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Evaluation of phosphorous fixation capacity on river alluvium, beach ridge and coastal plain sand of Akwa ibom state, Nigeria

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Abstract

Phosphorous fixation capacities of selected parent materials in Akwa Ibom State were assessed. The soils used were those derived from river alluvium, beach ridge sand and coastal plain sand. These soils were incubated with four rates of P ranging from 0, 20, 40, 80 mgl^{-1} prepared from KH_2PO_4 and incubated for 1, 7, 30, 60 and 90 days. The design was 3 x 4 factorial experiment (3 soil types and 4 rates of P) fitted into Completely Randomized Design (CRD) with three replications. At a set day, the exchangeable and water -soluble (available) P were extracted with Bray P – I extractant and P not extracted by this extractant was considered fixed in the soils, using fractional recovery of P to obtained. The results showed that the available P in the soils decrease with days of incubation. Beach ridge sand had the highest fractional recovery of P while river alluvium had the least. The trend were beach ridge sand (5.04 gkg^{-1}) > coastal plain sand (2.34 gkg^{-1}) > river alluvium (1.07 gkg^{-1}). The recovery of P increase with increasing P addition. The fixing capacity of the soils increased in this order: river alluvium (97%) > coastal plain sand (92%) > beach ridge sand (84%). The result also revealed that the amount of P fixed increases with increasing rates of P addition.

Keywords: **:** Phosphorous, parent material, fixing capacity, Fractional recovery, Soil properties

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1.0 Introduction

Phosphorous is the second most critical nutrient element influencing plant growth and production. Its uptake is through the root and from the amount present in soil solution as orthophosphate anions (Agbede, 2009). The soil solution P concentration depends on the amount of absorbed P in the soil solid phase. When the P concentration in soil solution or P intensity is diminished by P removal, it is replenished more slowly by non-labile P (Mokwonye and Bationo, 2002). Phosphorous fixation renders P unavailable in the short run. It is more common that plants utilize a little amount from P provided by fertilization. Research results show that the plants make use of 10-30% of phosphorous, the rest of phosphorous is within a proportion (70 - 90%) that has been made fixed in the soil. (Ibia and Udo 1993; Osodeke, 2005; Ukpong *et al.,* 2014; Umoh *et al.,* 2019). In acidic conditions, insoluble hydrate oxides of Fe, Al, Mn elements are present and in alkaline conditions, Ca and Mg present react with soil phosphorous, rendering the nutrient fixed. Soils of the humid tropics have widespread P deficiency, making it one of the most limiting crop nutrients, due to high fixing capacity related to exchangeable Fe and AI, low pH, types of clay and high amounts of added P fertilizers, low organic matter content and parent materials on which the soils are formed (Ibia, *et al.,* 2001). Umoh *et al.,* (2021) carried out a fixation study and discovered a variation in parent materials to fixed phosphorous and the amount of P fixed in shale and alluvium soils decrease with the length of incubation, a significant higher fixation was observed on day 1 (60.6$mgk5^{-1}$ shale and 50.6$mgkg^{-1}$ in alluvium). The amount observed in sandstone increased with the length of incubation and a significant amount fixed was observed in 30 days (54.4$mgkg^{-1}$). Agbede (2009) reported that plants can utilize calcium phosphate in a range of 5.5 – 7.5 pH. However, its utilization decline due to phosphate retention which causes tri-calcium phosphate in a range of pH above 7, fixation occurs in a form of clay – Ca – H_2PO_4 bound within Calcium among saturated Clays. Amhakhian *et al.,* 2009; Ukpong *et al.,* 2014) carried out a fixation study and discovered that the P fixing capacity of soils increased with increasing rate of added P. Umoh and Osodeke (2016) reported that high sorption capacities of soil required large phosphorous fertilizer dressing for optimum crop yield. Sufficient information on the fixation capacity of phosphorous in various soils in Akwa Ibom State is lacking. This study, therefore, aimed to examine the P fixing capacity of representative soils based on their parent materials and as influenced by the contact time and rates of P added to obtain efficient fertilization recommendations for high productivity.

