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Pedogenic Forms of Phosphorus in Soils Underlain by Amphibolite Rocks in Selected Areas of Southwestern Nigeria

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Abstract

The study was designed to examine the pedogenic forms of Phosphorus (P) in soils underlain by amphibolite rocks in Southwestern Nigeria. Two profile pits were dug at Ajindo, Ekiti State and Wonu, Apomu, Osun State. The soil samples collected from the identified horizons were analysed for particle size distribution, soil pH, organic matter, exchangeable acidity, exchangeable cations, total P, available P and water extractable P. Correlation analyses were carried out between the P forms and some soil chemical properties. Soil pH and water-soluble P increase down the soil profiles while soil organic matter, total P, available P, Exchangeable cations, and exchangeable acidity decrease down the soil profiles. Total P in the profiles ranged between 600 and 4800 mg kg^{-1}, available P varied between 20.80 and 33.00 mg kg^{-1} and water extractable P varied between 0.19 and 5.53 mg kg^{-}; there was a positive correlation between available P and water-soluble P and organic matter content in profiles 1 and 2. Such results indicate that the present level of available P favours an increase in water-soluble P. There was a significant positive correlation between water-soluble P and pH in profile 1 and a significant negative correlation in profile 2. The study concluded that Phosphorus would not be a factor limiting crop yield in the two areas. Therefore, soil fertility management should focus on maintaining the soil's phosphorus level through organic manure and mulching.

Keywords: Phosphorus, exchangeable acidity, exchangeable cations, water-soluble, soil fertility.

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Soil is a natural body consisting of layers (soil horizons) primarily composed of minerals that differ from their parent materials in their texture, structure, consistency, colour, chemical, biological, and other characteristics. The unconsolidated or loose covering of rock particles covers the surface of the earth. Soil is composed of broken rock particles by biological, chemical and physical processes, including weathering with associated erosion. It is created by altering parent materials by interacting with the lithosphere, atmosphere, hydrosphere, and biosphere (Chesworth, 2008). It can also be considered a mixture of mineral and organic materials in the form of solids, liquids, and gases (Voroney, 2006).

Pedogenesis is the science and study of the processes that lead to soil formation (Boul *et al.*, 1997). These processes are primarily controlled by some factors: the nature of the parent materials, climate, topography, biological factors, and time. These factors bring about variations in the properties of soils. Soils are formed from parent material that consists of consolidated organic and mineral materials and influences the soil's chemical and physical properties. Parent material can be sourced from many different sources. Most of the soil's mineral matter is derived from weathered bedrock or other inorganic materials transported and deposited by water, wind, or glaciers. Likewise, soil can also be formed from the sedimentation of organic material, such as peat. From these, we have two broad groups of soils: mineral and organic. Soil minerals play an important role in agriculture because minerals from rocks such as amphibolite contain elements that can be used to maintain and increase crop production. Some minerals like Plagioclase, amphiboles and pyroxene are easily weathered minerals that can release macronutrients such as Ca, Mg, Na and K (Pramuji, 2009; Nasir *et al.*, 2021). Amphibolite is a coarse-grained metamorphic rock composed of minerals amphibole and Plagioclase. They contain iron and magnesium and are composed of double-chain tetrahedral of SiO4. (Mahimut, 2023).

