TEXAS AGRICULTURAL EXPERIMENT STATION

BULLETIN NO. 178 SEPTEMBER, 1915

DIVISION OF CHEMISTRY

Effect of the Additions on Availability of Soil Phosphates

POSTOFFICE:
College Station, Brazos County, Texas

AUSTIN, TEXAS
Von Boeckmann-Jones Co., Printers
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BY

G. S. FRAPS, Ph. D.,
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*As of October 1, 1915.
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Effect of Additions on Availability of Soil Phosphates.

BY

G. S. FRAPS, PH. D., CHEMIST IN CHARGE; STATE CHEMIST.

It has been known for some time that lime and organic matter, in a general way, have a tendency to make the plant food of the soil more available. It has been claimed that manure applied with rock phosphate renders the phosphoric acid more available, but this, on the other hand, has been disputed (see Hartwell, Bulletin No. 151, Rhode Island Experiment Station). The writer has been able to find few facts on record in the literature referring to the action of lime on soil phosphates. Wheeler (Rhode Island Bulletins) has pointed out that an acid soil which responded to phosphoric acid before liming, after liming did not respond to phosphatic fertilizers. In experiments on different forms of phosphates, lime often increases the effect of the phosphate (Rhode Island Bulletin No. 118). It is, however, difficult to distinguish between the improvement of soil conditions due to the use of the lime, and increase in availability of the phosphate. Liming injuriously affects the phosphoric acid of the soil, rendering it less soluble according to B. Schulze (Experiment Station Record 16, 32).

Application of alkaline substances (lime, potassium carbonate) exerts an unfavorable influence on the assimilation of soil phosphoric acid according to M. Nagaoka (Experiment Station Record 16, 556).

Lime increased the phosphoric acid taken from the soil phosphates by oats, but it decreased that taken from bone meal or tricalcium phosphate (Soderbaum, Experiment Station Record 14, 951).

Lime exerts a retarding and injurious influence upon the availability of the phosphoric acid of organic manures to rice (in fish scrap, bone, rice bran, rape cake). M. Nagaoka (Experiment Station Record 16, 554).

A number of investigators find that lime decreases the phosphoric acid taken by crops from bone meal or rock phosphate, including Kellner, Nagaoka, Soderbaum, and Mooers.

The observations with respect to the action of lime on soil phosphates are contradictory. This may be due to the character of soil phosphates; the lime may exert a depressing effect when the phosphoric acid is in the form of tricalcium phosphate, and it may have a favorable action when the phosphoric acid is in the form of mono-calcium or di-calcium phosphate or united to iron or aluminium.

This matter is of considerable importance in soil chemistry. As pointed out in Bulletin No. 126 of this Station, the needs of soils for phosphatic fertilizer in pot experiments are, on an average, related to their content of active phosphoric acid. As there also pointed out, there are decided deviations from the average in various soil individuals. The quantity of phosphoric acid taken up by the crops may be affected by the lime, vegetable matter, or other soil constituents. If such is the case, deviations from the average may be due on the one hand to deficiency of favoring soil ingredients, or, on the other hand, to larger favorable quantities. Thus two soils containing the same quantity of active plant food might supply differing quantities of phosphoric acid to plants on account of deficiency of favoring substances in the one and a favorable quantity in the other. The quantity of lime and vegetable matter would thus be a factor to be taken into consideration along with the active phosphoric acid.

The matter is also of practical importance. If addition of lime or vegetable matter increases the quantity of phosphoric acid which plants may take from the soil, such addition would be equivalent to the use of a phosphatic fertilizer, at least to a limited extent. Phosphates must, however, eventually be supplied to replace those removed from the soil, since the low quantity of phosphates must in time reduce the productive powers of the soil.

DESCRIPTION OF THE EXPERIMENTS.

The experiments here described were undertaken for the purpose of studying the effect of carbonate of lime and vegetable matter upon the assimilation of the soil phosphates by plants. Precipitated carbonate of lime was used, and ground corn cobs, sawdust, and starch, were used for organic materials. These were selected for the reason that they contain only traces of phosphoric acid. The selection was not altogether fortunate, especially the starch, since it set up a fermentation that injured the first crops grown in its presence.

