ORGANIC PHOSPHORUS IN OKLAHOMA SOILS[1]

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INTRODUCTION

Early investigators discovered that part of the soil phosphorus was present in an organic form and that the latter may make up a high percentage of the total. More recent investigation has shown that organic phosphorus in soil can be separated quantitatively from the inorganic phosphorus compounds. Methods have been developed to fractionate the organic phosphorus and such substances as nucleic acid, lecithin, inositol, and phytin have been isolated and identified.

From the thousands of tests[3] that have been made in Oklahoma to determine the availability of soil phosphorus by extraction with solutions[4] of varying degrees of acidity, it is clearly evident that many soils are very deficient in inorganic phosphorus. The availability of organic phosphorus cannot be determined by these methods since organic phosphorus compounds are not soluble in dilute acids. When weather conditions are favorable, good crops are frequently produced on soils which are very low in available inorganic phosphorus but which are well supplied with organic matter from the addition of organic residue with a narrow carbon-nitrogen ratio. This evidence indicates that plants are utilizing organic phosphorus either directly or indirectly as a source of phosphorus.

This investigation was planned to study the relation between organic phosphorus and total nitrogen in soil organic matter as affected by cultivation.

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[2] The writer is indebted to Dr. H. J. Harper for his interest and cooperation in connection with this study.

[3] Available inorganic-phosphorus deficiencies vary from less than 3.0-percent deficient in the western prairie and high plains regions to more than 80-percent deficient in eastern Oklahoma. Phosphorus deficiency tends to decrease as annual rainfall decreases.

[4] Sulfuric acid (0.2N., pH 0.88) will extract from 1 to 2 percent of the total phosphorus from strongly acid soils using a 1-10 soil-acid ratio. Acetic acid (0.1N. pH 2.65) will not remove so much hydrated iron phosphates as the sulfuric acid. These phosphates are not available to all crops.

REVIEW OF THE LITERATURE

Mulder (1844) noted the presence of phosphorus in organic soil material.

Hopkins and Pettit (1908) noted that certain soils of uniform mineral composition contain more phosphorus in the surface than in the subsoil and suggested that the difference might be due to organic phosphorus.

Aso (1904) identified lecithin, the first organic phosphorus compound isolated from soil.

Shorey (1911) isolated nucleic acid from soil extracts.

Auten's (1921) experiments show that when compounds of organic phosphorus are incubated in silica sand for three months, 85 percent of the nucleic acid phosphorus, 67 percent of the phytin phosphorus, and 66 percent of the lecithin phosphorus change to inorganic form.

Whiting and Heck (1926) had remarkable success using phytin as a source of phosphorus for growing oats and red clover in sand cultures.

McGeorge and Breazeal (1932) in their studies with green and barnyard manures concluded that the organic phosphates in these fertilizers are of considerable importance. They believed that of the organic phosphorus compounds the most important and abundant are phytin, lecithin, and nucleic acid. Phytin is a calcium-magnesium salt of inositol phosphoric acid; lecithin is a choline-glycerol-phosphoric acid; and nucleic acid, the full composition of which is unknown, breaks down into phosphoric acid, a carbohydrate phosphoric acid, a carbohydrate, and a purine or pyrimidine base. Since they believed phytin to be the most abundant of the organic phosphorus compounds in soil, they checked the solublility of the pure compound and found it to be 9 ppm in pure water and 11 ppm in CO_2-saturated water. When the solubility was tested in solutions containing $CaCO_3$ and $NaHCO_3$, the solubility was further increased to 15.2 and 16.0 ppm respectively. This indicates that phytin should be readily soluble in alkaline soils. Their studies also indicate that phytin reacts toward changes in pH in a manner similar to the iron and aluminum phosphates in that it is much less soluble in an acid solution than in an alkaline solution. Above pH 7.0, the solubility steadily increases in the presence of NaOH, while in solutions of $Ca(OH)_2$, the solubility steadily decreases with increse in pH until it is practically all precipitated at pH 9.0.

