.2	105.4	28.5	.40	43.8	.48	1.38	1.87
Do 300 lbs.	11	38.6	.95	55.7	1.40	87.7	100.2	29.1	.41	46.9	.50	1.14	1.64
Do 200 lbs.	17	34.6	.93	52.3	1.18	72.8	84.6	24.0	.33	35.1	.37	.73	1.35
Do 100 lbs.	23	36.9	.87	44.9	1.09	69.2	65.6	22.1	.30	26.8	.35	.70	1.08
Average		39.7	1.01	50.8	1.25	86.1	89.2	25.8	.36	38.2	.42	1.09	1.45
Rock phosphate 1710 lbs.	2	29.6	.81	46.4	1.20	85.6	95.5	21.2	.27	29.7	.33	.77	1.32
Do 1370 lbs.	8	36.0	.96	45.9	1.09	104.7	98.5	26.8	.36	27.4	.37	1.14	1.30
Do 1030 lbs.	14	31.4	.88	54.3	1.38	87.1	80.3	25.7	.33	30.7	.36	.66	1.32
Do 690 lbs.	20	40.9	.99	49.7	1.22	80.7	61.1	23.5	.31	20.4	.30	1.00	.94
Do 340 lbs.	26	45.1	1.06	37.7	.95	72.2	57.6	24.0	.33	17.6	.25	.80	.69
Average		36.6	.94	46.8	1.17	86.0	78.6	24.2	.32	25.2	.32	.87	1.11
Acid phosphate 500 lbs.	3	28.6	.73	51.7	1.39	95.7	114.9	24.6	.29	40.3	.46	.94	1.71
Do 400 lbs.	9	37.5	.98	47.7	1.20	99.8	98.8	34.0	.40	42.2	.46	1.42	1.81
Do 300 lbs.	15	28.9	.80	52.3	1.06	97.4	98.5	30.7	.37	39.8	.41	.90	1.51
Do 200 lbs.	21	36.6	.96	54.6	1.28	78.7	84.0	23.4	.28	29.4	.37	.68	1.42
Do 100 lbs.	27	32.6	.82	38.6	.91	78.3	60.2	21.1	.25	21.5	.26	.56	.84
Average		32.8	.86	49.0	1.17	90.0	91.3	26.8	.32	34.6	.39	.90	1.46
T. C. Co. phosphate 225 lbs.	6	40.3	.99	52.0	1.34	95.6	103.1	29.1	.37	29.3	.39	1.37	1.65
Do 168 lbs.	12	42.0	.99	50.0	1.22	80.3	76.1	31.4	.41	31.2	.39	1.20	1.63
Average		41.2	.99	51.0	1.28	88.0	89.6	30.3	.39	30.3	.39	1.29	1.64
None	4	20.6	.59	32.6	.93	56.4	67.1	10.8	.22	24.4	.35	.43	.77
Do	7	29.4	.70	26.9	.80	54.5	60.2	13.7	.29	21.2	.33	.54	.84
Do	10	11.1	.41	35.4	.93	62.5	66.8	14.5	.30	25.2	.40	.42	.99
Do	13	30.3	.79	34.3	.96	57.0	60.0	15.2	.31	15.6	.35	.55	.81
Do	16	26.3	.68	34.3	.77	55.7	61.5	14.2	.35	22.9	.36	.56	.71
Do	19	12.3	.38	37.2	.93	28.7	45.1	7.5	.14	20.0	.32	.25	.56
Do	22	18.3	.57	33.8	.86	41.6	58.1	9.3	.20	21.8	.35	.25	.77
Do	25	28.6	.72	29.3	.75	36.3	43.5	10.9	.25	17.7	.30	.31	.50
Average		22.1	.61	33.0	.87	49.1	57.8	12.0	.26	21.1	.35	.41	.74

*Fifty pounds of muriate of potash per acre applied annually to all plots.

phoric acid. It was ground to the usual degree of fineness for agricultural use. Almost all of it would pass through a 100-mesh sieve. For the purpose of comparison the acid phosphate and the Duplex basic phosphate may be valued at $1.00 per cwt., the rock phosphate at 50 cents, and the T. C. Co. phosphate at $1.33.

Fertilizer Treatments

An annual application of 50 pounds per acre of muriate of potash was made to all plots. All the phosphates were applied annually except the rock phosphate, which was applied once in 3 years; that is, three times the annual rate specified in table 3 was applied every third year, beginning in 1919. All materials were applied broadcast and well worked into the soil for the broadcast-sown crops. For crops planted in rows the applications of all materials except the rock phosphate were made in the row at all rates up to and including 300 pounds per acre. Where heavier applications were called for, 300 pounds per acre were applied in the row and the balance was applied broadcast.