Phosphorus (P) is one of the essential macronutrients because plants require it in relatively large amounts. An essential plant nutrient often restricts plant productivity, especially in tropical regions (Elser *et al.,* 2007). Unlike nitrogen (N), supplied directly from the atmosphere in fixed form or by N-fixers, rock weathering is the major P source for terrestrial ecosystems. Due to its low solubility in soils, Phosphorus is regarded as the most important limiting soil nutrient in terrestrial ecosystems (Du *et al.*, 2020; Dzombak and Sheldon, 2020). One of the principal roles of Phosphorus in living organisms is in the transfer of energy. Organic compounds containing Phosphorus transfer energy from one reaction to drive another reaction within cells. Adequate phosphorus availability for plants enhances early plant growth and hastens maturity (Busman *et al.,* 2002). Phosphorus is reclaimed very slowly and in very small amounts, and the terminal state of a large proportion of Phosphorus used in agricultural production and industry is inappropriate or unreachable for recycling. The types of phosphorus compounds in the soil are largely determined by the type and amount of minerals in the soil by the soil pH. Phosphorus is found in soil in organic and mineral form, and its solubility in soil is low. The soil solution has an equilibrium between solid phase P and P (Busman *et al.,* 2002). Phosphorus occurs almost exclusively in nature as orthophosphate (PO_4^{3-}), principally in the mineral apatite $Ca_5(PO_4)_3(F, Cl, OH)$, but also in monazite (Ce, La, Nd, Th) (PO_4, SiO_4) and xenotime YPO_4. It is widely diffused in minerals such as olivine, pyroxene, amphibole and mica at the trace level. It is also in biological materials such as bone (Demetriades, 2011).

Phosphorus is found in both inorganic and organic forms in soils. The organic forms are associated with humus and plant residues, while the inorganic forms are commonly associated with soil colloids, minerals and rocks, particularly the iron, aluminium, and calcium constituents. Phosphorus in organic matter may account for up to one-half of the total P in the soils and is probably the more important source of Phosphorus in plants. It is a nutrient element required by all organisms for the basic processes of life. It is a natural element found in soil, rocks, and organic material, as it holds tightly to soil particles and is used by plants. However, Phosphorus is used widely in fertiliser and other chemicals, so it can be found in higher concentrations in areas of human activity. Many seemingly harmless activities when combined can result in phosphorus overloads.

The study aimed to assess the forms and distribution of Phosphorus in soils underlain by amphibolite rock.

Materials and Methods

Description of the study area

Soil samples were collected at different depths from two locations (Ajindo and Wonu). The Ajindo study site is located in Ekiti State with lat 7° 35′ N and long 5° 15′ E, and Wonu in Apomu area of Osun State with lat 7° 05′ N and long 4° 04′ E. All the sites fall within the Schist Belt of southwestern Nigeria and are in the same ecological zone with a hot, humid tropical climate having distinct dry and bimodal rainy seasons.

The study areas are underlain by rocks of the Basement Complex of the Ife-Ilesa Schist Belt, which has been of intense geological interest because of its gold mineralisation. It consists of mafic and ultramafic rocks of peridotitic composition intercalated with meta-sedimentary sequence (Elueze, 1988), which have been subjected to metamorphic grades ranging from greenschist to amphibolitic facies (Kehinde-Phillips and Tietz, 1995).

Vegetation and land use

As a result of cultivation, the vegetation of the areas consists of a mixture of bush regrowth, tree crop plantations, and arable crop farms.

Profile pit location and soil sampling

Two profile pits were dug at Ajindo, Ekiti State and Wonu-Apomu, Osun State. Bulk soil samples were collected from identified horizons, starting from the last horizon of each profile. The samples collected were taken to the laboratory for preparation for analysis.

Laboratory analysis

The soil samples were air-dried, crushed gently, and passed through a 2 mm sieve. The modified hydrometer method described by Gee and Or (2002) determined particle size distribution distribution. Soil pH was determined in water and 1N potassium chloride (KCl) solution using the method described by Burt (2004). Soil organic matter was determined using the chromic acid digestion method (Blakemore *et al.,* 1987). Exchangeable cations were determined using the ammonium ion displacement method. Exchangeable acidity was analysed using the 1N KCl extractant method as described by Blakemore *et al.* (1987). Total P was determined by acid digestion using perchloric acid (Olsen and Sommers 1982). Available and water-extractable P were determined using the Bray-1 and modified single solution methods, respectively (Burt, 2004).