Description of Soils.

No. 894—Depth 0"-6". This is Norfolk fine sandy loam. It was taken from the farm of J. M. Pluperts, Nacogdoches, Texas.

No. 895—Depth 0"-12". This is Lufkin fine sand. It was taken from the farm of F. M. Smith, one mile north of Lufkin, Angelina county, Texas.

No. 1145—Depth 12"-22". This soil is Lufkin fine sand. It was taken from the farm of F. M. Smith, Lufkin, Angelina county, Texas.

No. 992—Depth 0"-12". This soil is Orangeburg fine sandy loam. The sample was taken at Jacksonville, Cherokee county, Texas.

No. 993—Depth 0"-12". This soil is Orangeburg clay. The sample was taken from the farm of J. F. Burgess, Nacogdoches, Nacogdoches county, Texas.

No. 1144. This soil is Norfolk fine sandy loam. The sample was taken at Jacksonville, Cherokee county, Texas.

TABLE 1—COMPOSITION OF THE SOILS.

	Norfolk fine sandy loam. Nacogdoches County. Surface 894	Lufkin fine sandy loam. Angelina County. Surface 895	Orangeburg fine sandy loam. Cherokee County. Surface 992	Orangeburg clay. Nacogdoches County. Surface 993	Norfolk fine sandy loam. Cherokee County. Surface 1144	Lufkin fine sand. Angelin a County. Subsoil 1145
Percent—						
Phosphoric Acid	.04	.03	.15	.05	.09	.01
Nitrogen	.07	.06	.04	.05	.06	.07
Potash	.27	.08	.59	.22	....	.09
Lime	.06	.14	.29	.11	.17	.13
Magnesia	.04	.23	.27	.02	.11	.21
Alumina and Oxide of Iron	3.33	1.93	16.10	....	0.91	3.62
Insoluble and Soluble Silica	94.35	95.50	76.96	93.54	97.24	92.22
Loss on Ignition	1.50	2.09	5.42	1.48	....	2.74
Moisture	.27	.66	1.08	.45	....	1.76
Parts per Million—						
Active Phosphoric Acid	15.4	27.8	1.50	15.6	32.0	23.7
Active Potash	....	167.5	....	....	....	....
Acidity	....	300	....	....	....	200

The chemical composition of the soils is given in Table 1.

Details of the Experiments.—The quantity of soil used in the experiments was 5 kilograms. The additions were made at the rate of 25 grams per pot, equal to 0.5 per cent., or five tons per acre based on two million pounds to the depth of seven inches. The double addition of calcium carbonate (2Ca) was at the rate of 50 grams per pot of soil, or ten tons per acre. The humate was prepared by precipitating ammonium humate with calcium chloride and washing by decantation, then filtering. The amount used approximately corresponded to 20 grams humic acid per pot. The additions were made at the time of planting, and mixed thoroughly with the soil. Water was added three days before planting. All of the substances added were finely divided and the calcium carbonate was in the form of precipitated chalk. No additions of phosphoric acid were made to the soil, but additions of potash and nitrogen were made as described.

First Crop, Corn.—In each pot five grains of corn were planted, weighing 1.8 to 1.9 grams, seed being taken from a single ear of corn. One gram of sulphate of potash in 10 c.c. of water and one gram nitrate of soda in 10 c.c. of water were added before planting. In addition, 1 gram potassium sulphate in 200 c.c. water was added to soil 1145 on May 1; 1 gram ammonium nitrate in 200 c.c. water was added to soil 1145 on May 4; one-half gram each of nitrate of ammonia and sulphate of potash were added to soils 992, 895, 1145, on June 1.

Second Crop, Millet, 1908.—After the corn had been harvested, the pots were dug up, one gram each of sulphate of potash and ammonium nitrate added and ½ gram millet planted. The millet did not do so very well on any of the pots, as it went to seed before making a good growth.

Third Crop, Mustard.—After harvesting the millet, the pots were dug up, one gram each of sulphate of potash and nitrate of soda were put in and one-half gram mustard planted. The mustard was killed by a freeze and harvested at that time.