Spencer and Stewart (1934) studied the use of organic phosphates which might have a greater soil-penterating power than the common inorganic phosphate carriers. Their results showed that the phosphorus in organic phosphates escaped, to a marked degree, the fixation which occurs to a phosphate applied in some organic form. Specific examples of the organic phosphates used are calcium mono-ortho-phosphate of glycerol, $C_3H_5\ (OH)_2$ - OPO_3Ca, and potassium sorbityl di-orthophosphate, $C_6H_8\ (OH)_4$ - $(OPO_3K_2)_2$. Analysis of the water solutions passing through the soil demonstrated that whereas 88-99 percent of the inorganic phosphate was fixed, only 5-20 percent of the organic compounds were retained by the soil.

Wrenshall and others (W. and McKibben 1938; W. and Dyer 1939; D., W., and Smith 1940; D. and W. 1941; W. and D. 1941) at Macdonald College in Canada showed that phytic acid forms two distinct ferric salts, having formulas corresponding approximately to $(C_6H_{18}(PO_4)_6)_2Fe_4$ and $C_6H_6(PO_4)Fe_4$. They also found a compound of aluminum with phytic acid which was insoluble in an acid solution. Their studies on the decomposition of some of the organic phosphorus compounds in soil cultures tend to indicate that organic soil phosphorus represents an accumulation of stable forms and not a labile fraction maintained by synthetic activities. It was believed to be the inactive end product of soil processes and hence relatively unavailable to both plants and micro-organisms. They point out that soil conditions influence the degree of accumulation to a considerable extent. This being demonstrated by the fact that their analysis showed infertile acid soils to contain a higher percentage of organic phosphorus than the neutral or calcareous soils. Phytin, being one of the compounds that accumulates in soil, was believed to enter into insoluble combinations with sesquioxide constituents under acid condition, thereby becoming resistant to enzymatic hydrolysis.

Bower (1945) separated phytin from the soil in quantities large enough to study its composition. He found 25 to 35 percent of the organic phosphorus in three Iowa soils to be phytin and another 11 to 15 percent to be phytin derivatives. Since he was able to isolate some of the phytin derivatives, he concluded that the organic phosphorus was decomposing but at a rather low rate. The phytin derivatives precipitated as their calcium salts had an inositol-phosphorus ratio corresponding most closely with that of inositol triphosphate.

METHODS OF ANALYSIS

Fraps (1911) showed that organic phosphates are soluble in ammonia after extraction with hydrochloric acid. This was probably the first successful separation of organic from inorganic soil phosphorus. Later Potter and Benton (1916) originated a method for distinguishing between these two types of phosphorus in soils. Many others (Auten 1921, Dean 1938, Dickman and DeTurk 1938, Dyer and Wrenshall 1941, Odynsky 1936, Pearson 1940, Schollenberger 1918, Yoshida 1940) have made slight modifications in technique and have improved the original methods used by earlier investigators.

The method used by most investigators consists essentially of determining (by the Deniges' method) the inorganic phosphorus in one aliquot portion of the ammonia-soil extract after it has been decolorized with bromine water or carbon black. Total phosphorus is determined in a second aliquot of the same extract after ignition or digestion with strong acid. The difference between the quantities found in the two aliquots is considered to be organic. The ammonia-soil extract is prepared by digesting the soil sample in 0.5-N. ammonium or sodium hydroxide after the removal of calcium with dilute hydrochloric acid.

In general, the method suggested by Pearson (1940) with some modification was used in this study. Instead of ignition to decompose the organic phosphorus, a digestion with hot concentrated perchloric acid (70-72-percent $HClO_4$) was found to be more expedient.

SOURCE OF MATERIALS

The soil samples used in this study were obtained from fifteen counties in the State. A virgin and a cultivated sample from each of 30 different soil types was collected, the location being shown in Table I. The cultivated sample was collected as nearly adjacent to the virgin sample as was possible in order to minimize variance in parent material. All of the soils were taken to a depth of six inches.