Results and Discussion

Physical properties of the soil

The physical properties of the soil are shown in Table 1. The texture of the soils in most of the horizons in the two profiles ranged from sandy loam to clay. The sand content of profile 1 was low and varied from 160 to 480 g kg^{-1}. The horizon Cg had the highest sand content of 480 g $kg^{-1,}$ while AB had the lowest (160 g kg^{-1}). Sand fraction in profile 2 was higher and ranged from 320 to 660 g kg^{-1} with the Ap horizon having the highest value and C2 the least. The sand content generally decreased with profile depth, which may be due to clay illuviation (Isola *et al.*, 2020)

Table 1: Physical properties of the soils

Genetic Horizon	Horizon Depth (cm)	Sand ←	Silt gkg^{-1}	Clay →	Textural Class
Profile 1: Ajindo Site					
Ap	0-15	220	280	500	Clay
AB	15-32	200	260	540	Clay
BA	32-52	260	260	480	Clay
Bt	52-87	180	250	570	Clay
Btg	87-120	360	300	340	Clay loam
BCg1	120-136	220	310	470	Clay
BCg2	136-155	160	280	560	Clay
Cg	155-260	480	360	160	Loam
Profile 2: Wonu Site					
Ap	0-11	660	100	240	Sand clay loam
AE	11-18	610	110	260	Sand clay loam
E	18-58	600	100	300	Sand clay loam
Bc1	58-87	480	100	420	Sand clay
Bc2	87-135	460	80	460	Sand clay
BC	135-196	360	120	520	Clay
C1	196-237	340	180	480	Clay
C2	237-296	320	160	520	Clay

The clay content of profile 1 ranged from 160 to 570 g $kg^{-1,}$ which fairly increased with depth but showed a sharp decrease in horizon Cg. The Bt horizon contained the highest amount of clay (570 g kg^{-1}) followed by BCg2 (560 g kg^{-1}), making the soil retain a considerable amount of water for crop production. In profile 2, the clay content ranged between 240 g kg^{-1} in Ap horizon and 520 g kg^{-1} for BC and C2 horizons. The increase in the profile can be attributed to the eluviation of clay particles from the surface horizon to the subsoil (Ewulo *et al.,* 2002).

The silt content of the soil in profile 1 ranged from 250 to 360 g kg^{-1}. Cg had the highest value, while Bt had the lowest value. The silt content was lower than clay content in all the horizons, except for the Cg horizon, which agrees with the findings of Esu *et al.* (2008).

The silt contents exceeded the sand except in the Btg and Cg horizons and were the same in BA horizon. The high silt contents do not agree with Esu *et al.* (2008) who recognised that soils formed from basement complex rocks in the humid tropical lowlands of southwestern Nigeria have low silt contents. The silt content of profile 2 ranged from 80 to 180 g kg^{-1} .in horizons Bc2 and C2 respectively. . The lower silt content than the sand and the clay contents except in horizon C3 agrees with Esu *et al.* (2008).

Soil pH

Table 2 displays the results of the chemical properties as well as forms of Phosphorus in the soils. The pH measured in 1N KCl suspension were lower than those obtained in distilled water in both profile pits. The pH values were fairly constant in distilled water and also increased fairly down the profile in 1N KCl in profile 1, while in the other profile, the pH values decreased down the profile in distilled water. The pH in 1N KCl is less than that of water in both profiles, which showed a significant amount of exchangeable aluminum and because it measured reserved acidity. The pH range of the two profiles was 4.8 to 6.9 both in distilled water and 1N KCl which was similar to the observations of Agboola and Ayodele (1985) and Adisa *et al.,* (2018) that the pH in most agricultural soils in the humid tropics ranges from 5.0 to 6.8. The results show that the soils of the two pits were slightly acidic based on the soil pH rating set by Elrashidi *et. al.,* (2003). Thus, soil P would be available for plant use at this pH range in line with Tiessen (1992) and Mardamootoo *et al.* (2021), that soil P is most available for plant use at a pH value of 6 to 7.

