



DETERMINATION OF PHOSPHOROUS FIXATION CAPACITY ON ALLUVIUM, SANDSTONE AND SHALE SOILS OF AKWA IBOM STATE, NIGERIA

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ABSTRACT

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The study was aimed to determine the fixation capacity of phosphorous from three parent materials (Alluvium, Shale and Sandstone) in Akwa Ibom State. A composite soil samples were collected from three representative locations. A treatment solution containing 0, 20, 40 and 80mg^l⁻¹ of P prepared from KH₂PO₄ were added to 20g of soil samples in a cups and incubated for 1, 7, 30 and 60 days. The design was 3 x 4 factorial experiment (3 soil types and 4 rates of P) were fitted into Completely Randomized Design (CRD) with three replications. At a set day, the exchangeable and water soluble P were extracted with Bray P – 1 extractant and P not extracted was considered fixed in the soils. The results revealed that the soils were fertile and moderately acidic and than the amount of phosphorous fixed in shale and alluvium soils, decrease with length of incubation and a significant higher fixation were observed in day 1 (60.6 mgkg⁻¹ shale and 50.6mgkg⁻¹ in alluvium). The amount observed in sandstone increased with the length of incubation and a significant amount fixed was observed in 30 days (54.4mgkg⁻¹). The study also revealed that the concentration of P fixed increased with increasing rates of P added in all the soils. Base on the inherent fertility of the soils, the use of crop rotation and organic manure is recommended to maintain its fertility for high productivity.

Contribution/Originality: The study was aimed to determine the fixation capacity of phosphorous from three parent materials (Alluvium, Shale and Sandstone) in Akwa Ibom State.

1. INTRODUCTION

Phosphorous (P) is essential nutrient element needed in large quantity for growth and development of plants. When phosphorous is applied in the form of fertilizers in soils, it can either be absorbed on the clay minerals, taken up by plants or leached out beyond the root zone (Umoh, Gregory, & Udo, 2019). Phosphorous exists in soils in different forms as total P, organic P and inorganic P. A study by Ibia et al., 2008 shows, that the relative abundance of active P fraction were in the form of Fe – P, Al-P and Ca- P in all the soils, except those derived from shale and river alluvium where Ca-P was more abundant than others in soils of eastern Nigeria. Active P are the main sources of readily available P while P occluded within the oxides of Fe and Al are largely unavailable to crops, leading to a widespread P deficiency and as such limit crop production and productivity. Ukpong, Osodeke, and Akpan (2014)

carried out fixation study and discovered that the amount of P fixed in soils increased with increasing rate of P added, and the amount of phosphorous fixed decrease with days of incubation. Umoh and Osodeke (2016) reported that high sorption capacities soils required large phosphorous fertilizer application for optimum crop yield. When the concentration of P in the soil solution increases due to P fertilizer addition or P release from the minerals through weathering equilibrium is shifted resulting in fixation of P onto the specific sites in clay minerals. It was initially believed that fixation of applied P drastically reduces plant available P. However, the negative effect of P fixation on plant nutrition was challenged by several researchers who all suggested that fixation of added P is beneficial in a long run as it assists in retaining and recycling of P and protecting P from leaching, making P available for plant uptake. Research results show that plants make use of 10-30% of applied P while substantial percentage of about 70 – 90% of applied P are fixed in the soils (Agbede, 2009; Ukpong et al., 2014). Such nutrients may not be absolutely made available to the crops unless the soil equilibrium is maintained to satisfy the fixation complex. The factors influencing the equilibrium includes, the nature of parent material, types and amount of clay, organic matter, soil pH, P fertilizer application, contact time, soil moisture content, concentration of ions and other competing cation (Agbede, 2009; Brady & Weil, 2002; Umoh et al., 2019). For fertilizer application to have a positive impact in optimizing the yield of crops, a fixation study of P was to be determine using a simple laboratory incubation method to predict the fixation capacity of P in the soils over a long period of time with added P to give an effective and efficient P fertilizer recommendation for high crop productivity.