Three soil types were chosen for a study of the distribution of organic phosphorus in the soil profile. The Oswego silt loam and the Newtonia very fine sandy loam were developed under grass vegetation; the Bowie very fine sandy loam was developed under timber. All three were virgin soils. Their location is shown in Table IV.

EXPERIMENTAL RESULTS

Comparative Losses of Total Phosphorus, Total Nitrogen, and Organic Phosphorus as Results of Cultivation

From the standpoint of plant nutrition the soil organic matter furnishes all of the nitrogen, a large portion of the sulfur, and some of the phosphorus to growing plants. Very little information exists in the literature on the quantity of soil phosphorus present in organic form. There has also been question as to whether the organic phosphorus compounds are being decomposed into readily available forms which plants can utilize.

The data in Table I show that organic phosphorus compounds are accumulating in soil to a very marked extent. Tillman clay loam from Kiowa

County contained 173 ppm of organic phosphorus in the virgin condition; this amount is 50.6 percent of the total phosphorus present. Pratt loamy fine sand from Major County contained only 45 ppm organic phosphorus which was 47.9 percent of the total.

These two soils represent the extremes in the amount of organic phosphorus found in the soils studied; but, even though the quantities are widely different, the soils as a group show that when the organic phosphorus is low the total phosphorus is also low.

It is apparent from these analyses that a large portion of the total phosphorus in soil has been combined in organic form since these substances account for 46 percent of the total phosphorus. Pearson and Simonson (1940) found the organic-phosphorus content of seven Iowa soils to be from 27.2 to 65.2 percent of the total phosphorus. Since the soil organic phosphorus is present in relative large quantities, it should be made available for plant use through enzymatic hydrolosis even though the inorganic phosphorus fraction is held in unavailable combination. Some of the experiments of Whiting and Heck (1926) would confirm this opinion since they found that certain crops, like oats and red clover, could utilize phytin as a source of phosphorus when these crops were grown in sand cultures.

The data in Table I show that the average amount of inorganic phosphorus removed from the soil is only slightly higher than the average amount of organic phosphorus removed or lost through cultivation. The averages show about 19 percent of the organic phosphorus and 22 percent of the inorganic phosphorus was removed from the soils in this group. It is also interesting to note that some of the soils which are low in pH have lost virtually none of their organic phosphorus. This agrees closely with previous investigations (Bower 1945; Dyer, Wrenshall, and Smith 1940; McGeorge and Breazeale 1932; Spencer and Stewart 1934) concerning the fixing ability of the sesquioxide constituents on some organic-phosphorus compounds in acid soil. Phytin phosphorus, for example, when in combination with iron or aluminum is very insoluble and would resist enzymatic hydrolosis to a marked degree.

There has been a question as to whether nitrogen and organic phosphorus are chemically combined in certain of the organic compounds in soil. If they are, there is good reason to believe that their decomposition patterns would fall along parallel lines. In an effort to show this relationship the percentage of loss of each of these constituents in cultivated areas as compared with virgin conditions is shown in Table II. An average of the thirty soils studied shows total phosphorus lost through cultivation to be 21.61 percent as compared to 19.19 percent of the organic phosphorus lost. The amount of nitrogen lost, however, does not present such a close relationship. The analyses show that in 85 percent of the soils studied, the percentage of nitrogen lost through cultivation was appreciably higher than that of organic phosphorus. The average for all the soils shows that 31.04 percent of the nitrogen was lost, as compared to the afore-mentioned figure of 19.19 percent for the organic phosphorus. These figures are significant in that they show the nitrogen compounds in the soil are more rapidly decomposed and more quickly utilized than the organic phosphorus compounds. They are also significant in that they show that the phosphorus reserve in the soil is not being expended as rapidly as the nitrogen reserve.