Fourth Crop, Corn, 1909.—The pots were dug up and one gram of sulphate of potash and one gram of nitrate of soda added to each. Five grains corn, weighing 1.8 to 1.9 grams, were planted March 8, 1909, and the crop was harvested June 9, 1909. One gram ammonium nitrate was added May 14, 1909. After this crop was harvested, the soils Nos. 894, 895, and 1145 were registered for analysis. Soils Nos. 992, 993, 1144 were used in continued tests.

Fifth Crop, Kafir, 1909.—The pots were dug up, no addition made, and 1 gram kafir planted on June 14, and harvested on August 5, 1909. Soil No. 992 was registered for analysis.

Sixth Crop, Mustard.—On soil No. 993 and 1144 only. No additions were made; planted November 21, harvested December 22 on account of freeze, one gram mustard seed having been planted.

Seventh Crop, Corn, 1910.—Two grams nitrate of soda were added to all pots after they had been dug up, and five grains planted, weight 1.45 to 1.55 grams. Harvested June 17, 1910. The plants did very poorly and the experiment was discontinued after the harvesting of this crop, all of the pots of the two soils being registered for analysis.

WEIGHTS OF CROPS SECURED.

Weights of crops secured are given in Tables 6, 7, 8, 9, 10, 11, with summary in Table 2. Inspection of this Table 2 shows a gain due to the lime in every case, except with the double amount on soil No. 894. The minimum gain is about 20 per cent. of the original crops, and the maximum gain nearly 80 per cent. An examination of the detailed tables shows that while the effect of the lime on the first crop may be slight, its effect increases with subsequent crops.

TABLE 2—GAIN OF DRY MATTER OF CROP IN GRAMS DUE TO ADDITIONS.

Laboratory Number.	Original Crop Weight.	Gain by Ca.	Gain by 2 Ca.	Gain by Starch.	Gain by Sawdust.	Gain by Cobs.	Number of Crops.
894	40.0	22.1	0	0	0	1.8	4
895	52.8	11.8	11.2	0	....	0	4
1145	16.7	13.5	16.9	0	....	2.7	4
992	53.2	20.4	21.9	8.2	....	17.2	5
993	21.5	....	16.5	14.6	11.2	1.0	7
1144	77.0	....	....	0	1.2	2.9	7

Starch produced gains on two soils, sawdust on two, and corn cobs on five. However, five of these gains are so small that they may be almost disregarded. Soils Nos. 992 and 993 responded to the organic matter. The organic matter in many cases reduced the size of the first crops, especially the starch. This may be seen by referring to the detailed tables.

PHOSPHORIC ACID REMOVED BY THE CROPS.

Tables 12 to 17, inclusive, show the phosphoric acid removed from the soil, and Table 3 is a summary of the results.

TABLE 3—GAIN OF PHOSPHORIC ACID DUE TO ADDITIONS IN GRAMS PER POT.

Laboratory Number.	In Original Crop.	Gain by Ca.	Gain by 2 Ca.	Gain by Starch.	Gain by Sawdust.	Gain by Cobs.	Number of Crops.
894	.0880	.0434	.0072	.0225	.0060	.0203	4
895	.1123	.0059	.0234	0	....	0	4
1145	.0370	.0309	.0357	0	....	.0097	4
992	.1423	.0498	.0538	.0256	....	.0539	5
993	.0559	....	.0369	.0286	.0260	0	7
1144	.1876	....	....	.0127	.0020	0	7

Carbonate of lime causes a gain in phosphoric acid taken up in all cases. The gain ranges from 5 per cent. on soil No. 895 with a single application of lime to nearly 95 per cent. on soil No. 1145 with the double application of lime. Except in two instances, the gains are considerable.

Starch causes four gains out of six, two of which are small; sawdust, all three are gains, two small; corn cobs, three gains out of six, two small. Soils Nos. 894, 1145, 992 and 993 responded to the organic matter, while 895 did not respond well and Nos. 1144 and 1145 only a little.

TABLE 4—CORN POSSIBILITY OF PHOSPHORIC ACID REMOVED IN BUSHELS PER ACRE, AVERAGE PER CROP.