TABLE 2—*Average yields per acre for the* 10-*year period summarized with reference to rate of application of phosphate—limed and unlimed results from acid phosphate and Duplex basic phosphate averaged*

Annual acre application of phosphate	Corn		Potatoes	Oats		Clover and Grass Hay
	Grain	Stover		Grain	Straw	
Lbs.	Bu.	Tons	Bu.	Bu.	Tons	Tons
500	44.6	1.17	99.9	32.1	.36	1.38
400	44.1	1.13	101.6	37.2	.44	1.62
300	43.9	1.06	96.0	36.7	.43	1.30
200	44.6	1.09	80.1	28.8	.34	1.05
100	38.3	.93	68.4	22.9	.30	.80
None	27.6	.74	53.5	16.6	.31	.58

Discussion of the Experimental Results

The comparative efficiency of the different phosphates.—Table 3 gives in detail the annual acre yields of all crops by the individual plots. Table 1 summarizes the yields for the 10-year period with special reference to the kind of phosphate. It is evident at once that liming not only increased the yield of most of the crops but also materially changed the standing of the different phosphates. Another factor affecting their standing is the kind of crop. The relative standing of different phosphates in their effects on corn, for example, may be quite different from their standing when used on potatoes. The kind of crop, therefore, may well serve as a basis of discussion.

TABLE 3—*Yields per acre in the 10-year period, 1919-1928, in a comparison of the fertilizer values of various phosphates**

Kind of phosphate and annual rate of application	Plot No.	Yr. of harvest	Corn				Potatoes		Yr. of harvest	Oats				Yr. of harvest	Clover & Grass	
			Unlimed		Limed		Unlimed	Limed		Unlimed		Limed			Unlimed	Limed
			Grain	Stover	Grain	Stover				Grain	Straw	Grain	Straw		Hay	Hay
			Bu.	Tons	Bu.	Tons	Bu.	Bu.		Bu.	Tons	Bu.	Tons		Tons	Tons
Duplex basic phos. 500 lbs.	1	1919	40.6	.81	42.3	.84			1920	31.5	.46	53.3	.57	1921	1.72	1.02
Do		1922	68.6	1.60	60.6	1.52	153.3	114.6	1923	15.5	.23	25.7	.28	1923	1.48	1.02
Do		1925	27.4	1.00	30.9	1.12	33.3	44.0	1926	28.7	.42	35.9	.39	1924	.92	.92
Do		1928	54.9	1.60	66.3	1.72	109.6	112.0						1927	1.95	2.33
Average			47.9	1.25	50.0	1.30	98.7	90.2		25.2	.37	38.3	.41		1.52	1.32
Rock phosphate 1713 lbs.	2	1919	23.4	.54	36.6	.80			1920	32.8	.40	45.3	.50	1921	.44	1.44
Do		1922	34.4	.80	57.7	1.40	102.6	125.3	1923	11.0	.15	15.3	.17	1923	.50	.88
Do		1925	21.7	.76	27.4	1.16	45.3	38.7	1926	19.8	.27	28.6	.32	1924	.51	.70
Do		1928	38.9	1.12	64.0	1.44	109.0	122.6						1927	1.64	2.27
Average			29.6	.81	46.4	1.20	85.6	95.5		21.2	.27	29.7	.33		.77	1.32
Acid phosphate 500 lbs.	3	1919	40.0	.56	37.7	.84			1920	36.3	.42	57.5	.66	1921	.88	2.12
Do		1922	41.1	1.00	68.6	1.68	101.3	166.6	1923	13.2	.15	27.5	.32	1923	.56	1.14
Do		1925	13.7	.56	34.3	1.20	57.3	50.7	1926	24.4	.30	35.9	.39	1924	.75	1.02
Do		1928	19.4	.80	66.3	1.84	128.5	127.3						1927	1.57	2.54
Average			28.6	.73	51.7	1.39	95.7	114.9		24.6	.29	40.3	.46		.94	1.71
None	4	1919	29.7	.56	23.0	.40			1920	18.4	.37	42.9	.62	1921	.50	1.18
Do		1922	28.6	.60	53.7	1.36	82.6	108.0	1923	6.4	.13	15.4	.22	1923	.30	.70
Do		1925	12.7	.60	16.0	.76	26.7	32.0	1926	7.7	.15	14.8	.21	1924	.36	.35
Do		1928	11.4	.60	37.7	1.20	60.0	61.2						1927	.57	.83
Average			20.6	.59	32.6	.93	56.4	67.1		10.8	.22	24.4	.35		.43	.77
Duplex basic phos. 400 lbs.	5	1919	45.7	1.00	52.6	1.08			1920	40.0	.54	63.6	.68	1921	1.06	2.68
Do		1922	51.4	1.00	51.7	1.20	152.0	153.3	1923	19.0	.26	30.0	.32	1923	1.46	1.34
Do		1925	17.1	.80	33.1	1.20	57.3	58.7	1926	26.5	.39	37.7	.43	1924	1.10	1.11
Do		1928	46.9	1.32	66.3	1.60	97.2	104.3						1927	1.89	2.35
Average			40.3	1.03	50.9	1.27	102.2	105.4		28.5	.40	43.8	.48		1.38	1.87

*Fifty pounds of muriate of potash per acre applied annually to all plots.