Ratios of Organic Phosphorus to Nitrogen and to Organic Matter in Virgin and Cultivated Soils

Since, as previously pointed out, the nitrogen compounds of the soil are decomposing at a higher rate than the organic phosphorus compounds, it naturally follows that the ratio of organic phosphorus to nitrogen would increase as soils are cultivated. The ratio of organic phosphorus to nitrogen and to total organic matter are shown in Table III. The ratio of organic phosphorus to nitrogen was found to vary from 1:8.5 to 1:28.1 in the virgin soils and from 1:6.2 to 1:21.9 in the cultivated soils. In 90 percent of the soils the ratio of organic phosphorus to nitrogen increased in the cultivated soil. The ratio of

TABLE I

Soil type, location, and chemical analysis of samples collected for study from fifteen counties in Oklahoma

Sample No.	County location	Type of soil[a]	Status[b] of soil	pH	C. M. %	N %	Total ppm P	Organic phosphorus[c] ppm	Organic phosphorus[c] Percentage
3	Garfield	Grant vfsl	V	6.4	2.54	.151	248	91	36.7
4	Garfield	Grant vfsl	C	6.0	2.19	.097	177	80	35.2
5	Garfield	Pond Creek sil	V	6.2	1.74	.164	268	91	34.0
6	Garfield	Pond Creek sil	C	5.9	1.69	.101	193	66	34.2
7	Major	Pratt loamy fs	V	7.0	2.89	.082	95	45	47.9
8	Major	Pratt loamy fs	C	6.7	.80	.048	76	30	39.5
9	Major	Foard sicl	V	6.7	2.46	.155	284	90	31.7
10	Major	Foard sicl	C	6.4	1.54	.115	216	75	34.7
19	Carter	Durant cl	V	6.0	2.42	.120	248	87	35.1
20	Carter	Durant cl	C	6.4	2.08	.118	170	73	42.9
21	Murray	Newtonia vfsl	V	6.3	4.29	.166	357	155	43.4
22	Murray	Newtonia vfsl	C	6.3	1.61	.090	218	90	41.3
23	Murray	Denton cl, deep phase	V	6.0	5.30	.231	318	120	37.7
24	Murray	Denton cl, deep phase	C	6.0	3.23	.155	246	95	38.6
25	Nowata	Summit sil	V	6.7	—	.204	300	113	37.6
26	Nowata	Summit sil	C	6.0	—	.172	257	93	36.2
29	Kiowa	Tillman cl	V	6.3	2.28	.147	342	173	50.6
30	Kiowa	Tillman cl	C	6.6	1.53	.099	213	150	70.4
33	Greer	Hollister sil	V	7.3	2.42	.136	362	145	40.0
34	Greer	Hollister sil	C	7.2	1.90	.128	300	130	43.3
35	Greer	Tillman sil	V	6.9	2.40	.151	312	150	48.1
36	Greer	Tillman sil	C	6.5	1.87	.094	234	115	49.1
37	Garfield	Oswego sil	V	6.2	2.29	.151	181	115	63.5
38	Garfield	Oswego sil	C	6.1	1.37	.086	135	80	59.3
39	Garfield	Kirkland sil	V	6.0	2.66	.155	230	125	54.3
40	Garfield	Kirkland sil	C	5.9	2.22	.118	168	95	56.5
41	Garfield	Renfro sil	V	6.1	2.07	.155	177	116	65.5
42	Garfield	Renfro sil	C	5.8	1.15	.088	115	60	52.2
43	Garfield	Vernon vfsl	V	6.1	1.79	.115	116	92	79.3
44	Garfield	Vernon vfsl	C	6.0	1.26	.065	83	70	84.3
45	Noble	Vanoss sil	V	6.4	3.72	.178	329	140	42.6
46	Noble	Vanoss sil	C	6.2	1.71	.115	212	120	56.6

TABLE I (continued)

