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# PHYSICO-CHEMICAL AND GEOCHEMICAL PROPERTIES OF SOILS UNDER *SAWAH* SYSTEM OF INLAND VALLEYS IN NIGERIA

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## ABSTRACT

This study investigated the physico-chemical and geochemical properties of soils under *sawah* in Nigeria. It was found that soils under *sawah* were majorly sandy loam to sandy clay loam having acidic reactions, low exchangeable Ca, Mg, K and Na. These soils were deficient in available P, $SiO_2$, S, Total Nitrogen and Total Carbon while $SiO_2$, $Al_2O_3$ and $Fe_2O_3$ dominated total elemental composition, accounting for a cumulative average of 96.16%. Except total elemental $TiO_2$ and $K_2O$ which showed average values >1%, MnO, MgO, CaO, $Na_2O$ and $P_2O_5$ showed average values <1%. Soils under *sawah* exhibited intermediated to extreme weathering degree with majority of the soil sampled falling into the category of extreme weathering. With extreme degree of weathering, rapid loss of mobile species such as basic cations from soil is imminent which may account for the results observed in this study. Thus, combination of conservative agricultural practices is recommended.

**Keywords**: Physico-chemical properties, geological fertilization, *sawah*, inland valleys

## INTRODUCTION

Rice is widely grown in Nigeria under the upland rain fed, inland shallow swamps, deep water and lowland irrigated production systems (Olayemi, 1997; Oladele and Wakatsuki, 2010). However, production under these systems has not been able to meet the demand for rice in Nigeria. An average Nigerian consumes 24.8 kg of rice per year, representing 9 per cent of annual calorie intake (IRRI, 2001). There has been rapid growth in per capita rice consumption in Nigeria during the last three decades, from 5 kg in the 1960s to 25 kg in the late 1990s (WARDA, 2003). In 1990, Nigeria imported 224,000 metric tons of rice valued at US 60 million dollars. This increased to 345,000 metric tons in 1996 with a value of US130 million dollars. By 2001, rice import increased to 1.51 million metric tons valued at US288.1 million dollars (FAO, 1994). In 2004, about 5 million tons was estimated as the total domestic rice demand while the annual domestic output of rice still hovered around 3.0 million tons, leaving about 2 million tons gap annually (NAMIS, 2004). In

2010, Nigeria imported 2.0 million tons of rice mainly from Thailand and 73,000 tons of US parboiled rice, the highest level in the last 30 years (GAIN, 2011). At present, one of the important political-economic goals of the Nigerian government is self-sufficiency in rice production (Bello, 2004).

To improve rice production, attention must be shifted to the Inland Valleys (IVs) available across Nigeria, with high potential for lowland rice production. The values of IVs in crop production have been emphasised, especially for rice and rice-based cropping systems in West Africa (Annan-Afful *et al.,* 2004). The IVs offer considerable potential for agricultural intensification and diversification due to their natural fertility and water availability. Efficient management and sustainable utilization of these inland valleys could, therefore, result in an increase in rice production and reduction in importation. Study has shown that only 15% or less of the total inland valleys in Nigeria has to date been under cultivation despite the agricultural potential of the inland valleys (IITA, 1990; WARDA, 1997; Abe *et al.,* 2007) due to lack of understanding of inland valley ecosystems. Wakatsuki and Masunaga (2005) also reported that the inability to develop the lowland valleys for agriculture in West Africa accounted for the failure in achieving Green Revolution (GR). To this end, *sawah* technology for rice production was introduced to these inland valleys in Nigeria. *Sawah* refers to a levelled and bounded rice field with inlet and outlet for irrigation and drainage (Wakatsuki *et al.,* 1998). According to Wakatsuki and Masunaga (2005), *sawah* is a multifunctional constructed wetland which is a prerequisite for realization of the objectives of GR as well as maintaining a sustainable ecological environment. The geological fertilization process and nitrogen fixation inherent in *sawah* based rice production system compensate for nutrients losses.

*Sawah* system was introduced in Nigeria in 1986 through on-farm adaptive research in the two research sites of Gara and Gadza inland valleys of Bida (Hirose and Wakatsuki, 2002). On these sites, the Japanese researchers conducted on-farm adaptive and participatory trials on *Sawah* for four years (1986–1990). In partnership with Watershed Initiative in Nigeria, a Non-Governmental Organization (NGO), Agricultural Development Project (ADP), Ministry of Agriculture, Niger state and National Cereals Research Institute (NCRI), the dissemination of the *sawah* technology took off in 2001 from villages previously identified in a diagnostic survey (Oladele and Wakatsuki, 2010). Since then, the dissemination and adoption have continued in other parts of Nigeria.

*Sawah*-based system of rice production was reported to have contributed to the achievement of GR in Asia. The speedy and remarkable scale with which the food problem was solved was unprecedented. This resulted in a substantial reduction in poverty and the beginning of broader economic growth in Asia. With GR, per capita production of rice has increased from 200 kg to more than 250 kg in the last 40 years in Asia. With proper soil management of the IVs, the yield of rice in Nigeria could improve to a level that can favourably compete with Asia thereby meeting the increasing demand for rice and contribute to food security in Nigeria.

As part of efforts to effectively utilize *sawah* technology in improving rice production level and to alleviate persistence shortage in rice supply, there is need to understand the physico-chemical and geochemical properties of the *sawah* soils for the development and management of the inland valley ecosystems in Nigeria. Sustainable management of *sawah* in Nigeria will require a thorough evaluation of the soil fertility that is determined by physico-chemical and geochemical properties of the soils. Despite the importance of the physico-chemical and geochemical properties of the *sawah* soils in Nigeria, little information is available. Although Issaka *et al.,* (1996), Buri *et al.,* (2000) and Abe *et al.,* (2007) conducted some basic soil surveys in inland valleys of West Africa, detailed study on the physico-chemical and geochemical properties of the *sawah* soils in Nigeria is required. This study, therefore, aims at investigating the physico-chemical and geochemical status of the soils under *sawah* in Nigeria. This will provide basic information for sustainable management of soils under *sawah* in Nigeria in order to meet up with the desired increase in rice production as well as rice demand and consumption among Nigerians. This study also provides recommendations for soil management for sustainable *sawah* rice production in Nigeria.

