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PART I—THE UTILIZATION OF VARIOUS PHOSPHATES

BY

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KNOXVILLE, TENNESSEE

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Bulletins of this Station will be sent, upon application, free of charge, to any farmer in the State.

FERTILITY EXPERIMENTS IN A ROTATION OF COWPEAS AND WHEAT

PART I—THE UTILIZATION OF VARIOUS PHOSPHATES

INTRODUCTION

To make an accurate estimation of the total area of Tennessee soils which respond profitably to phosphatic fertilizers is impossible at the present time. There is no doubt, however, that it is large, probably equal to not less than three-fourths of the entire State, or some 20 million acres. Of this great amount one-half may safely be said to be so poor in phosphoric acid that general farming is not practicable without the aid of a commercial phosphate. The comparative worth, therefore, of the three common materials, acid phosphate, steamed bone meal, and finely ground phosphate rock, as phosphatic fertilizers is of great practical importance to the agricultural interests of the State. Thomas slag, "odorless" or "basic" phosphate, which is extensively used in Europe, would be included in the list but for the reason that at present it can not be cheaply obtained. In fact, few if any dealers in the State keep it in stock. Although only a small amount of this material is produced in America, its use along the Atlantic seaboard has increased greatly since the recent removal of the tariff on importations. Owing to the special adaptability of this substance to a soil poor in lime, the attention of Tennessee farmers may well be directed to it. There is also the possibility of the introduction of a new manufactured basic phosphate of high value. The large deposits of phosphate rock at various places in Middle Tennessee make the fertilizer value of this material, when finely ground but unacidulated, a matter of special interest; and the interest is intensified by the opposite recommendations of some investigators who have made it a subject of study.

The question of the relative availability of different phosphates is, of course, not new. In Europe the agricultural investigators have given the subject close attention and their verdict has been strongly against the use of phosphate rock, or even bone meal, under average farm conditions; but they recognize the fact that soils are sometimes found on which these "insoluble" phosphates may be used to advantage. However, liming, which in such a case is generally necessary

for the production of satisfactory crops of clover, reduces their value and may render them almost worthless, as is shown by some of the data which follow.

In the United States the use of phosphate rock has found some staunch supporters, notably Dr. C. G. Hopkins, of the Illinois Station, who has advocated its use in what he terms a "permanent system of agriculture," in which phosphate rock is to supply phosphoric acid in considerable excess over the amount removed by the crops, with the object of building up the soil supply so that it will be ample for future generations. In connection with this kind of phosphating he recommends both green manuring and liming, the decomposition products of the green manure to render the phosphoric acid of the rock soluble and the lime to enable the soil to produce clover and other legumes needed to maintain the supply of nitrogen. Director Patterson of the Maryland Station has published the results obtained from various phosphates in a rotation of crops grown on an acid silt loam at College Park.* These results were favorable to both Thomas slag and phosphate rock. Unfortunately no comparison was made in connection with liming, which he finds profitable in the production of general farm crops on the same character of soil. Director Thorne of the Ohio Station has made a very careful study of this subject and has published the results of 20 years' work on acid soils, which received one ton of burnt lime per acre every four years, and concludes that, "acid phosphate has been the most effective of the four carriers of phosphorus (bone meal, basic slag meal, dissolved bone black, and acid phosphate) employed in these experiments for the cereal crops, while bone meal and basic slag were preferable for clover on acid soils."† He concludes also that acid phosphate is much more profitable than phosphate rock when used as a reinforcement for stable manure. Director Wheeler of the Rhode Island Station found phosphate rock of value on acid soils, especially for certain crops, such as millet, crimson clover, and soy beans, but very inefficient for turnips, beets, and cabbage.‡ He also found that phosphate rock as compared with acid phosphate gave best returns, as a rule, on unlimed soil, but the results were quite variable. In a recent article‖ he lays much stress on the "lime factor" and points out that liming may, according to its extent, either increase or decrease the availability of the different phosphates. This is without doubt an important consideration and is ample reason for the making of comparative tests to determine the relative values of the different phosphates for each distinct type of soil, and, if the soil be poor in lime, both with and without the application of lime.

In connection with a green-manure and liming experiment, in which cowpeas as a summer crop were followed by winter wheat, the

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* Md. Exp. Sta., Bull. 68.
† Ohio Exp. Sta., Circular 93, p. 8.
‡ R. I. Exp. Sta., Bull. 114, "A Test of Nine Phosphates with Different Plants."
‖ J. Ind. and Eng. Chem., 2, 132-135, "After Effects of Certain Phosphates."

writer planned a series of trials with various phosphates, which has now been carried out at the Experiment Station farm for five years with the production of ten crops. Previous to the trials the soil had, so far as is known, never been manured or fertilized but for a number of years had been in grass which had been cut for hay. At the end of the first year of the experiments the fact that this soil was too fertile to give immediate and sharply defined results was apparent and an additional area of land, known to be poor in phosphoric acid, was obtained on the farm of W. P. Ford, about five miles south of Knoxville. Eight crops, four of cowpeas and four of wheat, have been harvested in this series. In 1907 the State appropriation for cooperative experiments in Middle Tennessee enabled us to make similar experiments on additional and distinct types of soil, so that three years' results in one series and two years' in another can now be reported. For each of the four series the land was carefully selected with regard to uniformity of fertility and all have appeared to be above the average in this respect. Attention has been given to the details of the field work in order that the results might be as trustworthy as possible. The lands have always been turned without diagonal dead furrows, and back-furrow plowing has regularly alternated with face-furrowing so as to disturb the original position of the soil as little as possible. Plowing has been done twice a year, once in preparation for each crop. The Whippoorwill variety of cowpeas has been used throughout the series and, as a rule, has been either drilled in with a grain drill or sown broadcast by hand at the rate of 1 1-2 bushel per acre. The date of seeding has varied somewhat with the season, but has seldom been later than July 15. Harvesting has been done either late in September or early in October, when about 1-3 of the seed were ripe Fulcaster wheat has been used continuously. It has been sown during the latter part of October (a little late) at the rate of 1 1-2 bushel per acre and has been harvested at the Station farm about June 15.

Table I gives the chemical analyses of the four soils as made by the Official Method, strong hydrochloric acid (1.115 Sp. Gr.) being used as a solvent. In Table II are the mechanical analyses of the Station and Ford soils, but in the lack of the other two, the composition of typical soils closely resembling them are inserted. Both sets of analyses were made by Mr. H. H. Hampton of this Station.

The phosphates used in Series I and II were from the same lots and their analyses are given in Table III. Those used in Series III and IV were so similar in composition to the others that every material may be assumed to be of practically constant composition throughout all the experiments. The phosphate rock, as sold for a fertilizer in the unacidulated, or "raw," form, frequently contains only 30 per cent, or less, of total phosphoric acid, so that the lot used in the experiments was of a higher grade by 13 per cent. It was ground to about the usual degree of fineness sought in the manufacture of acid phosphate. In this instance 90 per cent was found to pass through a 100-mesh

sieve. Unfortunately the Thomas slag, although finely ground, was of inferior grade, as is shown by the low content of available phosphoric acid by the standard Wagner method. Both the steamed bone meal and the acid phosphate were of excellent quality.

TABLE I—*Chemical analyses of soils from the experimental fields (by Official Method, using strong hydrochloric acid, 1.115 Sp. Gr.)*

Constituent	Lab. No. 636 Station soil	Lab. No. 821 Ford soil	Lab. No. 881 Weaver soil	Lab. No. 883 Story soil
	Per cent	Per cent	Per cent	Per cent
Insoluble residue	82.49	87.07	89.74	86.20
Potash (K_2O)	0.34	0 27	0.13	0.23
Lime (CaO)	0.13	0.10	0.11	0.13
Magnesia (MgO)	0.25	0.31	0.21	0.25
Manganese oxide (MnO)	0.24	0.17	0.08	0.29
Ferric oxide (Fe_2O_3)	3.27	2.48	1.67	2 21
Alumina (Al_2O_3)	6.61	4.92	4.36	5.92
Phosphoric acid (P_2O_5)	0.137	0.09	0.02	0 071
Sulphuric acid (SO_3)	0 042	0.026	0.032	0.024
Volatile matter	5 55	4.46	3.50	4.31
Humus	1.36	0.96	0.78	0.73
Nitrogen	0.128	0.094	0.076	0.095
Acidity by Veitch Method	0 07	0.083	Neutral	0.04

TABLE II—*Mechanical analyses of soils (by method of Bureau of Soils)*

Class	Size of particles in mm.	Lab. No. 636 Station soil	Lab. No. 821 Ford soil	Lab. No. 918 Typical gray soil of Highland Rim	Lab. No. 874 Typical dark red soil of Highland Rim
		Per cent	Per cent	Per cent	Per cent
1. Gravel	2-1	1.14	6.56	0.60	....
2. Coarse sand	1-.5	2.37	7.96	1.80	....
3. Medium sand	.5-.25	3.32	1.12	0.89	0.23
4. Fine sand	.25-.1	9.15	4 45	4 67	6.88
5. Very fine sand	.1-.05	17.68	6.62	10.63	27.99
6. Silt	.05-.005	47.85	59.18	72.87	48.65
7. Clay	.005-.0	19.63	13 85	9.30	16.41

TABLE III—*Analyses of phosphates used in Series I and II*

Kind of Phosphate	Total Phos. acid (P_2O_5)	"Available" phosphoric acid (P_2O_5)		
		By Official Method	By Wagner Method	By Dyer Method
	Per cent	Per cent	Per cent	Per cent
Acid phosphate	17.25	16.90	....	....
Steamed bone meal	23.85	....	....	....
Thomas slag meal	17.75	....	10.52	....
Phosphate rock	33.90	....	....	10.5