Sample No.	County location	Type of soil[a]	Status[b] of soil	pH	C. M. %	N %	Total ppm P	Organic phosphorus[c] ppm	Organic phosphorus[c] Percentage
47	Noble	Summit cl	V	6.4	4.72	.246	305	100	32.7
48	Noble	Summit cl	C	6.7	3.02	.153	234	70	29.9
49	Noble	Norge sil	V	5.9	4.11	.185	220	125	56.8
50	Noble	Norge sil	C	5.4	1.71	.105	135	87	64.4
51	Noble	Labette sicl	V	5.9	3.56	.176	183	115	62.8
52	Noble	Labette sicl	C	5.3	1.85	.122	155	105	69.1
53	Noble	Canadian fsl	V	6.6	2.62	.120	250	135	54.0
54	Noble	Canadian fsl	C	6.3	1.69	.082	245	130	53.1
55	Noble	Polo Loam	V	6.0	2.98	.189	201	112	55.7
56	Noble	Polo loam	C	6.0	2.02	.126	170	100	58.8
57	Noble	Otoe clay	V	7.4	4.20	.248	311	145	47.0
58	Noble	Otoe clay	C	6.9	3.91	.262	286	145	51.0
59	Noble	Labette sil	V	5.8	3.84	.197	213	88	41.3
60	Noble	Labette sil	C	5.4	2.61	.136	197	80	40.6
61	Kay	Labette sicl	V	5.5	3.20	.197	192	70	36.5
62	Kay	Labette sicl	C	5.2	1.90	.128	150	70	46.7
2341	Beaver	Richfield sil	V	7.4	3.42	.185	490	145	29.6
2343	Beaver	Richfield sil	C	7.5	2.20	.110	415	65	15.7
3991	Tulsa	Parsons vfsl	V	5.8	3.40	.120	205	85	41.5
3992	Tulsa	Parsons vfsl	C	5.8	2.47	.110	192	85	44.3
3975	Tulsa	Bates vfsl	V	6.1	4.15	.182	228	140	61.4
3975a	Tulsa	Bates vfsl	C	5.6	2.92	.126	210	135	64.3
4281	Tulsa	Yahola	V	7.6	2.47	.120	380	70	18.4
4284	Tulsa	Yahola	C	7.5	1.24	.060	315	50	1.64
6363	Woods	Miller cl	V	7.8	3.02	.150	535	150	28.0
6364	Woods	Miller cl	C	8.0	2.13	.115	505	145	28.7
6529	Payne	Field "O" (Manured)		5.6	2.32	.119	280	75	26.8
6559	Payne	Field "O"		5.1	1.69	.086	230	95	41.3
8148	Okfuskee	Parsons vfsl	V	6.2	2.60	.107	160	95	59.4
8147	Okfuskee	Parsons vfsl	C	5.2	1.65	.077	140	75	53.6

[a] Symbols: vfsl, very fine sandy loam; sil, silt loam; fs, fine sand; sicl, silty clay loam; cl, clay loam; fsl, fine sandy loam.

[b] C, cultivated; v, virgin.

[c] Average organic-phosphorus content: 114.1 ppm or 45.8 percent in virgin soils, 92.1 ppm or 47.0 percent in cultivated soils.

organic phosphorus to organic matter varies from 1:132 to 1.642 in the virgin soils and from 1:102 to 1:431 in the cultivated soils.

Other investigators who have studied ratios of organic phosphorus to nitrogen and to organic matter in soils have also found wide variation between soil types. Auten (1921) found the ratios of organic phosphorus to nitrogen to vary from 1:8 to 1:24, while Pearson and Simonson (1940) found these ratios to vary from 1:7 to 1:11 in Iowa soils.

All of the investigation shows that the abundance of organic phosphorus varies less relative to that of nitrogen than to that of organic matter.

