ISSN NO. 2320-5407

Journal homepage: http://www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH

RESEARCH ARTICLE

RELATIONSHIP BETWEEN P SORPTION AND SOIL PROPERTIES IN SOILS DERIVED FROM BASEMENT COMPLEX AND SEDIMENTARY PARENT MATERIALS

[*] Dada, Adebukola O[1], Omueti, John A[2], Thomas, Eunice Y [3]

1. (Mrs); Department of Agronomy, University of Ibadan, Nigeria.
2. Prof; Soil Mineraology / Soil Chemistry, Department of Agronomy, University of Ibadan, Nigeria.
3. PhD; Soil Chemistry, Department of Agronomy, University of Ibadan, Nigeria.

Manuscript Info

Manuscript History:

Received: 14 October 2015
Final Accepted: 26 November 2015
Published Online: December 2015

Key words:

Phosphorus sorption, phosphorus fractions, Fe and Al Sesquioxides, pH, parent materials

***Corresponding Author**

Dada, Adebukola O.

Abstract

This study was conducted to determine the different forms of Phosphorus and the impact of soil properties on the Phosphorus fixing capacity of soils overlying the basement complex and sedimentary parent materials of Oyo and Ogun States in Nigeria respectively.

The experiment was an incubation study which lasted a period of five weeks. Five representative top soil (0 – 15 cm) samples and five sub-surface soil (15 – 30 cm) samples were collected from five different locations in each of Oyo and Ogun States. This study was a factorial combination of the 20 soil samples, three rates of single superphosphate (SSP) fertilizer. (0, 30 and 60) kg/ha with three replications laid out in completely randomized design (CRD).

All the soils studied experienced desorption. In the soils derived from sedimentary parent materials, the Fe and Al sesquioxides both accounted for over 50% of the soil P fractions. Also for soils derived from basement complex, the Fe and Al sesquioxides both accounted for over 70% of the soil P fractions. Correlation analysis revealed that soil pH was the major soil property influencing sorption of P ($r = -0.49$, $P < 1\%$) followed by the soil age Fe_o/ Fe_d ($r = 0.40$, $P < 5\%$) for soils derived from basement complex.

For soils derived from sedimentary parent materials, correlation analysis revealed that Ammonium Oxalate extractable Al_o ($r = 0.54$, $P < 1\%$) dithionite-citrate-bicarbonate (DCB) extractable Al_d ($r = 0.49$, $P < 1\%$) and crystalline Al ($r = 0.39$, $P < 5\%$) are dominant factors influencing P sorption.

INTRODUCTION

Phosphorus is one of the major essential elements required by plants for normal growth. Phosphorus plays important roles in nearly all phases of the plant life, including photosynthesis, flowering and seed production, maturation, and root growth. Its deficiency can cause severe stunting and significant yield losses (Haven *et al.*, 1999; Zahedifar, 2011). It is an essential nutrient element for the production of ATP, DNA, RNA, and other cellular constituents of plants. Soil P is often a limiting nutrient for plant growth. The P concentration in soil solution is typically very low, because soluble forms of P are fixed by soil solid phase, making less than 0.01% of total soil P available to plants (Mengel and Kirkby, 2001; Gallaher, 2007). It is therefore one of the least mobile plant nutrients in soil.

Many soil properties have been identified to affect the availability of P for plant uptake and also P extracted from soil by chemical extractants. Among these properties are extractable Fe, Al and Mn oxides, clay content of the soil, $CaCO_3$, organic matter, soil pH and P-sorption capacity of the soil (Abdu, 2006).In tropical soils, the most expedient is amorphous and crystalline Fe oxides as well as citrate bicarbonate dithionite (CBD) extractable Fe and Al oxides (Agbenin, 2003). In highly weathered soils, the availability of phosphorus to plants can be greatly reduced through sorption to sesquioxides (Pushparajah, 1998). Early research showed that Fe and Al phosphates were prevalent in acidic soils, whereas Ca phosphates were dominant in calcareous soils (Lindsay, 1979). However, Beauchemin *et al*., (2003) found that Fe, Al, and Ca phosphates were all present in both alkaline and acid soils.

When phosphate fertilizer is applied to soil and dissolved by the soil water, several reactions occur between phosphate and soil constituents resulting to removal of P from the solution phase and rendering it less available. This phenomenon is called P fixation or sorption (the two terms are frequently used interchangeably). The ionic form in which P is predominantly absorbed depends on soil pH. $H_2PO_4^-$ is more readily absorbed in low pH soils whereas HPO_4^{2-} is preferentially absorbed in high pH soils. Phosphorus fixation is one of the major constraints to agriculture in highly weathered soils of the tropics. As reported by several authors, P fertilizers in soils are converted from a soluble state to a less soluble state through a phenomenon described as Phosphorus retention or fixation (Samadi, 2006; Matar *et al*., 1992; Ayed, 1984; White, 1981; Sample *et al*., 1980; Parfitt, 1978). Knowledge of P retention processes is necessary for the intelligent use of fertilizers with respect to the amount, kind, frequency and most effective placement of the P fertilizer.