Table 2: Chemical properties and forms of Phosphorus in the soils

Genetic Horizon	Horizon Depth (cm)	pH H_2O	pH KCl	SOM g kg^{-1}	TP ← mg kg^{-1}	Av.P mg kg^{-1}	H_2O P mg kg^{-1} →	Exchangeable Cations Ca^{2+}	Mg^{2+}	K^{+}	Na^{+} (← cmol $_{(+)}$ kg^{-1}soil →)	Ex.A Al^{3+}
Profile 1: Ajindo Site												
Ap	0-15	6.2	5.3	42.3	1200	28.69	1.03	11.57	0.096	1.123	0.207	0.30
AB	15-32	6.6	5.5	28.9	1800	28.50	5.53	12.47	0.097	0.323	0.168	0.10
BA	32-52	6.7	5.5	23.6	3600	24.56	3.10	12.87	0.096	0.247	0.172	0.10
Bt	52-87	6.6	5.4	19.4	960	23.25	0.19	12.07	0.100	0.214	0.165	0.10
Btg	87-120	6.6	5.2	16.9	600	26.62	0.66	12.72	0.104	0.147	0.228	0.35
BCg1	120-136	6.6	5.3	15.5	2400	27.94	0.19	14.63	0.104	0.188	0.200	0.30
BCg2	136-155	6.7	5.4	14.8	960	33.00	3.00	15.16	0.104	0.199	0.189	0.20
Cg	155-260	6.9	5.3	8.8	1200	25.88	1.60	12.94	0.103	0.086	0.230	0.25
Profile 2: Wonu Site												
Ap	0-11	6.3	5.6	19.4	4800	22.50	0.28	6.38	0.075	0.232	0.140	0.10
AE	11-18	6.1	5.3	29.6	3360	24.94	2.72	5.79	0.067	0.092	0.128	0.20
E	18-58	6.1	5.2	13.4	1800	21.75	3.47	4.95	0.043	0.113	0.121	0.20
Bc1	58-87	6.0	5.2	12.7	3360	24.56	3.66	6.94	0.044	0.150	0.142	0.25
Bc2	87-135	6.0	5.2	9.5	2400	21.56	0.85	6.45	0.047	0.91	0.175	0.20
BC	135-196	5.9	5.5	10.1	3600	24.00	0.28	5.76	0.048	0.067	0.145	0.10
C1	196-237	6.0	5.6	0.7	1800	20.80	2.53	6.49	0.050	0.083	0.136	0.15
C2	237-296	5.3	4.8	6.0	3600	23.25	3.38	5.69	0.045	0.047	0.144	0.45

The Al^{3+} content in profile 1 ranged between 0.1 and 0.35 $Cmol_{(+)}$ kg^{-1} obtained in horizon BA and Bt respectively. .

In profile 2, the Al^{3+} concentration ranged between 0.10 and 0.45 $Cmol_{(+)}$ kg^{-1} indicating an increase with profile depth in relation to the decrease in soil pH Horizon C2 had the highest exchangeable acidity while Ap had the least. The values show that Al would not be toxic to plants while high rates of P fixation would not be expected. There was a positive correlation between exchangeable acidity and available P in both profiles, which could be attributed to traces of P released from Al^{3+} (Mbah and Nkapaji 2010).Table 2 shows that the Ca contents of soil in profile 1 ranged between 11.57 and 15.16 $Cmol_{(+)}$ kg^{-1} soil. It increased down the profile such that BCg2 and $_{Ap}$ horizons had the highest and lowest contents respectively. Profile 1 generally have high Ca content in line with Holland *et al.* (1989) threshold value of 0.40-3.01 In profile 2, the Ca content varied between 4.95 and 6.94 $Cmol_{(+)}$ kg^{-1} obtained in horizons E and Bc1 respectively .