SERIES I, ON THE EXPERIMENT STATION FARM

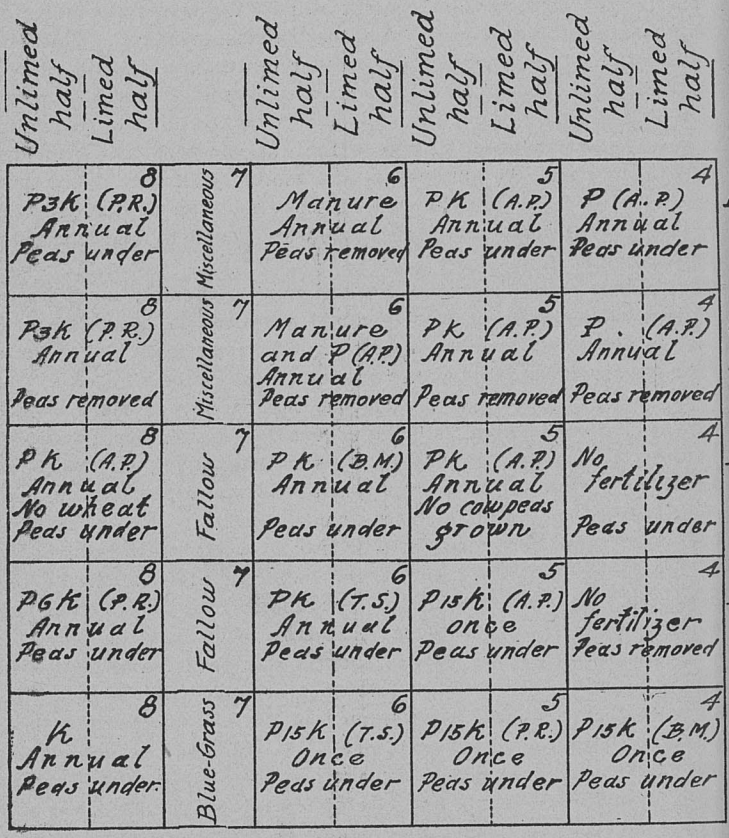
The soil at the Experiment Station farm, where the trials of Series I were conducted, has been designated by the Bureau of Soils as Cumberland loam. It was derived largely from the dolomite formation but in part also from an ancient alluvial deposit, as is indicated by its being the third bench from the Tennessee River. This soil was well supplied, as compared with other representative soils of this State, with plant food of all kinds and with humus, but was so much in need of lime that without it alsike clover was a failure on adjoining plats even when manured to the extent of 30 tons of farmyard manure to the acre. An application of 1 ton of burnt lime to the acre proved ample to make the clover a success. Both the mechanical condition and the drainage of these plots were excellent and markedly uniform throughout.

Diagram 1 gives the relative position of each plot, a matter of some importance, since at least a slight variation in the fertility of any set of field plots is to be expected. Each plot is 1-40 of an acre (30x36.3 feet), with a 2-foot path between plots.

The first application of the various fertilizers was made before the cowpeas were planted, but the application of the burnt lime, at the rate of about 1 ton per acre to the west half of all the plots, was not made until after the first crop of cowpeas was harvested and just previous to the seeding of the first crop of wheat.

The fertilizers were applied uniformly over the entire plot—both limed and unlimed halves—and turned under in preparation for the cowpea crop. All the phosphates were applied annually except the 500 pounds per acre of phosphoric acid from bone meal on plot J 4, from phosphate rock on J 5, from Thomas slag on J 6 and from acid phosphate on I 5, each of these lots being applied only once, at the outset of the experiments. For example, of the four plots which have been treated with phosphate rock, one (J 5) received one application of 1475 pounds per acre five years ago and none since then, but has received annually 50 pounds per acre of muriate of potash; plots F 8 and G 8 have received annual applications of 295 pounds of phosphate rock and also 50 pounds of muriate of potash per acre; and I 8 has received an annual application of 590 pounds of phosphate rock and 50 pounds of muriate of potash per acre. The rates per acre of all the materials and the yields for each year are given in Table IV. No fertilizers were applied directly for the wheat.

DIAGRAM 1—THE PLOTS AT THE STATION FARM



EXPLANATION OF SYMBOLS, ETC., USED IN DIAGRAM 1

P stands for 33⅓ lbs. of total phosphoric acid per acre.

P_3 indicates that 3 times 33⅓ lbs. of phosphoric acid were used.

A. P. indicates the source of the phosphoric acid to be acid phosphate.

B. M. " " " " " " steamed bone meal.

P. R. " " " " " " phosphate rock.

T. S. " " " " " " Thomas slag.

K stands for 50 lbs. of muriate of potash per acre.

TABLE IV—*Yields per acre of cowpea hay and of wheat for each of the first five years at the Experiment Station farm*

Plot	Year	Fertilizer per acre	Disposition of cowpea crop	Cowpea hay			Wheat					
							Unlimed		Limed		Average of unlimed and limed	
				Unlimed	Limed	Average	Grain	Straw	Grain	Straw	Grain	Straw
				Ton	Ton	Ton	Bu.	Ton	Bu.	Ton	Bu.	Ton
H 4	1905	None	Turned under	....	....	1.21	....	....	....	....	34.6	2.08
	1906	"	"	0.50	0.53	0.52	28.1	1.62	31.8	1.95	30.0	1.79
	1907	"	"	0.89	0.86	0.88	22.9	1.15	25.5	1.32	24.2	1.24
	1908	"	"	1.50	1.48	1.49	21.6	1.40	24.6	1.66	23.1	1.57
	1909	"	"	1.09	1.13	1.11	21.7	1.51	21.3	1.54	21.5	1.53
		Average		1.00	1.00	1.04	23.6	1.42	25.8	1.62	26.7	1.64
J 8	1905	50 lbs. muriate potash	Turned under	....	....	1.28	....	....	....	....	27.8	1.77
	1906	" "	"	0.59	0.73	0.66	26.7	2.00	30.0	1.98	28.4	1.99
	1907	" "	"	0.94	1.01	0.98	19.2	1.34	23.5	1.42	21.4	1.38
	1908	" "	"	1.24	1.45	1.35	21.7	1.35	24.0	1.60	22.9	1.48
	1909	" "	"	1.76	1.71	1.73	24.0	1.68	27.7	2.01	25.9	1.85
		Average		1.13	1.22	1.20	22.9	1.59	26.3	1.75	25.3	1.69
F 4	1905	193 lbs. acid phosphate	Turned under	....	....	1.23	....	....	....	....	34.5	2.01
	1906	" "	"	0.41	0.59	0.50	25.0	1.12	34.0	2.18	29.5	1.66
	1907	" "	"	1.11	1.13	1.12	21.2	1.08	30.5	1.53	25.9	1.31
	1908	" "	"	1.19	1.45	1.32	22.3	1.34	28.4	1.88	25.4	1.61
	1909	" "	"	1.17	1.27	1.22	24.6	1.55	31.0	2.00	27.8	1.78
		Average		0.97	1.11	1.08	23.3	1.27	31.0	1.63	28.6	1.67
F 5	1905	193 lbs. acid phosphate + 50 lbs. muriate of potash	Turned under	....	....	1.43	....	....	....	....	36.7	1.99
	1906	" "	"	0.47	0.64	0.56	27.8	1.65	30.1	1.86	29.0	1.76
	1907	" "	"	0.88	1.08	0.98	22.2	1.13	27.5	1.37	24.9	1.25
	1908	" "	"	1.37	1.66	1.52	25.3	1.57	27.1	1.72	26.2	1.65
	1909	" "	"	1.25	1.68	1.46	26.3	1.67	28.7	1.98	27.5	1.83
		Average		0.99	1.27	1.19	25.4	1.51	28.4	1.73	28.9	1.70

TABLE IV—*Yields per acre of cowpea hay and of wheat for each of the first five years at the Experiment Station farm—Cont'd*

Plot	Year	Fertilizer per acre	Disposition of cowpea crop	Cowpea hay			Wheat					
				Unlimed	Limed	Average	Unlimed		Limed		Average of unlimed and limed	
							Grain	Straw	Grain	Straw	Grain	Straw
				Ton	Ton	Ton	Bu.	Ton	Bu.	Ton	Bu.	Ton
I 5	1905	2900 lbs. acid phosphate, 50 " muriate of potash	Turned under	....	....	1.62	....	....	....	....	41.3	2.87
	1906	50 lbs. muriate of potash	"	0.56	0.84	0.70	26.7	1.56	34.3	1.96	30.5	1.76
	1907	" "	"	0.91	1.33	1.12	27.0	1.40	27.9	1.69	27.5	1.55
	1908	" "	"	1.39	1.48	1.43	25.7	1.64	27.7	1.82	26.7	1.73
	1909	" "	"	1.66	1.68	1.67	25.7	1.39	28.0	2.04	26.9	1.72
		Average		1.13	1.33	1.31	26.3	1.50	29.5	1.88	30.6	1.93
H 6	1905	140 lbs. bone meal, 50 " muriate of potash	Turned under	....	....	1.27	....	....	....	....	34.0	1.99
	1906	" "	"	0.48	0.59	0.53	28.3	1.67	28.0	1.88	28.2	1.78
	1907	" "	"	0.86	1.19	1.03	21.3	1.33	27.7	1.35	24.5	1.34
	1908	" "	"	1.01	1.55	1.28	25.7	1.67	25.3	1.68	25.5	1.68
	1909	" "	"	1.17	1.64	1.40	21.3	1.48	30.0	2.02	25.7	1.75
		Average		0.88	1.24	1.10	24.2	1.54	27.8	1.73	27.6	1.71
J 4	1905	2100 lbs. bone meal, 50 " muriate of potash	Turned under	....	....	1.48	....	....	....	....	31.4	3.12
	1906	50 lbs. muriate of potash	"	0.89	0.96	0.93	30.3	1.97	37.3	2.72	33.8	2.35
	1907	" "	"	1.24	1.40	1.32	28.0	1.64	27.0	1.69	27.5	1.67
	1908	" "	"	1.43	1.59	1.51	25.4	1.77	28.4	2.00	26.9	1.89
	1909	" "	"	1.64	1.76	1.70	27.3	1.92	31.0	2.15	29.2	2.04
		Average		1.30	1.43	1.39	27.8	1.83	30.9	2.14	29.8	2.21
F 8	1905	295 lbs. phosphate rock, 50 " muriate of potash	Turned under	....	....	1.42	....	....	....	....	34.8	2.30
	1906	" "	"	0.67	0.70	0.69	34.0	2.72	32.0	2.76	33.0	2.74
	1907	" "	"	1.16	0.92	1.04	27.9	1.72	30.5	1.73	29.2	1.73
	1908	" "	"	1.62	1.43	1.53	28.0	1.83	27.3	1.78	27.7	1.81
	1909	" "	"	1.51	1.50	1.51	28.3	1.83	27.7	1.87	28.3	1.85

