

## EFFECT OF ORGANIC RESIDUES APPLICATION ON PHOSPHATE MOBILIZATION IN MINNA, SOUTHERN GUINEA SAVANNA OF NIGERIA

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### ABSTRACT

The potentials of different residue materials on phosphate mobilization in Minna were studied during 2011 and 2012 cropping seasons. The treatment consisted of three organic residue sources (orange waste, tamarind pulp and amaranthus leaves) and five rates of application (0, 2, 4, 6 and 8 t ha<sup>-1</sup>). The treatment combinations were laid out in a split plot arrangement using the Randomized Complete Block Design with three replicates. Organic residue source occupied the main plot while their rates of application were assigned to the sub-plot. At the end of each cropping season, soil samples were collected and analyzed for soil available phosphorus (P) and inorganic – P fractions. The result indicated that Olsen- P and NH<sub>4</sub>Cl- P were significantly increased by the treatment of the three organic residues. While, Aluminium phosphate (Al – P), Iron – phosphate (Fe – P), Occluded phosphate (Occl – P) and calcium phosphate (Ca – P) were also mobilized and released to various degree as well irrespective of the cropping season. The relative fraction of inorganic P was in the order of Occl – P > Fe – P > Al – P > Ca – P. The order of increased mobilization of phosphate by these three organic residue appeared as orange waste > tamarind pulp > amaranthus leaves.

Key words: Phosphate mobilization, Organic residues, Olsen –P, NH<sub>4</sub>Cl – P, Occl –P

### INTRODUCTION

Phosphorus (P) is an essential nutrient element for plant growth. Although, the total P content of many soils appears more than adequate, plants can suffer from P deficiency because much of the P is bound to soil minerals and charged sites or complexed into organic forms that are in accessible to plants (Ryan, *et al.*, 2001; Gang, *et al.*, 2012). Also, fertilizer P can be fixed by Fe and Al oxides and clay minerals in acid soils, which makes it less available or effectively unavailable to plants (Shen, *et al.*, 2001; Zhang, *et al.*, 2010).

Recent studies have indicated that root exud-

ed organic acids and anions may be a strategic tools and a significant P acquisition mechanism operating in soils (Jones, *et al.*, 2003; Khademi, *et al.*, 2010). Soil organic acids are derived from the decomposition of plant and animal residues, microbial metabolism, canopy drip and rhizosphere activity (Huang and Violante, 1986; Hu, *et al.*, 2001). Gang, *et al.* (2012) further confirmed that secretion of organic acids by plant is an important mechanism for enhancing P availability in the rhizosphere because organic acids/anions significantly increased the resin – P (available P) content and thereby increased P availability and

uptake by plant. The rhizosphere is a favourable habitat for acid – producing bacteria and therefore the amount of low molecular weight organic acids in the immediate vicinity of the plant roots are much higher than in the bulk soil. The nonvolatile aliphatic acids such as oxalic, formic, malic, tartaric and citric acids are relatively abundant in the soil (Mo, 1986; Hu, *et al.*, 2001).

The chelation of  $\text{Fe}^{3+}$ ,  $\text{Al}^{3+}$  and  $\text{Ca}^{2+}$  by organic anions led to the release of inorganic bound P by these cations (Wang, *et al.*, 2009) and organic anions that compete with P adsorption on the surface of soil particle further stimulate the desorption of adsorbed phosphate ( $\text{PO}_4$ ) anion (Zhang, *et al.*, 2010).

Although Jones, *et al.* (2001) and Hocking (2001) reported that the addition of organic acids especially citric and oxalic acids can solubilize significant quantities of fixed P and reduce the sorption of newly applied fertilizer P. However, there are few studies on the transformations of P fractions induced by organic acids which are important for understanding the mobilization mechanisms P and exploring better ways of using different forms of P in soils (Zhang, *et al.*, 2010; Gang, *et al.*, 2012). Therefore, the exact mechanism among soil inorganic colloids and organic acids on P mobilization has not been well established.

For this reason, we investigate the effect of range of various organic residues on  $\text{PO}_4$  mobilization as to provide the scientific base for revealing the mechanism of  $\text{PO}_4$  mobilization and enhance the availability of P in a typical savanna soil.