Phosphorous is known to be the main limiting factor for plant growth (Hinsinger, 2001). This is more pronounced in tropical soils where there is preponderance of Fe and Al oxides. According to Adeoye and Agboola, 1984 and Ezeagu *et al.*, 2013, the P content of most of the soils in South Western Nigeria are below the critical requirement levels for crops. Therefore, many agricultural systems require the application of P to the soil to ensure plant productivity. Khorassani (2008) reported the work of Holford (1997), Mengel and Kirkby (1982), that the recovery of P added to soil by crop plants in a growing season is very minimal. These authors recorded that greater than 80% or 90% of the P becomes immobile and unavailable for plant use because of adsorption, precipitation, or conversion to the organic form.

Therefore, the study of P absorption in soils is very vital because until its deficiency in soil is corrected many plants have been found not to respond to nitrogen fertilizer (Ernest and Johnston, 2008) thus, making it the most important soil fertility problem after nitrogen. The knowledge of the different forms of P in the soil will inform us about the status of P and their availability in soil solution to crops grown on such soils. This will assist farmers to predict the fate of the P fertilizers applied to the soil. Hence, this study was conducted to investigate the different forms of P and the impact of soil properties on the P fixing capacity of the soils in Oyo and Ogun States.

MATERIALS AND METHODS

Collection of soil samples

Five representative top soil samples (0 – 15 cm) and five sub-surface soils (15 – 30 cm) were collected from different sites in each of cultivated and uncultivated sites (Table 1) from different locations in Oyo (8˚ 12′ N, 3˚ 42′ E) and Ogun (6˚ 90′ 98″ N 3˚ 25′ 8″ E) States. The selected sites were based on areas with underlying basement complex rocks which, is a major feature of the soils in Oyo State and the sedimentary rocks; a major characteristics of soils in Ogun State, Nigeria.

Experimental location and Laboratory procedure

The P sorption studies were carried out in soil chemistry laboratory of the Department of Agronomy, University of Ibadan, Southwest Nigeria between Nov. 2013 and Jan. 2014. The Samples were air dried and sieved through 2mm sieve, after this particle size analysis was determined using the Bouyoucos (hydrometer) method (1951). pH was determined in 1:1 soil to 1N KCl (Van Reeuwijk, 1991245) and in 1:2 soil to water using the glass electrode pH meter (Bates 1954). The macro-kjeldahl method was used to determine total N. Available P was extracted by the Bray P-1 method (Bray and Kurtz, 1945) while the P in the extract was determined by the Murphy and Riley method, (1962). The exchangeable cations were determined by extracting with neutral Normal NH_4OAC. The K and Na contents were read with the flame photometer, while Ca and Mg were determined with the Atomic Absorption Spectrometer. The ECEC was taken as the sum of exchangeable cations (Ca + Na + K + Mg) and the exchangeable acidity. The % base saturation was calculated as thus:

$$\% \text{ base saturation} = \frac{Ca + Mg + K + Na}{ECEC} \times 100$$

Phosphate fractionation

The soils were separated into their various phosphate fractions using the method described by Chang and Jackson (1957) with some modifications as regards the quantity of soil sample used and the reagents.

Incubation studies

This study was a factorial combination of the 20 soil samples, 3 rates of single superphosphate (SSP) fertilizer. (0, 30 and 60) kg/ha with 3 replications laid out in completely randomized design. The treatments that received 0 kg/ha served as control and the initial P was estimated from them. The fertilizer rates were used to develop the quantity of P in mgP/l in soil solution. Twenty g soil was placed in incubation cup which received 10ml of appropriate SSP fertilizer rates, while the controls received only distilled (10 ml) water. Cycles of wetting with distilled water were done to bring all treatments to field capacity and they were covered throughout the incubation periods which lasted 5 weeks. Laboratory temperature was maintained at 25 ±2 ^{o}C. Two g sub-samples were taken from each cup weekly and they were air-dried, P extraction by Bray P-1 method and the available P in the supernatant were done by the method described by Murphy and Riley (1962). The amount of P sorbed was obtained by subtracting the P concentration after fixation from the sum of initial available P and the P added.

Determination of free Fe and Al oxides in the soils

The free Fe and Al oxides were determined by 2 methods;

Dithionite – Citrate – Bicarbonate (DCB) Method described by Mehra and Jackson, (1960). It involved weighing 5 g soil sample into 100 ml centrifuge tube and adding 40 ml of 0.3 M sodium citrate and 5 ml of 1 M $NaHCO_3$ and contents were mixed. These tubes were placed in a water bath and the temperature increased to 75 ^{o}C while ensuring that the temperature do not exceed 80^{o}C to prevent formation of FeS. 1 g of sodium dithionite was added and the mixture was continuously stirred for 5mins. A second 1 g portion of $Na_2S_2O_4$ was added and occasionally stirred for another 10 mins. 10 ml of saturated NaCl solution was then added and 2.5 ml 100% acetone to promote flocculation and centrifuged. The suspension was then mixed and placed in water bath for 10 minutes and it was centrifuged for 15 minutes at 2000 rpm. The clear supernatant was then carefully decanted into 100 ml volumetric flask. The residue was washed twice with 20 ml 1 N NaCl and was centrifuged. The washings were added to the 100 ml volumetric flask and were made up to the mark with distilled water and mixed well. The Fe and Al in the solution were determined using the AAS.