## MATERIALS AND METHODS

### *Study area and soil sampling*

This study was carried out in five states in Nigeria where *sawah* rice production is being practiced. The states are Niger, Kaduna, Kwara, Ebonyi and Ondo. Data used in this study were collected in all the *sawah* sites in these states namely: Bida, Zaria, Ilorin, Abakaliki, and Akure. The sites are Ejeti, Emir, Etusegi, Nasarafu, Shabamaliki, Sheshibikun, Etundandan, Zaria, Ilorin, Abakaliki (Ishiagu) and Akure as shown in Fig. 1. Soils of the Bida area are of Mesozoic (Cretaceous) origin, and are generally believed to be formed from Nupe sandstone. The soils of Zaria were derived from Basement Complex rocks which are essentially granites, gneisses, migmatites, schists and quartzites that are rich in quartz and low in divalent cations (Wall, 1978). The soils of Ilorin were formed from the Precambrian basement complex rocks and under the grassland savannah forest cover and belong to the soil group called ferruginous soil (Abe *et al.,* 2007). The soils of Abakaliki were derived from Cretaceous black shale and siltstone or shale and limestone (Abe *et al.,* 2007). The soils of Akure were made up of ferruginous tropical soils. Crystalline acid rocks constitute the main parent material of these soils. The main features include a sandy surface horizon underlain by a weakly developed clayey, mottled and occasionally concretionary sub-soil. The soil is however prone to erosion and occasional water logging as a result of the clay sub-soil. The soils have an exceptional clayey texture, but combine good drainage and aeration with good properties of moisture and nutrient retention. The climatic information of the study area is shown in Table 1. Soil samples were collected at depth of 0-15 cm, 15-30 cm, 30-45 cm and 45-60 cm using auger sampler from all the sites.

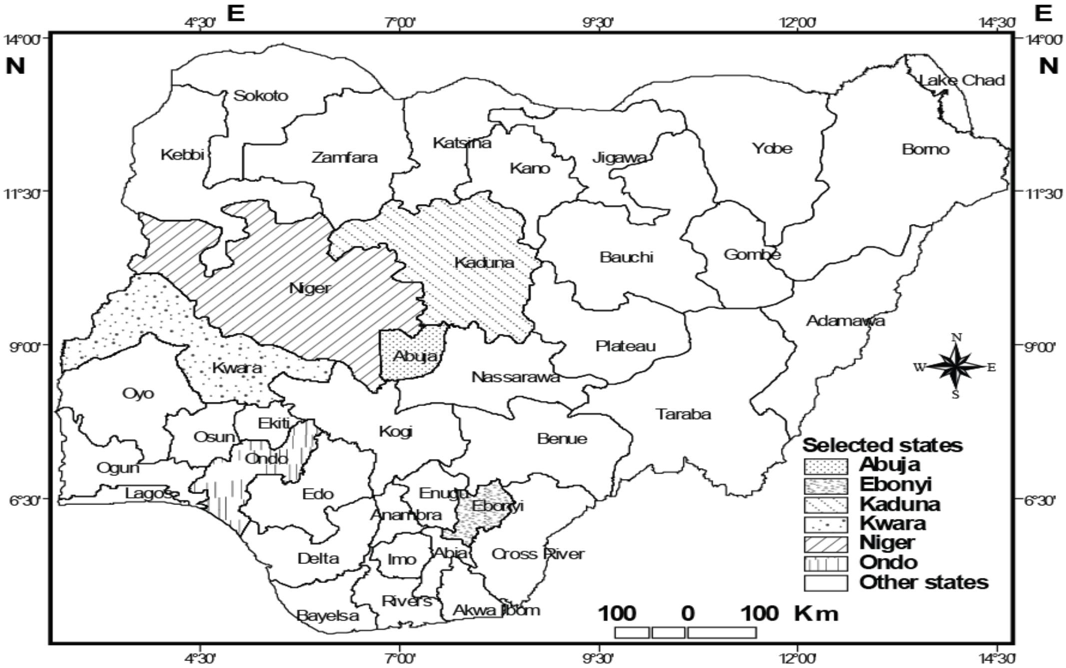


**Fig 1: Map of Nigeria showing the study locations**

**Table 1: Sampling locations**

| Site | State | Relative humidity (%) | Temperature (°C) | Annual Rainfall (mm) | Altitude (m) |
|---|---|---|---|---|---|
| EJT 1 | Niger | | | | 97 |
| EJT 2 | Niger | | | | 92 |
| EMR 1 | Niger | | | | 76 |
| EMR 2 | Niger | 45 - 87 | 23-34. | 1100 -1200 | 82 |
| ETS 1 | Niger | | | | 77 |
| ETS 2 | Niger | | | | 73 |
| NSF | Niger | | | | 71 |
| SHB | Niger | | | | 91 |
| SHE 1 | Niger | | | | 71 |
| SHE 2 | Niger | | | | 76 |
| ETD | Niger | | | | 126 |
| ZNK 1 | Kaduna | | | | 598 |
| ZNK 2 | Kaduna | 20-85 | 10- 42 | 1000 -1200 | 593 |
| ILA 1 | Kwara | | | | 384 |
| ILA 2 | Kwara | 75 - 80 | 34- 53 | 1130-1800 | 381 |
| ILA 3 | Kwara | | | | 376 |
| ISH 1 | Ebonyi | | | | 54 |
| ISH 2 | Ebonyi | 60 – 80 | 20- 38 | 1500 -2000 | 47 |
| AKR 1 | Ondo | | | | 367 |
| AKR 2 | Ondo | 80 | 28- 31 | 1405 - 2400 | 345 |

Note: EJT = Ejeti; EMR = Emi; ETS = Etusegi; NSF = Nasarafu; SHB = Shabamaliki; SHE = Sheshibikun; ETD = Etundandan; ZNK = Zaria, ILA = Ilorin, ISH = Abakaliki (Ishiagu) and AKR = Akure.