2. MATERIALS AND METHODS

2.1. Description of the Study Area

The study was carried in Akwa Ibom State, lies between latitudes $4^{\circ} 32^1$ and $5^{\circ} 33 N^1$ and longitudes $7^{\circ} 25^1$ and $8^{\circ} 25^1 E$. The area is in rainforest zone, characterized by heavy rainfall ranging from 2500 mm in land to over 3000mm along the coast, mean temperature range between 26° to $28^{\circ} C$ with relative humidity of 75-80% within a year. At the time of sampling, the plots carried different crops, viz: yam (*dioscorea* spp), cassava (*manihot esculanta*), cowpea (*vigna unguiculata*), corn (*zea mays*), okro (*hibiscus esculentus*), and oil palm (*elaeis guinease*). The soils are formed on shale, alluvium and sandstone parent material.

2.2. Soil Sampling and Handling

Surface soils (0 - 15cm) depth were collected from various tagged spots in each locations with soil augurs and bulked to form a composite soil sample. The bulk samples were air-dried and passed through 2-mm sieve and stored in a labeled cotton bag for laboratory analysis.

2.3. Laboratory Analyses

Particle size distribution was determined using Bouyous Hydrometer method (Gee & Or, 2002). The textural classes were determined using the USDA textural triangle. Soil pH was determined using a glass electrode pH meter (JENWAY 3520 MODEL) in a ratio of 1:2.5 both in water and in 1.0M KCl. Electrical conductivity was then measured by the electrical conductivity meter (DOS – 307 MODEL) as described by Udo, Ibia, Ogunwale, Ano, and Esu (2009). Total Nitrogen content was determined using the macro-KJELDHAL technique as described by Udo et al. (2009). Exchangeable acidity was determined by the method of Udo et al. (2009). Organic carbon was determined by the wet oxidation method and organic matter was determined by multiplying % OC by the convention van Bemmeler factor of 1.724. Available phosphorous was extracted using the Bray P. I extractant, the concentration was read using spectrophotometer 22PC MODEL at 860nm wavelength (Udo et al., 2009). Exchangeable bases (Ca, Mg, K and Na) in the soil were extracted with 1N ammonium acetate (1N $NH_4 OAc$) solution, buffered at pH 7.0. The concentration of Ca and Mg were determined with Atomic Absorption Spectrophotometer and K and Na by the use of flame photometer. Effective cation exchange capacity (ECEC) was obtained by the summation of the

exchangeable bases and exchangeable acidity (Udo et al., 2009). Percentage Base Saturation (%) was calculated as follows:

$$\% \text{ Base Saturation} = \frac{\text{Exchangeable Bases}}{\text{ECEC}} \times \frac{100}{1}$$

2.4. Incubation Procedure and Analysis

The method of Ukpong et al. (2014) was used for the study. Twenty grams (20g) of soil was weighed into the incubation cups and 20ml portions of treatment solution containing 0, 20, 40, 80mg^l⁻¹ P prepared from (KH₂PO₄) was added to each of the soil in the cups, mixed thoroughly for effective mixing of the P solution with the soils and allowed to dry. The cups were covered and allow to incubate for 1, 7, 30 and 60 days respectively. The soil samples were kept moist with distilled water at weekly intervals and cover for the duration of incubation. At the set days, 20ml of Bray P-1 extractant was used to extract available phosphorous in the soil samples and the extract was determined using the Murphy and Riley (1962). The fraction of applied phosphorous not recovered as extractable P after each incubation time was calculated as the difference between the quantity of P added and P in solution (recovered).

2.5. Experimental Design

The design was 3 x 4 factorial experiment in Completely Randomized Design (CRD), a two factor experiment with three (3) parent materials and four (4) rates of P application. Each of the treatments was replicated three times at five (5) difference incubation days and a total of 180 soils sample were generated.