## MATERIALS AND METHODS

### Soil sampling and sampling location

The site for soil sample collection was an ex-

perimental field (2011 and 2012 cropping season) located at Teaching and Research Farm of the Federal University of Technology, Minna Latitude  $9^{\circ} 31' \text{N}$  and Longitude  $6^{\circ} 30' \text{E}$  in the Southern Guinea Savanna of Nigeria. The treatment consisted of three organic residue sources (orange waste, tamarind pulp and amaranthus leaves) and five rates of application (0, 2, 4, 6 and  $8 \text{ t ha}^{-1}$ ). The treatment combinations were laid out in a split-plot arrangement using the Randomized Complete Block Design with three replicates. Organic residue source occupied the main plot while their rates of application were assigned to the sub-plot. The soil was tentatively classified as Haplic Plinthosol (Typic Plinthustalfs) (Lawal, *et al.*, 2012).

The soil samples used in this experiment for inorganic P studies were collected after each year's harvest in October 2011 and 2012. Ten sub samples were taken from each plot to form a composite for the analysis. The sampling depth was from 0 – 20 cm. Air-dried samples were ground to pass a 2-mm sieve for analysis

### Soil analysis

Soil samples were collected from a depth of 0 – 20 cm, they were air dried, sieved and then passed through 2 mm sieve. Particle size distribution was determined by the hydrometer method after dispersion with sodium hexametaphosphate according to the procedure described by IITA, (1976). pH values of the samples were determined in distilled water and 1N KCl solution using a soil - solution ratio of 1:2 (McLean, 1982). Organic carbon was determined by the Walkley – Black wet oxidation method described by Nelson and Sommer (1996). Olsen P (available P) was determined by the Bray P-1 method (Murphy and Riley, 1962). Total P was determined after digestion with 70 %  $\text{HClO}_4$ .

Phosphate in the digest was determined colorimetrically with the molybdate–ascorbic acid procedure. The content of ammonium oxalate extractable iron and aluminium oxides (Fed and Ald) were determined by the method described by Jackson, *et al.*, (1986). Selected properties of the soil samples are given in Table 1

#### Fractionation of soil inorganic phosphorus

Various fractions of soil inorganic P was extracted sequentially from the treated soils and measured according to the procedure described by Chang and Jackson (1957). At first, 1.0 mol L<sup>-1</sup> of NH<sub>4</sub>Cl was used for the extraction of loosely bound P (NH<sub>4</sub>Cl – P), then 0.5 mol L<sup>-1</sup> of NH<sub>4</sub>F for the Al phosphate (Al – P), 0.1 mol L<sup>-1</sup> of NaOH for the Fe phosphate (Fe – P), 0.3 mol L<sup>-1</sup> of Na<sub>3</sub>C<sub>6</sub>H<sub>5</sub>O<sub>7</sub> · 2H<sub>2</sub>O and Na<sub>2</sub>S<sub>2</sub>O<sub>4</sub> for the Occluded phosphate (Oc – P) and lastly, 0.25 mol L<sup>-1</sup> of H<sub>2</sub>SO<sub>4</sub> for the Ca – P. Phosphate in the supernatant were determined colorimetrically according to the procedure described by Murphy and Riley (1962) using spectrophotometer.

#### Statistical analysis

The data collected were subjected to analysis of variance (ANOVA) using a statistical package 'SAS' (2002) version 9.0. Means with significant differences were separated using the Least Significant Difference (LSD) at 5 % level of probability.

## RESULTS AND DISCUSSION

#### Characteristics of the studied soils

Major physical and chemical characteristics of the studied soil are presented in Table 1. The particle size distribution revealed that the texture of the soil was sandy clay loam with slightly acidic in reaction. The organic carbon

content of the soil was generally low (8.9g kg<sup>-1</sup>). Jones and Wild (1975) and Tsado *et al.* (2014) reported that low to medium organic carbon rate for savanna soil was attributed to paucity of vegetation cover, rapid mineralization of organic matter, inadequate return of crop residue, bush burning and short fallow periods. The total N, total P and Olsen P contents of the studied soils were also low. In the highly weathered and low activity clay soils of the tropics, organic matter is regarded as the major reservoir of P and N (Haynes and Mokolobate, 2001).