TABLE 3—*Continued*

Kind of phosphate and annual rate of application	Plot No.	Yr. of harvest	Corn				Potatoes		Yr. of harvest	Oats				Yr. of harvest	Clover & Grass	
			Unlimed		Limed		Unlimed	Limed		Unlimed		Limed			Unlimed	Limed
			Grain	Stover	Grain	Stover				Grain	Straw	Grain	Straw		Hay	Hay
			Bu.	Tons	Bu.	Tons	Bu.	Bu.		Bu.	Tons	Bu.	Tons		Tons	Tons
T. C. Co. basic phos. 224 lbs.	6	1919	42.3	.96	46.8	1.00			1920	40.1	.48	44.4	.59	1921	1.50	2.46
Do		1922	45.7	.80	64.0	1.44	142.6	161.3	1923	18.7	.25	18.8	.25	1923	1.14	1.06
Do		1925	30.9	.92	37.7	1.16	50.7	48.0	1926	28.6	.38	24.8	.33	1924	1.02	1.04
Do		1928	42.3	1.28	59.4	1.76	93.6	99.9						1927	1.82	2.05
Average			40.3	.99	52.0	1.34	95.6	103.1		29.1	.37	29.3	.39		1.37	1.65
None	7	1919	32.0	.56	23.0	.40			1920	21.6	.45	34.7	.54	1921	.70	1.40
Do		1922	44.6	.72	34.4	.96	88.0	92.0	1923	9.4	.20	13.7	.21	1923	.44	.60
Do		1925	13.7	.60	18.3	.84	34.7	33.3	1926	10.2	.22	15.2	.25	1924	.28	.29
Do		1928	27.4	.92	32.0	1.00	40.7	55.2						1927	.74	1.07
Average			29.4	.70	26.9	.80	54.5	60.2		13.7	.29	21.2	.33		.54	.84
Rock phosphate 1371 lbs.	8	1919	44.6	.88	31.4	.80			1920	36.0	.48	44.8	.52	1921	1.24	1.64
Do		1922	45.7	1.40	61.7	1.12	157.3	144.0	1923	18.3	.25	20.4	.24	1923	.84	1.12
Do		1925	17.1	.64	34.3	1.20	56.0	56.0	1926	26.1	.34	25.3	.35	1924	.86	.81
Do		1928	36.6	.92	56.0	1.24	100.7	95.5						1927	1.63	1.64
Average			36.0	.96	45.9	1.09	104.7	98.5		26.8	.36	30.2	.37		1.14	1.30
Acid phosphate 400 lbs.	9	1919	44.6	.96	41.1	.88			1920	42.9	.50	57.5	.64	1921	1.96	2.66
Do		1922	51.3	1.20	54.8	1.44	136.0	148.0	1923	21.2	.25	31.9	.36	1923	1.06	1.50
Do		1925	24.0	.84	38.9	1.12	60.0	52.0	1926	37.8	.45	37.1	.39	1924	1.02	1.15
Do		1928	25.1	.92	56.0	1.36	103.4	96.4						1927	1.65	1.91
Average			37.5	.98	47.7	1.20	99.8	98.8		34.0	.40	42.2	.46		1.42	1.81
None	10	1919	14.9	.32	27.4	.56			1920	22.4	.46	35.7	.56	1921	.46	1.68
Do		1922	22.8	.48	50.3	1.00	99.0	113.3	1923	12.0	.25	18.6	.29	1923	.34	.86
Do		1925	5.7	.40	25.1	.88	29.3	34.7	1926	9.0	.20	21.3	.35	1924	.30	.43
Do		1928	1.1	.44	38.9	1.28	59.2	52.5						1927	.56	.98
Average			11.1	.41	35.4	.93	62.5	66.8		14.5	.30	25.2	.40		.42	.99