***Laboratory analyses***

Soil samples were air-dried, ground and passed through a 2 mm mesh sieve. Soil pH ($H_2O$ and KCl) was measured with a pH meter (with a glass electrode) according to the method recommended by IITA (1979) and Mclean (1982) with a ratio of 1:2.5. Electrical Conductivity (EC) was determined using EC meter with glass electrode with a ratio of 1:5. Exchangeable cations were first extracted with 1M ammonium acetate solution pH 7. Exchangeable Ca (exch. Ca) and exchangeable Mg (exch. Mg) were determined using Inductive Coupled Plasma Atomic Emission Spectroscopy (Shimadzu ICPE 9000, Kyoto, Japan). Exchangeable K (exch. K) and exchangeable Na (exch. Na) were determined using atomic absorption spectrophotometer (AA-680; Shimadzu, Kyoto, Japan). Available phosphorus (avail. P) content was determined by Bray 2 method (Bray & Kurtz, 1945). Available Sulfur (avail. S) was first extracted with Di-potassium Hydrogen Phosphate ($KH_2PO_4$) and Inductively Coupled Plasma Atomic Emission Spectroscopy (Shimadzu ICPE 9000, Kyoto, Japan) was used to determine the avail. S. Available Silica (avail. $SiO_2$) was determined by colorimetric molybdenum blue method by extracting with acetate buffer with ascorbic acid as described by Yanai *et al.,* (1996). Soil was extracted with 1M acetate buffer at pH 4.0 at a ratio of 1:10 for 5 hours at 40°C with occasional shaking. After filtration with dry filter paper no 6, the concentration of Si was determined using the colorimetric molybdenum blue method. Total Carbon (TC) and Total Nitrogen (TN) were determined by the dry combustion method using N-C analyzer (MT-700 J-Science Co. Ltd., Kyoto, Japan) based on the same principle described by Nelson and Sommers (1982). For particle size distribution, sieving was employed to determine coarse sand (2.0-0.2 mm) and fine sand (0.2-0.02 mm), and the pipette method was used for silt (0.02-0.002 mm) and clay (<0.002 mm). Total elements were analysed using X-ray Fluorescence Spectrometry (XRF). The dried soil samples were ground for 20 minutes in an automatic agate mortar and pestle. Total $SiO_2$, $TiO_2$, $Al_2O_3$, $Fe_2O_3$ (total iron expressed as $Fe_2O_3$), MnO, $Na_2O$, MgO, $K_2O$, CaO, and $P_2O_5$ abundance in the samples were determined by XRF in the Department of Geoscience, Shimane University, using a RIX-2000 spectrometer (Rigaku Denki Co. Ltd.) equipped with Rh-anode X-ray tube. All samples were made on pressed powder disks, following Ogasawara (1987). Powdered soil samples were ignited at 1050 °C prior to major element analyses. Loss on Ignition (LOI) of samples was determined before preparing glass beads. A 1.8 g sample of soil was mixed with 3.6 g flux powder (a mixture of Li2B4O7: LiBo2 at ratio of 4:1), placed in a platinum crucible and put in a bead sampler machine (NT-2000, Tokyo Kagaku, Co) for making glass beads. The glass beads of soil samples were then placed in an XRF spectrometer (RIX-2000 spectrometer, Rigaku Denki Co. Ltd.) to determine major elements content. Ten elements (Si, Fe, Al, Ti, Mn, Mg, Ca, Na, K, and P) were analysed.

***Weathering degree***

The degree of weathering was determined by calculating the Chemical Index Alteration (CIA) (Fedo *et al.,* 1995). The CIA reflects the proportion of primary and secondary minerals measured in soil samples and provides accurate measure of the degree of chemical weathering (Nesbitt and Young, 1982). This was calculated using the formula below:

$$CIA = Al_2O_3 / (Al_2O_3 + CaO + Na_2O + K_2O) \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

The mineral alteration is regarded as low when CIA is in range of 50 to 60, intermediate when it is between 60 and 80 and extreme for CIA greater than 80 (Fedo *et al.,* 1995).

***Statistical analysis***

Statistical analysis was performed to determine the relationships between the soil fertility characteristics. Correlation analysis was used to determine the relationship that existed among soil fertility properties using the Statistical Package for Social Science (SPSS version 16).

## RESULTS

***Topsoil physico-chemical and geochemical properties***

***Soil particle size of soil texture***

The result of the study showed that *sawah* topsoils in Nigeria are majorly sandy loam to sandy clay loam in nature (Table 2) with average sand content of 60.60%. Majority of the sites had values above 50% except in ETS 2, AKR 2, EMR 1 and EJT 1 with 35%, 45%, 48% and 24% sand, respectively. The soils were low in both clay and silt with average values of 19.22% and 20.18%, respectively. Sand content across all the sampling sites ranged between 24.31% and 81.99%, silt content ranged between 9.18% and 52.94% while clay content ranged between 5.38% and 36.36%. As shown in Table 2, the topsoils are categorised as sand-clay loam found in AKR 1, EMR 1, EMR 2 and ILA 3; sandy clay found in AKR 2, silty loam found in EJT 1, loamy sand found in EJT 2 and ZNK 2; clay loam found ETS 2 and sandy loam found in ETS 1, ILA 1, ILA 2, NSF, SHB 1, ZNK 1, ISH 1, ISH 2, SHE 1, SHE 2 and ETD. In most cases, sand is higher than clay and silt added together.

***Chemical characteristics***

Generally, the soils under *sawah* in Nigeria showed low topsoil pH values. Topsoil pH ranged between 4.6 and 6.8 with a mean value of 5.2 for in $H_2O$. Topsoil pH in KCl ranged between 3.7 and 5.8 with a mean value of 4.2. Both pH in $H_2O$ and pH in KCl followed the same trend across the sampled soils. The pH was found to be moderately acidic to slightly acidic in the study area with few exceptions in Akure sites that showed slightly alkaline pH. Topsoil Electrical Conductivity (EC) values ranged between 0.007 $dSm^{-1}$ and 0.066 $dSm^{-1}$ with average of 0.016 $dSm^{-1}$. Although the values are low, the EC falls within the recommended limit of 0 - 4.0 $dSm^{-1}$ for crop production. As shown in Table 3, topsoil exch. Ca ranged between 0.57 cmol $kg^{-1}$ and 21.22 cmol $kg^{-1}$ with topsoil average of 3.51 cmol $kg^{-1}$. The values of exch. Ca were generally low across all the sampling locations. Highest value of exch. Ca was observed in Akure sites. Exch. K content of topsoil was low with mean content of 0.32 cmol $kg^{-1}$. Exch. K showed a range of between 0.12 cmol $kg^{-1}$ and 0.60 cmol $kg^{-1}$ with topsoil average of 0.32 cmol $kg^{-1}$. Soils under *Sawah* in Nigeria are characterised by low exch. K with highest values observed in Akure. Exch. Mg was low. The topsoil exch. Mg ranged between 0.11 cmol $kg^{-1}$ and 5.63 cmol $kg^{-1}$ with topsoil average of 0.99 cmol $kg^{-1}$. Topsoil exch. Na ranged between 0.09 cmol $kg^{-1}$ and 1.49 cmol $kg^{-1}$ and with topsoil average of 0.37 cmol $kg^{-1}$. Ex. Na was generally low in soils under *sawah* in Nigeria. Topsoil Avail. P was low, ranging from 4.36 mg $kg^{-1}$ to 323.35 mg $kg^{-1}$ with topsoil average of 41.12 mg $kg^{-1}$. There was considerably high avail. P in AKR 1 and 2. AKR 1 and 2 are located in the Southwest part of Nigeria. This high value agreed with Issaka *et al.,* (1996) that reported that soils in Southwest Nigeria had high Avail. P compared to other inland valleys in West Africa. Topsoil avail. $SiO_2$ values ranged between 24.65 mg kg$^{-1}$ and 688.46 mg kg$^{-1}$ with topsoil average of 130.71 mg kg$^{-1}$. There was considerably high avail. $SiO_2$ in Akure which considerably affected the average value. Avail. S level was generally low across all the sampling locations compared to the critical level of 8 mg kg$^{-1}$ as recommended by Yamaguchi (1997). Topsoil avail. S values ranged between 3.56 mg kg$^{-1}$ and 31.25 mg kg$^{-1}$ with topsoil mean value of 9.57 mg kg$^{-1}$. Although the average value is higher than the critical level, however majority of the sites have values below the critical level. Highest value of avail. S was observed in Akure sites which considerably affected the average value. The content of TN was generally low in soils under *sawah* in Nigeria. The content of topsoil TN ranged between 0.24 g kg$^{-1}$ and 3.01 g kg$^{-1}$ with topsoil average value of 0.80 g kg$^{-1}$. Following a similar trend, topsoil TC can be categorised as low. The content of TC ranged between 2.94 g kg$^{-1}$ and 29.10 g kg$^{-1}$ with topsoil average value of 8.97 g kg$^{-1}$.

