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FORMS OF PHOSPHORUS IN SOME IMPORTANT AGRICULTURAL SOILS OF NIGERIA[1]

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ABSTRACT

The phosphorus status of twenty-one selected soils from various parts of Nigeria was studied. Total P content in the surface soils studied ranged widely from 120 to 1880 ppm. In most cases, the relative abundance of the various fractions of inorganic P was in the order of occluded P ≫ Fe-P > Al-P ≥ Ca-P. The distribution of various P forms was related to the parent material, degree of weathering, and drainage conditions of the soils. Organic P constituted more than half of the total P in most of the forest soils. Multiple correlation showed that organic P content was significantly correlated with soil pH, organic carbon content and total P content in the soils.

INTRODUCTION

Phosphorus is among the most needed elements for crop production in the highly weathered soils of the tropics. Studies on the forms and distribution of various forms of phosphorus in soils provided useful information in assessing the available P status and in measuring the degree of chemical weathering of the soil. Chang and Jackson (1957) first related the distribution of inorganic P fractions in soils to the degree of soil chemical weathering and the weathering sequence being Ca phosphate, Al phosphate, Fe phosphate, and occluded phosphate. The occluded phosphate includes the reductant soluble Fe phosphate and the (Al, Fe) phosphate occluded in Fe oxides. Juo and Ellis (1968a), Westin and de Brito (1969), and Hawkins and Kunze (1965) further confirmed this theory in their studies on the inorganic P distribution in a number of soil profiles with different weathering stages in temperate and tropical regions.

The contents and distribution of the active form of inorganic P (Al-P, Fe-P, and Ca-P) in soils are also a useful index in assessing the P requirement of soils. Among the three fractions of active inorganic P, Al-P is relatively the most available form to plants under upland conditions, while the Fe-P is the major available P source under flooded conditions. The selection of a suitable routine soil chemical test for soil available P must be based on the distribution pattern of these active inorganic P forms present in soils.

Organic P under tropical environment may also supply a substantial portion of available P to plants during the process of mineralization (Eid et al. 1961). Enwezor and Moore (1966) and Bates and Baker (1960) reported that more than 40 percent of the total P in the surface layers of several forest soils in Nigeria was in the organic form. Similar findings were reported by Vieira and Bornemisza (1968) for some Brazilian soils and by Nye and Berteaux (1957) for Ghanian soils.

The purpose of this study is to evaluate the content and distribution of various forms of soil phosphorus in some important agricultural soils in Nigeria.

MATERIAL AND METHODS

Soil samples

Twenty-one soil samples from various parts of Nigeria were used for this study. Sampling locations, parent materials, and vegetation at the sampling sites are given in Table 1. Except the Musa soil, all soil samples are under natural vegetation (secondary forest, thicket, or savannah grass fallow). The Musa soil was taken from a local rice field in northern Nigeria. All samples were taken at two depths, 0 to 15 cm and 15 to 30 cm, air-dried, and passed through a 2-mm sieve.

Analytical methods

The pH of the soils was measured in water at one to one soil to water ratio using the Beckman Zeromatic pH meter. Mechanical analysis was

[1] IITA Journal Paper No. 22.

TABLE 1

Sampling location and parent material of the soils used

Sample number	Soils	Classification (USDA)	Sampling location	Parent material	Vegetation	Drainage
1	Egbeda	Alfisol	Ibadan	Banded gneiss	Secondary forest	Well drained
2	Iwo	Alfisol	Ibadan	Banded gneiss	Secondary forest	Well drained
3	Olorunda	Alfisol	Ibadan	Banded gneiss	Secondary forest	Well drained
4	Apomu	Entisol	Ibadan	Alluvium	Secondary forest	Well drained
5	Jago	Entisol	Ibadan	Alluvium	Secondary forest	Poorly drained
6	Origo	Mollisol	Iragberi	Colluvium	Grass fallow	Poorly drained
7	Alagba I	Alfisol	Iperu	Sandstones	Secondary forest	Well drained
8	Alagba II	Ultisol	Benin	Sandstones	Secondary forest	Well drained
9	Owode	Alfisol	Iperu	Sandstones	Secondary forest	Well drained
10	Nkpologu	Ultisol	Nsukka	Sandstones	Grass fallow	Well drained
11	Uvuru	Ultisol	Nsukka	Sandstones	Grass fallow	Well drained
12	Nsukka	Inceptisol	Nsukka	Alluvium	Secondary forest	Impeded drainage
13	Abakaliki	Inceptisol	Abakaliki	Shales	Thicket	Impeded drainage
14	Ezilo	Ultisol	Ezilo	Older alluvium	Grass fallow	Poorly drained
15	Bende	Inceptisol	Bende	Clay shales	Thicket	Impeded drainage
16	Ogoni	Ultisol	Ogoni	Coastal sediments	Thicket	Well drained
17	Umumasi	Ultisol	Port Harcourt	Coastal sediments	Thicket	Well drained
18	Ikom	Ultisol	Ikom	Olivine basalt	Secondary forest	Well drained
19	Funtua	Alfisol	Zaria	Eolian drift	Grass fallow	Well drained
20	Danggappe	Alfisol	Mokwa	Sandstones	Grass fallow	Well drained
21	Musa	Inceptisol	Baddegi	Alluvium	Native rice field	Poorly drained