The Mg contents of the soil in profile 1 ranged between 0.096 and 0.104 $Cmol_{(+)}$ kg^{-1} soil, which decreased with profile depth. Btg, BCg1, and BCg2 had similar Mg contents of 0.104 $Cmol_{(+)}$ kg^{-1} soil, which was the highest in the profile. Ap horizon had the lowest Mg content, which could be attributed to leaching Mg content in profile 2 soil ranged between 0.043 and 0.075 $Cmol_{(+)}$ kg^{-1} soil. Ap horizon had the highest Mg content, while E horizon had the least. Mg content reduced from Ap horizon to E horizon and later increased with depth.

Table 2 shows that the K contents of profile 1 varied between 0.086 and 1.123 and $Cmol_{(+)}$ kg^{-1} soil with surface horizon (Ap) having the highest and C horizon having the lowest. K content of profile 1 decreased with depth. Profile 2 had a K content ranged from 0.047 to 0.232 $Cmol_{(+)}kg^{-1}$ soil, with the Ap horizon having the highest K content and the C2 horizon having the least K content in the profile.

The exchangeable Na content of the soils varied between 0.165 and 0.230 $Cmol_{(+)}kg^{-1}$ in profile 1 with the Cg horizon having the highest and the Bt horizon having the lowest. In profile 2, the values ranged between 0.121 and 0.175 $Cmol_{(+)}kg^{-1}$ with E horizon having the lowest value and Bc2 having the highest. The results showed that cation content follow the order of Ca >K>Mg >Na at the exchange site in the two profile pits. Although exchangeable K supposed to be the least in the profiles due to their mineralogical composition (Ferromagnesian mineral) according to Oyinloye, (2011).

The organic matter content of profile 1 as shown in Table 2 ranged from 8.8 to 42.3 g kg^{-1} with Ap having the highest (42.3 g kg^{-1}) and Cg having the lowest (8.8 g kg^{-1}). Organic matter decreased with profile depth. In Profile 2, the organic matter content of the soil ranged from 0.7 g kg^{-1} to 29.6 g kg^{-1} in horizon Ap and AE respectively which is due to the presence of buried surface soil in AE horizon. Organic matter decreased gradually as profile depth increased from the Bc2 horizon to the BC C1 and C2 horizons. Tiessen (1992) attributes the high organic matter content of the surface horizon to the accumulation and decomposition of plants and animals' litter.

The total phosphorus content of profile 1, as shown in Table 2, was between 600 and 3600 mg kg^{-1} with BA having the highest and Btg having the least. The total phosphorus content of profile 2 ranged from 1800 and 4800 mg kg^{-1} obtained in horizons E and Ap respectively. The result showed that the two profiles contain high amounts of total P at different horizons. This could be as a result of the high organic matter content and it has been reported that organic matter and phosphate can form organophosphate which can be easily absorbed by plant (Nega and Heluf, 2013; Yihenew and Getachew, 2013)

The available P contents of profile 1 ranged between 23.25 and 33.00 mg kg^{-1} (Table 2) with BCg^2 having the highest value and Bt having the lowest value, The available P contents of the profile pit 2 ranged between 20.80 and 24.94 mg kg^{-1}. C1 horizon has the lowest value while AE horizon has the highest available P content. The range of available P content in both profiles showed that the soils can provide optimum amount of P needed for plant growth, (Isola *et al.*, 2020)

Water extractable P value in profile 1 ranged between 0.19 and 5.53 mg kg^{-1}, with AB horizon having the highest value, Bt and BCg1 having the lowest. The water extractable P values in Profile 2 ranged from 0.28 to 3.66 mg kg^{-1}, with Ap and BC having the lowest values and E, Bc1 and C2 horizons having the highest values. The result showed that water extractable P is low in the experimental soils and this is in agreement with Wang *et al.,* (2010).