***Geochemical properties and weathering degree***

The result of the study as shown in Table 3 revealed that topsoil total elemental $SiO_2$ ranged between 67.57% and 94.47% in soils under *sawah*. The average topsoil $SiO_2$ is 85.96%. Majority of the locations sampled had values above the average. $TiO_2$ ranged between 0.60% and 6.39% with an average of 1.77%. Majority of the locations sampled had values above the average $TiO_2$ value. $Al_2O_3$ values ranged between 2.60 % and 13.63% with a mean of 7.61%. $Fe_2O_3$ ranged between 0.49% and 9.18% with an average of 2.59%. The average value of MnO was 0.06% and ranged between 0.02% and 0.27%. MgO ranged between 0.06% and 0.70% with an average of 0.18%. CaO values ranged between 0.08% and 1.83% with a mean of 0.33%. $Na_2O$ ranged between 0.17% and 1.24% with an average of 0.42%. The result of the soils in Nigeria with average of 1.05%. $P_2O_5$ values on the other hand ranged between 0.01% and 0.23% with a mean of 0.04%. The result also showed that $SiO_2$, $Al_2O_3$ and $Fe_2O_3$ dominated, total elemental composition accounting for a cumulative average of 96.16%. Except $TiO_2$ and $K_2O$ which showed average values >1%, MnO, MgO, CaO, $Na_2O$ and $P_2O_5$ showed average values < 1%. The result of the study further revealed that soils under *sawah* have CIA values ranging from 67.45 and 91.50. Based on the interpretation of CIA value as prescribed by Fedo *et al.,* (1995), soils under *sawah* in Nigeria exhibited intermediated (CIA 60 - 80) to extreme degree weathering (CIA>80).

## Table 2: Topsoil physico-chemical properties of *sawah* soils in Nigeria

| | | pH | | | Exchangeable cations (cmol kg$^{-1}$) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S / N | Sites | $H_2O$ | KCl | EC (d Sm$^{-1}$) | Ca | K | Mg | Na | Bray-2 P (mg kg$^{-1}$) | Avail $SiO_2$ (mg kg$^{-1}$) | Avail S (mg kg$^{-1}$) | TN g kg$^{-}$ | TC gkg$^{-1}$ | C / N | Clay (%) | Silt (%) | C.Sand (%) | F.Sand (%) | Sand (%) | Textural Class |
| 1 | AKR 1 | 5.13 | 4.34 | 0.03 | 7.11 | 0.40 | 2.74 | 0.75 | 90.21 | 135.60 | 28.67 | 1.36 | 15.04 | 11.06 | 23.89 | 12.88 | 35.95 | 27.28 | 63.23 | Sand clay loam |
| 2 | AKR 2 | 6.43 | 5.75 | 0.07 | 21.22 | 0.48 | 5.63 | 1.49 | 323.35 | 688.46 | 31.25 | 3.01 | 29.10 | 9.67 | 34.64 | 20.31 | 12.24 | 32.81 | 45.05 | Sandy clay |
| 3 | EJT 1 | 4.93 | 4.28 | 0.02 | 3.56 | 0.49 | 0.77 | 0.22 | 49.21 | 106.39 | 10.88 | 1.49 | 17.86 | 11.99 | 22.75 | 52.94 | 1.31 | 23.00 | 24.31 | Silt loam |
| 4 | EJT 2 | 5.42 | 4.76 | 0.01 | 1.72 | 0.12 | 0.37 | 0.37 | 21.87 | 81.11 | 5.07 | 0.36 | 4.70 | 13.06 | 5.38 | 14.75 | 26.14 | 53.73 | 79.86 | Loamy sand |
| 5 | EMR 1 | 4.85 | 3.95 | 0.01 | 1.77 | 0.48 | 0.54 | 0.40 | 8.30 | 107.57 | 7.18 | 0.45 | 5.47 | 12.08 | 22.79 | 29.45 | 4.17 | 43.58 | 47.75 | Sandy clay loam |
| 6 | EMR 2 | 4.75 | 3.74 | 0.01 | 2.09 | 0.36 | 0.63 | 0.42 | 12.96 | 145.10 | 6.84 | 0.43 | 4.38 | 10.18 | 25.60 | 13.95 | 15.88 | 44.58 | 60.46 | Sandy clay loam |
| 7 | ETS 1 | 4.98 | 4.23 | 0.01 | 2.29 | 0.31 | 0.41 | 0.29 | 12.77 | 89.43 | 6.95 | 0.56 | 6.55 | 11.67 | 14.99 | 27.30 | 5.72 | 52.00 | 57.72 | Sandy loam |
| 8 | ETS 2 | 4.86 | 3.92 | 0.01 | 2.75 | 0.36 | 0.54 | 0.26 | 10.79 | 130.11 | 7.78 | 0.57 | 6.25 | 10.96 | 36.36 | 28.36 | 1.11 | 34.17 | 35.28 | Clay loam |
| 9 | ILA 1 | 4.64 | 3.79 | 0.01 | 3.54 | 0.37 | 1.12 | 0.49 | 29.26 | 260.30 | 9.45 | 0.87 | 9.81 | 11.28 | 16.91 | 14.64 | 41.01 | 27.44 | 68.45 | Sandy loam |
| 10 | ILA 2 | 4.79 | 4.02 | 0.01 | 2.74 | 0.58 | 0.79 | 0.41 | 4.36 | 174.44 | 5.85 | 0.29 | 3.05 | 10.52 | 20.97 | 24.43 | 25.54 | 29.06 | 54.60 | Sandy loam |
| 11 | ILA 3 | 4.63 | 3.91 | 0.01 | 1.47 | 0.27 | 0.62 | 0.16 | 54.95 | 24.65 | 9.87 | 1.27 | 14.94 | 11.76 | 29.50 | 15.37 | 24.44 | 30.69 | 55.13 | Sandy clay loam |
| 12 | NSF 1 | 6.11 | 4.55 | 0.01 | 2.34 | 0.13 | 1.19 | 0.28 | 6.95 | 28.25 | 3.56 | 0.24 | 3.85 | 16.04 | 13.07 | 10.95 | 38.13 | 37.85 | 75.97 | Sandy loam |
| 13 | SHB 1 | 4.98 | 4.65 | 0.02 | 1.83 | 0.19 | 0.89 | 0.16 | 32.59 | 63.42 | 6.71 | 0.60 | 7.37 | 12.28 | 16.15 | 19.13 | 33.20 | 31.53 | 64.72 | Sandy loam |
| 14 | ZNK 1 | 6.82 | 4.24 | 0.01 | 5.79 | 0.60 | 1.73 | 0.56 | 15.85 | 53.24 | 6.33 | 0.57 | 7.20 | 12.63 | 13.37 | 9.18 | 24.89 | 52.55 | 77.44 | Sandy loam |
| 15 | ZNK 2 | 5.08 | 4.42 | 0.02 | 0.58 | 0.13 | 0.13 | 0.09 | 19.03 | 39.73 | 10.44 | 0.71 | 9.38 | 13.21 | 6.03 | 11.98 | 19.87 | 62.12 | 81.99 | Loamy sand |
| 16 | ISH 1 | 4.76 | 4.12 | 0.02 | 1.37 | 0.50 | 0.35 | 0.27 | 34.54 | 55.01 | 8.39 | 0.94 | 10.37 | 11.03 | 18.95 | 13.21 | 12.17 | 55.67 | 67.84 | Sandy loam |
| 17 | ISH 2 | 4.71 | 3.73 | 0.01 | 0.57 | 0.16 | 0.11 | 0.14 | 20.58 | 77.98 | 6.75 | 0.93 | 10.23 | 11.00 | 20.16 | 24.42 | 3.15 | 52.27 | 55.42 | Sandy loam |
| 18 | SHE 1 | 5.25 | 4.03 | 0.01 | 2.32 | 0.15 | 0.43 | 0.22 | 5.46 | 54.62 | 5.15 | 0.33 | 3.66 | 11.09 | 7.51 | 19.40 | 23.08 | 50.02 | 73.09 | Sandy loam |
| 19 | SHE 2 | 5.97 | 4.05 | 0.01 | 1.50 | 0.13 | 0.31 | 0.16 | 6.06 | 74.36 | 6.24 | 0.29 | 2.94 | 10.14 | 19.40 | 16.98 | 13.69 | 49.93 | 63.62 | Sandy loam |
| 20 | ETD 1 | 4.75 | 3.96 | 0.01 | 3.58 | 0.21 | 0.54 | 0.29 | 63.25 | 224.34 | 8.06 | 0.64 | 7.22 | 11.28 | 15.96 | 23.95 | 3.24 | 56.85 | 60.09 | Sandy loam |