TABLE 3—*Continued*

Kind of phosphate and annual rate of application	Plot No.	Yr. of harvest	Corn				Potatoes		Yr. of harvest	Oats				Yr. of harvest	Clover & Grass	
			Unlimed		Limed					Unlimed		Limed			Unlimed	Limed
			Grain	Stover	Grain	Stover	Unlimed	Limed		Grain	Straw	Grain	Straw		Hay	Hay
			Bu.	Tons	Bu.	Tons	Bu.	Bu.		Bu.	Tons	Bu.	Tons		Tons	Tons
Duplex basic phos. 300 lbs.	11	1919	36.6	.72	51.4	1.12			1920	41.5	.58	69.0	.71	1921	1.24	2.18
Do		1922	51.4	1.20	75.4	1.68	144.0	174.6	1923	19.0	.27	28.2	.29	1923	.96	1.18
Do		1925	29.7	.84	37.7	1.24	37.3	48.0	1926	26.9	.39	43.6	.49	1924	.84	1.27
Do		1928	36.6	1.04	58.3	1.56	81.8	78.2						1927	1.53	1.91
Average			38.6	.95	55.7	1.40	87.7	100.2		29.1	.41	46.9	.50		1.14	1.64
T. C. Co. basic phos. 168 lbs.	12	1919	50.3	1.04	52.6	1.04			1920	45.1	.59	47.5	.61	1921	1.56	2.62
Do		1922	45.7	1.04	52.6	1.20	129.3	125.3	1923	19.3	.25	20.5	.27	1923	.94	1.04
Do		1925	30.9	.84	43.4	1.36	37.3	37.3	1926	29.9	.40	25.7	.28	1924	.84	1.16
Do		1928	41.1	1.04	51.4	1.28	74.2	65.8						1927	1.44	1.68
Average			42.0	.99	50.0	1.22	80.3	76.1		31.4	.41	31.2	.39		1.20	1.63
None	13	1919	36.6	.80	32.0	.88			1920	24.4	.49	30.9	.57	1921	.98	1.52
Do		1922	37.7	.72	40.0	.80	110.6	105.3	1923	9.0	.18	10.9	.20	1923	.34	.50
Do		1925	21.7	.68	24.0	.80	22.7	18.6	1926	12.1	.25	15.0	.28	1924	.34	.37
Do		1928	25.1	.96	41.1	1.36	37.7	56.0						1927	.52	.83
Average			30.3	.79	34.3	.96	57.0	60.0		15.2	.31	15.6	.35		.55	.81
Rock phosphate 1028 lbs.	14	1919	36.6	.80	50.3	.96			1920	37.1	.50	36.3	.47	1921	.62	2.04
Do		1922	45.7	1.20	57.1	1.40	125.3	122.6	1923	16.9	.23	19.5	.25	1923	.46	.78
Do		1925	21.7	.72	45.7	1.24	42.7	32.0	1926	23.0	.27	26.3	.36	1924	.49	.79
Do		1928	21.7	.80	64.0	1.84	93.4	86.3						1927	1.07	1.68
Average			31.4	.88	54.3	1.38	87.1	80.3		25.7	.33	27.4	.36		.66	1.32
Acid phosphate 300 lbs.	15	1919	36.6	.72	43.4	.84			1920	44.0	.53	57.6	.58	1921	1.02	1.88
Do		1922	37.7	.88	62.8	.84	148.0	161.3	1923	20.1	.24	27.0	.27	1923	.60	1.18
Do		1925	25.1	.88	44.6	1.20	49.3	38.7	1926	28.1	.33	34.7	.37	1924	.79	1.25
Do		1928	16.0	.72	58.3	1.36	94.9	95.4						1927	1.18	1.74
Average			28.9	.80	52.3	1.06	97.4	98.5		30.7	.37	39.8	.41		.90	1.51

TABLE 3—*Continued*

Kind of phosphate and annual rate of application	Plot No.	Yr. of harvest	Corn				Potatoes		Yr. of harvest	Oats				Yr. of harvest	Clover & Grass	
			Unlimed		Limed					Unlimed		Limed			Unlimed	Limed
			Grain	Stover	Grain	Stover	Unlimed	Limed		Grain	Straw	Grain	Straw		Hay	Hay
			Bu.	Tons	Bu.	Tons	Bu.	Bu.		Bu.	Tons	Bu.	Tons		Tons	Tons
None	16	1919	38.9	.80	29.7	.48			1920	24.8	.59	37.8	.59	1921	.98	1.18
Do		1922	34.4	.64	51.4	.80	101.3	113.0	1923	10.1	.24	15.8	.25	1923	.34	.58
Do		1925	16.0	.60	21.7	.76	26.7	24.0	1926	7.8	.22	15.1	.24	1924	.42	.33
Do		1928	16.0	.68	34.3	1.04	39.2	47.5						1927	.51	.73
Average			26.3	.68	34.3	.77	55.7	61.5		14.2	.35	22.9	.36		.56	.71
Duplex basic phos. 200 lbs.	17	1919	32.0	.80	45.7	.88			1920	35.4	.48	49.8	.52	1921	.56	1.90
Do		1922	42.3	1.00	62.8	1.40	108.0	146.6	1923	14.6	.20	21.3	.22	1923	.50	.92
Do		1925	28.6	1.00	42.3	1.08	36.0	29.3	1926	21.9	.30	34.1	.36	1924	.60	.90
Do		1928	35.4	.92	58.3	1.36	74.3	78.0						1927	1.25	1.67
Average			34.6	.93	52.3	1.18	72.8	84.6		24.0	.33	35.1	.37		.73	1.35
None	19	1919	19.4	.40	32.0	.60			1920	13.9	.24	35.4	.57	1921	.36	.78
Do		1922	21.7	.40	57.1	1.28	54.6	86.6	1923	4.8	.08	10.5	.17	1923	.12	.40
Do		1925	5.7	.28	22.9	.76	10.7	12.0	1926	3.9	.09	14.0	.22	1924	.21	.30
Do		1928	2.3	.44	36.6	1.08	20.9	36.8						1927	.29	.77
Average			12.3	.38	37.2	.93	28.7	45.1		7.5	.14	20.0	.32		.25	.56
Rock phosphate 685 lbs.	20	1919	50.3	1.04	44.6	.84			1920	35.7	.48	33.7	.48	1921	1.14	.98
Do		1922	57.1	1.00	57.1	1.44	120.0	94.6	1923	15.1	.20	12.1	.17	1923	.76	.70
Do		1925	28.6	.88	35.4	.96	30.7	21.3	1926	19.8	.25	15.3	.25	1924	.69	.57
Do		1928	27.4	1.04	61.7	1.64	91.3	67.5						1927	1.40	1.51
Average			40.9	.99	49.7	1.22	80.7	61.1		23.5	.31	20.4	.30		1.00	.94
Acid phosphate 200 lbs.	21	1919	52.6	1.24	52.6	1.00			1920	34.7	.42	46.2	.54	1921	.54	1.84
Do		1922	45.7	.80	62.8	1.40	104.0	146.6	1923	13.8	.15	23.7	.28	1923	.48	1.10
Do		1925	27.4	.88	40.0	1.16	33.3	25.3	1926	21.7	.26	18.2	.29	1924	.66	1.08
Do		1928	20.6	.92	62.9	1.56	98.9	80.0						1927	1.05	1.67
Average			36.6	.96	54.6	1.28	78.7	84.0		23.4	.28	29.4	.37		.68	1.42