2.0 Materials and Methods

2.1 Description of the study area

The study was carried out in selected locations; Obio Akpa (Oruk Anam), Okon and Uta Ewa (Ikot Abasi) in Akwa Ibom State, Nigeria. The area lies between latitude $4^0 31^1$, and 5^0 $33N^1$ and longitude 7^1 25^1 and 8^0 25 E. The soil is derived from Coastal Plain Sand (CPS), River Alluvium (RA) and Beach Ridge Sand (BRS) dominated by Kaolinite and Oxides of Fe and Al with high nutrient leaching potentials (Umoh *et al.,* 2019). This area has been hot, humid tropical climate with two distinct seasons; the rainy season which lasts from April to October and the dry season which spans from November to March. It is characterized by heavy annual rainfall of about 2500 – 3000mm. High temperature with a mean monthly temperature of 28^0c. The highest temperature are experienced between January through March, the period described by Enwezor *et al.,* (1990) as overhead passage of the sun. Relative humidity is high between 75% and 95% while solar radiation ranges from 6-15 hours per day.

2.2 Field studies and laboratory procedures

The soil samples were collected from 0 – 15cm depth, transported to the laboratory, air dried, crushed and sieved to pass through 2mm diameter mesh, and then used to determine some physicochemical characteristics of the soils as described by Udo *et al.,* (2009). Particle size distribution was determined by the Bouyoucous hydrometer method. Soil pH was determined in a 1:2.5 soil: water ratio with a pH meter. Organic carbon was determined by Walkley Black Dichromate Oxidation Method. Total nitrogen (N) was determined by the micro-Kjeldahl method. Available phosphorous (P) was extracted by the Bray 1 extraction method and the content of P was determined colorimetrically using a Technico AAll auto analyse (Technico, Oakland, Calif). Exchangeable bases (K, Na, Ca, and Mg) were extracted with O. I N ammonium acetate; K and Na were read with a flame photometer while Ca and Mg were determined through the EDTA titration method. Exchangeable acidity was determined by leaching the soils with IN KCl and titrating aliquots with 0.01 NaOH. Effective Cation Exchange Capacity (ECEC) was calculated as the sum of exchangeable bases (Ca, Mg, K and Na) and exchangeable acidity. Base saturation was calculated by dividing the sum of exchangeable bases by ECEC and multiplying by 100^0.

2.3 Incubation procedure and analysis

The Phosphorous fixation capacity of the three representatives soils was estimated using a simple laboratory incubation method. Twenty (20g) of each soil type was weighed into a treatment solution containing 0, 20, 40 and $80mgl^{-1}$ P concentration prepared from (KH_2 PO_4) was added to each cup and was mechanically shaken for 30 minutes to effect thorough mixing. The cup was then covered and allowed to incubate for 1, 7, 30, 60, and 90 days respectively the samples were kept moist with distilled water at weekly intervals. At the end of the incubation period, the samples were extracted with 20ml Bray p – 1 extractant. The P in the extract was measured using Murphy and Riley (1962) method. The data on the amount of P fixed was obtained as the difference between the quantity of P added and P in solution (recovered). The percentage of P fixed was calculated.

2.4 Statistical Analysis

The data obtained from this research were analyzed using analysis of variance (ANOVA) and the difference between treatments means were dictated using F – LSD at $P < 0.05$ level. Pearson's correlation coefficient was used to relate the fractional recovered with soil properties (GENSTAT, 2008).

3.0 Results and Discussion

3.1 Physicochemical Characteristics of the Studied Soils

The physicochemical properties of the soil are presented in Table 1a. The soil varied from sand to loamy sand. The texture shows a significant difference among the parent materials. These characters in the texture will affect water and nutrient retention as well as the suitability of a soil as a rooting medium (Aguilera *et al.,* 2012) the soil pH ranged from 5.0 to 5.4, respectively with a mean of 5.2. These ranges are slightly acidic conditions which is considered satisfactory for crop production in these zones (Aduayi *et al., 2002).* The soils are non-saline with low electrical conductivity values which ranged from ($0.07dsm^{-1}$) in beach ridge sand (BRS) to $0.12dsm^{-1}$) in river alluvium (RAS), indicating that the soils are salt-free. The organic matter content of the soils ranged from $3.02gkg^{-1}$ in beach ridge sand (BRS) to $3.76gkg^{-1}$ in Coastal Plain Sand (CPS). The values were above the critical level of $2gkg^{-1}$ proposed by Aduayi *et al., (2002)* for soils of Eastern Nigeria. All the soils had a total N below the critical level ($2gkg^{-1}$) set for crop production (Aduayi *et al., 2002)* The availability P in the soil were within the critical level of 12 $-15mgkg^{-1}$, except the soil of BRS with $11.32mgkg^{-1}$. The order of abundance of exchangeable base for the soils was Ca > Mg > K > Na. All the soils fall within the critical level of 1-3 $cmolkg^{-1}$ (except) Ca^{2+} in the three soils. The exchangeable acidity falls below the critical level of 2.0cmol/kg. Njoku *et al.,* (1987). The Effective Cation Exchange Capacity (ECEC) was within the critical of 12 $cmolkg^{-1}$ (except) coastal plain sand and base saturation were high. The physicochemical properties were significantly different from each parent material as shown in Table 1b.