TABLE IV—*Yields per acre of cowpea hay and of wheat for each of the first five years at the Experiment Station farm—Cont'd*

Plot	Year	Fertilizer per acre	Disposition of cowpea crop	Cowpea hay			Wheat					
							Unlimed		Limed		Average of unlimed and limed	
				Unlimed	Limed	Average	Grain	Straw	Grain	Straw	Grain	Straw
				Ton	Ton	Ton	Bu.	Ton	Bu.	Ton	Bu.	Ton
I 8	1905	590 lbs. phosphate rock, 50 " muriate of potash	Turned under	....	....	1.23	....	....	....	....	28.2	1.66
	1906	" "	"	0.53	0.64	0.59	29.3	1.76	34.3	2.05	31.8	1.91
	1907	" "	"	0.91	1.03	0.97	21.9	1.26	24.5	1.39	23.2	1.33
	1908	" "	"	1.39	1.44	1.42	23.3	1.50	25.0	1.65	24.2	1.58
	1909	" "	"	1.44	1.60	1.52	25.0	1.63	27.3	1.74	26.2	1.69
		Average		1.07	1.18	1.15	24.9	1.54	27.8	1.71	26.7	1.63
J 5	1905	1475 lbs. phosphate rock, 50 " muriate of potash	Turned under	....	....	1.40	....	....	....	....	32.9	2.13
	1906	50 lbs. muriate of potash	"	0.53	0.75	0.64	28.4	1.75	33.4	1.60	30.9	1.68
	1907	" "	"	1.00	1.07	1.04	24.5	1.31	27.5	1.42	26.0	1.37
	1908	" "	"	1.13	1.49	1.31	26.0	1.71	24.7	1.73	25.2	1.72
	1909	" "	"	1.49	1.87	1.68	23.0	1.92	30.3	2.15	26.7	2.04
		Average		1.04	1.30	1.21	25.5	1.70	29.0	1.73	28.3	1.79
I 6	1905	188 lbs. Thomas slag, 50 " muriate of potash	Turned under	....	....	1.44	....	....	....	....	33.3	1.99
	1906	" "	"	0.51	0.65	0.58	30.0	1.81	30.3	1.89	30.2	1.85
	1907	" "	"	0.75	0.92	0.84	23.3	1.30	28.0	1.56	25.6	1.43
	1908	" "	"	0.96	1.48	1.22	25.3	1.64	25.0	1.65	25.2	1.65
	1909	" "	"	1.62	1.75	1.68	22.7	1.42	32.3	2.25	27.5	1.84
		Average		0.96	1.20	1.15	25.3	1.54	28.9	1.84	28.4	1.75
J 6	1905	2816 lbs. Thomas slag, 50 " muriate of potash	Turned under	....	....	1.54	....	....	....	....	38.9	3.03
	1906	50 lbs. muriate of potash	"	0.78	0.73	0.76	34.7	2.44	32.7	2.38	33.7	2.41
	1907	" "	"	1.32	1.26	1.29	29.5	1.64	30.7	1.64	30.1	1.64
	1908	" "	"	1.61	1.59	1.60	29.0	1.97	28.0	2.16	28.5	2.07
	1909	" "	"	1.68	1.71	1.69	27.3	1.98	30.0	2.10	28.7	2.04
		Average		1.35	1.32	1.38	30.1	2.01	30.4	2.07	32.0	2.80

TABLE IV—*Yields per acre of cowpea hay and of wheat for each of the first five years at the Experiment Station farm—Concl'd*

Plot	Year	Fertilizer per acre	Disposition of cowpea crop	Cowpea hay			Wheat					
							Unlimed		Limed		Average of unlimed and limed	
				Unlimed	Limed	Average	Grain	Straw	Grain	Straw	Grain	Straw
				Ton	Ton	Ton	Bu.	Ton	Bu.	Ton	Bu	Ton
I 4	1905	None	Removed	....	....	1.15	....	....	....	....	25.9	1.32
	1906	"	"	0.42	0.63	0.53	20.3	1.15	25.3	1.36	22.8	1.26
	1907	"	"	0 68	0.75	1.72	15.5	0.90	19.9	1.60	17.7	0.95
	1908	"	"	0 90	1.20	1.05	16.3	0.92	17.7	0.96	16.7	0.94
	1909	"	"	0.77	1.04	0.90	09.3	0.68	17.3	1.00	13.3	0.84
		Average		0 69	0.91	0.87	15.4	0.91	20.1	1.08	19.3	1.06
G 4	1905	193 lbs. acid phosphate	Removed	....	....	1.36	....	....	....	....	31.0	1.73
	1906	" "	"	0 35	0.65	0 50	23.0	1.11	29.0	1.62	26.0	1.37
	1907	" "	"	0.89	1.04	0.97	16.5	0.87	25.9	1.30	21.2	1.09
	1908	" "	"	0.95	1.44	1.19	17.4	1.01	20.7	1.31	19.1	1.16
	1909	" "	"	0.62	1.87	0.75	14.6	0.93	19.6	1.26	17.1	1.10
		Average		0.70	1.00	0.95	17.9	0.98	23.8	1.37	22.9	1.29
G 5	1905	193 lbs. acid phosphate, 50 lbs. muriate of potash	Removed	....	....	1.52	....	....	....	....	30.5	1.57
	1906	" "	"	0.39	0.80	0.60	20.3	1.39	24.7	1.30	22.5	1.35
	1907	" "	"	0.91	1.25	1.08	16.6	0.87	21.9	1.30	19.3	1.09
	1908	" "	"	1.25	1.42	1.34	17.6	0.98	18.1	1.11	17.9	1.05
	1909	" "	"	1.17	1.48	1.32	14.3	0.97	21.7	1.15	18.0	1.06
		Average		0.93	1.24	1.17	17.2	1.05	21.6	1.22	21.6	1.22
G 8	1905	295 lbs. phosphate rock, 50 " muriate of potash	Removed	....	....	1.28	....	....	....	....	28 3	1.39
	1906	" "	"	0.51	0.71	0.61	22 0	1.30	21.3	1.20	21.7	1.25
	1907	" "	"	0.96	0.88	0 92	16.2	0.87	20.5	0.79	18.4	0.83
	1908	" "	"	1.22	1.09	1.16	16.0	0.96	15.7	0.97	15.9	0.97
	1909	" "	"	1 26	1.47	1.36	16.7	0.90	18.0	1.02	17.4	0 96
		Average		0.99	1.04	1.07	17.7	1.01	18.9	1.00	20.3	1.08

TABLE V—*Summary of yields of both cowpea hay and wheat at the Station farm—average yields per acre for seasons 1905-1910*

Plot	Fertilizer per acre—annual applications, except as indicated	Disposition of cowpea crop	Cowpea hay			Wheat					
						Unlimed (4 years)		Limed (4 years)		Average of unlimed and limed (5 years)	
			Unlimed (4 yrs)	Limed (4 yrs)	Av'r'ge of unlimed &limed (5 yrs)	Grain	Straw	Grain	Straw	Grain	Straw
			Ton	Ton	Ton	Bu	Ton	Bu.	Ton	Bu.	Ton
H 4	None	Turned under	1.00	1.00	1.04	23.6	1.42	25.8	1.62	26.7	1.64
J 8	50 lbs. muriate of potash	" "	1.13	1.22	1.20	22.9	1.59	26.3	1.75	25.3	1.69
	Average of checks H 4 and J 8		1.07	1.11	1.12	23.3	1.51	26.1	1.69	26.0	1.67
F 4	193 lbs. acid phosphate	Turned under	0.97	1.11	1.08	23.3	1.27	31.0	1.63	28.6	1.67
F 5	193 lbs. acid phosphate 50 " muriate of potash	" "	0.99	1.27	1.19	25.4	1.51	28.4	1.73	28.9	1.70
	Average of F 4 and F 5		0.98	1.19	1.14	24.4	1.39	29.7	1.68	28.8	1.69
I 5	2900 lbs. acid phosphate* 50 " muriate of potash	Turned under	1.13	1.33	1.31	26.3	1.50	29.5	1.88	30.6	1.93
H 6	140 lbs. steamed bone meal 50 " muriate of potash	" "	0.88	1.24	1.10	24.2	1.54	27.8	1.73	27.6	1.71
J 4	2100 lbs. st'm'd bone meal* 50 " muriate of potash	" "	1.30	1.43	1.39	27.8	1.83	30.9	2.14	29.8	2.21
F 8	295 lbs. phosphate rock 50 " muriate of potash	" "	1.24	1.14	1.24	29.6	2.03	29.4	2.04	30.6	2.09
I 8	590 lbs. phosphate rock 50 " muriate of potash	" "	1.07	1.18	1.15	24.9	1.54	27.8	1.71	26.7	1.63
J 5	1475 lbs. phosphate rock* 50 " muriate of potash	" "	1.04	1.30	1.21	25.5	1.70	29.0	1.73	28.3	1.79
	Average of phosphate r'k plots		1.12	1.21	1.20	26.7	1.76	28.7	1.83	28.5	1.84

* Only one application of phosphate.