TABLE 3—*Concluded*

Kind of phosphate and annual rate of application	Plot No.	Yr. of harvest	Corn				Potatoes		Yr. of harvest	Oats				Yr. of harvest	Clover & Grass	
			Unlimed		Limed					Unlimed		Limed			Unlimed	Limed
			Grain	Stover	Grain	Stover	Unlimed	Limed		Grain	Straw	Grain	Straw		Hay	Hay
			Bu.	Tons	Bu.	Tons	Bu.	Bu.		Bu.	Tons	Bu.	Tons		Tons	Tons
None	22	1919	25.1	.56	35.7	.68			1920	16.8	.35	38.4	.62	1921	.24	1.37
Do		1922	28.6	.48	45.7	1.00	66.6	113.3	1923	5.6	.12	12.8	.20	1923	.14	.56
Do		1925	14.9	.60	22.9	.72	16.0	21.3	1926	5.5	.12	14.2	.23	1924	.29	.37
Do		1928	4.6	.64	30.9	1.04	42.1	39.7						1927	.33	.78
Average			18.3	.57	33.8	.86	41.6	58.1		9.3	.20	21.8	.35		.25	.77
Duplex basic phos. 100 lbs.	23	1919	42.3	.84	42.3	.84			1920	37.1	.50	38.5	.52	1921	.62	1.56
Do		1922	45.7	1.00	52.6	1.40	99.0	109.3	1923	12.1	.16	16.0	.22	1923	.48	.68
Do		1925	28.6	.84	28.6	.88	29.3	24.0	1926	17.1	.24	25.8	.32	1924	.59	.70
Do		1928	30.9	.80	56.0	1.24	79.2	63.6						1927	1.11	1.36
Average			36.9	.87	44.9	1.09	69.2	65.6		22.1	.30	26.8	.35		.70	1.08
None	25	1919	37.7	.80	25.1	.36			1920	18.8	.44	30.0	.50	1921	.40	.76
Do		1922	34.4	.68	45.7	.88	61.3	89.3	1923	6.6	.15	10.8	.18	1923	.22	.42
Do		1925	19.4	.72	14.9	.64	13.3	12.0	1926	7.3	.15	12.3	.22	1924	.24	.26
Do		1928	22.9	.68	27.4	1.12	34.5	29.3						1927	.38	.55
Average			28.6	.72	29.3	.75	36.3	43.5		10.9	.25	17.7	.30		.31	.50
Rock phosphate 343 lbs.	26	1919	48.0	.88	36.6	.56			1920	36.5	.49	30.4	.44	1921	.92	.70
Do		1922	57.1	1.40	45.7	1.00	93.3	86.6	1923	16.7	.22	10.7	.15	1923	.56	.62
Do		1925	34.3	.92	26.3	.84	34.7	26.7	1926	18.7	.27	11.7	.16	1924	.50	.39
Do		1928	41.1	1.04	42.3	1.40	88.6	59.5						1927	1.20	1.03
Average			45.1	1.06	37.7	.95	72.2	57.6		24.0	.33	17.6	.25		.80	.69
Acid phosphate 100 lbs.	27	1919	37.7	.54	36.6	.68			1920	30.8	.37	34.5	.43	1921	.54	.79
Do		1922	40.0	.80	43.4	1.04	108.0	88.0	1923	12.9	.16	15.5	.19	1923	.44	.92
Do		1925	25.1	.80	35.4	.80	29.3	25.3	1926	19.5	.23	14.6	.16	1924	.44	.58
Do		1928	27.4	1.12	38.9	1.12	97.6	67.3						1927	.82	1.06
Average			32.6	.82	38.6	.91	78.3	60.2		21.1	.25	21.5	.26		.56	.84