Ammonium oxalate method was determined using the procedures as modified by Hodges and Zelazny, 1980. This involved weighing 2.5 g soil into 100ml centrifuge tubes and adding 50 ml of 0.2 M Ammonium oxalate solution at pH 3.0 to the weighed samples. This is covered and immediately wrapped in aluminium foil to eliminate air, and then shake for 2 hours. The samples were centrifuged and supernatant solution decanted from the sample into a tube for analyzing Al and Fe. The Fe and Al in the extracts were determined by using AAS.

Statistical Analysis

The adsorption data were subjected to Mean, and correlation analyses using the GenStat analytical tools.

Results and discussion

The physicochemical properties of the soils used for the study obtained from the routine soil analysis are shown in Tables 2 and 3. The sand contents of the soils were appreciably high ranging from 414-914 g/kg soil. The clay and the silt fractions were generally low with values ranging from 140-160 g/kg soil and 92-492 g/kg, respectively. The soils are generally classified texturally as sandy loam and loamy sand. Such soils usually have low adsorption capacity for basic plant nutrients and water (AkpanIdiok, 2012). The pH of the soils in water ranged from slightly acidic to slightly alkaline 6.0 - 7.4. The mean pH value is 6.7. The organic carbon content of the soils ranged from 8.7-31.9 g/kg soil (mean of 20.2 g/kg soil). The level of organic carbon is quite high when compared to 15 g/kg as given by Enwezor *et al.*, (1989) andAkpanIdiok, (2012). These levels of organic carbon are able to sustain intensive cropping system in these areas (AkpanIdiok, 2012). The relatively high amount of organic matter in these soils (consequence of the high organic carbon), are able to produce liming effects during mineralization which has invariably caused the high pH values of the soils. It also produces complexing agents which are able to bind the Fe and Al oxides and hydroxides; thereby reducing their fixation potentials, hence and making more phosphate available in solution.

Total N values ranged from 0.5 - 2.8 g/kg soil with the mean value being 1.34 g/kg soil which is lower than the 1.5 g/kg soil set by (Adeoye and Agboola 1984, Umor *et al.,* 2015) for optimum maize production. The soil available P ranged from 0.3-18.9 mg/kg soil (mean of 5.1 mg/kg soil). These values are below the 10 – 17 mg/kg which is usually considered as the critical value for the soils of South Western Nigeria (Adeoye and Agboola, 1984 and Ezeagu *et al.*, 2013) except for the surface soil of Wasimi where bush burning activity was carried out as a form of land clearing practice.

The exchangeable bases are in this order of abundance Ca >Mg >Na > K. The Ca content of the soils varied from 1.7 - 12.1 cmol/kg soil with a mean of 3.69 cmol/kg soil. The Mg content of the soils ranged from 0.2 - 1.7 cmol/kg soil (mean of 0.79 cmol/kg soil). The exchangeable K ranged from 0.1-1.1cmol/kg soil (mean of 0.37cmol/kg). The Na content of the soils ranged from 0.3 - 3.1cmol/kg soil. The exchangeable acidity ranged from 0.1 - 1.5 cmol/kg with mean value of 0.21 cmol/kg soil. The ECEC of the soils ranged from 2.5 - 15.2 cmol/kg soil which falls within the range (3 – 15 cmol/kg) typical of tropical soils dominated by kaolinitic clay (Ojo-Atere *et al.*,1987).

The values of free Fe oxide extracted by dithionite (Fe_d) as presented in Table 4 was generally higher than that extracted by ammonium oxalate (Fe_o) which implies that an appreciable quantity of the free Fe oxide has been transformed into the crystalline form of Fe in the soils under study. The Fe_d and Fe_o concentrations ranged from 5.41 – 38.97 g/kg (mean of 9.48 g/kg) and 0.15 -3.13 g/kg soil (mean of 1.14g/kg soil), respectively. This implies that a mean value of 9.18 (Fe_d less mean Fe_o) of the Fe is present in definite crystalline forms. Same trend was also seen with the other free oxides (Al_d and Al_o). The active ratio Fe_o /Fe_d (which helps to assess the degree of crystallinity and soil age) across the soils were generally low having values less than unity (0.02 – 0.27). This indicated the prevalence of crystalline form of Fe mainly goethite (Jones and Wild, 1975) which is a pointer to possibility of the soils being older soils and undergoing intensive weathering (Alexander, 1974). The active ratios of these soils cannot be used to classify the soils into well and poorly drained as used by Storehouse and Arnard, (1971) where they classify ratios below 0.35 as poorly drained soils and those above 0.35 as well drained. This is not true with these soils as the result of the particle size analysis classify them mainly as loamy sand and they are not poorly drained.