TABLE V—*Summary of yields of both cowpea hay and wheat at the Station farm—average yields per acre for seasons 1905-1910—Concluded*

Plot	Fertilizer per acre—annual applications, except as indicated	Disposition of cowpea crop	Cowpea hay			Wheat					
						Unlimed (4 years)		Limed (4 years)		Average of unlimed and limed (5 years)	
			Unlimed (4yrs)	Limed (4 yrs)	Av'r'ge of unlimed &limed (5 yrs)	Grain	Straw	Grain	Straw	Grain	Straw
			Ton	Ton	Ton	Bu.	Ton	Bu.	Ton	Bu.	Ton
I 6	188 lbs. Thomas slag 50 " muriate of potash	Turned under	0.96	1.20	1.15	25.3	1.54	28.9	1.84	28.4	1.75
J 6	2816 lbs. Thomas slag* 50 " muriate of potash	" "	1.35	1.32	1.38	30.1	2.01	30.4	2.07	32.0	2.80
I 4	None	Removed	0.69	0.91	0.87	15.4	0.91	20.1	1.08	19.3	1.06
G 4	193 lbs. acid phosphate	"	0.70	1.00	0.95	17.9	0.98	23.8	1.37	22.9	1.29
G 5	193 lbs. acid phosphate 50 " muriate of potash	"	0.93	1.24	1.17	17.2	1.05	21.6	1.22	21.6	1.22
	Average of G 4 and G 5		0.82	1.12	1.06	17.6	1.02	22.7	1.30	22.3	1.26
G 8	295 lbs. phosphate rock 50 " muriate of potash	Removed	0.99	1.04	1.07	17.7	1.01	18.9	1.00	20.3	1.08

* Only one application of phosphate.

COMMENTS ON THE RESULTS OBTAINED AT THE STATION FARM

The results of the first five years of this series do not give, so far as the relative availability of the various phosphates is concerned, the conclusive evidence desired. The soil deficiency in phosphoric acid was not sufficient for sharply defined differences to appear in that length of time. However, the summary in Table V of the yields of both cowpea hay and wheat undoubtedly furnishes some data of practical value, especially in connection with the other series, and is presented as follows:

1—THE EFFECT OF THE PHOSPHATES ON THE YIELDS OF COWPEA HAY WHERE THE CROPS WERE TURNED UNDER EACH YEAR

With regard to the effect of the various phosphates on the yield of cowpea hay, it is evident that the lime factor plays an important part, for while the limed side of nearly all of the plots produced each year a heavier and noticeably greener growth than the unlimed, these results were especially marked on all acid phosphate plots and also where the light applications of bone meal and Thomas slag were made. On the unlimed halves the only noteworthy increases attributable to the application of phosphate were where the extremely heavy dressings of Thomas slag, on J 6, and of bone meal, on J 4, had been made. These results must be attributed in large part to the facts that the slag furnished needed lime at the rate of about 1000 pounds per acre and the bone meal furnished nitrogen which would be utilized by the cowpeas. Of the limed halves which received the heavy dressings, bone meal produced the highest average yield, 1.43 ton per acre; acid phosphate came second, with 1.33 ton; and Thomas slag a close third, with 1.32 ton, as compared with the average of 1.21 ton for the three phosphate rock plots and 1.11 ton for the two check plots (H 4 and J 8). Of the light applications on the limed halves, acid phosphate came first (F 5), with an average of 1.27 ton; bone meal second, with 1.24 ton; and slag meal third, with 1.20 ton of hay per acre.

2—THE YIELDS OF HAY WHERE THE CROPS WERE REMOVED EACH YEAR

The removal of the cowpea hay as well as the wheat, both the straw and grain of which were annually taken from every plot, increased the drain on all the plant-food elements so that plot I 4, which was unfertilized, gave decidedly the lowest average yields of all the plots in the series. A comparison of the yields of the adjoining plots, F 4 with F 5, and G 4 with G 5, indicates that potash increased the production of hay and that this increase was especially marked in the fifth, or last, year of the experiment. As there was no check plot which received only potash where the hay was removed, the actual increase due to the addition of phosphate to plot G 5, which re-

ceived 193 pounds per acre of acid phosphate, and to plot G 8, which received 295 pounds per acre of phosphate rock, can not be determined. However, as each of these plots received the same amount of potash their yields can be fairly compared together, when it may be seen that without lime acid phosphate made a lower yield than the rock by 120 pounds of hay to the acre, but with lime a higher yield by 400 pounds—results which resemble those obtained where the crops were turned under.

3—THE EFFECT OF THE PHOSPHATES ON THE YIELDS OF WHEAT WHERE THE COWPEAS WERE TURNED UNDER EACH YEAR

As shown by the chemical analysis the soil where these experiments were made was fairly well supplied with nitrogen, but the amount made available under this system of cropping proved to be approximately ample only where the cowpea crop was turned under. Of the unlimed halves which received the heavy applications, Thomas slag is easily first with an average yearly increase over the check plots H 4 and J 8, of 6.8 bushels of grain per acre, a gain sufficient to allow a small margin of profit. Steamed bone meal comes second with a yearly increase of 4.7 bushels, but the too rank growth of straw on both halves of this plot caused lodging, so that the grain was not well filled and a yield below that which would otherwise have been obtained was the result. Acid phosphate comes third, with an annual increase of only 3 bushels, and the average for J 5 and I 8, which received the heaviest applications of phosphate rock, places them last, with an increase of only 1.9 bushel of grain per acre. Plot F 8 appears to the writer to be of appreciably better natural fertility than the others, but with this included the unlimed phosphate rock plots rank third, outyielding the heavy application of acid phosphate by 0.4 bushel per acre, on the average. The light applications of acid phosphate, Thomas slag, and bone meal gave increases in the order named, but the differences were too slight to permit satisfactory distinctions to be made. They show an annual average increase over the check plots of 1.7 bushel of grain per acre, or practically the same increase as that from the average of the two phosphate rock plots J 5 and I 8. The yields of the limed halves where phosphates were used averaged 3.2 bushels of grain per acre more than the check plots but agreed so closely that satisfactory distinctions can hardly be made.

4—THE YIELDS OF WHEAT WHERE THE COWPEAS WERE REMOVED FOR HAY EACH YEAR

As in the case of the cowpea crops, plot G 5, which received 193 pounds per acre of acid phosphate, can be compared with G 8, which received 295 pounds per acre of phosphate rock. On the unlimed side the ground rock appears to have increased the yield of

grain by 1-2 bushel per acre more than the acid phosphate, but on the limed side the acid phosphate surpasses the phosphate rock by 2.7 bushels per acre.

Little stress can rightfully be placed on many of the results of this series, when taken by themselves, because the chance for error is too great, but when considered along with others in the series that follow they become of value, as will be pointed out later.

SERIES II, ON THE FARM OF W. P. FORD, KNOX CO.

The soil used in Series II is a reddish yellow silt loam derived from the Chickamauga, or Blue, limestone formation and had been under cultivation for 50 or more years. Corn and wheat, with occasional crops of cowpeas or of clover and grass, had been grown. Only a little manure and no commercial fertilizer or lime had been used so far as known. Previous to the starting of the experiments this field had been in pasture for one or two years and it was fairly well set in Japan clover. The range, which ran through the middle of a field, was very carefully selected in order to get uniform soil conditions, and after four years' experience both with this and an adjoining range in corn experiments, the writer considers that the entire area was well suited to experimental purposes. Each plot in the range was 1-40 of an acre (18x60.5 ft.) with a 2-foot path between plots.

The first application of the various fertilizers was made immediately before the first crop of cowpeas was planted, but the lime, as in Series I, was not applied until fall and just before the seeding of the first crop of wheat. The lime, in the form of burnt lime, was applied at the rate of 1 ton per acre to the west half of all plots. Diagram 2 shows the arrangement of the plots. The symbols are similar to those of Diagram 1, but it should be noticed that although the general plan of the experiments is the same, the quantities of the different phosphates used in the two series are not alike throughout. To put the trials on a somewhat more practical basis, the heavy applications of phosphate made only once at the outset of the experiment, were reduced to 2-3 the quantity used at the Station farm. For a like reason acid phosphate was applied yearly at three rates, 97, 193 and 290 pounds per acre, as compared with only 193 pounds in the former series. As in Series I, muriate of potash at the rate of 50 pounds per acre was applied annually wherever indicated in the diagram. The phosphates were applied previous to the turning of the land in preparation for the cowpeas and none directly for the wheat.

Table VI gives in detail the yields for the first four years of this series; Table VII gives the summary of the eight crops grown, and Table VIII furnishes a financial comparison of the results.