2.6. Statistical Analysis

Data collected were subjected to analysis of variance (ANOVA). Mean separation was done using Fisher's Least significant difference (F-LSD) at 5% level of probability. Pearson's correlation coefficient was used to relate fixing P values with some soil properties.

3. RESULTS AND DISCUSSION

The physical and chemical characteristics of the soils are presented in Table 1. The particle size analysis showed that sandstone soil had the highest sand content (81.8%) while shale had the least sand content (74.2%). Soil formed from shale had the highest silt and clay contents with values of 11.4% and 14.4% while sandstone soil had the least silt and clay content of 7.6% and 10.6%. All the soils falls under the same textural class as loamy soil. The texture play dominant role in soil characteristics as it affects water and nutrient retention (Aduayi, Chude, Adebusu, & Olayiwola, 2002). The pH of the soil were moderately acidic, values ranging between 5.25 (Alluvium) and 5.67 (Sandstone) which is considered satisfactory for most crops (Aduayi et al., 2002). The electrical conductivity which measured the level of salt in soil indicated that the Alluvium and Sandstone soils had low salt content of 0.06 dsm⁻¹ while soils derived from shale had the highest (0.24dsm⁻¹). Organic matter content were fairly high. The values were above the critical level of 2gkg⁻¹ proposed by Aduayi et al. (2002) for soils of these zone. All the soils had total N below the critical level 2gkg⁻¹ proposed (Aduayi et al., 2002) for crop production. The available P in the soils were high, above the critical values of 12-15 mgkg⁻¹ proposed for most crops (Brady & Weil, 2002). The values ranging from 16.25 (Alluvium) to 37.50 (Shale) mgkg⁻¹. The order of abundance of exchangeable base for soils were Ca > Na > K > Mg. Exchangeable K varied from 0.17 Cmolkg⁻¹ in Alluvium 0.46 Cmolkg⁻¹ in sandstone. The exchangeable acidity were above the critical value of 2 Cmolkg⁻¹ for these soils (Aduayi et al., 2002). ECEC ranges from 8.51 in Alluvium to 10.18 Cmolkg⁻¹ for shale soil. The % base saturation were high values ranging from 65 to 74.8 Cmolkg⁻¹. Generally the soils were high in nutrient. Effect of parent material and P rates on P fixing capacity in 1 day contact time. The amount of P fixed in soils at different rates of P added varies as

shown in Table 2. Shale soil had the highest P fixing capacity (60.6 mgkg^{-1}) while sandstone had the least ability (34.9 mgkg^{-1}). The trend is as follows: shale (60.6 mgkg^{-1}) > Alluvium (50.6 mgkg^{-1}) > sandstone (34.9 mgkg^{-1}).

The highest P fixing capacity of shale could be attributed to high clay and organic matter content (Table 1). The fixing values in the day one (1) were found to significantly correlated with clay ($r = 548^{**}$) organic matter ($r = 505^{**}$) percent base saturation ($r = 528^{**}$) and a weak correlation with PH ($r = 342$) observing that more P was absorbed into the inter-layer site of clay, while sandstone fixed less P and could be attributed to sandy nature of soils with the present of dominant sesquioxides mostly found in excessively leached soils. The study revealed that the amount of P fixed increased with increasing rate of P added. The finding also confirmed with a weak correlation with exchange acidity ($r = 546^{**}$) as shown in Table 7. This finding is in agreement with the work of Osodeke (2000) who reported high fixation of P due to high clay content.