Relationship between phosphorus forms

Total P had a positive correlation with available P in profile 2, implying that increasing total P will increase available P as shown in Table 4. Also, there was a positive correlation between available P, water- soluble P and organic matter content in profiles 1 and 2. This implies that as organic matter content increases, the available P and water- soluble P increase as shown in Table 3, which agrees with Burt (2004). It means that organic manure can be used to improve the available Phosphorus in the soil.

Table 3: Pearson correlation coefficient for profile pit 1: Ajindo

	Sand	Silt	Clay	pH (H_2O)	pH (KCl)	Ca	Mg	K	Na	Exch. Al^{3+}	Total P	Av. P	Water P	SOM
	← g kg^{-1} →					← $cmol_{(+)}kg^{-1}$ soil →					← mg kg^{-1} →			g kg^{-1}
Sand														
Silt	.814**													
Clay	-.989**	-.892**												
pH(H_2O)	.486	.433	-.490											
pH(KCl)	-.499	-.631*	.551	.163										
Ca	-.171	.248	.069	.446	-.009									
Mg	.300	.593	-.387	.482	-.600	.674*								
K	-.299	-.255	.298	-.897**	-.070	-.507	-.615							
Na	.765*	.853**	-.816**	.079	-.877**	.054	.535	.010						
Exch. Al^{3+}	.412	.633*	-.484	-.257	-.935**	.146	.526	.198	.884**					
Total P	-.135	-.211	.160	.131	.569	.121	-.450	-.070	-.427	-.402				
Av. P	-.345	.059	.253	-.167	-.035	.587	.260	.204	.121	.274	-.246			
Water P	-.198	-.315	.236	.191	.743*	.044	-.428	-.050	-.451	-.580	.301	.341		
SOM	-.439	-.538	.480	-.880**	.206	-.603	-.816**	.912**	-.277	-.075	.109	.090	.202	

**. Correlation is significant at the ($p < 0.01$) level.

*. Correlation is significant at the ($p < 0.05$) level.

Table 4: Pearson correlation coefficient for profile pit 2: Wonu

	Sand	Silt	Clay	pH (H₂0)	pH (KCl)	Ca	Mg	K	Na	Exch. Al^{3+}	Total P	Av. P	Water P	SOM
	← g kg^{-1} →					← cmol(+)kg^{-1} soil →					← mg kg^{-1} →			gkg^{-1}
Sand														
Silt	-.591													
Clay	-.972**	.384												
pH(H20)	.745*	-.498	-.707*											
pH(KCl)	.233	.000	-.267	.749*										
Ca	-.143	-.061	.182	.192	.285									
Mg	.631*	-.061	-.705*	.530	.503	.139								
K	.090	-.593	.071	.193	-.061	.329	-.060							
Na	-.351	-.336	.500	-.184	-.134	.502	-.184	.833**						
Exch. Al^{3+}	-.375	.299	.342	-.845**	-.934**	-.184	-.392	-.264	-.075					
Total P	.251	-.166	-.238	.001	.075	.217	.622*	-.174	.065	.022				
Av. P	.134	-.113	-.121	-.123	-.220	.026	.179	-.369	-.185	.228	.569			
Water P	-.077	.321	-.006	-.353	-.586	-.177	-.446	-.417	-.497	.698*	-.409	.145		
SOM	.812**	-.403	-.811**	.486	.091	-.165	.683*	-.066	-.327	-.191	.445	.598	-.065	

**. Correlation is significant at the ($p < 0.01$) level.

*. Correlation is significant at the ($p<0.05$) level.

Summary

The study was designed to examine the pedogenic forms of Phosphorus in soil underlain by amphibolite rocks in selected areas of southwestern Nigeria. Two profile pits were dug in different locations. Each was described and sampled based on identified horizons. The physical and chemical properties of the samples were determined.