3.2 Effect of P rates and days of Incubation on Parent Materials

The amount of P extracted at different rates of P added over different days of incubation are shown in Table 2. Soils that developed from beach ridge sand (BRS) had the highest extractable P ($5.04mgkg^{-1}$) at different rates of K addition and at different incubation periods (days) while soils that developed from river alluvium had the least

(1.07mgkg^{-1}). The highest extracted P in soils developed from Beach ridge sand could be attributed to the sandy nature of that parent materials (Table 1). While the least values obtained in river alluvium could be attributed to the amount of clay present as indicated in Table 1. The amount of P extracted at different incubation period increase with increasing rates of P added, 0 mgl^{-1} added being the lowest and 80mgl^{-1} being the highest for all the parent materials. This result is in agreement with the result of Ibia *et al., (2009).* The more the amount of P added the more the amount of P extracted.

3.3 Effect of incubation days on parent materials.

The effect of time of incubation on parent materials is shown in Figure 1. Among the parent materials, soils that developed from beach ridge sand had the highest fractional recovery of P at a different rate of P addition and at different incubation days, while soils that developed from river alluvium had the least. The highest fractional recovery of beach ridge sand could be attributed to the high sand content of that soils (Table 1), which has large pore spaces. The low recovery of river alluvium soils could be attributed to high clay contents (Table 1). These results agree with the findings of Subek and Cimrin (2006) that soil rich in clay has a high degree of charge density which retain nutrients in soils.

The concentration of P extracted at different incubation days increased with an increasing level of P added in all the parent materials. The result is in agreement with the results of Ibia, (2009). The more the amount of P added, the more the amount of P extracted.

3.4 Effects of Contact Time in the recovery of applied P

Figure 2 – 4 below shows the effect of contact time (incubation days) on the recovery of applied P in the different parent materials. The results revealed a decrease in the proportion of phosphorous with days of incubation across the three parent materials. This corroborates with the work of Warren (1992), who observed that availability of phosphorous to plants decreased with an increase in contact time and attributed it to the formation of less soluble phosphorous products with time. Phosphorous mixed with soil is converted to compound less available to plant and produce a significant reduction in the recovery of added P. This affirms the positive relationship with the soil properties in (Table 4). The concentration of P increases in the order of beach ridge sand > coastal plain sand > river alluvium.

3.5 Phosphorous fixing capacity (PFC) of the studied soils

The result shows that the phosphorous fixing capacity of soils varies from parent materials. This showed that river alluvium had the highest P fixing capacity (97%), while Beach ridge sand had the least. The trend is as follows: River alluvium (97%) > Coastal Plain Sands > Beach Ridge Sand. The high P fixing capacity of river alluvium could be attributed to a high content of clay and organic matter (Table 1), while the low P fixing capacity of beach ridge sand is a result of low organic matter and low activities clay. (Table 1) This finding is in agreement with that of Ibia *et al.,* (2012) who reported high fixation of P in the alluvium soil of Akwa Ibom.

Table 1a: Physico-chemical Properties of the Soil

Soil Properties	**River alluvium (Ikot Abasi)**	**Beach ridge sand (Ikot Abasi)**	**Coastal Plan sand (Obio-Akpa)**
Sand	84.2	95.2	87..2
Silt %	6.8	1.4	3.8
Clay	10.0	3.4	9.0
Texture	Loamy Sand	Sand	Sand
PH(H_20)	5.4	5.0	5.1
Ec (dsm^{-1})	0.12	0.07	0.08
Organic Matter (gkg^{-1})	3.2	3.01	3.76
Total N gkg^{-1}	0.09	0.08	0.14
Av. P gkg^{-1}	15.74	11.32	13.72
Ex.Ca	8.0	5.2	8.8
Mg	2.1	1.6	2.6
Na	0.07	0.06	0.08
K cmolkg^{-1}	0.21	0.08	0.20
EA	1.97	1.88	1.93
ECEC	12.4	8.9	13.8
Base Saturation (%)	84.01	77.8	85.82

le 1b: *Physico-chemical characteristics of the studied soils showing their* significance