The concentration of Al extracted by dithionite (Al_d) and ammonium oxalate (Al_o) has a mean of 2.47 and 0.59 g/kg soil, respectively .The Al_d values were higher than what was reported by Agbenin, (2003) for savanna Alfisols while that of Al_o is within the range reported by Agbenin (2003).

Phosphorus fractionation before incubation

The fractionation data as presented in Table 5 for soils derived from sedimentary parent materials revealed that over 38% of the soil P is present in the form Fe-P and over 20% as Al-P. The Fe and Al sesquioxides both accounted for over 50% of the soil P. The Saloid P is also relatively high. This explains why the free Fe and Al oxides are the major sinks for P in the soils. This corroborates the findings of Harrell and Wang (2006) that in mildly calcareous soils, Fe and Al oxides were likely to govern the P retention.

Table 6 represents soil P fractionation data for the soils derived from basement complex parent material. The data revealed that over 50% of the soil P is present in the form of Fe-P and over 17% as Al-P. The Fe and Al-sesquioxides accounted for over 70% of the soil-P forms. The Saloid P is the lowest form of P present in the soil. This is because most of the soil P has been fixed by Fe; thereby, making it unavailable in solution. Therefore, an increase in Fe-P and Al-P leads to a decrease in P in soil solution.

Phosphorus fractionation after incubation for soils derived from sedimentary parent materials

P fractionation for soils incubated with no fertilizer addition i.e. 0 rate of fertilizer application is presented in Table 7A. Worth noting is the fact that there is an increase in the Saloid P revealing that more P are available in solution which is a clear evidence of the desorption process observed during the incubation period. The source of the P in solution is likely from the occluded P and Ca-P due to a decrease in their values. P fractionation after incubation of soils at 60 kg/ha P rate of fertilizer application is presented in Table 7B. There is also the presence of the soil P in the forms Fe-P and Al-P being the largest form. But at this rate, the Saloid P gives the lowest value showing that there is reduced quantity of P in solution.

Phosphorus fractionation after incubation for soils derived from basement complex rocks

P fractionation for soils incubated with no fertilizer addition i.e. 0 rate of fertilizer application is presented in Table 8A. The Fe-P and Al-P forms have the highest values of the P fractions observed at 0 kg/ha P fertilizer application.There is a very high increase in the Saloid P and Ca-P from a mean value of 3.84 to 16.00 mg/kg and 3.54 to 12.89 mg/kg soil, respectively. Also there is an increase in the mean value of Al-P from 16.93 to 41.04 mg/kg of soil. P fractionation for soils incubated with 60 kg/ha P rate of fertilizer application is presented in Table 8B. Al-P also has the highest mean value across the soils being the largest observed P form. There is also an appreciable increase in the Saloid P which depicts greater quantity of P in solution.

Incubation study and phosphorus fractionation

The soil samples used for this study greatly experienced desorption rather than fixation. The soils from the sedimentary rock parent materials desorbed more than 300% of the actually P concentration rates added, while the soils derived from the basement complex desorbed more than 140%. This result is similar to the findings of Peretyazhko and Sposito (2005); Chaco'n *et al.*, 2006 that P bound to Fe and Al oxides and hydroxides can be released during short term low redox fluctuations. This is also confirmed by the result obtained from the phosphate fractionation process carried out before and after the incubation study presented in Tables 6 – 9. In the sedimentary parent materials, the data reveal that the predominant forms of P in these soils are Fe-P, Al-P, and the Occluded Fe-P & Al-P. Both Fe and Al sesquioxides accounted for over 50% of the soil P. The Saloid P is also relatively high. This explains why the free Fe oxides and Al oxides are the major sinks for P in the soils. This corroborates the findings of Harrell and Wang (2006) that in mildly calcareous soils, Fe and Al oxides were likely to govern the P retention. Also, due to the high pH values of these soils which cause the Fe and Al oxides to be reduced, it therefore leads to the release of P bound to the oxides into solution. At high pH (6.0 - 7.4), there are fewer quantities of Fe and Al in solution; they are easily saturated and the excess P is released into soil solution. Also, since the pH of the Point of Zero Charge for most pure Fe oxides ranges from 7-9 (Schwertmann and Taylor, 1989), which is the characteristic of these soils, the ability of the surface to adsorb P is at a minimum.

Correlation for soils derived from basement complex

There is a significant negative correlation between the sorbed P and the pH of the soils ($r = -0.49$, $P < 1\%$, Table 9). This shows that as the soil pH increases, less P is fixed or sorbed. This may be due to the quantity of the free oxides capable of fixing P reduces, thereby causing a fast saturation of the exchange sites available and the excess P is left in solution. It also depicts that as the pH value of the soils increases, there is reduction in the quantity of metallic oxides especially Fe and Al in soil solution capable of fixing P. This therefore causes the availability of more P in solution.

