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Research Paper

Forms and distribution of phosphorus in Ebonyi State, Southeastern Nigeria

AZU, DONATUS E. O*., NWANJA, OKEZIE UGWU AND ODIMBA, V. O.

Department of Agricultural Technology, School of Industrial Technology,Akanu Ibiam Federal Polytectnic, Unwana, Afikpo Ebonyi, Nigeria.

*Corresponding author E-mail: donblessed01@gmail.com.

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This study was carried out to determine the forms and distribution of phosphorus (P) fractions in Ebonyi State, Southeastern Nigeria. Fifteen soil samples from five selected local Governments of the State were collected with soil auger at three depths (0-20 cm, 20-40 cm and 40-60 cm).These were subjected to physico-chemical analysis, while the different fractions of P were determined using standard method. Results obtained indicated that the total soil P varied from 351.11 to 671.61 mg/kg, organic P from 80.00 to 149 mg/kg, available P from 6.70 to16.30 mg/kg and all these P fractions decreased with soil depth. The active inorganic P forms had values that varied from 13.14 to 67.70 mg/kg for Al-P, 32.00 to187 mg/kg for Fe-P and 1.00 to 3.99 mg/kg for Ca-P. The relative abundance of the various P forms were in the order inactive P>Fe-P>Al-P>Ca-P and these decreased down the soil profile. Available P correlated significantly with Al-P, but its interaction with Fe-P could not reach significance level. The higher correlation coefficient between available P and Al-P indicated that Al-P contributes more to soil available P and hence soil productivity with respect to P. Identification of the amount of the various P forms will aid in making efficient soil management policies and practices in respect to P fertilization in this agro-ecological zone.

Key words: Phosphorus, forms and Ebonyi

INTRODUCTION

With increasing demand of agricultural production due to the drastic increase in global population in recent years, phosphorus (P) is receiving more attention as a strategic soil fertility resource (Cordell *et al*., 2009; Gilbert, 2009). In plant nutrition, P is classified as a essential and macronutrient because of the relatively large amount required by plants (Brady and Weil, 2006). It plays a major role in energy transfer, stimulation of early growth and development, fruiting and seed formation (Warren, 1992; Bi et al., 2013; Ali et al., 2014); consequently, it is one of the three nutrients generally added to soils in fertilizer. It is usually present in forms of low availability in the highly weathered soils of tropical and subtropical regions, a phenomenon that has been suggested as one of the main limiting factors for agricultural production (Osodeke, 2005; Rowe et al., 2016). In spite of the total P content, usually exceeding the plant requirement, the low mobility/diffusion and high fixation of soil P can restrict its availability and biological utilization by plants (Cessa *et al*., 2009; Yi-Halla, 2016). The lack of available P is attributed to its strong adsorption by mineral surfaces, making a part of the total P unavailable to plants

(Almeida *et al*., 2003; Cessa *et al*., 2009; Osodeke, 2005). The main minerals related to the adsorption of P in soils are different forms of iron (Fe) and aluminum (Al) oxides (Osodeke and Uba, 2005), which together with kaolinite, make up the dominant mineralogy in the clay fractions of most soils in the tropical and subtropical regions (Nitzsche *et al*., 2008; Schaefer *et al*., 2008).