3.1. Effect of Parent Material and P Rates on P Fixing Capacity in 7 Days Contact Time

Alluvium soil had the highest fixing ability ($49.7 \text{ mgkg}^{-1}\text{P}$) and was not significantly different from Shale. This observation could be due to high level of organic matter and high clay content. While sandstone had the lowest fixing capacity ($36.5 \text{ mgkg}^{-1}\text{P}$) and gradually higher than day one indicating that soluble P was converted into insoluble Al/Fe phosphate. In the soil the result affirmed with the positive relationship with clay and silt. This finding is in agreement with the report of Ibia, Udo, and Omueti (2009) that alluvium soils had the highest P fixing capacity among the soils of Akwa Ibom State and could be as a result of the seasonal deposition of organic material from plant debris during flooding and the slow rate of decomposition.

3.2. Effects of Parent Material and P Rates on P Fixing Capacity in Day 30

Sandstone soil had the highest capacity to fixed P while shale had the lowest. The trend were as follows: Sandstone (54.4 mgkg^{-1}) > Alluvium (27.2 mgkg^{-1}) > Shale (19.1 mgkg^{-1}) as shown in Table 4. The highest amount of P fixed in sandstone increased with days of incubation, indicated that more P was held into the inter-layer site of clay while the amount fixed in shale soils decreased with day indicating a gradual release of P into the soil system. The amount of P fixed in the soils increased with increasing rates of P added. This finding is in agreement with work of Ibia et al. (2009). The more the amount of P added, the more the amount fixed in soils.

3.2.1. Effect of Parent Material and P Rates on the Amount of P Fixed at Day 60

The amount of P fixed at day 60 is shown in Table 5. A gradual decreased in P fixation capacity in all the soils with length of incubation was observed. Sandstone had the highest fixing ability and shale had the lowest P fixed. The trend were as follows: Sandstone (19.4 mgkg^{-1}) > Alluvium (14.8 mgkg^{-1}) > Shale (12.8 mgkg^{-1}). The decrease in P fixed observed in the soil shown that more P was released into the soil system as affirmed with the negative or weak relationship of Silt ($r = -0.270$), clay ($r = -0.299$), ECEC ($r = -0.156$) and Base saturation ($r = 0.257$) and positive relationship was observe in term of sand ($r = 0.287$) PH ($r = -0.260$) and Exchange acidity ($r = 0.302$) as presented in Table 7.

3.3. Interaction Effects of Parent Material and P Rate on the Amount of P Fixed in Soil at Day 1, 7, 30 and 60

The amount of P fixed in soils as affected by parent material and P rates at different incubation days are presented in Table 6. The amount of P fixed was significantly decreased at ($P < 0.05$) probability levels with length of incubation. The trend was in the order. Day 1 (13.67 mgkg^{-1}) > Day 7 (7.45 mgkg^{-1}) > Day 30 (6.43 mgkg^{-1}) > Day 60 (3.64 mgkg^{-1}). This finding could be attributed to the inherent fertility of the soils with moderate acidic condition which permit the release of P and no new chemical was form in the process. The interaction effects are fully presented in Figure 1. It shows the interaction effect of parent material and P rate on the amount of P fixed in soil at (a) Day 1 (b) Day 7 (c) Day 30 and (d) Day 60, the letters A to D denote the days of incubation. The graphs

are plots of the concentration of P fixed and rate of P added in the soil. Shale and Alluvium soils had the highest concentration of P fixed in soil at day one (1) and a gradual decline in P fixed was observed in day 7, 30 and 60 respectively. The observation could be attributed to the inherent fertility of the soil and well as the moderate acidic condition of the soil, which affirmed with the negative correlation with pH (Table 7). This results are in agreement with those obtained by Warren (1992) who observed that availability of phosphorous to plant decreased with an increase in contact time and attributed it to the formation of less soluble phosphorous product with time. Ibia, Effiong, Ogban, and Obi (2008) also observed a reduction in yield, as well as fertilizer uptake by rye grass as reaction time increased. They attributed it to the formation of non-available form of P with time while sandstone parent material had the lowest fixing ability of Phosphorous in day one (1) and a gradual increased in P fixed was observed in other days in the soils. This could be attributed to the amount of clay and organic matter content in the soils. The result is in agreement with that of Ukpong et al. (2014). Table 7 Correlation matrix between the amount of P fixed and soil properties. The correlation analysis in Table 7 shows the level of association with some soil properties and amount of P fixation. The positive correlation that existed between clay, silt, ECEC, Base sat, Ca, suggested that these factors contributed to fixation P in the soils and negative correlation existed between clay Om, and pH indicating no relationship with fixing ability. The decrease in P fixed by length of days indicated that P were made available for plant uptake. Similar finding was observed by Ukpong et al. (2014).