Laboratory Number.	Original.	Increase Due to Gain.					No. Crops.	Total Phosphoric Acid.	Corn Possibility of Active Phosphoric Acid of soil
		Ca.	2 Ca.	Starch	Sawdust.	Cobs.			
894	14	7	1	3.5	1	3.3	4	.04	12
895	18	1	3.8	0	......	0	4	.03	18
1145	6	5	5.8	0	......	1.5	4	.01	18
992	18.2	6.4	6.8	3.2	0	6.8	5	.15	12
993	5.2	......	3.4	2.6	2.4	0	7	.05	12
1144	17	......	......	1.1	0.2	0	7	....	....

Table 4 shows the phosphoric acid removed in terms of the "corn possibility" in bushels per acre, based on a weight of two million pounds soil per acre to the depth of 7 inches, and a requirement of 0.625 pounds phosphoric acid per bushel of corn. One bushel corn would require .0015 grams phosphoric acid per pot of 5000 grams of soil. The effect of the lime has been to decidedly increase the assimilation of the phosphoric acid. The gain expressed in corn is 3 to 7 bushels per acre, with two exceptions. Addition of carbonate of lime to these soils clearly increased the assimilation of phosphoric acid by the crops. The gain due to the vegetable matter on three of the soils is 2 to 3 bushels.

Thus, the phosphoric acid absorbed by plants from the soil depends not only upon the forms of phosphoric acid in the soil, but also on the presence of other substances, such as carbonate of lime and organic matter. Soils Nos. 895 and 1145 are acid, but the carbonate of lime has no greater effect upon their phosphoric acid than on soils Nos. 992 and 993, which are not acid. It will require further investigations to trace the relation between the character of the soil and the effect of lime upon its phosphoric acid. It is of course impossible to state definitely whether the phosphoric acid was rendered more available, or whether the crops took up more phosphoric acid, because conditions were made more favorable by the additions. The effect, however, is the same; namely, through the aid of the additions made to the soil, the plants secured more phosphoric acid.

PHOSPHORIC ACID CONTENT OF THE CROPS.

The phosphoric acid content of the crops grown on various soils with the various treatments, expressed in percentages, is shown in Tables 18 to 23, inclusive. No particular relations can be traced in these percentages, as there is little variation. When the crop was unusually low, it usually contained a higher percentage of phosphoric acid. This may be noted especially with soil No. 895—corn, 1909, pot 9, starch. The crop weighing 5.3 grams contains 0.38 per cent. phosphoric acid, while the crop in pot 1, 21.9 grams, contains 0.19 per cent.

COMPOSITION OF THE SOILS AFTER GROWING THE CROPS.

After the crops had been grown as described, the contents of the pots were mixed and subjected to analysis. The results are given in Table 5.

TABLE 5—PHOSPHORIC ACID IN PARTS PER MILLION IN SOIL AFTER CROPS WERE GROWN.

	894	895	1145	992	993	1144
Original, before growing crops	15.4	27.8	23.7	15.0	15.6	
After growing crops—addition O	16.3	23.8	20.4	11.9	15.7	37.
O		27.0	18.5	11.9		
Ca	15.2	27.3	15.1	11.2		
Ca		25.6	15.2	12.5		
2 Ca	15.9	26.6	19.9	5.0	28.7	
2 Ca		26.9				
Cobs	15.2	25.0	18.7		11.6	39.0
Cobs		26.0	25.5	12.5		
Starch	13.5	25.0	27.0	10.0	12.7	35.6
Starch		25.0	24.0	8.5		38.1
Sawdust	12.3				10.9	
Removed by crops, no addition per million	17	22	7	28	11	37

The additions of carbonate of lime, etc., had practically no effect upon the quantity of active phosphoric acid remaining in the soils at the end of the experiment. There is a slight increase with the starch on soil 1145, and with the carbonate of lime on soil No. 993, but the differences are almost in the limit of error.

The phosphoric acid removed in the cropping also has had practically no effect upon the active phosphoric acid. Although 17 parts per million phosphoric acid have been removed by plants from soil No. 894, the cropped soil contains practically the same active phosphoric acid as the uncropped. A slight decrease appears with soils Nos. 1145 and 992, but practically within the limit of error.