In making the calculations for Table VIII, and also for Tables XI and XIII, which follow, high retail prices for the phosphates and medium prices for the wheat and cowpea hay—the latter being in-

TABLE VI—*Yields per acre of cowpea hay and of wheat for each of the first four years at the farm of W. P. Ford, Knox County*

Plot	Year	Fertilizer per acre	Disposition of cowpea crop	Cowpea hay			Wheat			
							Unlimed		Limed	
				Unlimed	Limed	Average	Grain	Straw	Grain	Straw
				Ton	Ton	Ton	Bu.	Ton	Bu.	Ton
10	1906	None	Turned under	(1.96)	(1.96)	1.96	27.3	2.06	27.3	2.18
	1907	"	"	0.27	0.29	0.28	13.3	0.84	17.3	1.08
	1908	"	"	0.58	0.74	0.66	18.7	1.00	24.0	1.48
	1909	"	"	0.30	0.35	0.33	4.7	0.42	9.3	0.64
		Average		0.78	0.84	0.81	16.0	1.08	19.5	1.35
14	1906	50 lbs. muriate of potash	Turned under	(1.62)	(1.62)	1.62	25.3	1.66	28.0	1.96
	1907	" "	"	0.22	0.23	0.23	14.0	0.78	15.7	0.93
	1908	" "		....	....	....	13.7	0.71	19.3	0.94
	1909	" "					1.7	0.07	3.7	0.21
		Average		....	....	....	13.7	0.81	16.7	1.01
5	1906	193 lbs. acid phosphate	Turned under	(2.17)	(1.17)	2.17	25.3	1.90	25.3	2.40
	1907	" "	"	0.50	0.60	0.55	19.3	1.14	24.3	1.59
	1908	" "	"	0.71	1.46	1.08	22.0	1.14	26.7	1.56
	1909	" "	"	0.30	0.66	0.48	8.0	0.64	15.3	0.98
		Average		0.92	1.22	1.07	18.7	1.21	22.9	1.63
8	1906	97 lbs. acid phosphate 50 " muriate of potash	Turned under	(2.05)	(2.05)	2.05	31.0	2.07	28.0	2.22
	1907	" "	" "	0.55	0.57	0.56	16.0	0.96	23.0	1.11
	1908	" "	" "	0.75	1.23	0.99	20.3	0.99	29.0	1.65
	1909	" "	" "	0.36	0.68	0.52	9.3	0.58	17.3	0.96
		Average		0.93	1.13	1.03	19.1	1.15	24.4	1.49

TABLE VI—*Yields per acre of cowpea hay and of wheat for each of the first four years at the farm of W. P. Ford, Knox County—Continued*

Plot	Year	Fertilizer per acre	Disposition of cowpea crop	Cowpea hay			Wheat			
				Unlimed	Limed	Average	Unlimed		Limed	
							Grain	Straw	Grain	Straw
				Ton	Ton	Ton	Bu.	Ton	Bu.	Ton
4	1906	193 lbs. acid phosphate, 50 " muriate of potash	Turned under	(1.94)	(1.94)	1.94	27.3	1.98	27.7	2.25
	1907	" "	"	0.68	0.42	0.55	17.0	1.09	24.0	1.36
	1908	" "	"	0.88	1.23	1.05	22.0	1.14	24.0	1.44
	1909	" "	"	0.47	0.61	0.54	9.3	0.62	14.7	0.86
		Average		0.99	1.05	1.02	18.9	1.21	22.7	1.48
12	1906	290 lbs. acid phosphate, 50 " muriate of potash	Turned under	(2.02)	(2.02)	2.02	32.7	2.24	28.0	2.44
	1907	" "	"	0.64	0.68	0.66	21.3	1.20	25.3	1.32
	1908	" "	"	0.85	1.26	1.06	24.0	1.18	31.3	1.62
	1909	" "	"	0 45	0.44	0.45	10.0	0.60	18.0	0.92
		Average		0.99	1.10	1.05	22.0	1.31	25.7	1.58
15	1906	1740 lbs. acid phosphate, 50 " muriate of potash	Turned under	(2.15)	(2.15)	2.15	35.3	2.70	31.0	2.91
	1907	50 lbs. muriate of potash	"	0.61	0.66	0.64				
	1908	" "	"	0.70	1.28	0.99	20.0	0.84	27.3	1.42
	1909	" "	"	0.29	0.53	0.41				
		Average		0.94	1.16	1.05				
11	1906	1260 lbs. bone meal, 50 " muriate of potash	Turned under	(1.88)	(1.88)	1.88	30.7	3.16	28.0	3.20
	1907	50 lbs. muriate of potash	"	0.95	0.81	0.88	22.7	1.32	26.3	1.45
	1908	" "	"	0.80	1.32	1.06	27.0	1.39	32.0	1.76
	1909	" "	"	0.46	0.83	0.65	12.7	0.76	18.0	0.96
		Average		1.02	1.21	1.12	23.3	1.48	26.1	1.84

TABLE VI—*Yields per acre of cowpea hay and of wheat for each of the first four years at the farm of W. P. Ford, Knox County—Continued*

Plot	Year	Fertilizer per acre	Disposition of cowpea crop	Cowpea hay			Wheat			
				Unlimed	Limed	Average	Unlimed		Limed	
							Grain	Straw	Grain	Straw
				Ton	Ton	Ton	Bu.	Ton	Bu.	Ton
2	1906	590 lbs. phosphate rock, 50 " muriate of potash	Turned under	(1.92)	(1.92)	1.92	26.3	1.69	26.3	1.88
	1907	" "	"	0.37	0.25	0.31	17.0	0.97	19.0	1.07
	1908	" "	"	0.85	0.89	0.87	23.0	1.15	24.0	1.32
	1909	" "	"	0.51	0.49	0.50	10 7	0.64	13.3	0.72
		Average		0.91	0.89	0.90	19.3	1.11	20.7	1.25
13	1906	885 lbs. phosphate rock, 50 " muriate of potash	Turned under	(1.82)	(1.82)	1.82	31.0	2.05	30.0	2.26
	1907	" "	"	0.39	0.34	0.37	21.7	1.17	22.0	1.18
	1908	" "	"	0 61	0.96	0.79	23.3	1.18	24 7	1.26
	1909	" "	"	0.34	0.38	0.36	9.0	0.57	13.3	0.72
		Average		0.79	0.88	0.84	2.13	1.24	22.5	1.36
9	1906	1690 lbs. Thomas slag, 50 " muriate of potash	Turned under	(2.51)	(2.51)	2.51	32.7	3.19	28.0	2.92
	1907	50 lbs. muriate of potash	"	0.95	0.82	0.89	23.3	1.26	27.0	1.33
	1908	" "	"	1.03	1.28	1.16	25.7	1.31	31.3	1.70
	1909	" "	"	0.54	0.65	0.60	12.7	0.78	17.0	0.95
		Average		1.26	1.32	1.29	23.6	1.64	25.8	1.73
6	1906	None	Removed	(1.55)	(1.55)	1.55	15.7	1.03	22.3	1.63
	1907	"	"	0.14	0.14	0.14	10.7	0.64	18.7	1.04
	1908	"	"	0 22	0.55	0.39	12.7	0.68	17.7	0.90
	1909	"	"	0.11	0.21	0.16	1.0	0.09	6.7	0.44
		Average		0.51	0.61	0.56	10.0	0.61	16.4	1.00

TABLE VI—*Yields per acre of cowpea hay and of wheat for each of the first four years at the farm of W. P. Ford, Knox County—Concluded*

Plot	Year	Fertilizer per acre	Disposition of cowpea crop	Cowpea hay			Wheat			
				Unlimed	Limed	Average	Unlimed		Limed	
							Grain	Straw	Grain	Straw
				Ton	Ton	Ton	Bu.	Ton	Bu.	Ton
7	1906	290 lbs. acid phosphate, 50 lbs. muriate of potash	Removed	(2.22)	(2.22)	2.22	26.7	1.76	28.7	2.02
	1907	" "	"	0.68	0.68	0.68	16.0	0.86	23.0	1.11
	1908	" "	"	0.64	1.18	0.91	16.3	0.75	25.7	1.19
	1909	" "	"	0.37	0.56	0.47	8 7	0.50	15.7	0.80
		Average		0.98	1.16	1.07	16.9	0.97	23.3	1.28
3	1906	590 lbs. phosphate rock, 50 " muriate of potash	Removed	(2.01)	(2.01)	2.01	25.3	1.86	26.3	2.01
	1907	" "	"	0.47	0.23	0.35	16.0	1.00	16.3	0.91
	1908	" "	"	0.96	0.82	0 87	21.0	1.01	18.3	0.97
	1909	" "	"	0.61	0.61	0.61	9.3	0.66	10.7	0.68
		Average		1.01	0.92	0.96	17.9	1.13	17.9	1.14

TABLE VII—*Summary of yields of both cowpea hay and wheat at the farm of W. P. Ford, Knox County—average yields per acre for seasons 1906-1910*

Plot	Fertilizer per acre—annual applications, except as indicated	Disposition of cowpea crop	Cowpea hay		Wheat			
					Unlimed		Limed	
			Unlimed	Limed	Grain	Straw	Grain	Straw
			Ton	Ton	Bu.	Ton	Bu.	Ton
10	None	Turned under	0.78	0.84	16.0	1.08	19.5	1.35
14	50 lbs. muriate of potash	"			13.7	0.81	16.7	1.01
5	193 lbs. acid phosphate	"	0.92	1.22	18.7	1.21	22.9	1.63
8	97 lbs. acid phosphate 50 " muriate of potash	"	0.93	1.13	19.1	1.15	24.4	1.49
4	193 lbs. acid phosphate 50 " muriate of potash	"	0.99	1.05	18.9	1.21	22.7	1.48
12	290 lbs. acid phosphate 50 " muriate of potash	"	0.99	1.10	22.0	1.31	25.7	1.58
15	1740 lbs. acid phosphate* 50 " muriate of potash	"	0.94	1.16	....	....	....	....
	Average for acid phosphate		0.95	1.13	19.7	1.22	23.9	1.55
11	1260 lbs. bone meal* 50 " muriate of potash	Turned under	1.02	1.21	23.3	1.48	26.1	1.84
2	590 lbs. phosphate rock 50 " muriate of potash	"	0.91	0.89	19.3	1.11	20.7	1.25
13	885 lbs. phosphate rock* 50 " muriate of potash	"	0.79	0.88	21.3	1.24	22.5	1.36
	Average for phosphate rock		0.85	0.89	20.3	1.17	21.6	1.31
9	1690 lbs. Thomas slag* 50 " muriate of potash	Turned under	1.26	1.32	23.6	1.64	25.8	1.73
6	None	Removed	0.51	0.61	10.0	0.61	16.4	1.00
7	290 lbs. acid phosphate 50 " muriate of potash	"	0.98	1.16	16.9	0.97	23.3	1.28
3	590 lbs. phosphate rock 50 " muriate of potash	"	1.01	0.92	17.9	1.13	17.9	1.14

* Only one application of phosphate.