4. CONCLUSION

The findings of this research work revealed that, soils were riched in nutrients with a moderately acidic condition. Phosphorous fixed in Shale and Alluvium soil decrease with length of incubation days, and significantly higher in day one. The trend were Day 1 (50.6) > Day 7 (49.67) > Day 30 (27.2) > Day 60 (14.8) mgkg⁻¹ in Alluvium and Day 1 (60.6) > Day 7 (42.4) > Day 30 (19.1) > Day 60 (12.02) mgkg⁻¹ in shale. The amount fixed in sandstone increased with length of incubation days and a significantly higher in 30 days. The trends were: Day 1 (34.9) < Day 7 (36.5) < Day 30 (54.4) > Day 60 (19.4) mgkg⁻¹. The study also revealed that the amount of P fixed increased with the rates of P added in all the soils. In recommendation, for the fertility of the soil to maintained and to gives adequate yield of crops, the soil should be incorporate with organic manure and crop rotation should be used.

Table-1. Physical and chemical characteristic of soils in the study area.

Tested Parameters	Unit	Aluminum	Shale	Sand Stone
Particle size Analysis Sand	%	78.6	74.2	81.8
Silt	%	8.8	11.4	7.6
Clay	%	12.6	14.4	10.6
Textural class		Ls	Ls	Ls
pH		5.25	5.38	5.67
EC	ds/m	0.06	0.24	0.06
Organic Matter	%	2.59	3.01	2.54
Total Nitrogen	%	0.06	0.08	0.06
Av. P.	mg/kg	16.25	23.75	37.50
Exchangeable Basis				
K	Cmol/kg	0.17	0.25	0.46
Ca		3.12	4.28	2.68
Mg		0.11	0.33	0.23
Na		2.31	2.76	2.41
EA		2.80	2.56	3.11
ECEC		8.51	10.18	8.89
B. Sat.		%	67.1	74.84

Note: EC - Electrical Conductivity, EA- Exchange Acidity, LS- Loamy Sand, B.Salt - Base Saturation.

Table-2. Effect of parent materials and P rate on the amount of P fixed in soil at day 1.

Parent Material	Rate				PM Tot	Means
	0	20	40	80		
Alluvium	113.19	156.6	165.7	171.4	606.89	50.57
Sandstone	48.7	70.6	137	162.33	418.63	34.89
Shale	121.09	186	204.1	215.5	726.69	60.56
Rate Total	282.98	413.2	506.8	549.23	1752.21	
Rate Men	31.44	45.91	56.31	61.03		

Table-3. Effect of parent materials and P rate on the amount of P fixed in soil at day 7.

Parent Material	Rate				PM Tot	Means
	0	20	40	80		
Alluvium	109.6	139.9	166.6	180	596.1	49.68
Sandstone	27.8	96.5	121.6	191.6	437.5	36.46
Shale	73.5	104.9	127.2	203.7	509.3	42.44
Rate Total	210.9	341.3	415.4	575.3	1542.9	
Rate Mean	23.43	37.92	46.16	63.92		

Table-4. Effect of parent materials and P rates on the amount of P fixed in soil at day 30.