As pointed out in Texas Bulletin No. 126, active phosphoric acid of about 10 parts per million is probably derived from a large quantity of difficultly soluble phosphates of iron and alumina, and not from a small quantity of the more easily soluble phosphates of lime. The active phosphoric acid in the soils used in these experiments varies from 15 to 27 parts per million, and thus a considerable portion of it results from the highly insoluble iron and aluminum phosphate. The plants have evidenty drawn upon the total phosphoric acid, rather than upon the active phosphoric acid.

ACKNOWLEDGMENT.

Laboratory work, pot tests, and other work involved in the investigations in this bulletin, have been participated in by Messrs. E. C. Carlyle, J. B. Kelly, T. L. Ogier, and perhaps other members of the staff.

TABLE 6—WEIGHT IN GRAMS OF CROPS GROWN ON SOIL NO. 894.

Additions and Pot Numbers.	Corn 1908	Millet 1908	Mustard 1908	Corn 1909	Total.	Gain.
1—O	13.9	5.7	5.9	14.5	40.0	....
2—Ca. (Carbonate of lime)	13.2	6.3	10.5	32.1	62.1	22.1
3—2 Ca	11.8	6.3	4.5	11.8	34.4	0
4—Cobs	11.1	6.6	10.1	14.0	41.8	1.8
5—Starch	5.4	7.2	9.8	16.6	39.0	0
6—Sawdust	13.4	8.3	3.4	12.0	37.1	0

TABLE 7—WEIGHT CROPS ON SOIL 895.

Additions.	Corn 1908	Millet 1908	Mustard 1908	Corn 1909	Total.	Average	Gain.
1—O	21.9	8.1	7.5	15.0	52.5	52.8	....
2—O	28.2	7.1	6.5	11.4	53.2	....	....
3—Ca. (Carbonate of lime)	27.0	8.4	12.8	18.8	67.0	64.6	11.8
4—Ca.	26.3	6.5	12.7	16.6	62.1	....	....
5—2 Ca	26.8	8.2	11.1	16.5	62.6	64.0	11.2
6—2 Ca	27.9	10.6	7.5	19.5	65.5	....	....
7—Cobs	22.5	8.0	12.5	12.0	55.0	50.0	0
8—Cobs	17.7	6.8	11.6	9.0	45.1	....	....
9—Starch	13.5	10.0	10.9	13.5	47.9	45.9	0
10—Starch	5.3	10.2	13.1	14.8	43.4	....	....

TABLE 8—WEIGHT OF CROPS GROWN ON SOIL NO. 1145.

Additions	Corn 1908	Millet 1908	Mustard 1908	Corn 1909	Total.	Average.	Gain.
1—O	7.4	3.6	1.5	3.7	16.2	16.7	....
2—O	6.3	3.8	0.4	6.5	17.3	....	....
3—Ca (Carbonate of lime)	9.0	4.1	5.0	11.1	29.2	30.2	13.5
4—Ca	9.4	3.8	5.4	12.5	31.1	....	....
5—Cobs	5.2	4.2	3.3	7.4	20.1	19.4	2.7
6—Cobs	7.0	3.4	0.4	8.0	18.8	....	....
7—Starch	2.2	4.5	0.2	4.8	11.7	12.8	0
8—Starch	3.2	3.4	1.1	6.2	13.9	....	....
9—2 Ca	10.2	3.8	9.0	10.6	33.6	33.6	16.9

TABLE 9—WEIGHT CROPS IN GRAMS GROWN ON SOIL NO. 992.

Additions.	Corn 1908	Millet 1908	Mustard 1908	Corn 1909	Kaffir 1909	Total.	Average.	Gain.
1—O..........	17.5	6.6	7.5	11.8	11.2	54.6	53.2	0
2—O..........	*17.5	1.6	6.5	16.8	9.3	51.7	....	....
3—Ca.........	19.6	4.5	12.8	21.4	10.1	68.4	73.6	20.4
4—Ca.........	26.5	3.5	12.7	23.5	12.5	78.7	....	....
5—2 Ca.......	25.3	5.7	11.1	21.5	11.5	75.1	75.1	21.9
6—2 Ca.......	22.1	4.7	7.5	....	....	34.3	....	....
7—Cobs.......	26.7	6.3	12.5	14.4	12.3	72.2	70.4	17.2
8—Cobs.......	23.8	3.8	11.6	17.8	11.6	68.6	....	....
9—Starch.....	22.5	4.2	10.9	15.0	7.0	59.6	61.4	8.2
10—Starch....	16.1	4.9	13.1	16.8	12.2	63.1	....	....