**Table 3: Topsoil total elements composition of *sawah* soils in Nigeria**

| Site | $SiO_2$ (%) | $TiO_2$ (%) | $Al_2O_3$ (%) | $Fe^2O_3$ (%) | MnO (%) | MgO (%) | CaO (%) | $Na_2O$ (%) | $K_2O$ (%) | $P_2O_5$ (%) | LOI | CIA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AKR 1 | 73.77 | 6.39 | 8.96 | 8.03 | 0.10 | 0.45 | 1.09 | 0.58 | 0.56 | 0.07 | 4.49 | 80.07 |
| AKR 2 | 67.57 | 5.04 | 13.61 | 9.18 | 0.27 | 0.70 | 1.83 | 0.62 | 0.93 | 0.23 | 9.26 | 80.09 |
| EJT 1 | 85.77 | 2.29 | 8.87 | 1.48 | 0.03 | 0.13 | 0.19 | 0.21 | 0.99 | 0.05 | 5.56 | 86.45 |
| EJT 2 | 94.26 | 1.25 | 2.60 | 1.05 | 0.04 | 0.07 | 0.12 | 0.18 | 0.42 | 0.01 | 1.63 | 78.40 |
| EMR 1 | 86.98 | 1.49 | 7.72 | 1.74 | 0.04 | 0.12 | 0.25 | 0.33 | 1.31 | 0.02 | 3.19 | 80.39 |
| EMR 2 | 87.07 | 1.02 | 7.85 | 2.58 | 0.03 | 0.12 | 0.21 | 0.26 | 0.84 | 0.02 | 3.47 | 85.66 |
| ETS 1 | 89.49 | 1.48 | 6.40 | 0.96 | 0.04 | 0.11 | 0.15 | 0.21 | 1.14 | 0.02 | 3.14 | 81.13 |
| ETS 2 | 80.24 | 1.73 | 13.63 | 2.07 | 0.04 | 0.17 | 0.20 | 0.26 | 1.63 | 0.03 | 5.13 | 86.71 |
| ILA 1 | 88.36 | 1.54 | 6.10 | 3.13 | 0.05 | 0.13 | 0.17 | 0.22 | 0.29 | 0.04 | 4.02 | 90.03 |
| ILA 2 | 84.49 | 2.18 | 7.87 | 4.21 | 0.07 | 0.19 | 0.20 | 0.23 | 0.51 | 0.04 | 3.28 | 89.26 |
| ILA 3 | 88.65 | 1.62 | 6.91 | 1.85 | 0.04 | 0.14 | 0.20 | 0.24 | 0.32 | 0.03 | 4.66 | 90.09 |
| NSF 1 | 94.47 | 0.97 | 2.89 | 0.49 | 0.02 | 0.06 | 0.09 | 0.19 | 0.81 | 0.01 | 1.24 | 72.58 |
| SHB 1 | 91.32 | 1.25 | 5.34 | 0.90 | 0.02 | 0.08 | 0.08 | 0.18 | 0.82 | 0.02 | 2.51 | 83.10 |
| ZNK 1 | 82.05 | 0.60 | 10.38 | 1.77 | 0.03 | 0.16 | 0.34 | 0.71 | 3.96 | 0.01 | 2.53 | 67.45 |
| ZNK 2 | 85.51 | 0.66 | 8.37 | 1.37 | 0.03 | 0.14 | 0.42 | 0.73 | 2.76 | 0.01 | 2.64 | 68.18 |
| ISH 1 | 88.25 | 0.72 | 6.58 | 2.34 | 0.03 | 0.21 | 0.22 | 1.22 | 0.40 | 0.04 | 2.84 | 78.24 |
| ISH 2 | 84.38 | 0.89 | 9.11 | 3.15 | 0.02 | 0.28 | 0.22 | 1.24 | 0.67 | 0.04 | 3.35 | 81.00 |
| SHE 1 | 90.37 | 1.10 | 4.96 | 1.56 | 0.18 | 0.08 | 0.26 | 0.31 | 1.17 | 0.01 | 1.59 | 74.08 |
| SHE 2 | 88.18 | 1.17 | 7.32 | 1.41 | 0.03 | 0.11 | 0.29 | 0.31 | 1.18 | 0.01 | 2.52 | 80.53 |
| ETD 1 | 88.03 | 1.92 | 6.74 | 2.50 | 0.04 | 0.11 | 0.10 | 0.17 | 0.36 | 0.04 | 3.38 | 91.50 |