TABLE II

Percentages of total phosphorus, organic phosphorus, and nitrogen lost through cultivation

Sample number	Type of soil[a]	Percent, total phosphorus lost through cultivation	Percent, organic phosphorus lost through cultivation	Percent nitrogen lost through cultivation
8148,47	Parsons vfsl	12.5	21.1	28.0
3,4	Grant vfsl	28.6	12.1	35.8
5,6	Pond Creek sil	28.0	27.4	38.4
7,8	Pratt lfs	20.0	33.3	41.5
9,10	Foard sicl	23.9	16.6	25.8
19,20	Durant cl	29.8	16.1	1.7
21,22	Newtonia vfsl	39.4	41.9	45.7
23,24	Denton cl	22.6	20.8	32.9
25,26	Summit sil	14.3	17.6	15.7
29,30	Tillman cl	37.7	13.3	32.7
33,34	Hollister sil	17.1	10.3	5.8
35,36	Tillman sil	25.0	23.3	37.7
37,38	Oswego sil	25.4	30.4	43.0
39,40	Kirkland sil	27.0	24.0	23.8
41,42	Renfro sil	35.0	48.3	43.2
43,44	Vernon vfsl	28.4	23.9	43.5
45,46	Vanoss sil	35.6	14.3	35.3
47,48	Summit cl	23.3	30.0	37.8
49,50	Norge sil	38.6	30.4	43.2
51,52	Labette sicl	15.3	8.7	30.7
53,54	Canadian fsl	2.0	3.7	31.6
55,56	Polo loam	15.4	10.7	33.3
57,58	Otoe clay	8.1	0.0	5.3
59,60	Labette sil	7.5	9.1	30.9
61,62	Labette cl	21.9	0.0	35.0
2341,42	Richfield sil	15.3	55.1	40.5
3991,92	Parsons vfsl	6.3	0.0	8.3
3975,76	Bates vfsl	7.9	3.6	30.8
4281,84	Yahola	17.1	28.6	50.0
6363,64	Miller cl	20.0	1.0	23.3
8148,47	Parsons vfsl	12.5	21.1	28.0
	Averages	21.61	19.19	31.04

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[a] For meaning of symbols see footnote a, Table I.

TABLE III

Ratios of organic phosphorus to nitrogen and to organic matter in virgin and cultivated soils

Sample number	Type of soil[a]	Organic phosphorus to nitrogen Virgin	Organic phosphorus to nitrogen Cultivated	Organic phosphorus to organic matter Virgin	Organic phosphorus to organic matter Cultivated
3,4	Grant vfsl	1:16.6	1:12.1	1:279	1:274
5,6	Pond Creek sil	1:18.0	1:15.3	1:191	1:256
7,8	Pratt loamy fs	1:18.2	1:16.0	1:642	1:267
9,10	Foard sicl	1:17.2	1:15.3	1:273	1:206
19,20	Durant cl	1:13.7	1:16.1	1:278	1:285
21,22	Newtonia vfsl	1:10.1	1:10.0	1:277	1:179
23,24	Denton cl	1:19.3	1:16.3	1:442	1:340
25,26	Summit, sil	1:18.0	1:18.4	—	—
29,30	Tillman cl	1: 8.5	1: 6.6	1:132	1:102
33,34	Hollister sil	1:10.5	1: 8.8	1:186	1:131
35,36	Tillman, sil	1:10.1	1: 8.2	1:160	1:163
37,38	Oswego sil	1:13.1	1:10.7	1:199	1:171
39,40	Kirkland sil	1:12.4	1:12.4	1:212	1:233
41,42	Renfro sil	1:13.4	1:14.6	1:178	1:192
43,44	Vernon vfsl	1:12.5	1: 9.3	1:194	1:180
45,46	Vanoss sil	1:12.7	1: 9.6	1:265	1:142
47,48	Summit cl	1:24.6	1:21.9	1:472	1:431
49,50	Norge sil	1:14.8	1:12.0	1:329	1:197
51,52	Labette sicl	1:15.3	1:11.6	1:310	1:176
53,54	Canadian fsl	1: 8.9	1: 6.3	1:194	1:130
55,56	Polo loam	1:16.9	1:12.6	1:266	1:202
57,58	Otoe clay	1:18.1	1:17.1	1:270	1:290
59,60	Labette sil	1:22.4	1:17.0	1:436	1:326
61,62	Labette, cl	1:28.1	1:18.3	1:457	1:271
2341,42	Richfield sil	1:12.8	1:16.9	1:236	1:338
3991,92	Parsons vfsl	1:14.1	1:12.9	1:400	1:290
3975,75A	Bates vfsl	1:13.0	1: 9.3	1:297	1:216
4281,84	Yahola	1:17.1	1:12.0	1:353	1:248
6363,64	Miller cl	1:10.0	1: 7.9	1:201	1:146
6529,59	Field "O"	1:15.9[b]	1: 9.1[c]	1:309	1:178
8248,47	Parsons vfsl	1:10.7	1:10.3	1:260	1:220