Parent Material	Rate				PM Tot	Means
	0	20	40	80		
Alluvium	46.7	75.6	96.2	108.3	326.8	27.23
Sandstone	21.89	177.01	182.7	270.9	652.5	54.38
Shale	21.18	39.89	62.4	106.2	229.67	19.14
Rate Total	89.77	292.5	341.3	485.4	1208.97	
Rate Mean	9.97	32.50	37.92	53.93		

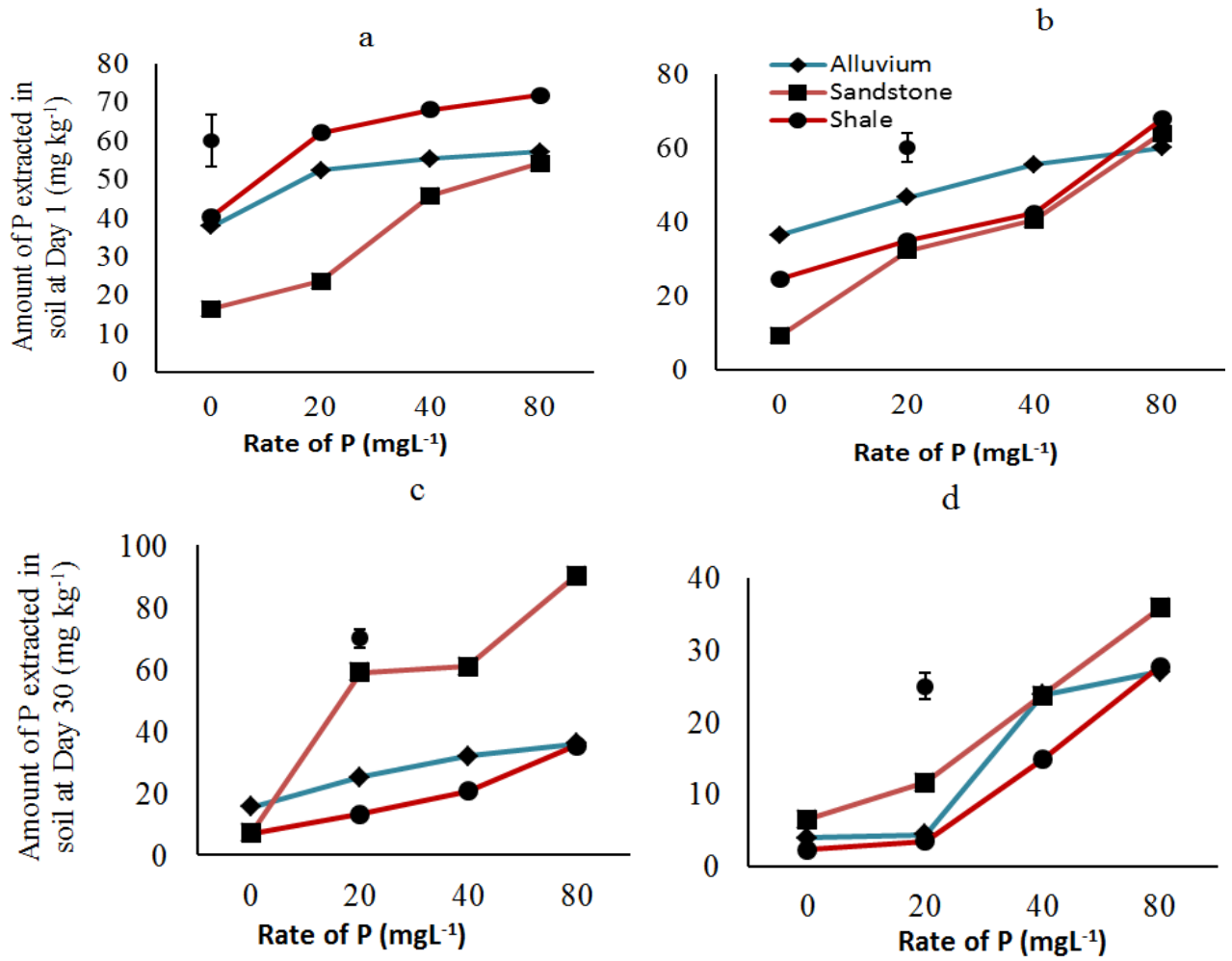
Table-5. Effect of parent materials and P rates on the amount of P fixed in soil at day 60.