TABLE VIII—*Financial outcome from the phosphates in Series II, on the farm of W. P. Ford, Knox County—average annual results per acre for four years*

Plot	Phosphate	Disposition of cowpea crop	Annual cost of phosphate	Calculated increase of wheat from phosphate				Calculated profit from phosphate	
				Unlimed		Limed		Unlimed	Limed
				Grain	Straw	Grain	Straw		
				Bu.	Ton	Bu.	Ton		
5	193 lbs. acid phosphate	Turned under	$1.54	2.7	0.13	3.4	0.28	$1.16	$1.86
8	97 " " "	"	0.78	3.1	0.07	4.9	0.14	2.32	4.12
4	193 " " "	"	1.54	2.9	0.13	3.2	0.13	1.36	1.66
12	290 " " "	"	2.32	6.0	0.23	6.2	0.23	3.68	3.88
	Average		1.55	3.7	0.14	4.4	0.20	2.13	2.88
11	1260 lbs. steamed bone meal—once for the four years	Turned under	4.73	7.3	0.40	6.6	0.49	2.57	1.87
2	590 lbs. phosphate rock	"	2.36	3.3	0.03	1.2	0.00	0.94	1.16
13	885 " " " —once for the four years	"	0.88	5.3	0.16	3.0	0.01	4.42	2.12
	Average of phosphate r'k plots		1.62	4.3	0.10	2.1	0.01	2.68	0.48
9	1690 lbs. Thomas slag—once for the four years	Turned under	4.23	7.6	0.56	6.3	0.38	3.37	2.07
7	290 lbs. acid phosphate	Removed	2.32	6.9	0.36	6.9	0.28	9.28*	13.78*
3	590 " phosphate rock	"	2.36	7.9	0.16	1.5	0.00	10.54*	2.24*

* Increase of cowpea crop included.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Unlimed half	PK (A.P.) Annual	P6K (P.R.) Annual	P6K (P.R.) Annual	PK (A.P.) Annual	P (A.P.) Annual	No fertilizer	P1½K (A.P.) Annual	P½K (A.P.) Annual	P9K (T.S.) Once	No fertilizer	P9K (B.M.) Once	P1½K (A.P.) Annual	P9K (P.R.) Once	K Annual	P9K (A.P.) Once
Limed half	No peas grown	Peas under	Peas removed	Peas under	Peas under	Peas removed	Peas removed	Peas under	Peas under	Peas under	Peas under	Peas under	Peas under	Peas under	Peas under

DIAGRAM 2—THE PLOTS ON THE FORD FARM

	1	2	3	4	5	6	7	8	9	10	11
Limed half	No fertilizer	No fertilizer	P1½K (A.P.) Annual	P1½K (A.P.) Annual	P1½ (A.P.) Annual	K Annual	P9K (P.R.) Once	P9K (P.R.) Once	P1½K (B.M.) Annual	No fertilizer	P3K (B.M.) Once
Unlimed half	Peas under	Peas removed	Peas under	Peas removed	Peas under	Peas under	Peas removed	Peas under	Peas under	No peas	Peas under

DIAGRAM 3—THE PLOTS ON THE WEAVER FARM

cluded in the estimates only when removed for hay—were taken, as follows:

Acid phosphate	$16.00 per ton
Steamed bone meal	30.00 " "
Phosphate rock	8.00 " "
Thomas slag	20.00 " "
Wheat	1.00 per bu.
Cowpea hay	10.00 per ton

No account was taken of the applications of muriate of potash, which does not appear to have influenced the production of either cowpeas or wheat during the four-year period.

COMMENTS ON THE RESULTS OBTAINED ON THE FARM OF W. P. FORD, KNOX COUNTY

Because of the scant supply of available phosphoric acid the eight crops harvested in this series furnish much more important data in regard to the practical worth of the different phosphates than were obtained at the Station farm. Not only was the original amount of phosphoric acid in the soil less, but the long continued and hard cropping had reduced it more than was the case with the Station soil.

1—THE EFFECT OF THE PHOSPHATES ON THE YIELDS WHERE THE COWPEA CROPS WERE TURNED UNDER

This second series was conducted, like the first, on a soil which was plainly in need of lime, so that the effects of the different phosphates when used with and without the addition of lime form an especially valuable part of the results.

WITHOUT THE ADDITION OF LIME

Inspection of Table VII, which gives a summary of the yields, shows that on the unlimed side acid phosphate with its high content of soluble phosphoric acid, produced on plots 4, 5, 8, 12 and 15, the average of only 200 pounds of cowpea hay per acre more than the relatively insoluble phosphate rock on plots 2 and 13; the heavy application of 1260 pounds of bone meal per acre, made only once, at the outset of the experiments, produced a yield of only 340 pounds of hay more than the phosphaate rock; but the heavy application of Thomas slag, with its high content of lime, increased the yield per acre over the phosphate rock by 820 pounds of hay. The effects on the yields of wheat were similar to the foregoing, except that the average of the three unlimed halves of the acid phosphate plots yielded less than the two unlimed halves of the phosphate rock plots by 0.6 bushel of grain per acre, and the Thomas slag, although producing an annual average of 3.3 bushels of grain more than the phosphate rock, surpassed the bone meal by only 0.3 bushel per acre.

WITH THE ADDITION OF LIME

Liming, however, produced a marked change in the comparative effects of the different phosphates. In particular it decreased the relative values of both phosphate rock and Thomas slag. The limed side of the phosphate rock plots as compared with the unlimed produced an average yearly increase of only 80 pounds of hay and 1.3 bushel of wheat per acre. On the other hand, in the case of the acid phosphate the average increase was 260 pounds of hay and 4.2 bushels of wheat and the production surpassed that for the phosphate rock by 480 pounds of hay and 2.3 bushels of wheat per acre, the latter being nearly sufficient to pay for the rather heavy application of 300 pounds of acid phosphate. With the bone meal the limed side yielded at the rate of 380 pounds of hay and 2.8 bushels of wheat per annum more than the unlimed, and as compared with phosphate rock was superior by 640 pounds of hay and 4.5 bushels of wheat. With an amount of phosphoric acid from Thomas slag equal to that from the bone meal, the lime increased the yield of hay by only 120 pounds and of wheat by 2.2 bushels, but as compared with phosphate rock the increase was 860 pounds of hay and 4.2 bushels of wheat per acre. This increase in grain would, at $1.00 per bushel, practically pay for the heavy dressing of the slag. In like manner the yield of grain from bone meal over the average yields from phosphate rock would nearly pay for the meal. Also it may be noted that with either the slag or the bone the superior effects are by no means ended but would be fully expected to appear in succeeding crops.

2—THE EFFECT OF ACID PHOSPHATE AND OF PHOSPHATE ROCK WHERE THE COWPEA CROP WAS REMOVED EACH YEAR

In this comparison the acid phosphate and the phosphaate rock gave nearly the same results on the unlimed side of the plots and each material was used with profit. The slight difference between the yields of both cowpea hay and wheat was, however, in favor of the phosphate rock and, as the cost of each material as used was practically the same, the profit would also be somewhat in favor of the rock. On the limed side, however, the phosphate rock, as with the plots where the peas were turned under, failed to make the decided gain either of hay or of grain that was obtained from the acid phosphate, the superior increase produced by the latter being a yearly average of 480 pounds of hay and 5.4 bushels of wheat per acre. These superior yields would thrice pay for a 300-pound application of acid phosphate, the phosphoric acid of which would more than twice replace the quantity removed by the crops.

SERIES III, ON WEAVER BROS.' FARM, NEAR McMINNVILLE, WARREN COUNTY

The experiments of Series III were made on a typical gray-colored silt loam with light red subsoil of the Highland Rim, a soil known to be very poorly supplied with both phosphoric acid and lime and, as a rule, also with nitrogen. The range was selected with regard to uniformity of drainage and fertility, and the appearance of the growing crops indicated that it was well suited to the purpose. Neither manure nor fertilizer had been previously applied, so far as could be learned, and the cropping had been that commonly followed in that section of the State—wheat, corn, and occasionally cowpeas. Land of this character is seldom seeded to clover, but is often left to grow up in weeds "to rest" for a year or two, in which time enough available plant food accumulates to produce a remunerative farm crop.

As in the previous series, one-half of the entire range was limed at the outset of the experiments, but before the seeding of the first cowpea crop, at the rate of one ton of burnt lime to the acre.

The trials have run for three years with the production of six crops, three each of cowpeas and wheat. The yields of cowpea hay were not accurately obtained for every plot each year, so that a large proportion of the data for this crop in Table IX are only estimates based on the comparative growth on the plots, some of which, as indicated in the table, were always carefully harvested. All the yields of wheat were accurately gotten and furnish, therefore, the more reliable data.