CIA = Chemical Index Alteration; LOI = Loss on Ignition

**Table 4: Correlation matrix between topsoil fertility parameters of *sawah* soils in Nigeria (N = 18)**

| | pH H2O | pH KCl | EC | Ca | K | Mg | Na | P2O5 | SiO2 | S | N | C | C/N | Clay % | Silt | Sand | $SiO_2$ | $TiO_2$ | $Al_2O_3$ | $Fe_2O_3$* | MnO | MgO | CaO | $Na_2O$ | $K_2O$ | $P_2O_5$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| pH KCl | 0.44 | | | | | | | | | | | | | | | | | | | | | | | | | |
| EC | -0.42 | 0.26 | | | | | | | | | | | | | | | | | | | | | | | | |
| Ex. Ca | 0.42 | -0.03 | -0.18 | | | | | | | | | | | | | | | | | | | | | | | |
| Ex. K | -0.04 | -0.28 | 0.18 | 0.56 | | | | | | | | | | | | | | | | | | | | | | |
| Ex. Mg | 0.53 | 0.15 | -0.15 | 0.81 | 0.47 | | | | | | | | | | | | | | | | | | | | | |
| Ex. Na | 0.25 | -0.15 | -0.29 | 0.69 | 0.63 | 0.64 | | | | | | | | | | | | | | | | | | | | |
| Av. P2O5 | -0.38 | -0.03 | 0.56 | 0.12 | 0.00 | -0.01 | -0.21 | | | | | | | | | | | | | | | | | | | |
| Av. SiO2 | -0.43 | -0.47 | -0.12 | 0.38 | 0.28 | 0.12 | 0.49 | 0.19 | | | | | | | | | | | | | | | | | | |
| Av. S | -0.51 | -0.26 | 0.62 | -0.02 | 0.24 | -0.17 | -0.24 | 0.63 | 0.20 | | | | | | | | | | | | | | | | | |
| TN | -0.42 | -0.19 | 0.69 | 0.01 | 0.23 | -0.05 | -0.28 | 0.74 | -0.01 | 0.82 | | | | | | | | | | | | | | | | |
| TC | -0.35 | -0.09 | 0.73 | 0.02 | 0.20 | -0.01 | -0.29 | 0.74 | -0.08 | 0.82 | 0.99 | | | | | | | | | | | | | | | |
| C/N | 0.47 | 0.70 | 0.24 | 0.05 | -0.27 | 0.36 | -0.03 | -0.04 | -0.44 | -0.24 | -0.11 | 0.01 | | | | | | | | | | | | | | |
| Clay | -0.40 | -0.59 | 0.09 | 0.03 | 0.40 | 0.01 | -0.01 | 0.14 | 0.21 | 0.30 | 0.33 | 0.26 | -0.45 | | | | | | | | | | | | | |
| Silt | -0.37 | -0.12 | 0.50 | 0.12 | 0.28 | -0.17 | -0.16 | 0.23 | 0.23 | 0.35 | 0.44 | 0.43 | -0.22 | 0.37 | | | | | | | | | | | | |
| Sand | 0.46 | 0.39 | -0.39 | -0.09 | -0.40 | 0.11 | 0.11 | -0.23 | -0.26 | -0.40 | -0.47 | -0.42 | 0.38 | -0.78 | -0.87 | | | | | | | | | | | |
| $SiO_2$ | 0.09 | 0.54 | 0.04 | -0.29 | -0.55 | -0.05 | -0.12 | 0.07 | -0.21 | -0.40 | -0.25 | -0.20 | 0.46 | -0.53 | -0.28 | 0.47 | | | | | | | | | | |
| $TiO_2$ | -0.46 | -0.18 | 0.21 | 0.25 | 0.28 | 0.02 | 0.06 | 0.34 | 0.55 | 0.27 | 0.25 | 0.23 | -0.27 | 0.44 | 0.73 | -0.73 | -0.12 | | | | | | | | | |
| $Al_2O_3$ | -0.09 | -0.50 | 0.01 | 0.24 | 0.47 | 0.01 | 0.02 | -0.04 | 0.14 | 0.42 | 0.27 | 0.23 | -0.44 | 0.63 | 0.33 | -0.56 | -0.97 | 0.14 | | | | | | | | |
| $Fe_2O_3$* | -0.47 | -0.71 | -0.18 | 0.10 | 0.46 | -0.03 | 0.32 | 0.04 | 0.63 | 0.18 | 0.11 | 0.02 | -0.63 | 0.35 | 0.06 | -0.22 | -0.52 | 0.29 | 0.37 | | | | | | | |
| MnO | -0.07 | -0.17 | -0.39 | 0.04 | -0.10 | -0.14 | 0.00 | -0.25 | 0.03 | -0.25 | -0.27 | -0.30 | -0.26 | -0.25 | 0.03 | 0.12 | 0.12 | 0.11 | -0.19 | 0.10 | | | | | | |
| MgO | -0.29 | -0.53 | 0.08 | -0.15 | 0.36 | -0.22 | -0.07 | 0.03 | 0.06 | 0.26 | 0.38 | 0.31 | -0.42 | 0.39 | 0.12 | -0.29 | -0.68 | -0.08 | 0.60 | 0.67 | -0.23 | | | | | |
| CaO | 0.26 | -0.20 | -0.12 | -0.06 | 0.17 | -0.13 | -0.08 | -0.30 | -0.30 | 0.30 | 0.04 | 0.06 | -0.16 | -0.11 | -0.17 | 0.17 | -0.55 | -0.43 | 0.48 | 0.09 | 0.11 | 0.31 | | | | |
| $Na_2O$ | 0.00 | -0.19 | 0.15 | -0.29 | 0.10 | -0.27 | -0.19 | -0.03 | -0.32 | 0.13 | 0.26 | 0.23 | -0.11 | -0.08 | -0.22 | 0.19 | -0.34 | -0.61 | 0.27 | 0.26 | -0.20 | 0.76 | 0.47 | | | |
| $K_2O$ | 0.63 | 0.17 | -0.15 | 0.38 | 0.22 | 0.33 | 0.16 | -0.33 | -0.34 | 0.03 | -0.14 | -0.08 | 0.22 | -0.20 | -0.17 | 0.22 | -0.50 | -0.45 | 0.48 | -0.25 | -0.09 | 0.04 | 0.72 | 0.23 | | |
| $P_2O_5$ | -0.59 | -0.48 | 0.40 | 0.16 | 0.44 | -0.09 | -0.02 | 0.54 | 0.53 | 0.55 | 0.65 | 0.58 | -0.46 | 0.47 | 0.59 | -0.64 | -0.46 | 0.60 | 0.41 | 0.67 | -0.12 | 0.62 | -0.17 | 0.20 | -0.38 | |
| CIA | -0.70 | -0.48 | 0.11 | 0.05 | 0.17 | -0.09 | 0.05 | 0.47 | 0.68 | 0.33 | 0.32 | 0.24 | -0.53 | 0.63 | 0.42 | -0.62 | -0.10 | 0.79 | 0.13 | 0.51 | -0.05 | 0.12 | -0.53 | -0.41 | -0.70 | 0.66 |