Parent Material	Rate				PM Tot	Means
	0	20	40	80		
Alluvium	11.9	13.19	71.2	80.9	177.19	14.77
Sandstone	19.31	34.7	71	107.4	232.41	19.37
Shale	6.7	10.33	44.34	82.9	144.27	12.02
Rate Total	37.91	58.22	186.54	271.2	553.87	
Rate Mean	4.21	6.47	20.73	30.13		

Table-6. Effect of parent material and P rate on the amount of P fixed in soil at days 1, 7, 30 and 60.

Parent Material	DAY 1	DAY 7	DAY 30	DAY 60
Alluvium	50.57	49.68	27.23	14.77
Sandstone	34.89	36.46	54.38	19.37
shale	60.56	42.44	19.14	12.02
LSD (0.05)	6.84	3.72	3.21	1.82
P Rate				
0	31.44	23.43	9.97	4.21
20	45.91	37.92	32.50	6.47
40	56.31	46.16	37.92	20.73
80	61.03	63.92	53.93	30.13
LSD (0.05)	7.89	4.30	3.71	2.10
Parent Material x P Rate Interaction*				
LSD (0.05)	13.67	7.45	6.43	3.64

Note: * Interaction effects are presented in full in Figures that follow.



Figures-1. Interaction effect of Parent material and P rate on the amount of P fixed in soil at (a) Day 1 (b) Day 7 (c) Day 30 and (d) Day 60.

Table-7. Correlation of P fixed in soil with soil physical and chemical properties.

	Fixed P -Day1	Fixed P -Day7	Fixed P -Day30	Fixed P -Day60	Sand	Silt	Clay	pH	E.C	OC	OM	TM	Av. P.	K	Ca	Mg	Na	EA	ECEC	B. Sat.
Fixed P - Day1	1.000																			
Fixed P - Day7	.688**	1.000																		
Fixed P - Day30	0.058	.530**	1.000																	
Fixed P - Day60	.406*	.769**	.750**	1.000																
Sand	-.548**	-0.064	.614**	0.287	1.000															
Silt	.540**	0.042	-.571**	-0.270	-.993**	1.000														
Clay	.548**	0.086	-.650**	-0.299	-.992**	.969**	1.000													
pH	-.342*	-0.182	.614**	0.260	.573**	-.469**	-.672**	1.000												
E.C	.482**	-0.018	-.420*	-0.210	-.905**	.950**	.844**	-0.170	1.000											
OC	0.195	-0.135	0.038	-0.012	-.412*	.520**	0.294	.510**	.761**	1.000										
OM	.505**	0.001	-.471**	-0.231	-.942**	.976**	.892**	-0.265	.995**	.694**	1.000									
TN	.482**	-0.018	-.420*	-0.210	-.905**	.950**	.844**	-0.170	1.000**	.761**	.995**	1.000								
Av. P.	-0.320	-0.184	.597**	0.251	.532**	-.425**	-.635**	.999**	-0.121	.552**	-0.217	-0.121	1.000							
K	-.358*	-0.180	.626**	0.266	.604**	-.502**	-.699**	.999**	-0.207	.477**	-0.301	-0.207	.996**	1.000						
Ca	.535**	0.033	-.552**	-0.263	-.986**	.999**	.957**	-.428**	.963**	.559**	.985**	.963**	-.383*	-.462**	1.000					
Mg	0.268	-0.115	-0.063	-0.057	-.540**	.639**	.430**	.380*	.847**	.989**	.791**	.847**	.425**	.345*	.673**	1.000				
Na	.416*	-0.056	-0.296	-0.158	-.796**	.864**	.713**	0.040	.978**	.880**	.953**	.978**	0.089	0.002	.886**	.939**	1.000			
EA	-.546**	-0.093	.660**	0.302	.985**	-.957**	-.999**	.704**	-.819**	-0.251	-.871**	-.819**	.669**	.731**	-.943**	-.389*	-.681**	1.000		
ECEC	.414*	-0.057	-0.292	-0.156	-.793**	.861**	.710**	0.045	.977**	.882**	.951**	.977**	0.094	0.007	.883**	.941**	1.000**	-.677**	1.000	
B. Sat.	.525**	0.021	-.522**	-0.252	-.972**	.994**	.935**	-.366*	.979**	.614**	.994**	.979**	-0.319	-.400*	.998**	.722**	.916**	-.918**	.913**	1.000