Because of the relatively small pool of native soil solution P, chemical P fertilizers and organic P sources are imported into Agricultural systems to supplement soils with water soluble P in order to maintain adequate amount of soluble orthophosphate ($H_2PO_4^-$ and HPO_4^{2-}) in soil solution for satisfactory crop growth and productivity (Schaefer *et al.,* 2008; Rowe et al., 2016; Roy et al., 2016). Limited availability of P in soil attributed to immobile nature and strong fixation makes P- fertilization practices to differ somewhat from those of Nitrogen (N) and potassium (Raheb and Heidari, 2012). Phosphatic fertilizers react with soil component to form a variety of compounds and P forms which cause the P to become slowly available to unavailable to plant. The identification of these P bond compounds such as $AlPO_4.2H_2O$, $FePO_4$ have helped to provide a better understanding of the fate of P added to the soil (Nemery and Garnier, 2016). Finding solution to the problem of low and variability in P distribution in Nigerian soils has been a major preoccupation of soil chemists in the last several years (Osodeke and Ubah, 2005). This is consequent of the highly weathered nature of most acidic soils of southeastern Nigeria coupled with high content of sesquioxides and kaolinite which renders P unavailable to growing plants (Osodeke and Kamalu, 1992). Soil P exist in various chemical forms including organic and inorganic which differ in their behaviour and fate in soils (Hansen, et al., 2004; Osodeke and Uba, 2005; Turner *et al*., 2007; Rowe et al., 2016). Organic forms are derived from humus and other organic materials and exist mainly in stabilized forms as inositol phosphate and phosphonates and in active forms as orthosphate diesters, labile or thioposphate monoesters and organic polyphosphates (Condron *et al*., 2005). The P in organic materials is released through mineralization process involving soil organisms (Orhue and John, 2015). The inorganic P is derived from primary minerals such as apatites, strengites, variscite and secondary minerals (Turner *et al*., 2007). The chemistry of inorganic P in the soil is rather complex and in order to understand the inorganic P status and availability in soil, diverse fractionation schemes and soil test have been developed. Whether from inorganic or organic, some of the P will form compounds with Ca, Fe and Al. Most of these compounds are relatively unavailable to plants (Tiessen, 1998). The distribution of these P fractions and their abundance in soil are dependent on pH, solubility product of the different phosphates, parent materials, cations present and the degree of weathering (Osodeke and Ubah, 2005; Rowe et al., 2016). Understanding the different P forms is crucial in making useful P fertilizer management policies. Although, a number of studies on P have been conducted in the southeastern zone of Nigeria, most of these have been limited to the surface soil horizon (Osodeke and Ubah, 2005; Ibia and Udo, 1993). Nigeria has a decline in crude oil extraction and all government efforts are focused on Agriculture and Ebonyi State in particular under the leadership of David Umahi as the incumbent governor of Ebonyi State. Recently the minister of Agriculture visited Ebonyi State capital Abakaliki to educate and show case the need and support of federal government in Ebonyi's choice to follow the trend of Agricultural development as an alternative.

Phosphorus both distribution and usage is an important aspect of manure and innovation seeing Ebonyi as a young state. Because of the soil type and the mineralogical composition, coupled with the strategic agricultural potentials of Ebonyi State in Nigeria, there is urgent need for intensive evaluation of the different forms of P in these highly weathered tropical soils. This study was therefore carried out to provide information on the different forms of phosphorus in soils of Ebonyi state, southeastern Nigeria to update information available in this zone for efficient and productive P fertilizer management in order to ensure sustained food production.

MATERIALS AND METHODS

The study was carried out in Ebonyi State, South Eastern Nigeria. It lies within latitude 6° 15N and longitude 8° 05 E (Obasi *et al*., 2015). The climate and vegetation type are generally humid tropical rainforest with annual rainfall of about 3500mm and daily temperature range of 32- 21°C According to Njoku *et al*. (2006), the temperature is generally high throughout the year with annual relative humidity of between 60-80%.The parent materials from which the soils are derived include shale, sand stone and limestone. The soil belongs to the order ultisol and has been classified as typic hapludult (Federal Department of Agriculture and land Resources 1985).

Soil sampling

Soil samples were collected from five local government area of the state (Izzi, Abakaliki,Ikwo, Afikpo and Ivo) (Figure 1), representing the North, central and Southern part of the state at three depths (0-20 cm, 20-40 cm, and 40- 60 cm) given a total of fifteen (15) observational unit.