COMMENTS ON THE RESULTS OF SERIES III

Table X, which gives a summary of the crop production for the three years, and Table XI, which affords a financial comparison, show plainly that whether used with or without liming, both acid phosphate and bone meal far surpassed the phosphate rock with regard either to the yield of grain or to financial returns. For either material the increase in yield over the production on the phosphate rock plots would much more than have paid for the phosphate. The comparisons are fair because there were two plots for each of the sources of phosphoric acid. The excellent financial returns from the steamed bone meal, whether used with or without liming, are noticeable. On plot 11 the heavy dressing of 600 pounds per acre of the meal at the beginning of the trials was followed with especially favorable results. Superior effects from a single heavy application of this material as compared with annual light applications of either bone meal or acid phosphate have been observed by the writer several times in cases of very poor soils and are worthy of consideration.

As this soil was decidedly the poorest in phosphoric acid of the four types, and also was not acid by the Veitch test, the effect of

TABLE IX—*Yields per acre of cowpea hay and of wheat for each of the first three years at Weaver Bros.' farm, near McMinnville, Warren County*

Plot	Year	Fertilizer per acre	Disposition of cowpea crop	Cowpea hay		Wheat			
						Unlimed		Limed	
				Unlimed	Limed	Grain	Straw	Grain	Straw
				Ton	Ton	Bu.	Ton	Bu.	Ton
1	1907	None	Turned under	0.26*	0.46*	6.5	0.36	16.2	0.95
	1908	"	"	0.12	0.11	6.4	0.37	11.0	0.61
	1909	"	"	0.26*	0.26*	2.7	0.16	3.8	0.23
		Average		0.21	0.28	5.2	0.30	10.3	0.60
6	1907	50 lbs. muriate of potash	Turned under	0.26*	0.46*	9.4	0.52	13.2	0.78
	1908	" "	"	0.12*	0.11*	7.1	0.45	6.2	0.40
	1909	" "	"	0.26*	0.26*	6.3	0.38	4.4	0.26
		Average		0.21	0.28	7.6	0.45	7.9	0.48
5	1907	300 lbs. acid phosphate	Turned under	0.69*	0.94*	18.8	1.09	24.4	1.45
	1908	" "	"	0.18*	0.30*	18.1	0.93	19.8	0.97
	1909	" "	"	0.53*	0.73*	14.8	0.89	17.7	1.06
		Average		0.47	0.66	17.3	0.97	20.6	1.16
3	1907	300 lbs. acid phosphate 50 " muriate of potash	Turned under	0.69*	0.94*	13.9	0.81	22.5	1.34
	1908	" "	"	0.18	0.30	19.5	1.00	18.8	0.92
	1909	" "	"	0.53	1.11	16.3	0.98	15.6	0.93
		Average		0.47	0.78	16.6	0.93	19.0	1.06
9	1907	200 lbs. bone meal 50 " muriate of potash	Turned under	0.69*	0.94*	20.1	1.16	22.3	1.33
	1908	" "	"	0.27	0.29	16.0	0.86	18.1	0.98
	1909	" "	"	0.53*	0.73*	15.9	0.95	15.7	0.94
		Average		0.50	0.65	17.3	0.99	18.7	1.08

* Estimated by comparative appearance.

TABLE IX—*Yields per acre of cowpea hay and of wheat for each of the first three years at Weaver Bros.' farm, near McMinnville, Warren County—Concluded*

Plot	Year	Fertilizer per acre	Disposition of cowpea crop	Cowpea hay		Wheat			
						Unlimed		Limed	
				Unlimed	Limed	Grain	Straw	Grain	Straw
				Ton	Ton	Bu.	Ton	Bu.	Ton
8	1907	900 lbs. phosphate rock, 50 " muriate of potash	Turned under	0.65*	0.64*	13.0	0.75	21.9	1.30
	1908	" "	"	0.27	0.23	13.0	0.67	11.3	0.58
	1909	" "	"	0.30	0.23	11 0	0 66	6 7	0.40
		Average		0.41	0.37	12.3	0.69	13 3	0.76
2	1907	None	Removed	0.26	0.46	6 2	0.35	11.9	0.70
	1908	"	"	0.12	0.11	6.6	0.38	11.1	0.62
	1909	"	"	0.26	0.21	3.1	0.19	4.7	0.28
		Average		0.21	0.28	5.3	0.31	9.2	0.53
4	1907	300 lbs. acid phosphate, 50 " muriate of potash	Removed	0.69	0.94	15.4	0.88	19.1	1.04
	1908	" "	"	0.18	0.25	17.8	0.95	17.3	0.92
	1909	" "	"	0.53	0.73	11.6	0.69	13.1	0.79
		Average		0.47	0.64	14.9	0.84	16.5	0.92
11	1907	600 lbs. bone meal, 50 " muriate of potash	Removed	1.20	1.30	23.5	1.36	23.0	1.37
	1908	50 lbs. muriate of potash	"	0.41	0.39	15.0	0.91	18.3	1.11
	1909	" "	"	0.54	0.87	9.0	0.54	9.8	0.59
		Average		0.72	0.85	15.8	0.94	17.0	1.02
7	1907	900 lbs. phosphate rock, 50 " muriate of potash	Removed	0.65	0.64	13.5	0.64	15.0	0.87
	1908	50 lbs. muriate of potash	"	0.27	0.20	10.3	0.57	7.5	0.44
	1909	" "	"	0.30	0.23	8.0	0.48	3.8	0.23
		Average		0.41	0.37	10 6	0.57	8.8	0.56

* Estimated by comparative appearance.

TABLE X—*Summary of yields of cowpea hay and of wheat at Weaver Bros.' farm—average yields per acre for seasons 1908-1910*

Plot	Fertilizer per acre—annual applications except as indicated	Disposition of cowpea crop	Cowpea hay		Wheat			
					Unlimed		Limed	
			Unlimed	Limed	Grain	Straw	Grain	Straw
			Ton	Ton	Bu.	Ton	Bu.	Ton
1	None	Turned under	0.21	0.28	5.2	0.30	10.3	0.60
6	50 lbs. muriate of potash	" "	0.21	0.28	7.6	0.45	7.9	0.48
	Average of check plots 1 and 6		0.21	0.28	6.4	0.38	9.1	0.54
5	300 lbs. acid phosphate	Turned under	0.47	0.66	17.3	0.97	20.6	1.16
3	300 lbs. acid phosphate + 50 " muriate of potash	" "	0.47	0.78	16.6	0.93	19.0	1.06
	Average of acid Phos. plots 3 & 5		0.47	0.72	17.0	0.95	19.8	1.11
9	200 lbs. steamed bone meal + 50 " muriate of potash	Turned under	0.50	0.65	17.3	0.99	18.7	1.08
8	900 lbs. phosphate rock* + 50 " muriate of potash	" "	0.41	0.37	12.3	0.69	13.3	0.76
2	None	Removed	0.21	0.28	5.3	0.31	9.2	0.53
4	300 lbs. acid phosphate + 50 " muriate of potash	"	0.47	0.64	14.9	0.84	16.5	0.92
11	600 lbs. steamed bone meal* + 50 " muriate of potash	"	0.72	0.85	15.8	0.94	17.0	1.02
7	900 lbs. phosphate rock* + 50 " muriate of potash	"	0.41	0.37	10.6	0.57	8.8	0.56

* Only one application of phosphate.

TABLE XI—*Financial outcome from the phosphates in Series III, on Weaver Bros.' farm, Warren County—average annual results per acre for three years*

Plot	Phosphate	Disposition of cowpea crop	Annual cost of phosphate	Calculated increase of wheat from phosphate				Calculated profit from phosphate	
				Unlimed		Limed		Unlimed	Limed
				Grain	Straw	Grain	Straw		
				Bu.	Ton	Bu.	Ton		
5	300 lbs. acid phosphate	Turned under	$2.40	10.9	0.59	11.5	0.62	$8.50	$9.10
3	" " " "	" "	2.40	10.2	0.55	9.9	0.52	7.80	7.50
	Average		2.40	10.6	0.57	10.7	0.57	8.15	8.30
9	200 lbs. steamed bone meal	" "	3.00	10.9	0.61	9.6	0.54	7.90	6.60
8	900 " phosphate rock—once for three years	" "	1.20	5.9	0.31	4.2	0.22	4.70	3.00
4	300 lbs. acid phosphate	Removed	2.40	9.6	0.53	7.3	0.39	9.80*	8.50*
11	600 " steamed bone meal—once for three years	"	3.00	9.4	0.56	7.9	0.48	11.50*	10.60*
7	900 lbs. phosphate rock—once for three years	"	1.20	5.3	0.26	0.0	0.03	6.10*	–0.40*

* Increase of cowpea hay included.

liming on the availability of the phosphates is of special interest. According to Table XI the application of lime did not lessen the increase produced by the acid phosphate except on plot 4, where the cowpeas were removed, but even there the cowpea hay shows an increase. For both of the bone meal plots and for phosphate rock plot (8), where the cowpeas were turned under, there is a falling off in every case of about 1 1-2 bushel of wheat per acre, but on plot 7, where phosphate rock was applied and the cowpea crop removed annually, there was no increase in wheat and a scarcely noticeable increase in hay. The first three series agree, therefore, in showing a serious decrease in the value of phosphate rock under liming.