PM	**sand**	**silt**	**clay**	**pH**	**EC**	**ORG**	**TN**	**AVP**	**Ca**	**Mg**	**Na**	**K**	**EA**	**ECEC**	**BS**
BRS	95.14	1.44	3.42	5.0	0.07	3.01	0.08	11.32	5.2	1.6	0.06	0.08	1.88	8.92	77.8
CPS	87.14	3.86	9	5.1	0.08	5.76	0.14	13.72	8.8	2.6	0.08	0.2	1.93	13.61	85.82
AS	83.14	6.86	10	5.4	0.12	3.2	0.09	15.74	8	2.1	0.07	0.21	1.97	12.35	84.05
LSD	6.11	2.72	3.55	0.21	0.11	1.54	0.03	2.21	1.89	0.50	0.01	0.07	0.05	2.43	4.21

Table 2: The amount of P extracted at different rates of P addition over different time periods in soil samples

Parent Material/Location	Rates of P added mgl-1	Incubation period (d) Amount of P Extracted from soils ($mgkg^{-1}$)					
		1	7	30	60	90	Mean
	0	0.40	0.30	0.08	0.10	0.50	
RAS	20	3.00	0.40	0.08	0.13	0.88	
River Alluvium	40	2.48	0.50	0.36	0.18	1.75	
Ik. Abasi	80	4.50	0.80	2.40	0.20	2.25	
Mean		2.60	0.50	0.73	0.15	1.35	1.07
	0	4.88	3.50	2.13	1.60	3.10	
BRS	20	7.76	6.40	2.20	3.50	3.40	
Beach Sand	40	9.84	7.10	2.52	2.70	4.20	
Ikot Abasi	80	13.41	9.30	2.84	8.10	4.70	
Mean		8.97	6.58	2.42	3.40	3.85	5.04
	0	3.80	2.30	1.04	0.15	1.00	
CPS	20	4.48	2.60	1.08	0.93	1.75	
Costal Plain Sand	40	4.48	2.80	2.08	1.25	1.78	
Obio Akpa	80	8.16	7.20	0.82	1.38	1.90	
Mean		4.18	3.73	1.26	0.93	1.81	2.34

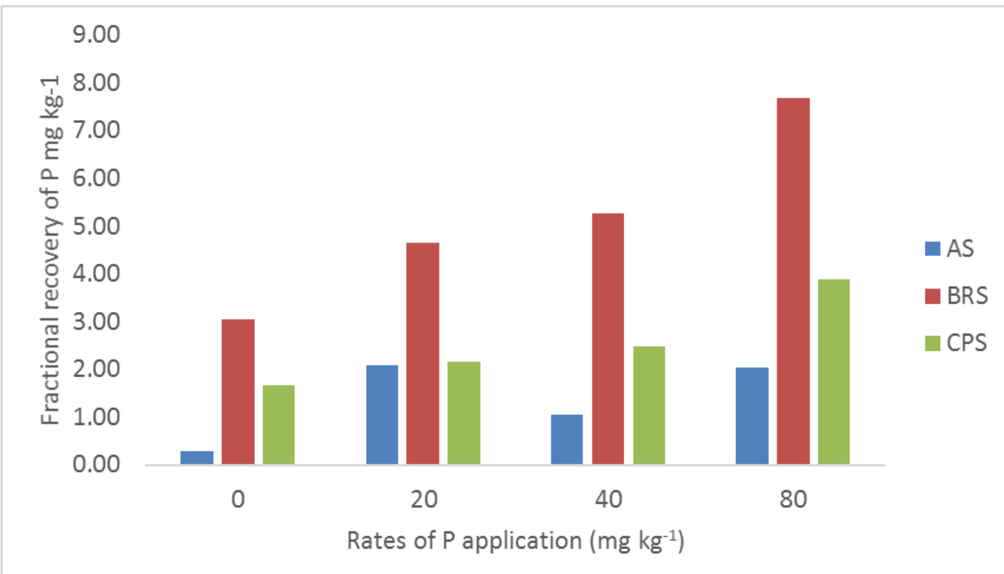

Fig. 1: Effect of time of incubation on recovery of P in the studied soils.