[a] For meaning of symbols see footnote a, Table I.

[b] Cultivated soil, manured.

[c] Cultivated soil, untreated.

DISTRIBUTION OF ORGANIC PHOSPHORUS IN THREE VIRGIN SOIL PROFILES

Soil samples were taken at varying depths to 24 inches from Oswego, Newtonia, and Bowie soil types for a study of the distribution of organic phosphorus in the profile. The analysis of the three soils (Table IV) shows that the percentages of organic phosphorus down through the Oswego and Newtonia profiles are relatively constant below the surface inch to depths of 24 and 18 inches respectively, whereas the percentage of organic phosphorus in the Bowie profile drops from 60 percent in the surface inch to 13 percent in the 10-18-inch layer. This difference in the three soil types may partially be explained by the fact that the Oswego and Newtonia were developed under grass while the Bowie, a coastal-plains type, was developed under timber.

The organic phosphorus made up about 45 percent of the total phosphorus in the Oswego profile, 35 percent in the Newtonia profile, and about 30 percent in the Bowie profile.

The general trends of the ratios of the organic phosphorus to nitrogen in the Oswego and Newtonia soils are similar in that the ratios increase with depth, however, the converse is true in the Bowie profile where the ratio decreases with depth. Fig. 1 shows graphically the distributions of organic phosphorus and nitrogen in the profiles where concentration is plotted against depth. It is readily seen from these graphs that the distributions of nitrogen and organic phosphorus in the soil profiles follow nearly parallel patterns.

DISCUSSION

In the surface layers of many soils, 15 to 85 percent of the phosphorus has been found to be organic. Many of the soils in which the concentration of organic phosphorus is high are very deficient in available inorganic phosphorus as determined by extraction with dilute acids.

When organic matter is incorporated in soil, a rapid decomposition ensues through the action of fungi and bacteria. After the utilization of most of the easily decomposed energy material, such as hemicellulose and cellulose, bacterial decomposition becomes dominant. Thus organic phosphorus in the soil may originate from the organic residues added to soil, and also through synthesis by micro-organisms.

The stability of the organic phosphorus like that of the organic matter should probably be regarded as relative rather than absolute, and the substance should gradually become available through decomposition. The data presented in this study indicate that soil conditions influence the degree of accumulation to a considerable extent. Acid soils usually contain a higher proportion of organic phosphorus than the neutral or calcareous soils. The type of vegetation under which soil is developed would no doubt influence the rate of accumulation.

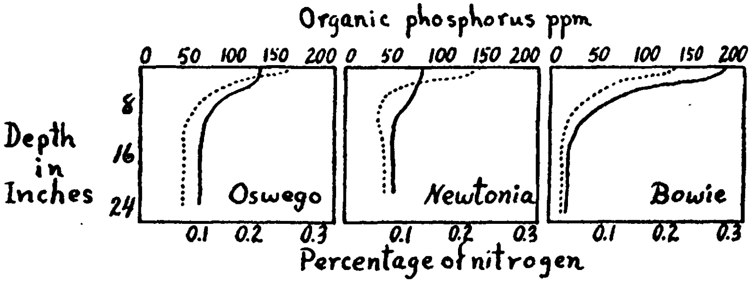

Fig. 1. Distributions of organic phosphorus (solid lines) and nitrogen (broken lines) in profiles of three virgin soils, namely, Oswego silt loam, Newtonia very fine sandy loam, and Bowie very fine sandy loam.