done by the hydrometer method of Bouyoucos (1951). Organic carbon was determined by the dichromate oxidation method of Walkley and Black as described in ASA Monograph No. 9 (1965). Cation exchange capacity was determined by the summation of all the exchangeable cations extracted by *N* NH_4OAc for exchangeable bases and by *N* KCl for exchangeable Al and H. The contents of K, Ca, and Na in the extracts were determined on the EEL flame photometer and Mg and Mn on the Perkin Elmer model 403 atomic absorption spectrophotometer. Total exchange acidity in the KCl extracts was determined by titration and the exchangeable Al by the modified aluminon colorimetric method described by Hsu (1964).

Total P was determined by the sodium carbonate fusion method of Muir (1952). Inorganic P fractions were determined according to the method of Chang and Jackson (1957) as modified by Peterson and Corey (1966). Phosphorus in all extracting solutions was determined colorimetrically by the ascorbic acid-molybdate blue method of Murphy and Riley (1962). Organic P in soils was obtained by subtraction of the sum of the total inorganic P determined by Chang and Jackson's method from the value of total P. Results of a separate experiment showed that organic P contents obtained by the above method were in good agreement with the extraction method of Mehta et al. (1954) but not with the ignition method of Saunders and Williams (1955). In all cases, organic P contents obtained from both the subtraction and the extraction methods were considerably higher than those obtained by the ignition methods. Bray P_1 available P was determined according to the procedure described in the ASA Monograph No. 9 (1965).

RESULTS AND DISCUSSION

Some general properties of the surface 0 to 15 cm layer of the soils used in this study are given in Table 2. As indicated by the mechanical analysis, all the well-drained upland soils are of a coarse texture—sandy loam or loamy sand —except the Funtua soil formed on eolian drift and the Ikom soil derived from basalts, which have a fine texture. The poorly drained hydromorphic and alluvial soils—Nsukka, Abakaliki, Bende, and Musa—generally have a finer texture. The pH of these soils varies from 4.1 of the Ogoni soil to 6.6 of the Olorunda soil. In general, soils from southwestern and northern Nigeria are only slightly acidic and have a high degree of base saturation while soils from southeastern Nigeria generally are strongly acidic. Total P, organic P, and the various forms of inorganic P contents in soils are given in Tables 3 and 4.

Total P

As shown in Table 3, for soils from southwestern Nigeria total P in soils derived from base-

TABLE 2

Some properties of the soils used in this study (surface soil, 0-15 cm)

Sample number	Soil*	Mech. analysis (< 2 mm)			pH H_2O	Organic C	Effective† CEC	Base saturation
		Sand	Silt	Clay				
		%				%	me/100 g	%
1	Egbeda	67	12	21	6.5	1.54	5.45	97
2	Iwo	76	10	15	6.0	2.60	13.23	93
3	Olorunda	56	17	27	6.6	1.36	6.46	97
4	Apomu	78	11	11	6.0	2.48	6.27	97
5	Jago	75	13	12	5.6	1.39	6.39	94
6	Origo	73	14	13	5.8	3.12	8.59	95
7	Alagba I	75	8	17	6.2	1.41	5.68	94
8	Alagba II	73	5	21	5.5	1.50	2.29	90
9	Owode	71	7	22	6.1	0.91	4.56	98
10	Nkpologu	67	7	26	4.8	1.23	1.87	20
11	Uvuru	34	16	50	4.9	2.22	2.38	16
12	Nsukka	13	55	32	4.7	1.50	5.16	60
13	Abakaliki	41	20	39	4.3	2.54	5.23	58
14	Ezilo	54	32	14	6.0	0.86	5.15	92
15	Bende	29	39	32	4.5	3.87	32.03	90
16	Ogoni	85	4	11	4.1	1.04	1.95	53
17	Umumasi	75	8	17	4.5	1.56	2.76	30
18	Ikom	49	30	21	5.0	2.72	6.09	58
19	Funtua	26	50	24	5.5	0.68	4.41	95
20	Danggappe	66	14	20	6.4	0.59	3.93	96
21	Musa	38	42	20	4.5	0.26	1.73	51

* Soils 1 to 4 contain moderate amount of quartzite gravel in the A and B horizons. Soil 11 contains large amounts of iron concretions throughout the profile.