#### Inorganic phosphate mobilization

The result of Olsen- P and NH<sub>4</sub>Cl – P of the study revealed that their concentrations were significantly increased by the additions of organic residues (Table 2) in both cropping seasons. Their capacity for P mobilization appears to follow the order of orange waste > tamarind

Table 1. Selected properties of the experimental soils used in the study

Soil properties	Values
<b>Particle size distribution (g kg<sup>-1</sup>)</b>	
Sand	640
Silt	100
Clay	260
<b>Textural class</b>	
	Sandy Clay Loam
<b>pH: 0.01M CaCl<sub>2</sub></b>	5.21
H <sub>2</sub> O	6.07
Org. C. (g kg <sup>-1</sup> )	8.9
Total N. (g kg <sup>-1</sup> )	0.51
Available P. (mg kg <sup>-1</sup> )	4.21
Total P. (g kg <sup>-1</sup> )	0.48
Fe <sub>d</sub> (mg kg <sup>-1</sup> )	4.81
Al <sub>d</sub> (mg kg <sup>-1</sup> )	0.17

Table 2: Soil Olsen -P and NH<sub>4</sub>Cl -P (mg kg<sup>-1</sup>) of 2011 and 2012 cropping seasons as affected by organic residue source and their rates of application.

Treatments	Olsen - P		NH <sub>4</sub> Cl - P	
	2011	2012	2011	2012
<b>Organic residue source (OR)</b>				
Orange waste	54.27	58.09	65.33	69.22
Tamarind pulp	49.17	51.48	54.20	49.52
Amaranthus leaves	41.66	44.45	33.39	39.37
LSD (0.05)	0.58	0.67	0.82	0.83
<b>Rates (t ha<sup>-1</sup>)</b>				
0	31.87	34.07	35.68	38.11
2	45.28	48.61	45.62	49.98
4	49.73	53.13	50.11	54.94
6	56.13	59.32	54.77	59.04
8	58.87	61.57	56.72	61.43
LSD (0.05)				
Rates	0.78	0.88	1.06	1.08
OR * Rates	NS	NS	NS	NS

NS = Not Significant (P &lt; 0.05)

pulp > amaranthus leaves. This implied that the ability of organic residues for P mobilization was related to the number of carboxylic functions and molecular weight of their organic acids they produced during their decomposition. Wang, *et al.*, (2010), Gang, *et al.* (2012) and Tsado, *et al.* (2014) in their related findings, reported that the effectiveness of organic acids to mobilize P from the soil occurred in the or-

der of tricarboxylic > dicarboxylic > monocarboxylic acid. Orange waste, tamarind pulp and amaranthus leaves are sources of citric, tartaric and oxalic acids respectively (Tsado, 2014). The basic component of organic acids mineralization of orange waste, tamarind pulp and amaranthus leaves are citric, tartaric and oxalic acids respectively (Tsado, 2014). It was further observed that the effect of rates of application of organic

Table 3: Soil Occl -P and Fe -P (mg kg<sup>-1</sup>) of 2011 and 2012 cropping seasons as affected by organic residue source and their rates of application

Treatments	Occl - P		Fe - P	
	2011	2012	2011	2012
<b>Organic residue source (OR)</b>				
Orange waste	151.29	146.66	104.61	98.59
Tamarind pulp	188.92	184.93	145.04	110.12
Amaranthus leaves	218.91	212.13	150.53	115.35
LSD (0.05)	0.97	1.04	4.04	0.54
<b>Rates (t ha<sup>-1</sup>)</b>				
0	237.21	234.37	136.54	119.90
2	183.31	178.19	135.44	110.98
4	177.64	171.66	129.77	108.97
6	170.36	164.02	128.22	106.12
8	163.33	157.62	127.03	104.17
LSD (0.05)				
Rates	1.25	1.34	5.12	0.69
OR * Rates	NS	NS	NS	NS

NS = Not Significant (P &lt; 0.05)

residues (compared with control) on the mobilization of Olsen – P and  $\text{NH}_4\text{Cl} - \text{P}$  was also significant. Most importantly, addition of organic residues significantly increased  $\text{NH}_4\text{Cl} - \text{P}$  and Olsen – P which are important for plant growth because the latter is defined as plant available P. Secretion of organic acids by plant is an important mechanism for enhancing P availability in the rhizosphere because organic acids/anions significantly increased the resin – P (available P) content and thereby increased P availability and uptake by plant (Jones, 1998; Wang, *et al.*, 2012).