*Assumed.

TABLE 10—WEIGHT OF CROPS GROWN ON SOIL 993.

Additions.	1908 Corn.	1908 Millet.	1908 Mustard	1909 Corn.	1909 Kaffir.	1909 Mustard.	1910 Corn.	Total.	Gain.
1—O.........	4.5	2.7	5.4	1.5	1.9	3.6	1.9	21.5	....
2—Ca........	6.3	1.7	....	....	....	....	....	....	....
3—2 Ca.......	6.3	2.3	7.5	8.0	5.2	2.6	5.8	37.7	16.5
4—Cobs......	2.1	0.8	3.9	3.8	9.2	1 0	1.7	22.5	1.0
5—Starch.....	2.5	2.3	7.4	5.7	6.5	4.7	7.0	36.1	14.6
6—Sawdust...	6.5	2.9	5.1	8.5	6.2	3.5	....	32.7	11.2

TABLE 11—WEIGHT OF CROPS IN GRAMS GROWN ON SOIL NO. 1144.

Additions.	1908 Corn.	1908 Millet.	1908 Mustard.	1909 Corn.	1909 Kaffir.	1909 Mustard.	1910 Corn.	Total.	Gain.
1—O.........	26.2	6.7	8.1	17.0	8.8	2.2	8.0	77.0	......
2—Cobs......	35.7	3.8	4.8	19.0	6.1	3.5	7.0	79.9	2.9
3—Starch.....	9.7	8.2	10.9	20.5	0.9	4.7	8.2	63.1	0
4—Sawdust...	26.9	4.0	8.1	19.6	8.9	2.0	8.7	78.2	1.2

TABLE 12—PHOSPHORIC ACID IN GRAMS REMOVED BY CROPS FROM SOIL NO. 894.

Additions to Pots.	Corn.	Millet.	Mustard.	Corn 1909	Total.	Gain.
O.............................	.0264	.0148	.0142	.0326	.0880	....
Ca............................	.0277	.0239	.0284	.0514	.1314	.0434
2 Ca..........................	.0224	.0233	.0176	.0319	.0952	.0072
Cobs..........................	.0266	.0251	.0237	.0329	.1083	.0203
Starch........................	.0162	.0245	.0255	.0443	.1105	.0225
Sawdust.......................	.0281	.0274	.0099	.0290	.0940	.0060

TABLE 13—PHOSPHORIC ACID IN GRAMS REMOVED FROM SOIL 895 BY CROPS.

Additions.	Corn.	Millet.	Mustard.	Corn.	Total.	Average.	Gain.
1—O.................	.0405	.0162	.0158	.0405	.1130	.1123	0
2—O.................	.0451	.0149	.0174	.0342	.1116	....	....
3—Ca................	.0405	.0235	.0105	.0404	.1149	.1182	.0059
4—Ca................	.0447	.0182	.0207	.0380	.1216	....	....
5—2 Ca..............	.0350	.0343	.0222	.0396	.1311	.1357	.0234
6—2 Ca..............	.0391	.0278	.0266	.0468	.1403	....	....
7—Cobs..............	.0270	.0160	.0131	.0308	.0869	.0852	0
8—Cobs..............	.0283	.0177	.0121	.0254	.0835	....	....
9—Starch............	.0230	.0210	.0213	.0330	.0983	.0965	0
10—Starch...........	.0207	.0226	.0143	.0370	.0946	....	....

TABLE 14—PHOSPHORIC ACID IN GRAMS REMOVED BY CROPS GROWN ON SOIL NO. 1145.