Results indicated that the soils varied in pH, and organic matter contents, which generally decreased with depth in the two profile pits. Profile 1 generally has high clay content, while Profile 2 is mostly sand clay. Total P and available P were both high in both profiles. Water soluble P was also low in both profiles. There was a link between phosphorus forms and content in soils and the soil development stage.

Conclusion and Recommendation

The study concluded that soil formed from the same parent materials, under the same vegetation, climatic conditions, and time may have different physical and chemical properties and that Phosphorus would not be a factor limiting crop yield in the soil studied. Therefore, soil fertility management should focus on maintaining the soil's phosphorus level through organic manure and mulching.

References

Adisa, K. F., Ojetade, J. O., Muda, S. A. and Amusan, A. A (2018). Characterisation and fertility capability classification of the soils of Shasha River floodplain, Osun state, Nigeria. Ife Journal of Agriculture, 28 (1): 1-15

Agboola, A. A. and O.J. Ayodele. (1985). Prospects and problems of using soil testing for adoption of fertiliser use in ekiti-akoko agricultural development project area. Proceedings of the Workshop on Appropriate Technologies for Farmers in Semi-Arid West Africa, April 2-5, Purdue University, West Layette, 123-136.

Blakemore, L. C., P. L. Searle, and B. K. Daly. 1987. Methods for Chemical Analysis of Soils. NZ Soil Bureau Sci. Rept. 80.

Boul, S. W., F. D. Hole and R. J McCraken. (1997). Soil genesis and Classification 4th ed. Iowa State University Press Ames, ISBN 0-8138-2873-2

Burt R, (2004). *Soil Survey Laboratory Methods Manual* Soil Survey Investigations Report No. 42 Version 4.0: 213-240

Busman L.; J. Lamb, G. Randall, G. Rehm and M. Schmitt, (2002). The nature of Phosphorus in soils. University of Minnesota.

Chesworth, Edited by Ward (2008). *Encyclopedia of soil science,* Dordrecht, Netherlands: Springer, xxiv, ISBN 1-4020-3994-8

Du, E.; Terrer, C.; Pellegrini, A.F.A.; Ahlstrum, A.; Van Lissa, C.J.; Zhao, X.; Xia, N.; Wu, X.; Jackson, R.B. (2020). Global patterns of terrestrial nitrogen and phosphorus limitation. *Nat. Geosci. 13*, 221–226.

Dzombak, R.M and Sheldon, N.D (2020). Weathering Intensity and Presence of Vegetation Are Key Controls on Soil Phosphorus Concentrations: Implications for Past and Future Terrestrial Ecosystems. *Soil Syst.* (4),73: 1-38; doi:10.3390/soilsystems4040073

Elrashidi, M.A., M.D. Mays, and P.E. Jones. 2003. A technique to estimate release characteristics and runoff phosphorus for agricultural land. Commun. Soil Sci. and Plant Anal. 34:1759-1790.

Elser, J. J., Bracken, M. E. S., Cleland, E. E., Gruner, D. S., Harpole, W. S., Hillebrand, H. (2007). Global analysis of nitrogen and phosphorus limitation of primary producers in freshwater, marine and terrestrial ecosystems. Ecol. Lett., 10, 1135– 1142

Elueze, A. A. (1988). Geology of the precambian schist belt in Ilesha Area of Southwestern Nigeria. In Oluyinde, P. O. (ed). Precambian Geology of

Nigeria. Geological Survey of Nigeria, Lagos. pp.77-82

Esu I. E, Akpan-Idiok A. U, Eyong M. O (2008). Characterization and Classification of soils along a typical Hillslope in Afikpo Area of Ebonyi state, Nigeria. *Nigerian Journal of Soil and Environment* 8: 1-6

Esu, I. E (2010). Soil Characterisation, Classification and Survey. HEBN publishers PLC.

FAO (2010). Soil Map of the World, Revised legend. World Soil Resources Report 60. FAO, Rome.