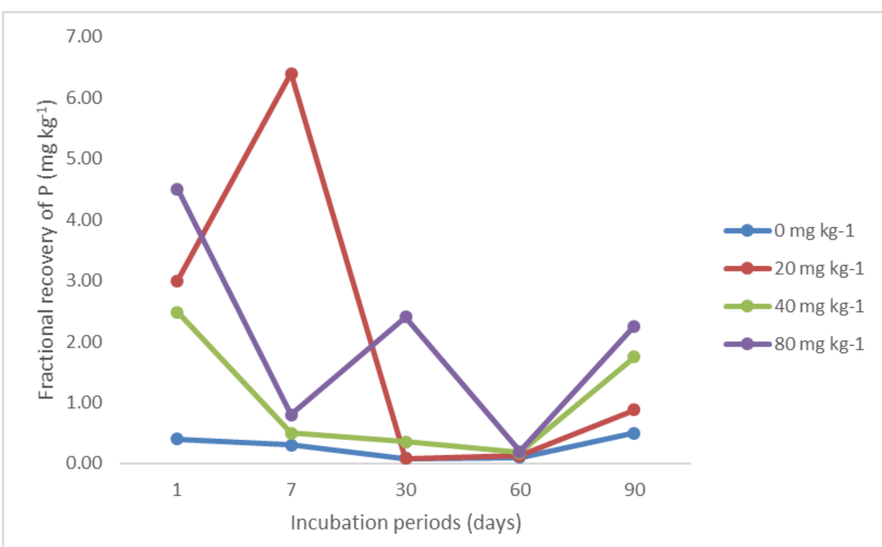

Fig 2: Effect of contact time (incubation days) on the recovery of applied P in alluvium Soils

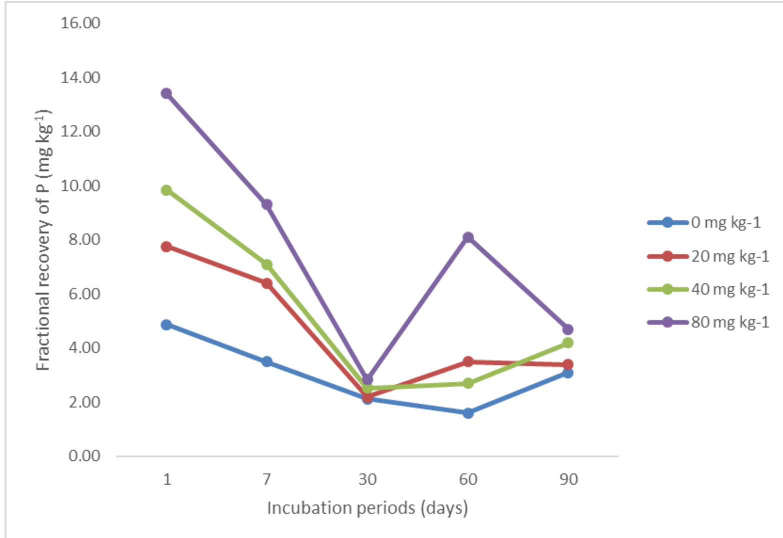

Fig 3: Effect of contact time (incubation days) on the recovery of applied P in beach ridge sand

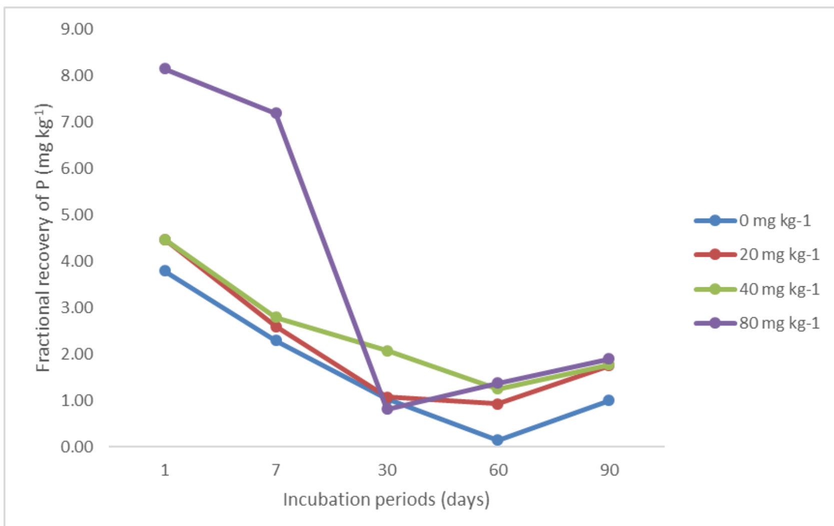

Fig. 4: Effect of contact time (incubation days) on the recovery of applied P in coastal plain sand