† "Effective CEC" was determined by summation of exchangeable bases and exchange acidity. Percentage base saturation was calculated accordingly.

TABLE 3

Contents of various forms of phosphorus in soils from southwestern Nigeria

Sample number	Soils	Depth*	Ca-P	Al-P	Fe-P	Occluded P	Organic P	Total P	Bray P_1
					ppm P in soil				
1	Egbeda	A	3	17	49	152	417	638	10
		B	3	3	62	195	—	—	—
2	Iwo	A	1	10	23	71	267	372	tr
		B	2	7	18	131	136	294	tr
3	Olorunda	A	1	9	22	115	253	400	5
		B	2	3	21	148	178	352	1
4	Apomu	A	3	18	15	36	145	217	12
		B	3	2	6	68	40	119	3
5	Jago	A	43	23	36	69	229	400	5
		B	16	16	28	49	177	286	3
6	Origo	A	12	12	32	67	243	366	4
		B	9	80	20	32	101	242	1
7	Alagba I	A	2	7	13	170	51	243	7
		B	1	1	7	106	76	191	2
8	Alagba II	A	2	7	16	165	59	249	8
		B	2	2	15	191	33	243	4
9	Owode	A	1	3	11	86	90	191	2
		B	2	1	10	113	91	217	1

* Depth A: 0 to 15 cm; B: 15 to 20 cm.

TABLE 4

Contents of various forms of phosphorus in soils from southeastern and northern Nigeria

Sample number	Soils*	Depth	Ca-P	Al-P	Fe-P	Occluded P	Organic P	Total P	Bray P_1
					ppm P in soil				
10	Nkpologu	A	2	8	17	134	30	191	6
11	Uvuru	A	5	9	35	244	105	398	—
		B	4	6	26	185	290	511	—
12	Nsukka	A	7	15	35	54	153	264	1
		B	5	5	32	48	124	214	[illegible]
13	Abakaliki	A	26	13	89	197	398	723	3
		B	6	1	35	211	227	480	2
14	Ezilo	A	2	6	16	49	118	191	—
		B	1	1	9	47	107	165	—
15	Bende	A	24	147	157	376	669	1373	51
		B	38	190	278	370	449	1325	42
16	Ogoni	A	6	160	126	37	156	485	115
		B	8	144	117	140	152	561	75
17	Umumasi	A	7	63	137	77	276	567	47
		B	7	45	126	209	136	519	20
18	Ikom	A	63	182	180	552	901	1878	75
		B	48	175	366	641	478	1708	20
19	Funtua	A	0.5	3	9	50	61	124	2
		B	0.5	tr	6	63	120	190	0.5
20	Danggappe	A	1	6	5	73	86	171	tr
		B	1	2	5	61	102	171	tr
21	Musa	A	2	1	4	127	37	171	tr
		B	2	1	6	60	60	129	tr

* Soils 10 to 18 are from southeastern Nigeria and soils 19 to 21 are from northern Nigeria.

ment complex rocks ranges from 217 to 638 ppm in the surface 15 cm of the soil while the total P content in equal depth in soils derived from sedimentary rocks is lower (191 to 243 ppm). Generally, the total P content in the subsurface soil (15 to 30 cm) is lower than that in the surface soil apparently because of the accumulation of organic P in the surface soil.

Total P content in soils from southeastern Nigeria (Table 4) varies widely, ranging from 190 to 1880 ppm depending upon the parent material, degree of weathering, and vegetation. The Bende soil, derived from clay shales, and the Ikom soil, derived from basalt, contain the highest amount of total P (1370 and 1880 ppm, respectively). The Nkpologu and the Ezilo soils contain the lowest amount of total P among the nine soils from southeastern Nigeria. The total P content in the three northern soils—Funtua, Danggappe, and Musa—is also low (less than 220 ppm).