CORN

Under the unlimed condition the highest yields of corn were obtained from the basic phosphates. That furnished by the Tennessee Chemical Company gave an average yield of 41.2 bushels per acre for the four crops grown; the Duplex phosphate came second, with an average yield of 39.7 bushels per acre; the rock phosphate ranked third, with an average of 36.6 bushels; and the acid phosphate fourth, with an average of 32.8 bushels. The average yield of the eight unphosphated plots was only 22.1 bushels per acre.

Under the limed condition the T. C. Co. phosphate, the Duplex phosphate, and the acid phosphate yielded alike—within the limits of error for work of this kind—with an average yield of 50.3 bushels per acre, or an increase of 17.3 bushels per acre over the limed but unphosphated check plots.

It is evident that under both the limed and the unlimed condition the use of a phosphate is highly important on soil of this kind.

Allowing $1.00 a bushel for the corn, the acre values of the crop-increases attributable to the different phosphates are as follows:

	Unlimed	Limed
From T. C. Co. phosphate	$19.10	$16.00
From Duplex basic phosphate	17.60	17.80
From acid phosphate	10.70	16.00
From rock phosphate	14.50	13.80
Average	$15.48	$15.90

For the corn crop, therefore, the basic phosphates proved to be as profitable as any under the limed condition and appreciably the most profitable of all where no liming was done.

POTATOES

Without liming, the best average yield of potatoes was obtained from acid phosphate; the average for the five plots being 90 bushels per acre, or an increase of 40.9 bushels over the average of the unlimed check plots. The yields from all other phosphated plots averaged only 3.3 bushels per acre less than the yield from acid phosphate, and could be considered as practically the same, within the limits of error.

Under the limed condition acid phosphate ranked first, with an average yield of 91.3 bushels per acre; the two basic phosphates were tied for second place, with a yield of 89.4 bushels; and rock phosphate came last, with a yield of only 78.6 bushels.

Allowing $1.00 a bushel for the potatoes, the acre values of the crop-increases attributable to the different phosphates are as follows:

	Unlimed	Limed
From T. C. Co. phosphate	$38.90	$31.80
From Duplex basic phosphate	37.00	31.40
From rock phosphate	36.90	20.80
From acid phosphate	40.90	33.50
Average	$38.43	$29.40

It is evident, therefore, that acid phosphate was somewhat the most profitable fertilizer for the potato crops, both with and without liming. Rock phosphate came last, with an especially poor showing under the limed condition, but ranking with the basic phosphates where no lime was applied.

OATS

Without liming, the highest average yield of oats, 30.3 bushels per acre, was obtained with the T. C. Co. phosphate. The second highest yield was from acid phosphate, 26.8 bushels per acre, and this was closely followed by Duplex phosphate, with 25.8 bushels. Rock phosphate came last, with 24.2 bushels per acre. These yields are all close together. The average for the check plots was only 12 bushels.

Under liming the plots receiving the Duplex phosphate are decidedly in the lead, with an average yield of 38.2 bushels; acid phosphate comes second, with a yield of 34.6 bushels; the T. C. Co. phosphate is third, with 30.3 bushels; and the rock phosphate ranks lowest, with only 25.2 bushels. The average for the check plots was 21.1 bushels.

Allowing 60 cents a bushel for the oats, the acre values of the crop-increases attributable to the different phosphates are as follows:

	Unlimed	Limed
From T. C. Co. phosphate	$10.98	$ 5.52
From Duplex basic phosphate	8.28	10.26
From rock phosphate	7.32	2.46
From acid phosphate	8.88	8.10
Average	$ 8.87	$ 6.59

HAY

Under the unlimed condition the best yields of hay were obtained from the T. C. Co. phosphate, with an average of 1.29 tons per acre; the Duplex phosphate ranked second, with a yield of 1.09 tons; acid phosphate third, with a yield of .90 ton; and rock phosphate last, with a yield of .87 ton. The average for the check plots was only .41 ton.

Under liming the T. C. Co. phosphate was first, with a yield of 1.64 tons; acid phosphate second, with 1.46 tons; Duplex phosphate third, with 1.45 tons; and rock phosphate fourth, with 1.11 tons. The average for the check plots was .74 ton.