Table 3: Phosphorous Fixing Capacity (PFC) base on fractional recovery from Table 2 in the studied soils

Location	**Parent Materials**	**Fractional recovery from extracted P**	**Fixing capacities of P (FR x 100)**
Ikot Abasi	River Alluvium	0.97	97%
Ikot Abasi	Beach Ridge Sand	0.84	84%
Obio Akpa	Coastal Plain Sand	0.92	92%

Table 4: Correlation Matrix between fractional recovery of added P soils with soil properties

	sand	*silt*	*clay*	*Ph*	*EC*	*ORG*	*TN*	*AVP*	*Ca*	*Mg*	*Na*	*K*	*EA*	*ECEC*	*BS*	*FR_1*	*FR_7*	*FR_30*	*FR_60*	*FR_90*
sand	1																			
silt	-0.968	1.000																		
clay	-0.982	0.903	1.000																	
Ph	-0.891	0.976	0.788	1.000																
EC	-0.408	0.167	0.575	-0.051	1.000															
ORG	-0.249	0.000	0.430	-0.217	0.986	1.000														
TN	-0.339	0.094	0.513	-0.125	0.997	0.996	1.000													
AVP	-0.990	0.994	0.945	0.946	0.276	0.111	0.204	1.000												
Ca	-0.854	0.698	0.938	0.525	0.823	0.716	0.779	0.773	1.000											
Mg	-0.655	0.446	0.787	0.240	0.957	0.895	0.933	0.542	0.952	1.000										
Na	-0.655	0.446	0.787	0.240	0.957	0.895	0.933	0.542	0.952	1.000	1.000									
K	-0.965	0.870	0.997	0.742	0.632	0.494	0.573	0.919	0.960	0.829	0.829	1.000								
EA	-0.992	0.992	0.950	0.941	0.290	0.126	0.218	1.000	0.782	0.554	0.554	0.925	1.000							
ECEC	-0.828	0.662	0.919	0.483	0.850	0.750	0.809	0.741	0.999	0.966	0.966	0.945	0.750	1.000						
BS	-0.855	0.699	0.938	0.527	0.822	0.715	0.778	0.774	1.000	0.952	0.952	0.961	0.783	0.999	1.000					
FR_1	-0.844	0.683	0.931	0.508	0.834	0.730	0.791	0.760	1.000	0.958	0.958	0.955	0.770	1.000	1.000	1.000				
FR_7	-0.756	0.569	0.867	0.376	0.906	0.822	0.872	0.657	0.986	0.990	0.990	0.901	0.668	0.993	0.986	0.847	1.000			
FR_30	-0.627	0.413	0.764	0.205	0.967	0.911	0.946	0.511	0.940	0.999	0.999	0.808	0.524	0.956	0.940	0.719	0.391	1.000		
FR_60	-0.218	-0.032	0.400	-0.249	0.980	0.999	0.992	0.079	0.693	0.880	0.880	0.465	0.093	0.728	0.692	0.887	0.739	0.658	1.000	
FR_90	-0.364	0.120	0.535	-0.099	0.999	0.993	1.000	0.230	0.795	0.942	0.942	0.595	0.244	0.824	0.794	0.882	0.645	0.850	0.838	1

Table 4**:** Relationship between Fractional Recovery of P and Soil Properties

The relationship between Fractional Recovery of P with Soil properties in the study area are presented in Table 4 indicated that the recovery of P was Positive correlated with soil properties (at 5%) except sand, PH and silt at 60 and 90 of incubation with the (- r) values, contributing to the recovery of P while the positives relationship contributed to the high fixation of P to these soils.

4.0 Conclusions and Recommendations

Physico-chemical properties of the soils derived from three different parent materials were assessed. The results showed that the soils were moderately acidic, light-textured and salt-free. The results from the incubation experiment showed that soils of beach ridge sand had the highest P recovery, lowest fixing while river alluvium soil, on the other hand, had the lowest P recovery and highest fixing capacity. Clay, pH and organic matter were identified as the agent of fixation. Those had significant negative correlations with fractional recovery. The amount of P added decreases with days of incubation. Arising from the results obtained from the study, lighted liming may be added to increase pH for the high fixing soils and split dosage of P and another nutrient may be recommended for low fixing soils.

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