SERIES IV, ON THE FARM OF W. P. STORY, SPARTA, WHITE COUNTY

This series was conducted for two years on a typical dark red ("mulatto") soil derived from limestone of the Highland Rim. This type of soil is heavier than the preceding and is known to be naturally deficient in phosphoric acid. In this particular case a greatly impoverished knoll was purposely selected. The plots were of the same size as in the other series, 1-40 acre each (18x60.5 feet), with 2-foot paths between them, and one-half the area was limed as in Series III. The appearance both of the soil and of the growing crops indicated exceptional uniformity in fertility. On each of the four plots the growth of cowpeas was turned under each year. Unfortunately it proved impossible to conduct this series with proper regard to preparation of soil and time of seeding, which accounts in large part for the low yields obtained. However, the conditions were the same so far as a comparison of the phosphates is concerned. The results given in Table XII indicate that neither phosphate rock nor bone meal was a profitable source of phosphoric acid under the conditions of the trial; whereas, acid phosphate practically doubled the yields and proved to be the economical material to use in the building up of such a soil.

TABLE XII—*Average yields of wheat per acre in a comparison of acid phosphate, bone meal, and phosphate rock, on the farm of W. P. Story, Sparta, White County—two seasons, 1908 and 1909*

Plot	Fertilizer per acre*	Unlimed		Limed	
		Grain	Straw	Grain	Straw
		Bu.	Ton	Bu.	Ton
6	50 lbs. muriate of potash	4 4	0.26	4.8	0.29
4	300 lbs. acid phosphate 50 " muriate of potash	8.5	0.51	9.9	0.59
8	900 lbs. phosphate rock 50 " muriate of potash	5.2	0.31	5.2	0.31
9	200 lbs. bone meal 50 " muriate of potash	6.3	0.37	6.2	0.36

* Annual applications of acid phosphate and bone meal, but only one application of the phosphate rock.

REMARKS ON THE FOUR SERIES CONSIDERED AS A WHOLE

The chemical analyses indicate that all four soils are similar with respect to content of lime and magnesia, which were low in each. The combined percentages of these two constituents were greatest in the Ford soil, but amounted to only 0.41 per cent, and least in the Weaver soil, which contained 0.32 per cent, the difference between them being only 0.09 per cent. None of the soils contained more than a "trace" of carbonate of lime, the form which is most readily soluble in the soil and which quickly neutralizes acidity. All four series were conducted, therefore, on soils distinctly poor in lime, so that a similarity of results, especially with regard to the effect of liming on the relative availability of the different phosphates, might be expected. In order to make a satisfactory field test of this nature, a prime essential is a soil in great need of phosphoric acid. Because of the good supply of this element the soil of Series I was poorly suited to this purpose, but even here there is a distinct tendency of liming to lower the availability of the phosphate rock, but not to affect the acid phosphate, whose relative standing is appreciably advanced. Series II was on a soil which gave fair response to phosphating and, as in Series I, the rock acts well where no lime was applied. In fact, the financial returns according to Table VIII are in its favor. But under liming the standing of the two materials is reversed to such an extent that the rock is next to unprofitable while the acid phosphate is highly profitable, in particular where the removal of the cowpea crop exhausted the soil supply of phosphoric acid to the greatest extent. In Series III, where the soil was poorest in phosphoric acid, although there is the same marked tendency of the phosphate rock to give inferior returns under liming, there is a difference from the results of the first two series in that on the unlimed plots the rock is decidedly inferior to acid phosphate. The explanation which the writer thinks most plausible for this result is that in Series I and II the solvents, such as acid humus and carbnoic acid in the unlimed soil, were present in greater quantity than in either Series III or IV. This is indicated by the amounts, as determined by chemical analysis, of both humus and acidity, which are greater for the soils of the first two than the last two series. In each series the liming was ample to correct acidity and, at least in Series III and IV, would be expected to render the soil slightly alkaline, a condition which is recognized as unfavorable to the solution of the so-called insoluble phosphates. With acid phosphate, however, a moderate excess of lime in the soil is not considered detrimental, for the precipitated phosphate of lime, which would then be produced, is known to be highly available to plants and much superior to the phosphates of iron, aluminum, etc., which would otherwise be formed.

The steamed bone meal, although included among the relatively insoluble phosphates, appears in these experiments to occupy an inter-

mediate place, with returns little inferior to those from acid phosphate. As compared with phosphate rock the mechanical condition of the meal is in its favor; also its content of organic matter is supposed to assist in its decomposition. But in these experiments the influence of the nitrogen contained in the meal must not be overlooked and probably gives it a higher standing than can be attributed to the phosphoric acid alone. Evidently it is a valuable fertilizer for soils like these, and the confidence placed in it by many farmers of the Highland Rim and other parts of the State seems not to have been misplaced.

The experiments with Thomas slag were not sufficiently extended to afford all the evidence desired, but the results are very much in its favor, especially if a large enough application be made to take the place of liming, in which event it promises to be the most profitable of all the phosphates. Of course the initial cost of such an application is large, but otherwise there does not appear to be any objection to it. There are probably conditions under which a very heavy application of bone meal may be made to advantage once in a term of years, as in a rotation of crops when the land is to be laid down to grass, and to start profitable production on land very poor in both phosphoric acid and nitrogen, but acid phosphate should probably be applied frequently and in small quantity as is the custom. An attempt was made in both Series I and II to test this point with regard to acid phosphate, but for different reasons the outcome was unsatisfactory. The yields from plot 15 of Series II indicate a rather rapid falling off in availability where no lime was applied, but are fairly good under liming, though it should be remembered that two more years are needed to finish the comparison with plot 12, which received annually 1-6 the quantity of acid phosphate.

Although each series should be considered by itself, the fact that these are common types of soil makes their average production under the different conditions of value by affording some indication of the probable worth of the different materials when used on other farms. With this object in view, Table XIII has been prepared. In this table the profit has been calculaated only on the phosphate basis, as in Tables VIII and XI; that is, without consideration being taken of the application of potash, which seems not to have been necessary. According to this table, without liming acid phosphate ranks first, bone meal second, and phosphate rock third in profitableness of returns whether the cowpeas be turned under for green manure or removed for hay, but any one of the three may be used with profit. Under liming, which is necessary in order to get remunerative crops of clover on these soils, and is therefore fundamental to their most successful management, acid phosphate is easily first, bone meal may be used with profit, but phosphate rock is liable to be used at a loss.

There is a somewhat popular opinion, especially among those who are interested in the sale of phosphate rock, that the rock increases

TABLE XIII—*The results of Series I, II, and III averaged for both annual yields and financial returns per acre—Series I, last four years; Series II, four years; Series III, three years. The results of each series were allowed one-third in the estimates*

No. of plots included	Kind of phosphate	Disposition of cowpea crop	Yield of wheat				Calculated increase of wheat from phosphate				Annual average quantity of phosphate	Cost of phosphate	Calculated profit from phosphate	
			Unlimed		Limed		Unlimed		Limed				Unlimed	Limed
			Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw				
			Bu.	Ton	Bu.	Ton	Bu	Ton	Bu.	Ton	Lbs.			
5	None	Turned under	15 2	0 99	18.2	1.19								
8	Acid phosphate	" "	20.4	1.19	24.5	1.45	5.2	0.20	6.3	0.26	229	$1 83	$3.37	$4.47
3	Steamed bone meal	" "	21.6	1.34	24.2	1.55	6.4	0.35	6.0	0.36	218	3.27	3.13	2.73
5	Phosphate rock	" "	19.3	1.20	21.1	1.32	4.1	0 21	2 9	0.13	383	1.53	2.57	1.37
3	None	Removed	10.2	0.61	15 2	0.87								
4	Acid phosphate	"	16.5	0 94	20.8	1.17	6.3	0 33	5.6	0.30	261	2.09	5.34*	5 98*
3	Phosphate rock	"	15.4	0.90	15.2	0.90	5.2	0.29	0.0	0.03	385	1.54	4.73*	-0.77*

* Value of the increased yield of cowpea hay included.

appreciably in effectiveness with the lapse of time after incorporation with the soil. A comparison of the last crops harvested throughout the series gives little ground for this opinion. A consideration of the per cent of decrease in yield from the first to the last crop of wheat, for each phosphated and unphosphated plot where the cowpeas were turned under, shows that the unphosphated plots, as an average of the first three series, declined most and that phosphate rock, bone meal, and acid phosphate followed in the order named.

Another argument advanced in favor of phosphate rock is that its cheapness will permit the making of heavy applications, supplying an excess of phosphoric acid over that removed by the crops, so that there will be a "permanent" increase in the soil supply. The results obtained here, however, demonstrate that under liming, which should be considered necessary, acid phosphate would without doubt be a more profitable material than phosphate rock. In fact, where there is an evident deficiency of phosphoric acid, as in the soils of Series II, III, and IV, the increased yield from acid phosphate over the yield from phosphate rock would pay for at least a 300-pound application of acid phosphate, an amount which would not only replace the phosphoric acid removed by 25 bushels of wheat, including the straw, but also leave for "permanent" improvement a balance of about 180 pounds of the phosphate. If a soil be well supplied with phosphoric acid, as in Series I on the Station farm, then only a light application of the acid phosphate would be warranted, say not more than enough to replace the quantity removed, or, for a 25-bushel crop of wheat, about 120 pounds, which would be expected to surpass in profitableness an equal money value of phosphate rock. There seems, therefore, to be little promise in phosphate rock on soils like those under consideration, unless liming be omitted, and even then the results of Series III and IV show that acid phosphate may be much more profitable than the untreated rock.

NOTE—For the most excellent manner in which the field work on which this bulletin is based was carried out, the author is especially indebted to Mr. S. M. Spanger, who had in his care both the Station and the Ford series. Also thanks are due to Mr. W. N. Rudd, who had supervision of the series on Weaver Brothers' farm and that on the Story farm.