Allowing $1.00 per cwt. for the hay, the acre values of the crop-increases attributable to the different phosphates are as follows:

	Unlimed	Limed
From T. C. Co. phosphate	$17.60	$18.00
From Duplex basic phosphate	13.60	14.20
From rock phosphate	9.20	7.40
From acid phosphate	9.80	14.40
Average	$12.55	$13.50

Under the unlimed condition the basic phosphates were decidedly the most profitable. Under liming, acid phosphate was highly profitable, along with the basic phosphate. Rock phosphate, on the other hand, gave poor returns.

The Most Profitable Amount of Phosphate

Table 4 has been prepared to indicate the most profitable rate of application of the leading phosphates. The yields given in the table are averages from the acid phosphate and Duplex basic phosphate plots, both the limed and the unlimed results being included. The conclusions reached, though not on an entirely satisfactory basis, probably serve as a fair guide for practical purposes, and are considered to be applicable to the T. C. Co. phosphate when proper allowance is made for its much higher content of total phosphoric acid.

In the case of the corn crop a yield as good as any was obtained from the 200-pound application. The increase from the 100-pound application was 10.7 bushels, whereas that from the 200-pound was 17.0 bushels.

In the case of the potatoes the 400-pound rate appears best, but the yield from 300 pounds lacked only 5.6 bushels of being equally good. The increase attributable to the 400-pound application was 48.1 bushels per acre.

Three hundred pounds per acre appears to be the most profitable application for the oat crop. The increase per acre from this amount was 20.1 bushels.

In the case of the clover-and-grass hay, 400 pounds per acre gave the best returns, but the little difference in yield between the 500-pound and 300-pound applications leaves a doubt as to whether 400 pounds is more profitable than 300 pounds. It is evident, however, that the grass and clover responded extra well to a fairly heavy application; the increase in yield from the 300-pound application being .72 ton over the unphosphated and .25 ton over the 200-pound application.

It is difficult to determine the most profitable application of rock phosphate because of evident irregularities in the yields of the different plots. The total value of all the crops for each rate of application was calculated to be as follows:

Annual rate of application of rock phosphate Lbs.	~~Gross~~ crop valuation
340	$133.68
690	148.77
1030	163.27
1370	183.21
1710	164.72

According to this computation, at least 1030 pounds per acre was required for largest returns.

Comparative Net Returns

An approximation of the total net returns from the different phosphates is possible on a comparative basis, but it is difficult to make a highly satisfactory comparison. After careful consideration the following basis for making a concise comparison of this kind was decided upon:

1. The average yield for each kind of phosphate, as given in table 1, was taken as the most reliable for comparative purposes.

2. The most profitable acre rate of application for each phosphate was taken in accordance with the previous calculations; that is, 200 pounds for corn, 400 pounds each for potatoes and hay, and 300 pounds for oats, in the case of the acid phosphate and the Duplex basic phosphate; and equivalents of the same for the T. C. Co. phosphate, based on the total content of phosphoric acid. For the rock phosphate 3000 pounds per acre once in the rotation was selected, but the cost was charged to the crops in the same proportions as the other phosphates.

3. The costs of the phosphates and the crop valuations were the same as those specified previously.

Table 4 gives the results obtained by this method of calculation.

TABLE 4—*The calculated values of the crop-increases after deduction of the cost of the phosphate when used at its most profitable rate*

Crop	Kind of phosphate							
	Duplex		T. C. Co.		Acid phosphate		Rock phosphate	
	Unlimed	Limed	Unlimed	Limed	Unlimed	Limed	Unlimed	Limed
Corn	$15.60	$15.80	$17.10	$14.00	$ 8.70	$14.00	$11.50	$10.80
Potatoes	33.00	27.40	34.90	27.80	36.90	29.50	30.90	14.80
Oats	5.28	7.26	7.98	2.52	5.88	5.10	2.82	—2.04
Hay	9.60	10.20	13.60	14.00	5.80	10.40	3.20	1.40
Total	63.48	60.66	73.58	58.32	57.28	59.00	48.82	24.96

Table 4 shows that the basic phosphates proved especially well suited to unlimed land, under which condition they were, on the whole, appreciably superior to acid phosphate. Under liming the

basic phosphates and acid phosphate gave practically the same profit. Rock phosphate, on the other hand, gave returns decidedly inferior to any of the others on both the limed and the unlimed land.

ADAPTABILITY OF THE FINDINGS TO OTHER TYPES OF SOIL

The question may well be asked whether experimental results such as the preceding, from one soil type will be applicable to another. Soils originating from different geologic formations differ in color, texture, and other properties, even though formed under the same climatic conditions. We might expect, therefore, that the results from one soil would not coincide completely with those from another. There is, however, a certain similarity between soils of materially different origin in this State. In general they resemble one another in being low in both lime and humus, which are considered important factors in the utilization of phosphates. It is of considerable interest, therefore, that the data obtained at Crossville are quite in harmony with those previously reported from this Station in Bulletin No. 90, which contains the results of experiments on four types of soil—two in East and two in Middle Tennessee.