Sample preparation

The soil samples were air-dried, crushed and sieved

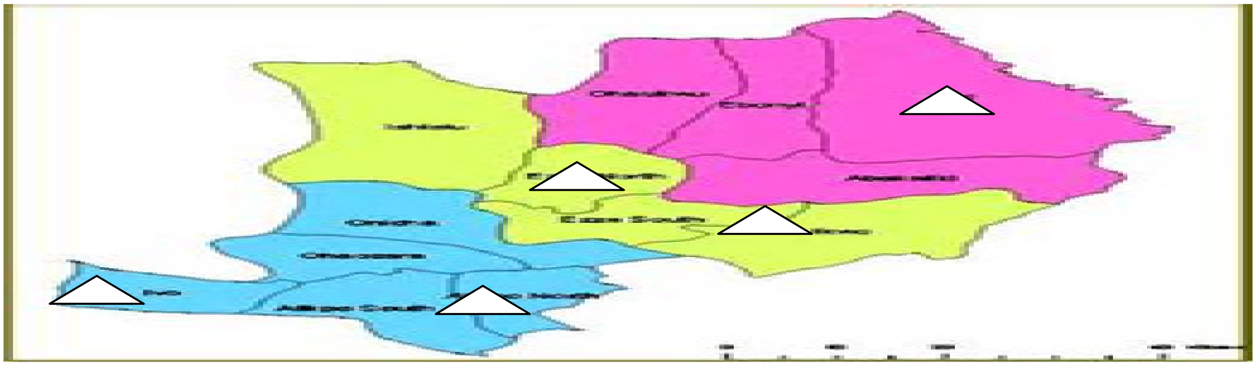

Figure 1. Map of Ebonyi State showing sampling locations. The map is not clear provide help

through a 2 mm sieve. The particle size distribution was determined using the Bouyocous hydrometer method as describe by Gee and Or, (2002). The pH was determined in soil to water and soil to $CaCl_2$ at a ratio 1:2 soil water and soil $CaCl_2$ respectively using glass electrode pH meter (Udo *et al*., 2009).Organic carbon was determined by the wet oxidation method according to Pansu and Gautheyrous, (2006) and converted to organic carbon by multiplying by 1.792. The total nitrogen determination was done by the macro Kjeidahl digestion method (Simmone *et al.,* 1994). Exchangeable acidity was determined by the nikel extraction procedure as described by Kamprath, (1967). Exchangeable basic cations (K^+, Ca^{2+}, Mg^{2+}, Na^+) were determined by the ammonium acetate method (Carter and Gregoich, 2008). Ca and Mg in the extract were determined using the atomic absorption spectrophotometer, while K and Na were determined using the flame photometer. Effective cation exchange capacity **(**ECEC**)** was obtained by summation of all the exchangeable cations and exchangeable acidity as described by Udo *et al*. (2009). The base saturation was obtained mathematically with:

$$BS\ (\%) = \text{Total}\ \frac{\text{cation}}{\text{ECEC}} \times \frac{100}{1}$$

Available P was determined using the Bray II method of Bray and Kurtz, (1945) as described by Udo *et al*. (2009), while the sequential fractionation of inorganic P and organic P forms were carried out by methods of Udo *et al*. (2009). Total P was determined by $HCl0_4$ digestion method (Jackson, 1962) and organic P was estimated by the difference between extractable inorganic P, before and after ignition (Leg and Black, 1955). Correlation between some soil properties and forms of P were determined using Spearman correlation coefficient as outlined by Wahua, (1999).

RESULTS AND DISCUSSION

Physical and chemical properties of the soils used for the study

The physical and chemical properties of the soil used the study is presented in (Table 1). The result generally indicated that the soil textural class was clay loam except in Ikwo where the soil indicated a sandy clay loam texture. Generally, the sand fraction decreases with soil depth while the clay fractions increase down the profile. The silt fractions did not show any particular distribution trend down the profile. These results are in agreement with the findings of Ahukaemere and Akpan, (2012) who reported a textural class of clay loam in most soils of Ebonyi State. The low clay content of the surface horizon could be due to sorting of soil minerals by biological and or Agricultural activities, clay migration or surfaces erosion by run off or combination of these (Malgwi *et al*., 2000). Idoga and Azagaku, (2005) reported that the increased in clay content of soil with depth may be the consequences of elluviation-illuviation processes as well as contributions of the underlying geology through weathering. The soil pH indicates strongly to slightly acidic condition which generally increased with soil depth. These could be as a result of high rainfall that characterized the tropical Regions of Ebonyi State which encourages the leaching of basic cations leaving behind Al and Fe oxide and hydroxides that result in soil acidity (Brady and Weil, 2008). The slightly acidic conditions found in most of the study areas which are ideal for crop production especially rice, shows nutrient availability, thus indicating little incidence of leaching of nutrient down the profile. Onweremmadu *et al*. (2007) reported similar soil reaction in selected wetland soils of south eastern Nigeria. The pH values range from 5.0 to 6.6 in line with the reports of other researchers on pH of soils of southeastern Nigeria (Onwuka *et al*., 2007; Eneje and Azu, 2009). The organic carbon content of the soil varied form 1.28 to 3.75%. Generally the organic carbon and