There is a significant positive correlation between the sorbed P and the age of the soils (Fe_o/Fe_d) ($r = 0.397$, $P < 5\%$, Table 9). This shows that the soils are old and their clay mineral structures are breaking down to cause the release of their structural Al into solution. The significant correlation ($r = 0.744$, $P < 5\%$, Table 10) between clay and Fe_d shows that some of the free Fe oxides are found as coatings on the clay minerals which are made easily available in solution to fix P. This is confirmed from the result of P fractionation in Table 9A where the Fe-P has the largest amount of P.

Correlation for soils derived from sedimentary rocks

There is significant correlation between the sorbed P and Al extracted by dithionite Al_d, ammonium oxalate Al_o and crystalline Al. This result is similar to the findings of Pierzynski *et al.*, 1990 that Al, rather than Ca, was the predominant cation associated with P-rich particles of heavily fertilized soils regardless of soil pH (since these soils are under continuous cultivation, there must have been series of fertilizer applications). Also there is significant correlation ($r = 0.837$, $P < 1\%$) between clay and crystalline Al. This may be due to the fact that these soils are very old and the silicate clay minerals are breaking down to release its structural crystalline Al; some of which are also part of Al_d ($r = 0.780$, $P < 1\%$) between clay and Al_d. They all act as sorption sites for P in these soils (Table 10).

Table 1: Description of the sampling sites

No	Soil location	Coordinates	Land use / cover	Usda classification
		OGUN STATE		
1	Owode, Obafemi LGA	6° 57′ 19″ N, 3° 12 ′ 56″ E	Cultivated to arable crops	Alfisol
2	Itori, Ewekoro LGA	6° 55′ 59″ N, 3° 30′ 54″ E	Cultivated to sugarcane	Alfisol
3	Ilishan, Ikenne LGA	6° 54′ 25″ N, 3° 40′ 59″ E	Cultivated to cassava	Alfisol
4	Ikenne, Ikenne LGA	6° 52′ 5″ N, 3° 41′ 43″ E	Rubber plantation	Alfisol
5	Wasimi, Ewekoro LGA	6° 59′ 19″ N, 3° 13′ 25″ E	Fallow land	Alfisol
		OYO STATE		
6	Idi-Ayunre,Oluyole LGA	7° 14′ 8″ N 3° 51′ 58″ E	Fallow land	Alfisol
7	Abadina,Akinyele LGA	7° 27′ 80″ N 3° 53′ 58″ E	Uncultivated land	Alfisol
8	Tech Road,UI, Akinyele LGA	7° 26′ 24″ N 3° 53′ 31″ E	Cultivated to cassava	Alfisol
9	NIHORT,OLuyole LGA	7° 24′ 27″ N 3° 50′ 51″ E	Fallow land	Alfisol
10	ParryRoad,UI, Akinyele LGA	7° 27′ 10″ N 3° 53′ 20 ″ E	Cultivated land	Alfisol

Table 2: Particle size analysis of the soil samples

Soil no	Location	Sand	Silt g/kg	Clay	Textural class
1.	Owode 1	834	54	112	Loamy sand
2.	Owode 2	714	54	232	Loam
3.	Itori 1	794	74	132	Loamy sand
4.	Itori 2	854	34	112	Loamy sand
5.	Ilishan 1	414	194	392	Clay loam
6.	Ilishan 2	434	74	492	Clay
7.	Ikenne 1	834	54	112	Loamy sand
8.	Ikenne 2	794	54	152	Loamy sand
9.	Wasimi 1	914	14	72	Sand
10.	Wasimi 2	794	34	172	Loamy sand
11.	Idi-ayunre 1	854	34	112	Loamy sand
12.	Idi-ayunre 2	774	34	192	Loamy sand
13.	Abadina 1	834	74	92	Loamy sand
14.	Abadina 2	794	74	132	Loamy sand
15.	Tech 1	794	74	132	Loamy sand
16.	Tech2	714	74	212	Sandy loam
17.	NIHORT 1	794	74	132	Loamy sand
18.	NIHORT 2	574	134	292	Sandy loam
19.	Parry 1	814	74	112	Loamy sand
20.	Parry 2	834	54	112	Loamy sand