Gee, G. W and Or, D. (2002): Particle size analysis. In: Methods of soil analysis. Part 4.Pyhsical methods. J.H Dane and G.C.P Topp (eds.) pp. 255-293. American society of Agronomy, Madison,WI.

Harshavardhana, B.G. and Shankar R., (2021). Topographical influence on pedogenesis – Insights from Rock Magnetism. CATENA 198: 1-35

Holland, M. D., R. K. G. Allen, D. Barten and S. T. Murphy, (1989). Land evaluation and agricultural recommendations for Cross River National Park, Oban Division. Report Prepared by the Overseas Development Resources Institute in Collaboration with WWF for the Federal Republic of Nigeria and the Cross River State Government.

Isola, J. O., Asunlegan O. A., Abiodun, F. O and Smart, M. O. (2020). Effect Of Soil Depth And Topography On Physical And Chemical Properties Of Soil Along Federal College Of Forestry, Ibadan North West, Oyo State Journal of Research in Forestry, Wildlife & Environment 12(2) : 382-390

Kehinde-Phillips, O. O. and G. F. Tietz, (1995). The mineralogy and geochemistry of the weathering profiles over amphibolites, anthophyllite and talc-schist in Ilesha schist belt, Southwestern Nigeria. *Journal of Mining and Geology.* 31 (1):53-62

Mahmut, M (2023). Amphibolite. http:// geologyscience.com> rocks

Mardamootoo, T., du Preez, C. C., and Barnard, J. H. (2021). Phosphorus management issues for crop production: A review. African Journal of Agricultural Research, 17(7), 939-952.

Mbah, C. N. and D. Nkpaji (2010). Response of Maize (*Zea mays*) to different rates of wood ash application in acid Ultisol in Southeast Nigeria. *Journal of American Science* 2010; 6(1): 53-57.

Nasir,K., Jayadi, M and Ahmad, A (2021). Minerals of parent material as an indicator of soil fertility Earth and Environmental Science 807: 04 2007 doi:10.1088/1755-1315/807/4/042007

Nega, E., & Heluf, G. (2013). Effect of land use changes and soil depth on soil organic matter, total nitrogen and available phosphorus contents of soils in Senbat watershed, western Ethiopia. ARPN Journal of Agricultural and Biological Science, 8(3), 206-212.

Olsen, S.R. and Sommers, L.E. 1982. Perchloric Acid Digestion. In: Carter, M.R. and Gregorich, E.G., editors. 2008. Soil Sampling and Methods of Analysis, Second Edition. Canadian Society of Soil Science, Pinawa, MB.

Oyinloye, A. O. (2011): Beyond Petroleum Resources: Solid Minerals to the rescue: 31st Inaugural Lecture of the University of Ado-Ekiti, Nigeria Press, 1-36.

Pramuji dan Bastaman M 2009 Teknik analisis mineral tanah untuk menduga cadangan sumber

hara Buletin Teknik Pertanian 14 80–82

Tiessen, H., I. H. Salced and E.V.S.B. Sampard (1992). Nutrient and Soil Organic matter dynamics under shifting cultivation in Semiarid North Eastern Brazil. *Ecosystem Environ* 38: 139-151.

Voroney, R. P., (2006). "The Soil Habitat". In Soil Microbiology, *Ecology and Biochemistry*. Eldor A. Paul ed. ISBN 0-12-546807-5

Wang, Y.T, Zhang T.Q, Drury C.F, Reid D.K, Lauzon J.D, Reynolds W.D and Welacky T. (2010). Estimating dissolved P loss from Ontario soils in surface Runoff. Journal of Environmental Quality. Vol.39, Sept-Oct 2010 pp. 1771-1781

Yihenew, G., and Getachew, A. (2013). Effects of different land use systems on selected physicochemical properties of soils in Northwestern Ethiopia. Journal of Agricultural Science, 5(4), 112-120.