TABLE IV

The pH, nitrogen, total phosphorus, organic phosphorus, percentage of organic phosphorus, and organic-phosphorus—nitrogen ratios in three soil profiles

Type of soil[a]	Depth, inches	pH	Percentage, nitrogen	Total phosphorus ppm	Organic phosphorus ppm	Percentage, organic phosphorus	Organic phosphorus to nitrogen
	0–1	6.7	0.224	255	125	49.0	1:17.9
	1–2	6.5	0.167	230	120	52.2	1:13.9
Oswego silt loam	2–4	6.0	0.144	200	110	55.0	1:13.1
(Grant County)	4–6	6.0	0.091	180	85	47.2	1:10.7
	6–12	6.2	0.077	145	60	41.4	1:12.8
	12–18	6.6	0.075	150	65	43.3	1:12.1
	18–24	7.2	0.070	165	65	39.4	1:10.8
	0–1	7.0	0.193	272	85	31.3	1:22.7
Newtonia vfsl	1–3	6.2	0.134	224	85	37.9	1:15.8
(Choctaw County)	3–8	5.4	0.054	126	60	47.6	1: 9.0
	8–16	6.4	0.070	143	50	34.9	1:14.0
	0–1	5.4	0.176	280	170	60.7	1:10.4
Bowie vfsl	1–6	5.3	0.051	160	50	31.2	1:10.2
(Choctaw County)	6–10	5.4	0.020	100	15	15.0	1:13.0
	10–18	5.1	0.020	100	13	13.0	1:15.3

[a] For meaning of symbols see footnote a, Table I.

Analyses of virgin and cultivated soils under a wide range of conditions indicate that the organic phosphorus compounds are being decomposed and lost from the soil at a lower rate than the inorganic phosphates.

There is considerable opinion expressed in the literature that organic phosphorus compounds such as phytin, accumulate in the soil, through interaction with sesquioxide constituents. Such compounds would no doubt be quite resistant to enzymatic nydrolysis. The partial dephosphorylation of phytin may produce phosphoric esters of inositol, according to Bower (1945). There is no evidence regarding the relative stability of these compounds in the soil, but it is possible that they account for a significant part of the organic phosphorus.

The possibility exists, therefore, that other phosphorus compounds, yet unidentified in soils, occur and become available for plant use as the loss of organic phosphorus in cultivated soils indicates.

SUMMARY

Virgin and cultivated samples of thirty soil types occurring in Oklahoma were analyzed for organic phosphorus. The organic phosphorus content of these samples varied from 30 to 173 ppm in the surface six-inch depth of soil. The virgin soils averaged 114 ppm as compared to 92 ppm in the cultivated soils. The organic phosphorus averaged 46 percent of all the phosphorus in the soil, with the average in the virgin soils being slightly less and that in the cultivated soils slightly more.

In profile studies the proportion of organic phosphorus was found to be fairly constant in the Oswego and Newtonia types. These soils averaged 45 and 35 percent from the surface to a 24-inch depth. In the Bowie soil the proportion of organic phosphorus dropped from 70 percent in the surface inch to 13 percent in the 10-to-18-inch layer.

The ratio of organic phosphorus to nitrogen varied from 1:6 to 1:28 and was greater in the cultivated soils as was expected. The ratio of organic phosphorus to organic matter was less regular than that of organic phosphorus to nitrogen; it varied from 1:102 to 1:642.

The data presented herein establish the presence of large quantities of organic phosphorus in Oklahoma soils, which are being utilized by plants at a rate about equal to that of inorganic phosphorus.

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