Table 3: Chemical properties of the soil samples

Soil no.	pH H_2O	Total N	Org C	Base sat.	Avail. P	Ca	Mg	K	Na	Ex. Acidity	ECEC
		----------	g/kg	-------	mg/kg	-----	------	cmol/kg	------	--------	-------
1.	7.1	1.7	22.7	98	9.0	3.1	1.2	0.4	0.9	0.1	5.7
2.	6.9	1.1	21.4	98	0.9	2.3	1.0	1.0	3.1	0.2	7.6
3.	7.6	2.8	31.9	89	4.3	12.1	0.8	0.2	0.6	1.5	15.2
4.	6.5	1.4	20.5	97	0.9	4.9	0.5	0.1	0.5	0.2	6.2
5.	6.5	1.9	31.9	98	9.0	4.9	1.7	0.1	0.4	0.1	7.2
6.	6.7	1.1	19.1	96	0.3	3.0	1.2	0.1	0.4	0.2	4.9
7.	6.6	0.7	9.9	94	0.3	1.8	0.2	0.1	0.4	0.2	2.7
8.	6.5	0.8	8.7	95	1.3	1.7	0.2	0.1	0.4	0.1	2.5
9.	7.0	1.5	17.4	98	18.9	3.7	1.1	0.6	0.3	0.1	5.8
10.	7.4	1.0	18.5	96	1.0	3.0	0.7	0.5	0.4	0.2	4.8
11.	7.0	1.4	20.7	98	2.0	3.6	1.1	1.1	0.4	0.1	6.3
12.	6.7	0.9	15.9	97	9.3	3.0	1.1	0.2	0.3	0.1	4.7
13.	6.7	1.8	29.4	98	0.8	4.0	0.8	0.6	0.4	0.1	5.9
14.	6.7	1.5	21.7	98	0.9	3.6	0.6	0.6	0.4	0.1	5.3
15.	6.5	2.0	21.3	97	5.9	4.3	0.6	0.5	0.4	0.2	6.0
16.	6.5	1.1	20.1	98	8.7	3.3	1.6	0.5	0.4	0.1	5.9
17.	6.4	1.2	18.2	97	0.4	3.8	1.7	0.2	0.3	0.2	6.2
18.	6.3	0.5	16.0	97	10.1	2.5	0.4	0.2	0.3	0.1	3.5
19.	6.2	1.0	20.4	97	9.6	2.8	0.3	0.1	0.4	0.1	3.7
20.	6.4	0.7	16.9	97	9.8	2.3	0.8	0.1	0.4	0.1	3.7

NOTE: Odd and even numbers on the first column represent top soils (0-15) cm and sub soils (15-30) cm ,respectively

Table 4: Distribution of Fe and Al oxides in the soils studied

Soil no	Fe_d	Fe_o	$Fe_d – Fe_o$	Al_d	Al_o	$Al_d – Al_o$	Fe_o/Fe_d
	-----------	-----------	------g/kg	---------	----------	----------	----------
1.	11.72	0.33	11.39	2.30	0.89	1.41	0.03
2.	9.68	0.15	9.52	4.75	1.95	2.80	0.02
3.	38.97	3.13	35.84	3.34	1.01	2.33	0.08
4.	12.29	1.37	10.92	5.88	1.28	4.60	0.11
5.	9.09	1.15	7.94	2.45	1.48	0.97	0.13
6.	11.83	0.68	11.15	2.33	0.92	1.41	0.06
7.	6.28	0.58	5.70	1.91	0.89	1.02	0.09
8.	6.73	1.85	4.88	3.56	0.73	2.83	0.27
9.	9.72	0.65	9.06	0.86	0.32	0.54	0.07
10.	11.82	0.52	11.30	1.76	0.60	1.16	0.04
11.	5.77	0.98	4.79	1.13	0.36	0.77	0.17
12.	6.07	0.79	5.27	2.37	0.13	2.24	0.13
13.	10.24	1.76	8.48	1.90	0.31	1.59	0.17
14.	10.05	1.66	8.39	1.18	0.47	0.71	0.17
15.	9.37	1.53	7.84	1.99	Nd	1.99	0.16
16.	11.08	1.95	9.13	2.88	0.40	2.48	0.18
17.	5.53	0.90	4.63	2.24	0.15	2.09	0.16
18.	5.41	1.05	4.36	1.96	0.17	1.79	0.19
19.	7.11	1.40	5.71	2.68	0.25	2.43	0.20
20.	7.63	1.06	6.57	1.82	Nd	1.82	0.14

NOTE: Odd and even numbers on the first column represent top soils (0-15) cm and sub soils (15-30) cm, respectively. Nd- Not detected, Fe_d– Fe oxide extracted by dithionite citrate bicarbonate, Fe_o– Fe oxide extracted by ammonium oxalate, Fe_d - Fe_o– Definite crystalline forms of Fe oxide, Fe_o / Fe_d – Active ratio, Al_d– Al oxide extracted by dithionite citrate bicarbonate, Al_o – Al oxide extracted by ammonium oxalate, Al_d – Al_o – Definite crystalline forms of Al oxide.

Table 5: Soil P fractions before incubation study for soils derived from sedimentary parent materials

Soil No	Saloid P	Al –P	Fe-P	Occluded P	Occluded Fe and Al –P	Ca-P
	----------------	---------------	-mg/kg--	-----------------	-----------------	----------
1	3.84	16.91	41.92	41.92	10.11	4.34
2	15.71	11.76	51.72	8.66	10.69	11.87
3	7.92	31.13	36.12	4.66	1.16	7.53
4	0.81	9.68	0.64	3.20	22.68	6.85
5	47.61	20.96	67.68	7.06	18.20	7.76
6	11.99	10.29	11.75	11.46	13.43	10.73
7	4.19	16.30	35.96	3.46	19.36	7.65
8	1.16	15.13	39.00	4.40	Nd	8.45
9	11.17	44.12	53.42	8.52	Nd	7.99
10	3.96	13.24	27.32	17.72	10.83	7.88
Mean	10.84	18.95	36.55	9.27	10.65	8.11

NOTE: Odd and even numbers on the first column represent top soils (0-15) cm and sub soils (15-30) cm ,respectively.