Organic P

Organic P content in the surface soils varies widely depending upon the parent material and vegetation, with the lowest being the Nkpologu soil (30 ppm) while the highest is the Ikom soil (900 ppm). Multiple correlation and regression analysis showed that the level of organic P in these soils is significantly correlated with soil pH, organic matter, and total P content in the soil:

$$Y\,(\text{Org. P}) = -277.4 + 43.2\,\text{pH} + 25.9\,\text{Org. C} + 0.488\,\text{Total P}\quad R^2 = 0.960^{**}.$$

It is important to point out that in many tropical soils recently cleared from long-term forest fallow, a large portion of the soil P exists in organic forms. Inorganic P released through mineralization of organic P under tropical environment may supply a substantial portion of plant-available P during the cropping season. The average organic P content and the percentage of organic P with respect to total P of the two groups of soils (soils derived from basement complex rocks and soils from sandstones) were calculated. The basement complex soils mostly under secondary forest contain more organic P (260 ppm) than the sandstone soils (87 ppm) under thicket or savannah grass fallow. On the

average, 65 percent of the total P in the former group of soils exists in organic form, while in the latter group, organic P constitutes 30 percent of the total P.

Inorganic P forms

The amount and distribution of the various forms of inorganic P are also given in Table 3. In the well-drained upland soils (Alfisols) from southwestern Nigeria, occluded P (36 to 195 ppm) and Fe-P (6 to 62 ppm) comprise more than 90 percent of the total inorganic P. This indicates the high degree of chemical weathering of these soils (Chang and Jackson 1958). The contents of Ca-P and Al-P are very low particularly in the three soils derived from sandstones (Alagba I, Alagba II, and Owode). The low Al-P content suggests that the capacity of these soils to supply plant-available P from the inorganic pool is, therefore, limited (Chang and Juo 1963; Juo and Ellis 1968b; Smith 1965).

In the case of the poorly drained Jago and Origo soils the relative abundance of Ca-P, Al-P, and Fe-P is nearly equal whereas the occluded P remains the predominant form of inorganic P. It is also interesting to note that the content of occluded P in the surface soil of the two poorly drained soils is higher than that in the subsurface soil. This is contrary to that of the well-drained soil derived from the same parent materials where the content of occluded P is higher in the lower horizons of the profile. The amounts of Al-P and occluded P in the poorly drained soils may be more affected by the degree of dryness, impeded drainage, and seasonal redox fluctuations of the soil than by weathering as suggested by Westin and Brito (1969).

For soils from southeastern Nigeria (Table 4), the two well-drained Nkpologu and Uvuru soils (Ultisols) formed on sandstones contain predominantly occluded P (134 to 234 ppm) in both the surface and subsurface layers, while Ca-P is the lowest among all the four inorganic P fractions. The alluvial soil (Nsukka) contains less occluded P than the two upland soils derived from the same parent material though Fe-P and occluded P are the predominant forms of inorganic P in the soil. The Abakaliki soil with impeded drainage contains more inorganic P than the Ezilo soil formed on old alluvial sediments. The surface layer of the Abakaliki soil contains appreciable amounts of Al-P and Ca-P though Fe-P and occluded P are the most abundant. The low total inorganic P content in the Ezilo soil again indicates a high degree of chemical weathering of the soil.

The Ogoni and Umumasi soils formed from recent coastal sediments contain large amounts of Al-P. In the surface layer of Ogoni soil, Al-P is the most abundant form followed by Fe-P and occluded P; however, in the subsurface soil, the three forms become equally distributed. In the surface layer of Umumasi soil, the sequence is Fe-P > occluded P > Al-P, while in the subsurface soil, the order becomes occluded P > Fe-P > Al-P. In both soils, the content of occluded P is more in the subsurface than in the surface soil.

Among the nine soils collected from southeastern Nigeria, the Bende and Ikom soils contain the highest amount of total inorganic P in the surface soil (704 and 977 ppm, respectively). In both soils, the subsurface contains more inorganic P than the surface layer of the soil. Occluded P in both soils is the most abundant form, followed by Fe-P, Al-P, and Ca-P. The Al-P and Ca-P consist of a significant proportion of the total inorganic P.

The high amount of Al-P and Bray P_1 test values in the Bende, Ikom, Ogoni, and Umumasi soils suggests that these soils have relatively higher P-supplying power to upland crops, providing other chemical conditions of these soils such as pH and exchangeable Al content are made favorable.

The inorganic P contents in the three northern soils are among the lowest of all soils studied. Occluded P and Fe-P comprise more then 90 percent of the total inorganic P in the soil. The subsurface soil contains higher amount of occluded P than the surface soil. The alluvial soil (Musa) sampled from a local rice field contains an extremely low level of active inorganic P (Ca-P, Al-P, and Fe-P).