	Corn.	Millet.	Mustard.	1909 Corn.	Total.	Average.	Gain.
1—O	.0126	.0093	.0050	.0089	.0359	.0370	—
2—O	.0113	.0091	.0012	.0166	.0382		
3—Ca	.0162	.0094	.0100	.0305	.0661	.0679	.0309
4—Ca	.0179	.0106	.0149	.0263	.0697		
5—Cobs	.0109	.0100	.0089	.0167	.0465	.0467	.0097
6—Cobs	.0133	.0092	.0023	.0220	.0468		
7—Starch	.0040	.0104	.0008	.0127	.0279	.0299	0
8—Starch	.0048	.0095	.0025	.0149	.0317		
2—Ca	.0173	.0091	.0198	.0265	.0727	.0727	.0357

TABLE 15—PHOSPHORIC ACID IN GRAMS FROM SOIL 992.

Additions.	Corn.	Millet.	Mustard.	Corn.	Kaffir.	Total.	Average.	Gain.
1—O	.0376	.0305	.0236	.0342	.0303	.1462	.1423	....
2—O	.0400	.0070	.0221	.0432	.0260	.1383	....	....
3—Ca	.0421	.0176	.0442	.0535	.0283	.1807	.1921	.0498
4—Ca	.0504	.0105	.0432	.0705	.0288	.2034	....	....
5—2 Ca	.0453	.0217	.0333	.0677	.0322	.2002	.1961	.0538
6—2 Ca	.0569	.0169	.0184	....	....	†.1921	....	....
7—Cobs	.0507	.0252	.0375	.0432	.0344	.1910	.1962	.0539
8—Cobs	.0510	.0137	.0348	.0752	.0267	.2014	....	....
9—Starch	.0484	.0160	.0322	.0420	.0203	.1589	.1679	.0256
10—Starch	.0403	.0191	.0364	.0470	.0341	.1769	....	....

†Estimated for Corn.

TABLE 16—PHOSPHORIC ACID (GRAMS) FOR SOIL 993.

Additions.	Corn.	Millet.	Mustard.	Corn.	Kaffir.	Mustard.	Corn.	Total.	Gain.
O	.0081	.0059	.0108	.0056	.0061	.0137	.0057	.0559	....
Ca	.0101	.0051	....	....	....	....	....	....	....
2 Ca	.0113	.0060	.0210	.0184	.0083	.0104	.0174	.0928	.0369
Cobs	.0036	.0020	.0020	.0091	.0175	.0038	.0051	.0431	0
Starch	.0033	.0046	.0155	.0118	.0151	.0188	.0154	.0845	.0286
Sawdust	.0111	.0078	.0097	.0200	.0136	.0140	.0057	*.0819	.0260

*Estimated.

TABLE 17—PHOSPHORIC ACID IN GRAMS REMOVED FROM SOIL 1144.

	Corn.	Millet.	Mustard.	Corn.	Kaffir.	Mustard.	Corn.	Total.	Gain.
O	.0459	.0288	.0227	.0400	.0218	.0112	.0172	.1876	....
Cobs	.0615	.0190	.0108	.0456	.0050	.0210	.0161	.1790	0
Starch	.0204	.0377	.0343	.0482	.0165	.0282	.0160	.2013	.0127
Sawdust	.0430	.0236	.0194	.0500	.0220	.0120	.0196	.1896	.0020

TABLE 18—PER CENT PHOSPHORIC ACID IN CROP GROWN IN SOIL 894.

	Corn 1908	Millet 1908	Mustard 1908	Corn 1909
O	.19	.26	.24	.21
Ca	.21	.36	.27	.21
2 Ca	.19	.37	.37	.20
Cobs	.24	.38	.24	.20
Starch	.30	.34	.26	.19
Sawdust	.21	.33	.29	.21

TABLE 19—PER CENT PHOSPHORIC ACID IN CROP GROWN IN SOIL 895.

	Corn 1908	Millet 1908	Mustard 1908	Corn 1909
1—O	.19	.20	.20	.27
2—O	.16	.21	.21	.30
3—Ca	.15	.28	.19	.22
4—Ca	.17	.28	.18	.24
5—2 Ca	.14	.37	.19	.24
6—Ca. S	.13	.33	.21	.24
7—Cobs	.16	.20	.18	.26
8—Cobs	.12	.26	.17	.28
9—Starch	.19	.22	.19	.25
10—Starch	.38	.24	.19	.25
11—Hematite	.12	.15	.19	.24
12—Hematite	.10	.26	.23	.24

TABLE 20—PER CENT PHOSPHORIC ACID IN CROPS GROWN IN SOIL 993.