Nd – Not detected

Table 6: Soil P fractions before incubation study for soils derived from basement complex

Soil No	Saloid P	Al –P	Fe-P	Occluded P	Occluded Fe and Al –P	Ca-P
	----------------	-----------------	-mg/kg-	-----------------	-----------------	----------------
1	2.44	15.07	28.98	4.80	16.03	4.34
2	2.56	18.38	37.33	8.79	7.08	4.22
3	5.59	39.95	51.44	7.06	6.93	3.54
4	8.50	13.97	39.76	14.92	9.39	5.14
5	1.86	24.63	34.42	9.99	15.31	7.99
6	2.33	20.34	93.90	6.79	10.83	7.76
7	1.63	12.50	45.98	9.59	16.18	4.79
8	1.28	13.87	83.92	12.25	2.46	4.91
9	8.26	7.84	90.08	8.52	13.43	5.14
10	3.96	2.70	20.33	7.33	8.52	3.54
Mean	3.84	16.93	52.61	9.00	10.62	5.61

NOTE: Odd and even numbers on the first column represent top soils (0-15) cm and sub soils (15-30) cm ,respectively

Table 7A:Soil P fractions after incubation study 0 kg/ha for soils derived from sedimentary parent materials

Soils	Rates	Saloid P	Occluded P	AL-P	Fe-P	Occluded Al- P & Fe-P	Ca-P
		-------------	----------------	-----mg/kg--	---------------	----------------	----------------
Owode 1	0	13.62	5.86	22.43	43.70	18.35	4.34
Owode 2	0	13.62	20.11	34.56	52.44	5.78	5.94
Itori 1	0	11.29	9.06	28.80	52.35	8.96	5.14
Itori 2	0	13.27	6.53	21.20	50.71	18.78	10.50
Ilishan 1	0	11.76	6.93	27.57	49.90	4.33	8.56
Ilishan 2	0	19.09	5.19	67.53	51.63	0.14	11.76
Ikenne 1	0	9.89	6.53	25.98	52.35	2.02	2.85
Ikenne 2	0	11.76	3.60	44.24	51.26	2.89	5.37
Wasimi 1	0	11.29	3.60	27.08	50.26	36.11	9.13
Wasimi 2	0	12.34	7.06	29.41	49.44	17.19	4.22
Mean		12.79	7.45	32.88	50.40	11.46	6.78

Table 7B: Soil P fractions after incubation study at 60 kg/ha for soils derived from sedimentary parent materials

Soils	Rates	Saloid P	Occluded P	AL-P	Fe-P	Occluded Al- P & Fe-P	Ca-P
		-------------	----------------	-----mg/kg--	---------------	----------------	----------------
Owode 1	60	15.71	6.13	17.03	51.35	22.25	8.22
Owode 2	60	14.20	10.39	18.63	45.62	Nd	84.93
Itori 1	60	11.52	4.53	18.38	42.70	10.83	6.39
Itori 2	60	11.06	7.86	27.21	43.43	15.89	3.42
Ilishan 1	60	19.90	18.12	45.22	42.25	Nd	4.68
Ilishan 2	60	9.89	5.59	38.36	51.17	13.00	9.02
Ikenne 1	60	12.80	4.00	51.59	51.26	Nd	5.25
Ikenne 2	60	10.48	6.26	42.40	41.06	30.48	9.59
Wasimi 1	60	13.74	8.26	29.41	41.97	10.40	13.70
Wasimi 2	60	51.80	5.86	27.45	48.17	5.78	5.48
Mean		7.11	7.70	31.57	45.90	15.25	15.07

*Nd - Not detected

Table 8a: Soil P fractions after incubation study at 0 kg/ha for soils derived from basement complex

Soils	Rate	Saloid P	Occluded P	Al-P	Fe-P	Occluded Al-P & Fe-P	Ca-P
		---------------	----------------	-mg/kg	-----------------	--------------------------	---------
Idi-ayunre 1	0	53.19	5.59	33.09	49.80	6.07	6.39
Idi-ayunre 2	0	11.06	6.66	14.46	50.35	1.59	4.11
Abadina 1	0	10.01	7.06	13.48	50.35	12.13	3.20
Abadina 2	0	20.14	6.39	241.02	84.34	15.75	4.00

Tech road 1	0	14.67	3.06	23.53	38.03	0.14	74.31
Tech road 2	0	12.57	4.26	31.25	82.86	12.28	6.05
NIHORT 1	0	11.76	7.73	13.97	44.61	Nd	3.54
NIHORT 2	0	11.41	5.73	7.11	48.62	14.01	2.51
Parry 1	0	11.77	4.53	9.44	29.41	Nd	14.73
Parry 2	0	3.38	5.99	23.04	33.84	11.56	5.02
Mean		16.00	5.70	41.04	51.22	9.19	12.89