There was also a significant difference in Occl – P, Fe – P, Al – P and Ca – P among the type of organic residues used in both seasons of the trial (Tables 3 and 4). However, the magnitude of these forms of P mobilization was observed to be higher when orange waste was applied to the soil compared to when tamarind pulp and amaranthus leaves were added. Our result clearly demonstrated that, addition of organic residues can significantly change the P fraction and the quantity of P released was highly dependent on

the type of organic residue. The addition of organic acids especially citric and oxalic acids can solubilize significant quantities of fixed P and reduce the sorption of newly applied fertilizer P (Jones, *et al.*, 1994; Hocking, 2001). Al and Fe oxides are the main phosphates adsorbents in many soils. Moradi *et al.* (2012) reported that organic acids (citrate, tartrate etc) has a greater affinity for  $\text{Fe}^{3+}$  and  $\text{Al}^{3+}$  than P and may release the P predominantly held in Fe and Al – phosphate minerals. Wang, *et al.* (2009) and Tsado *et al.* (2014) further confirmed that phosphate predominantly precipitate as Fe – and Al – phosphate in acid soil while Ca – phosphate is the main inorganic P fraction in calcareous soils. Similarly, the effect of the rates of application of organic residues on the mobilization of Occl – P, Fe – P, Al – P and Ca – P was however significant in the two cropping seasons (Tables 3 and 4). It was observed that the effectiveness of organic residues to change the different P fraction significantly decreased with increase in their rates of application as compared with control (0 ton  $\text{ha}^{-1}$ ) in both cropping seasons. The reduction in these forms of P will thereby increase the avail-

Table 4: Soil Al –P and Ca –P ( $\text{mg kg}^{-1}$ ) of 2011 and 2012 cropping seasons as affected by organic residue source and their rates of application

Treatments	Al – P		Ca – P	
	2011	2012	2011	2012
<b>Organic residue source (OR)</b>				
Orange waste	32.21	29.12	8.20	7.69
Tamarind pulp	35.52	33.42	9.45	8.77
Amaranthus leaves	36.65	34.59	10.41	10.10
LSD (0.05)	0.42	0.50	0.17	0.12
<b>Rates (<math>\text{t ha}^{-1}</math>)</b>				
0	40.82	37.77	10.66	9.89
2	36.96	34.79	9.39	8.86
4	34.60	31.98	9.13	8.67
6	31.98	29.54	9.02	8.47
8	29.61	27.80	8.54	8.64
LSD (0.05)				
Rates	0.55	0.65	0.22	0.15
OR * Rates	NS	NS	NS	NS

NS = Not Significant ( $P < 0.05$ )

able P content and uptake by plants. There is a considerable evidence for the importance of organic acids exuded from roots in the acquisition of soil and fertilizer P by Plants (Jones, 1998; Palomo, *et al.*, 2006; Khademi, *et al.*, 2010).

Generally, there were no significant interactions between the source of organic residues and their rates of application on the different fractions of P studied in both seasons. The result of these experiments however, further revealed better P mobilizations effect of organic residues addition during 2012 compared with 2011 cropping seasons. These could be attributed to the residual effect of the first cropping season's organic residues applications as also suggested by Tsado (2014).

## CONCLUSION

Our study has clearly demonstrated that the addition of the three organic residues greatly increased the Olsen – P and  $\text{NH}_4\text{Cl}$  – P, thus increasing the availability of P in the soil. While, Al – P, Fe – P, Occl – P and Ca – P were also mobilized and released to various degree as well irrespective of the cropping season. Orange waste displayed the greatest capability to mobilize soil inorganic P followed by tamarind pulp and amaranthus leaves. Our results suggested that organic residues application rates of  $8 \text{ t ha}^{-1}$  accelerate the transformation of P from more stable fractions to more labile forms.

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