	1908 Corn.	1908 Millet.	1908 Mustard.	1909 Corn.	1909 Kaffir.	1909 Mustard.	1910 Corn.
O	.18	.22	.20	.38	.34	.35	.30
Ca	.16	.30	....	....	....	....	....
2 Ca	.18	.26	.27	.23	.16	.40	.30
Cobs	.17	.26	.23	.24	.19	.75	.30
Starch	.13	.20	.21	.21	.24	....	.22
Sawdust	.17	.27	.19	.24	.22	....	....

TABLE 21—PER CENT PHOSPHORIC ACID IN CROPS GROWN IN SOIL 1144.

	1908 Corn.	1908 Millet.	1908 Mustard.	1909 Corn.	1909 Kaffir.	1909 Mustard.	1910 Corn.
O	.18	.37	.28	.23	.25	.51	.22
Cobs	.18	.50	.23	.22	.27	.60	.23
Starch	.21	.46	.30	.20	.39	....	.20
Sawdust	.16	.59	.24	.26	.25	.53	.23

TABLE 22—PER CENT PHOSPHORIC ACID IN CROPS GROWN IN SOIL 992.

	1908 Corn.	1908 Millet.	1908 Mustard.	1909 Corn.	1909 Kaffir.
1—O	.22	.31	.32	.29	.27
2—O	....	.36	.34	.26	.28
3—Ca	.22	.28	.35	.25	.28
4—Ca	.19	.36	.34	.39	.23
5—2 Ca	.21	.38	.30	.29	.28
6—2 Ca	.23	.36	.25	....	....
7—Cobs	.21	.35	.30	.27	.28
8—Cobs	.15	.36	.30	.29	.23
9—Starch	.22	.34	.30	.29	.29
10—Starch	.25	.59	.27	.26	.28

TABLE 23—PER CENT PHOSPHORIC ACID IN CROPS GROWN IN SOIL 1145.

	1908 Corn.	1908 Millet.	1908 Mustard.	1909 Corn.
1—O	.17	0.26	.34	.20
2—O	.18	0.24	.31	.33
3—Ca	.18	0.23	.20	.22
4—Ca	.19	0.28	.28	.21
5—Cobs	.21	0.24	.27	.22
6—Cobs	.19	0.27	.58	.24
7—Starch	.18	0.23	.38	.23
8—Starch	.15	0.25	.23	.22
9—2 Ca	.17	0.24	.22	.13

SUMMARY AND CONCLUSIONS.

1. When nitrogen and potash are supplied, the addition of carbonate of lime at the rate of 0.5 per cent. or five tons per acre increased the size of the crop and the amount of phosphoric acid withdrawn from the soil phosphates on the six soils tested in the pot experiments. The effect of the lime was small at first, but usually increased with succeeding crops.

2. The addition of starch, sawdust, or cobs had some effect on the crop in two soils but little with the other four soils.

3. With the six soils which gave up phosphoric acid equal to 5 to 18 bushels of corn per acre per crop, the addition of carbonate of lime caused an increase in the quantity of phosphoric acid taken up equal to 3 to 7 bushels per acre per crop.

4. The vegetable matter in three cases caused a gain in phosphoric acid taken up equal to two or three bushels corn per acre.

5. The presence of carbonate of lime or of vegetable matter may bring about differences in the quantity of phosphoric acid assimilated by plants from soils containing equal quantities of active phosphoric acid.

6. No relation can be traced between the additions and the phosphoric acid content of the crops. When the crops are unusually small, the phosphoric acid content usually runs higher than the average.

7. The additions of carbonate of lime or vegetable matter had practically no effect upon the quantities of active phosphoric acid remaining in the soil at the ends of the experiments.

8. The phosphoric acid removed in the cropping also had practically no effect upon the quantity of the phosphoric acid remaining in the soil at the ends of the experiments. The active phosphoric acid in the soils used varied from 15 to 27 parts per million. The phosphoric acid taken up by the plants was evidently drawn largely from the more insoluble phosphates.