Table 1. Physical and chemical properties of the soil used for the study.

location	Depth (Cm)	Sand (%)	Silt (%)	Clay (%)	Texture	pH (CaCl2)	pH (H_20)	Org. C. (%)	OM (%)	TN (%)	TEB (cmol/kg)	TEA (cmol/kg)	ECEC (cmol/kg)	BS (%)
Afikpo	0-20	52.3	16.3	31.4	CL	5.0	5.3	2.0	3.46	0.27	4.21	1.11	5.32	79.1
	20-40	50.1	14.7	35.1	CL	4.6	5.1	1.8	3.15	0.23	3.16	2.00	5.16	61.2
	40-60	47.9	14.8	37.3	CL	4.9	5.1	1.2	2.14	0.16	3.10	2.03	5.13	60.4
Abakaliki	0-20	54.7	14.6	30.1	CL	5.0	5.5	2.3	4.03	0.29	3.27	0.97	4.24	77.1
	20-40	50.1	13.9	36.0	CL	4.7	5.0	1.1	1.97	0.26	3.10	1.07	4.17	74.3
	40-60	45.2	17.7	37.1	CL	4.7	4.6	1.0	1 71	0.20	2.84	1.88	4.72	60 2
Izzi	0-20	40.0	20.0	40.0	CL	5.0	6.0	2.0	3.44	0.89	3.40	0.79	4.19	759
	20-40	40.0	18.6	41.4	CL	5.4	6.2	1.3	2.16	0.19	2.99	1.00	3.99	74.9
	40-60	37.2	14.8	48.0	CL	4.8	5.1	0.7	1.28	0.15	2.79	1.04	3.83	72.9
Ikwo	0-20	70.0	12.0	18.0	SCL	5.66	6.0	1.4	2.49	O.15	2.02	1.00	4.02	50.2
	20-40	55.1	15.8	29.1	CL	5.9	6.4	0.8	1.40	0.18	3.48	1.78	5.26	66.2
	40-60	50.6	13.7	35.8	CL	4.8	5.1	0.8	1.31	0.13	2.00	2.00	4.00	50.0
Ivo	0-20	55.6	18.5	25.9	CL	5.2	6.6	2.2	3.80	0.31	4.20	0.87	5.07	82.8
	20-40	49.2	13.9	39.9	CL	5.0	6.4	2.0	3.46	0.27	4.12	1.01	5.13	80.3
	40-60	44.1	12.0	43.9	CL	4.3	5.3	1.1	2.0	0.26	3.00	1.21	4.21	71.3

CL=Clay-loam, SCL=Sandy clay loam; Org.C= Organic carbon; OM= Organic matter; TN=Total nitrogen; TEB=Total exchangeable bases; TEA=Total exchangeable acidity; ECEC=Effective cation exchange capacity.

organic carbon content decreased down the soil profile. Several authors (Osedeke 2005; Eneje and Azu, 2009) have also reported similar trend. Organic carbon is one of the important parameter used in judging soil quality and productivity. It has been reported to have significant positive influence on soil pH, cation exchange capacity, colour, buffering capacity, base saturation and water holding capacity (Akamigbo, 1999).

In view of this, steps should be taken to increase the organic carbon content of the soil so as to improve the organic potentials of soils. These can be achieved through appropriate land use type and use of organic residue to conserve, maintain favourable soil temperature and encourage biological activities of soil organism. The total Nitrogen content of the soils was moderately low and were within the range of 0.11 to 0.36% which is slightly lower than the critical level for crop production in the tropical environment (Osodeke, 2005). In a similar vein, the total nitrogen concentration decrease down the profile for all soils studied.