Note: r = 0.468 significance <5%; r = 0.590, significance <1%

***Correlation analysis between soil fertility parameters***

Correlation analysis shown in Table 4 revealed that there is a significant relationship between TC and Avail. S and Avail. P. Total Carbon was also found to be significantly related to total elemental $P_2O_5$. The results also showed similar significant relationship between TN and Avail. S and Avail. P. Total Nitrogen was also found to be significantly related to total elemental $P_2O_5$. Clay content showed a significant relationship with total elemental $P_2O_5$. Sand content showed a negative correlation TC, TN and total elemental $P_2O_5$. The result also revealed that CIA is correlated with Avail. P., Avail. $SiO_2$, clay content, total elemental CaO, $Na_2O$, $K_2O$, $TiO_2$, $Fe_2O_3$ and $P_2O_5$.

***Distribution of soil fertility parameters with depth***

Particle size analysis revealed that clay content of soils under *sawah* increased with increase in depth from topsoil down to subsoil except in few cases with erratic distribution. Silt content showed a decreasing trend in depth from topsoil down to subsoil. Silt content however showed variations in some sampling points without clear-cut trends. Sand showed erratic trend in most of the sampling points with variations in depth from topsoil down to subsoil. Soil pH increased with increase in depth from topsoil down to subsoil. The profile distribution revealed that the pH level increased with depth with few exceptions where the pH level decreased with depth. AKR 1, EMR 2, ETU 2, ILA 1, SHB, ZNK 2, ISH 1, ISH 2 and SHE 1 showed the same trend with an increase in the pH from topsoil down to subsoil. The EC values generally followed the opposite trend as pH with decrease in the value of EC with the depth from topsoil down to subsoil with only few exceptions. With exception in few cases, exch. Ca decreased with increase in soil depth from topsoil to subsoil. Exch. K decreased with increase in depth from topsoil down to subsoil. Exch Mg increased slightly in some locations and also decreased with depth from topsoil down to subsoil in other locations. Exch. Na increased with depth from topsoil down to subsoil which may be due to leaching of the topsoil and accumulation in the subsoil. Avail. P decreased with depth from topsoil down to subsoil. Avail. $SiO_2$ values increased with depth from topsoil down to subsoil except in few occasions. Avail. S level was comparatively higher in the topsoil across all the sampling locations. Avail. S decreased with increase in depth from topsoil down to subsoil with some exceptions where there was erratic distribution within the soil profile. TN values were comparatively higher in the topsoil across all the sampling locations and decreased with increase in depth of the profile. As observed in TN, TC values were comparatively higher in the topsoil across all the sampling locations and decreased with increase in depth from topsoil down to subsoil.

## DISCUSSION

The physical characteristics of a soil, particularly texture significantly influence the other characteristics of the soil. Particle size distribution is critical in relation to soil behaviour and management. The properties of individual particles and their distribution in the soils are subjected to limited human control. According to Lund *et al.,* (1999), the diverse ratios of sand, silt, and clay in the soil results in soil variations which has a direct effect on crop yield. These variances affect the water-holding capacity, nutrient leaching, and plant root stability in soils. Soil physical properties also play a significant role in the chemical properties of soil. As reported by previous authors (Buri *et al.,* 2000 and Issaka *et al.,* 1996) inland valleys in West Africa are dominated by low clay content having been derived from granites and Pre-Cambrian metamorphic rocks, generally referred to as Basement Complex. The result revealed a positive correlation although not significant between sand and total elemental $SiO_2$ (r = 0.47) which means high sand content in soil increases the $SiO_2$ content. The high content of sand fraction means that the soils water retention capacity was low and as such could not hold nutrients resulting into high level of leaching which have contributed to the generally low fertility status of these soils. The low content of clay in these soils contributes to high leaching especially as observed in exch. Na which increases in values with increase in soil depth. The high content of clay in ETS 2 and silt in EJT 1 will be an advantage for these locations for *sawah* rice development. The clay content of soil play a major role in its nutrient supplying ability as well as it water holding capacity (Buri *et al.,* 1999).