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REFERENCES

- Aduayi, E., Chude, V., Adebuseyi, B., & Olayiwola, S. (2002). Fertilizer use and management practices for crops in Nigeria (pp. 63-65). Nigeria: Federal Ministry of Agriculture and Rural Development Abuja.
- Agbede, O. O. (2009). Understanding of soil and plant nutrition (pp. 175 – 179). Nasarawa State: Salman Press.
- Brady, N. C., & Weil, R. R. (2002). *The nature and properties of soils* (13th ed.). Upper Saddle River, NJ, USA: Prentice – Hall.
- Gee, G. W., & Or, D. (2002). Particle size, In: Dane, J. H, and Topp, G.C. (eds). *Methods of Soil Analysis. Part 4 Physical Methods* (pp. 255- 293): Soil Science Society of America Madison, WI, Book Series No.5 ASA and SSA.
- Ibia, T., Effiong, G., Ogban, P., & Obi, J. (2008). Relationships between phosphorus forms and parent materials in soils of Southeastern Nigeria. *Acta Agronomica Nigeriana*, 8(2), 104-110.
- Ibia, T., Udo, E., & Omueti, J. (2009). Fractional recovery of applied phosphorus in soils of Akwa Ibom State, Niger Delta Region of Nigeria. *Environmental Research Journal*, 3(1), 1-3.
- Murphy, J., & Riley, J. P. (1962). A modified single solution method for the determination of phosphate in natural waters. *Analytica Chimica Acta*, 27, 31-36. Available at: [https://doi.org/10.1016/s0003-2670\(00\)88444-5](https://doi.org/10.1016/s0003-2670(00)88444-5).
- Osodeke, V. (2000). Determination of the residual values of applied phosphorus in some soils of Southeastern Nigeria. *Journal of Sustainable Agriculture and the Environment*, 2(1), 139-143.
- Udo, E. J., Ibia, T. O., Ogunwale, J. A., Ano, A. O., & Esu, I. V. (2009). *Manual of soil plant and water analysis* (pp. 56 - 59). Lagos, Nigeria: Sibon Books Ltd.
- Ukpong, I. M., Osodeke, V. E., & Akpan, U. S. (2014). Determination of phosphorous fixing capacities and residual values of soils of Akwa Ibom State, Nigeria. *Merit Research Journals*, 2(8), 096 – 103.
- Umoh, F. O., Gregory, S. E., & Udo, E. I. (2019). Phosphorous fixation capacity of selected soils under Mungbean (*Vigna radiata* (L) Wilczek) Cropping System in South Eastern Nigeria. *AKSU Journal of Agriculture and Food Sciences*, 2(1), 216-226.
- Umoh, F., & Osodeke, V. (2016). Estimation of phosphorus requirement of mung bean (*Vigna radiata* L.) Wilezek in the acid soils of South Eastern Nigerian using P-sorption isotherm. *American-Eurasian Journal of Agricultural and Environmental Sciences*, 16(3), 487-493.
- Warren, G. P. (1992). Fertilizer phosphorous sorption and residual value in tropical African soils (pp. 89). Chatham: WRI Bulletin 37, UK Natural Resources Institute.

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