The total exchangeable bases which ranged from 2.81 to 4.22 (cmolkg) also decreased down the profile for some soils studied (Afikpo). This could be attributed to leaching of basic cations and the dominance of Fe and Al oxides at the upper soil horizon .The total exchangeable acidity ranged from 0.97 – 3.00 and increased down the slope which can be attributed to the chemical and biological properties of the individual soils used for the studies. Generally, the base saturation indicated highest ion concentration of exchangeable bases at the 20 – 40 cm depth for most of the soils studied. The high base saturation in all the soils studied indicates high cation availability and hence great potentials for crop production if other management practices are improved.

Total phosphorus

The total P content of the soils ranged from 351.11 to671.61 mg/kg with a mean of 573 m/kg and it decreased with soil depth (Table 2) which is in agreement with reports of other researchers (Osodeke and Kamalu,1992; Orhue and John, 2015. Similarly, Ibia and Udo, (1993) reported that total values varied between the soils and within the profiles. They reported a consistent decreasing trend with depth in the distribution of total P in soils studied. Generally, the trend of the abundance of the mean values of total P in a decreasing order was Afikpo >Izzi >Abakaliki>Ivo>Ikwo. The range of values of total P was higher than those reported by Osodeke and Ubah, (2005) in soils of southeastern Nigeria.Total P correlated positively with sand, silt and clay(r=0.74, 0.69.0.73 respectively), and these relationships were highly significant.

Organic P

The soil organic P ranged from 80.00 mg/kg in Ikwo to 149 mg/kg in Ivo with a mean value of 141.34 mg/kg. These values are higher than the

Table 2. Forms and Distribution of phosphorus in the soils (mg/kg).

Location	Depth cm	Av. P	Active P			Inactive	Organic	Total
			Al-P	Fe-P	Ca-P			
	0-20	10.0	27.4	157.0	2.33	343.27	98.00	639.44
Afikpo	20-40	8.23	28.0	163.10	2.00	340.88	90.00	632.21
	40-60	8.00	24.00	160.00	1.10	331.14	90.00	627.47
	0-20	6.70	28.01	166.00	3.50	222.00	120.00	646.21
Abakaliki	20-40	6.50	30.15	171.00	3.00	217.49	112.00	640.14
	40-60	4.97	26.22	153.46	2.77	200.00	103.00	520.42
	0-20	13.24	23.71	143.00	2.43	361.00	120.00	663.38
Izzi	20-40	13.00	23.70	159.81	1.92	353.18	100.00	671.61
	40-60	12.73	22.49	144.00	0.60	217.66	96.00	511.80
	0-20	6.00	16.33	37.60	1.18	10.00	80.00	351.11
IKWO	20-40	6.20	14.14	32.00	0.97	366.00	130.00	549.74
	40-60	7.70	10.00	141.00	0.24	197.27	100.00	461.83
	0.20	16.30	67,70	189.00	3.99	230.00	160.00	666.99
IVO	20-40	14.11	52.30	189.00	3.72	200.00	149.00	606.13
	40-60	10.10	19.83	170.00	2.28	65.47	140.00	407.68

Table 3. Correlation Coefficient (r) between forms of P and some soil properties.

Sample	Total P	Organic P	Al-P	Fe-P	Ca-P
Sand	0.74*	0.74*	0.21	0.59*	0.23
Silt	0.69*	–0.65	–0.02	0.44*	0.05
Clay	0.73*	–0.71	0.34	0.66*	0.32
P^H	–0.52	0.83	–0.28	–0.25	0.01
Org.C	0.69	–0.73	0.90*	0.94*	0.74*
Av.P	0.29	–0.26	0.60*	0.45	0.30

*significant at $P<0.05$

values of 20 to 92.19 mg/kg reported by Osodeke and Ubah, (2005) in ultisols of southeastern Nigeria. Results also indicated that organic P decreased down the soil profile in agreement to Ibia and Udo, (1993) who also reported a decreasing organic P with depth in line with the trend in organic carbon distribution. The decreases in organic P with increasing depth can be as a result of the higher concentration of organic carbon and microorganism within the soil surface horizon (Brady and Weil, 2008). According to Stevenson and Cole, (1999) organic P content of the soil follows closely that of total organic carbon and organic P decreased with depth. The moderately high organic P content of these soils is a reflection of their fertility potentials for crop production. Organic P also had a significant relationship with organic carbon (r=0.73) (Table 3). The strong relationship between organic P and organic carbon and soil organic carbon indicates the role of soil organic carbon in P reserve in these soils in line with the reports of Osodeke and Ubah, (2005).