To further illustrate the relative abundance of the various forms of inorganic P in these soils, four representative soils (Egbeda, Alagba II, Origo, and Bende) having different drainage conditions and parent materials were selected and their distribution of inorganic P forms are shown in Fig. 1. In the highly weathered and well-drained Egbeda soil (Alfisol) and Alagba soil (Ultisol), occluded P consists of more than 70% of the inorganic P in the soil. The relative abundance of the various P forms is in the order

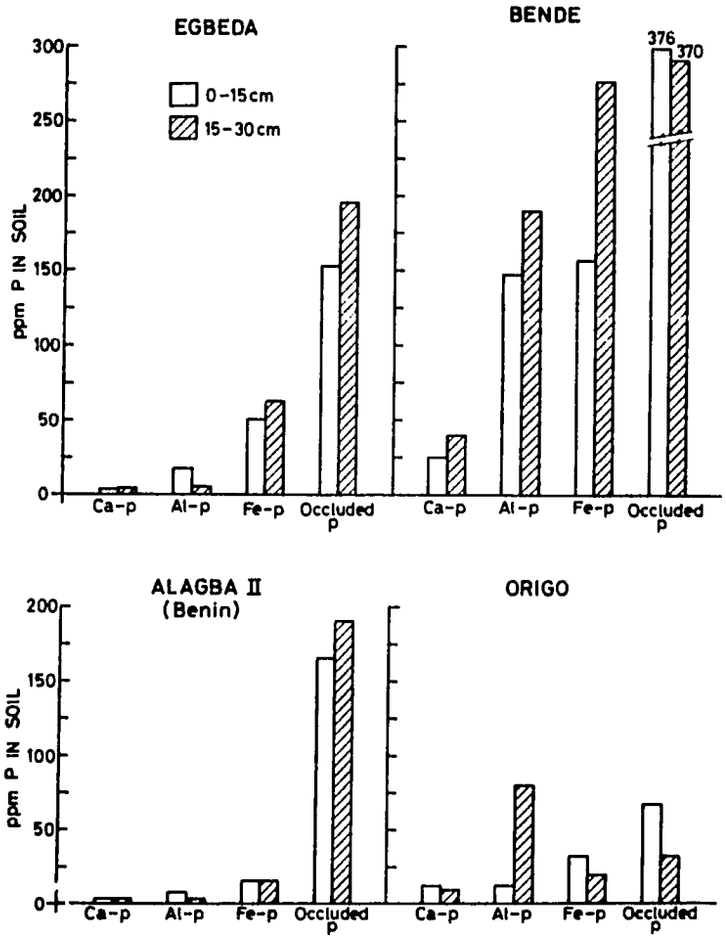

FIG. 1. Distribution of inorganic P forms in Egbeda, Alagba II, Bende, and Origo soils.

of occluded P ≫ Fe-P > Al-P > Ca-P. The Al-P content in the surface soil is slightly higher than that in the subsurface soil.

The distribution of inorganic P forms in the two poorly drained soils (Bende and Origo) differed considerably from the soils under well-drained conditions. The P-enriched Bende soil derived from clay shales and under impeded drainage contains a large amount of Al-P in addition to Fe-P and occluded P. The relative abundance is in the order of occluded P > Fe-P > Al-P ≫ Ca-P. The lower layer (15 to 30 cm) of the soil contains more Al-P, Fe-P, and Ca-P than the surface soil while the occluded P is slightly lower in the lower layer than in the surface soil. In the case of the poorly drained Origo soil, the total inorganic P level is lower than the Bende soil. The relative occluded P > Fe-P > Al-P ≈ Ca-P, while in the subsurface soil (15 to 30 cm) the order becomes Al-P > occluded P > Fe-P > Ca-P. The Ca-P content in both poorly drained soils is significantly higher than that in the two well-drained soils. The high content of Al-P in the lower horizon of the Bende and Origo soils is due to poor drainage conditions rather than degree of weathering. Similar results were also reported by Westin and de Brito (1969) and Juo and Ellis (1968a).

The low levels of Al-P and Fe-P fractions and the predominance of the occluded P in the majority of the soils studied indicate the limited capacity of these soils to supply available P to crops from the inorganic pool (Chang and Chu 1959; Juo and Ellis 1968b). Further investigations are underway to study the phosphate

retention and fixation capacities of these soils and to evaluate retention and fixation capacities of these soils and to evaluate P requirements for optimum crop yield.

Organic P, under the traditional farming practices in the forest zone of West Africa, may be the most important source of P for crops grown in recently cleared land. Nevertheless, the contribution of organic P to plant nutrition in many tropical soils depends to a large extent on the method of soil and crop management. In addition to the rapid rate of decomposition of organic matter under tropical environment, the traditional practices of burning and excessive land preparation may result in significant loss of organic P from the sandy top soils due to erosion and surface run-off.

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