*Nd - Not detected

Table 9b: Soil P fractions after incubation study at 60 kg/ha for soils derived from basement complex

Soils	Rate	Saloid P	Occluded P	Al-P	Fe-P	Occluded Al-P & Fe-P	Ca-P
		---------------	----------------	-mg/kg	-----------------	------------------------	---------
Idi-ayunre 1	60	7.57	7.46	26.96	50.35	1.88	3.42
Idi-ayunre 2	60	13.39	2.13	31.01	48.07	9.39	2.40
Abadina 1	60	30.50	7.73	234.89	49.90	4.33	15.52
Abadina 2	60	57.39	2.80	296.57	88.59	20.08	66.89
Tech road 1	60	12.22	3.73	21.94	82.43	6.50	3.54
Tech road 2	60	11.17	8.26	33.70	42.88	Nd	4.22
NIHORT 1	60	9.89	7.19	20.83	57.06	16.32	8.56
NIHORT 2	60	11.06	2.66	10.66	37.06	7.94	4.68
Parry 1	60	3.26	5.73	49.63	53.11	9.68	2.74
Parry 2	60	2.68	2.93	21.20	56.30	Nd	5.94
Mean		15.91	5.06	74.74	56.58	9.52	11.59

Nd – Not detected

Table9: Correlations matrix between phosphate sorped and some soil properties for soils derived from basement complex

	Sorped P	pH	Clay	Org C	Fe_d	Fe_o	Fe_d-Fe_o	Fe_o/Fe_d	Al_d	Al_o	Al_d-Al_o
Sorped P											
Ph	$-.494^{**}$										
Clay	.126	.070									
Org C	-.166	.346	.099								
Fe_d	.162	.107	$.744^{**}$	$.631^{**}$							
Fe_o	.267	-.018	$.681^{**}$	$.679^{**}$	$.939^{**}$						
Fe_d-Fe_o	.136	.133	$.746^{**}$	$.610^{**}$	$.997^{**}$	$.910^{**}$					
Fe_o/Fe_d	$.397^{*}$	$-.365^{*}$	-.046	.262	.043	$.380^{*}$	-.033				
Al_d	.154	$-.623^{**}$	.243	-.191	.091	.165	.073	.152			
Al_o	-.074	$.432^{*}$	$.490^{**}$	$.439^{*}$	$.381^{*}$	$.506^{**}$	.347	$.401^{*}$	-.202		
Al_d-Al_o	.160	$-.682^{**}$	.095	-.289	-.016	.019	-.024	.034	$.967^{**}$	$-.445^{*}$	

* = Correlation is significant at 5%,
** = Correlation is significant at 1%

Table 10: Correlations matrix between phosphate sorped and some soil properties for soils derived from sedimentary parent material

	Sorped P	pH	Clay	Org C	Fe$_d$	Fe$_o$	Fe$_d$-Fe$_o$	Fe$_o$/Fe$_d$	Al$_d$	Al$_o$	Al$_d$-Al$_o$
Sorped P											
pH	-.110										
Clay	.249	.171									
Org C	.234	.392*	.328								
Fe$_d$	.180	.705**	.567**	.620**							
Fe$_o$	.210	.233	.562**	.336	.762**						
Fe$_d$-Fe$_o$	.172	.735**	.552**	.632**	.998**	.718**					
Fe$_o$/Fe$_d$	.107	-.518**	.031	-.371*	-.173	.493**	-.237				
Al$_d$	.490**	-.272	.780**	.119	.133	.265	.116	.180			
Al$_o$	.539**	-.264	.301	.422*	.009	-.072	.017	-.173	.683**		
Al$_d$-Al$_o$	.394*	-.232	.838**	-.014	.159	.351	.135	.286	.961**	.455*	1

* = Correlation is significant at 5%,
** = Correlation is significant at 1%

CONCLUSIONS

The results revealed that the soils studied greatly experienced desorption rather than fixation. This was observed from the pronounced increase noticeable in the Saloid P fraction of the soils after the incubation study. The soils derived from the sedimentary rock parent materials desorbed more phosphorus than those derived from the basement complex.

An appreciable quantity of the free Fe and Al oxide has been transformed into the crystalline forms in these soils. The active ratio Fe$_o$ /Fe$_d$ across the soils were generally low having values less than unity which indicated the prevalence of crystalline form of iron mainly goethite which is a pointer to possibility of the soils being older soils and undergoing intensive weathering. The Phosphorus in the soils exists predominantly in Fe-P and Al-P fractions.

Considering soils derived from the basement complex, pH was the major soil property influencing the sorption of Phosphorus and this was followed by the soil age. For soils derived from the sedimentary rock parent materials, Al_o was found to be the strongest predictor of desorbed Phosphorus of all the soil properties considered followed by Al_d, and crystalline Al.

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