Inorganic P

According to Osodeke and Ubah, (2005) inorganic P fraction is classified into active and inactive forms, the former consisting of Al-P, Fe-P and Ca-P and the latter occluded, reductant and residual P. The relative proportion of the various P forms is presented in (Table 2). The Al-P, Fe-P, Ca-P ranged from 14.86-52.30 mg/kg, 32.00-189.00 mglk and 1.00–3.99 mg/kg respectively and these decreased with increase soil depth. The active form constituted a lower percentage of the total P and Fe-P dominated the active form. For all soils studied, Fe-P was found to be highest at the 20 - 40 cm soil depth and this could be probably due to the presence of abundant Fe concentration at that particular soil depth, consequent of the presence of abundant Fe in the parent material and intensive weathering that characterized this region. This result is in agreement with the findings of other researchers (Orhue and John, 2015: Osedeke and Uba 2005). Studies have shown that Fe-P and Al-P are readily available forms of soil P in Nigerian soils and these studies have also shown that Al-P is more readily available to crops than Fe-P (udo Udo and Uzu; 1972: Osodeke and Kamalu, 1992). The relative abundance of the various forms of active inorganic P was in the order Fe-P>Al-P>Ca-P. A similar trend has been reported by several authors (Osodeke and Kamalu,1992; Osedeke and Uba 2005; Orhue and John, 2015). Fe-P had a significant correlation with sand, silt and clay, while Al-P correlated negatively with silt (r=-0.02).

The inactive inorganic fraction was relatively higher than the active P forms and values ranged from 65.47-366 mg/kg. Also the inorganic inactive P decreased down the profile.

Available P

Despite relatively high amount of total P in the soils which ranged from 345.11 - 650.69 mg/kg, only a very small percent occurred in the available forms. Result showed that the available P ranged from 6.70 - 16.30 mg/kg which is slightly lower than the critical value of 15.0 0mKg suggested by Osodeke, (2000) as ideal for optimum crop production in south Eastern Nigeria, therefore the need for P fertilizer application. It was observed that the available P decreased down the profile for most of the soil studied. This can be, attributed to the relatively low mobility of phosphorusP within the soil system (Brady and Weil, 2008). Available P correlated significantly with Al-P, but non significantly with Fe-P(r=0.60 and 0.45 respectively) indicating the higher contribution of Al-P to available P in line with the report of Osodeke and Ubah, (2005). This study has ascertained that Fe-P and Al-P are the most dominant active inorganic forms of P as far as the P availability of these soils is concerned.

Conclusion

From the study, it was discovered that the inactive forms of P were consistently higher than the active forms indicating high fixation and low availability. Within the active fractions it was discovered that the Fe-P were consistently higher than the Al-P while the Ca-P were least indicating high acidity and low calcium content. It is therefore recommended that for optimum and profitable crop production in Ebonyi state, the following should be observed:

(i) Liming to decrease soil acidity and thereby reduces P adsorption by Fe and Al oxides.
(ii) Large amount of phosphorus fertilizer should be continually added to take care of phosphate adsorption and plant requirement.
(iii) Large organic manure should be consistently use since, organic anions saturate the exchange sites of clay minerals hence it will increase soluble phosphate for plant uptake.
(iv) Since added P in the soil is rapidly adsorbed by the soil component, time and method of P fertilizer application should be planned in other to reduce much contact of P fertilizer to the soil. It is therefore suggested that P should be added in split doses and banding method should be encouraged.

This research findings and the necessary recommendations will help in the improvement of soil fertility status of Ebonyi State in respect to phosphorus availability and hence, food production. Both farmers and the government of Ebonyi State will benefit from the improved crop yield as a result of the implementation of the recommendations of this research finding. Farmers will make more profits as a result of higher yield and this will encourage youth's participation in agriculture, thereby reducing unemployment and the consequent crimes. It is hoped that this findings will not only promote economic growth, but will also help to ensure food security in Ebonyi State.

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