THE BASING OF ACID PHOSPHATE

Acid phosphate is made by treating rock phosphate with strong sulphuric acid. In the main the product is a mixture of acid phosphates of lime and sulphate of lime. To a certain extent acid phosphate acts as a true acid. The by-product sulphate of lime has no acid-neutralizing, or basic, properties.

The acid properties of acid phosphate can be offset by the mixing with it of ground limestone. Approximately 475 pounds of high-grade (95 per cent) ground limestone would be required to neutralize the acidity of a ton of 16 per cent acid phosphate. To make it as highly basic as high-grade Thomas slag meal, no further addition of limestone would be required, which, according to estimates based on the analysis of a high-grade sample made in the Station's laboratory, would amount to nearly 1000 pounds.* Therefore, in round numbers, easily remembered, it may be said that 1500 pounds of finely ground limestone per ton of acid phosphate would make a basic mixture comparable to the basicity of the slag meal. This mixture would contain also a large amount of sulphate of lime, or land plaster, which the basic phosphate does not contain.

For use on land not recently limed, a mixture of acid phosphate and ground limestone is highly recommended, and under usual conditions throughout the State the proportion of the ground

*This figure was obtained by allowing that all calcium over that required to make tricalcium phosphate would be available to neutralize soil acidity, and to this amount was added the calcium equivalent of all the magnesium.

limestone might well be increased to three times that of the acid phosphate.

LOW-GRADE BASIC PHOSPHATE

At the present time there is being sold a low-grade basic phosphate that is guaranteed to contain only 8 per cent of total phosphoric acid. Numerous analyses of this material have been made, and it has been found to contain about 8 per cent of total phosphoric acid but only 5 per cent, or thereabouts, of available phosphoric acid. A sample of this low-grade material was analyzed further in the Station laboratory and was found to contain a total of 43.8 per cent of lime and 5.32 per cent of magnesia. After addition of the magnesia equivalent and allowance for the lime necessary to account for the phosphoric acid in the form of tricalcium phosphate, there was left the equivalent of 40.75 per cent of lime in other forms, such as silicate, oxide, carbonate, and tetracalcium phosphate. Upon the assumption that all these forms neutralize soil acidity, the total bases per ton would be equivalent to 1532 pounds of a high-grade (95 per cent) limestone.

It would require 625 pounds of acid phosphate to furnish the same amount of available phosphoric acid that is contained in a ton of the low-grade basic phosphate. This estimate is based, of course, on the assumption that the "available" for each material was of equal value, which may not be true. For some crops, at least, a higher rating should probably be given to the "available" phosphoric acid of acid phosphate than to the "available" of slag meal. A mixture of 625 pounds of acid phosphate and 1532 pounds of high-grade ground limestone would therefore be approximately equal to one ton of the low-grade basic phosphate. At $20.00 per ton for the acid phosphate and $3.00 for the limestone, the cost of the material for the mixture would be $8.55. In addition, the cost of mixing and other labor must be reckoned. This could easily bring the total within the neighborhood of $10.00, which figure may be taken as the approximate valuation of a ton of the low-grade basic phosphate to the farmer.

ROCK PHOSPHATE

The use of finely ground rock phosphate for fertilizer purposes has been advocated, not only by persons commercially interested, but also by some Station workers and practical farmers. This Station has found repeatedly, in different parts of the State, that rock phosphate could be used with profit, especially where no liming was done. Its worth in comparison with other phosphates is another, if not the most important, problem. In the Crossville experiments it was evidently the least profitable material, even on unlimed land, where the margin of profit from its use was very small for both oats and hay. It showed to better advantage for both corn and potatoes. Under liming, rock phosphate proved actually unprofitable for oats and hay, and it gave only a compara-

tively small profit for the other crops. In some instances the Station has conducted experiments where rock phosphate on limed land gave results even superior to acid phosphate. In the vicinity of phosphate mines, and wherever sold at a very low price it may be used to advantage.

The fineness of grinding of phosphate rock is important, but its importance may easily be overrated. As usually ground for agricultural use, nearly all will pass through a 100-mesh sieve. Any finer grinding that is practicable can hardly be expected to make a material change in its availability to plants. It is at best a material that is not readily soluble when applied to the average soil, and the experimental evidence does not indicate any noticeable increase in availability on long contact with the soil, as has sometimes been claimed.

The difference in the size of particles of rock phosphate as ordinarily ground and as ground by special machinery to increase its fineness is illustrated in the following examples, showing the per cent of material that passed through a 100-mesh and a 200-mesh sieve:

Samples ground October, 1927

	As commonly ground Per cent	As specially ground Per cent
100-mesh sieve	94.2	99.7
200-mesh sieve	71.2	89.2

Samples ground June, 1928

	As commonly ground Per cent	As specially ground Per cent
100-mesh sieve	96.8	99.5
200-mesh sieve	74.0	84.4