The pH was found to be moderately acidic to slightly acidic in the entire site but with few exceptions in Akure site that showed slightly alkaline pH. The acidic nature of parent rocks and intense leaching under high rainfall is responsible for the acidic reaction of the soils (Abe *et al.,* 2007). Application of nitrogen fertilizers commonly adopted by farmers in Nigeria account for the acidic condition which in turn worsens the fertility of the soils. Electrical conductivity (EC) values ranged between 0.005 $dSm^{-1}$ and 0.26 $dSm^{-1}$ with topsoil average of 0.02 $dSm^{-1}$. The EC values were generally low and followed opposite trend as pH, decreasing in value with depth with only few exceptions. Chabra *et al.,* (1980) and Pereir *et al.,* (1986) reported that soils exposed to high rainfall have low soluble salts concentration because of leaching losses and in turn results in decreased electrical conductivity. The EC values are low in the study area but fall within the recommended limit for crop production. Corresponding with the low pH, the contents of exchangeable bases were very low. The values of exch. Ca were generally low across all the sampling locations in Nigeria. Exch. K content of the soils was low with mean content of 0.26 cmol $kg^{-1}$. Exch. Na was generally low except in few occasions where exch. Na was moderate and increased slightly with depth of the soil profile. The low level of exchangeable bases is due to leaching of the topsoil and accumulation in the subsoil. In addition, flooding condition of the soils which reduced the pH at the surface also account for the nature of the exchangeable cations found in soils under *sawah* in Nigeria. Low exchangeable bases could also be associated with the low level of clay across all the sample locations. The soils are low in clay and hence may be susceptible to leaching. Buri *et al.,* (2000) also reported that low colloidal activity as a result of low organic matter and erratic rainfall distribution and low clay activity in West Africa provided an environment where cations retention and overall build-up soil plant nutrient is very low. The low content of exchangeable bases is also due to high degree of weathering as shown by high CIA values obtained in this study. As prescribed by Fedo *et al.,* (1995) soils under *sawah* in Nigeria exhibited intermediate CIA (60-80) to extreme degree of weathering (CIA>80). Majority of the soil sampled fell into the category of extreme degree of weathering. With extreme degree of weathering, rapid loss of mobile species such as base cations (Ca, Mg, K and Na) from soil is eminent which account for the results observed in this study. The high level of SiO2, $Al_2O_3$ and $Fe_2O_3$ and low level of total base elements ($K_2O$, CaO, $Na_2O$ and MgO) is also an indication of low fertility status obtained in this study. Avail. P in the soils under *sawah* in Nigeria is low. The result is supported by previous reports of Annan-Afful *et al.,* (2004) and Abe *et al.,* (2007) who reported an average avail. P of 4.9 mg $kg^{-1}$ in soils under *sawah* in Ashanti region of Ghana and a range of between 1.0 mg $kg^{-1}$ and 9.0 mg $kg^{-1}$ in eastern Nigeria, respectively.

As there has not been any study on availability of silica in lowland soils in Nigeria to the best of our knowledge, we compare the result to the critical level recommended by authors in tropical Asia and Japan. According to Sumida (1992), the critical value of avail. $SiO_2$ content for rice growth is 300 mg $kg^{-1}$ of $SiO_2$. Also, Bollich & Matichenkov (2002) described values less than 300 mg $kg^{-1}$ of $SiO_2$ as deficient and values less than 600 mg $kg^{-1}$ of avail. $SiO_2$ as low for rice and sugarcane. According to IRRI (2000), the critical value of avail. $SiO_2$ content for rice growth is 86 mg $kg^{-1}$. Based on Sumida (1992), soils under *sawah* in Nigeria are deficient in avail. $SiO_2$ except in Akure 2 where the topsoil recorded a high level of silica, other sites ranged from low to deficient in available silica. Based on IRRI (2000), majority of the soils had values below the critical level of 86 mg $kg^{-1}$. Silicon is as beneficial element for rice plants and as one of the major factors affecting the sustainability of rice production (Husnain *et al.,* 2008), *sawah* soils in Nigeria need silicate amendment for optimum rice production. Silicon can control rice diseases such as blast, sheath blight in rice, and powdery mildew in cucumber (Ishizuka & Hayakawa, 1951; Kawashima, 1927; Miyake & Takahashi 1983; Ma *et al.,* 2001). Silica according to Iler (1979) is able to displace phosphate ions from the soil surface. Ma *et al.,* (2001) also reported that silicon is essential in alleviating water stress by decreasing transpiration and is beneficial to rice under P deficiency (as found in the present study locations) and excess of P, Na, Mn, N and Al.

Avail. S level was low in the topsoil across all the sampling locations showing values below the critical level of 8 mg $kg^{-1}$ as recommended by Yamaguchi (1997). According to Yamaguchi (1997), sulfur status is a key factor controlling rice productivity. The result of this study is in agreement with previous results of Osiname and Kang (1975), Enwezor (1976) Kang *et al.,* (1981) and Buri *et al.,* (2000) who reported similar low level of sulfur in West Africa. The result also showed that avail. S significantly correlated with TC and TN. According to Buri *et al.,* (2000), poor organic matter management has a great effect on sulfur deficiency. In addition to organic matter, volcanic activity which supply sulfur to soil through precipitation is absent in the study area (Buri *et al.,* 2000) and may also account for the low level of sulfur observed in this study. Total Carbon and Total Nitrogen were observed to be low across all the soils under *sawah*. Organic matter according to Oyediran (1990) is effective in increasing and retaining most cations. Poor organic matter content resulting in low TC and TN plays a major role in low cation level found in this study. In addition, farming practices that encourage the burning of plant residue and annual burning of vegetation especially during the dry season (slash and burn) commonly found in the study areas also account for the low content of TC and TN. The values of TC and TN decreased with increase in depth down the soil profile. The comparably high TC and TN on the topsoil was as a result of large biomass production in the tropical condition found in the study locations.

Total elemental $SiO_2$, $Al_2O_3$ and $Fe_2O_3$ dominated total elements, accounting for a cumulative average of 96.16%. Total elemental $SiO_2$ was the most abundant element accounting for between 67.57% and 94.47% of total weight. There also existed a positive correlation between total elemental $SiO_2$ and sand. This implies a strong chemical weathering process of the soils and sand size particles are dominated by $SiO_2$. $Al_2O_3$ values ranged between 2.60 % and 13.63% with a mean of 7.61%. $Fe_2O_3$ ranged between 0.49% and 9.18% with an average of 2.59%. Both $Al_2O_3$ and $Fe_2O_3$ were positively correlated with clay contents ($r = 0.63$; $r = 0.35$, respectively) suggesting that $Al_2O_3$ occurs in the form of clay and alluminosilicate minerals, and consists of $SiO_2$ and $Al_2O_3$ produced through weathering of parent materials. The correlation also suggests that the clay fraction not only consists of alluminosilicate minerals but also free iron oxides, which is formed from iron released from parent materials during weathering processes. Total elemental MgO content was low and ranged between 0.06% and 0.70%. The low level of total elemental MgO may also be responsible for low level of Ex. Mg found in this study. $P_2O_5$ values ranged between 0.01% and 0.23% and positively correlated with clay content. The result was also supported by Yichu *et al.,* (1984) who reported a similar relationship between phosphorus and clay. According to Lair *et al.,* (2009), phosphorus retention and release was correlated with clay-sized particles. Clay-sized particles represent the soil fraction with the highest and most reactive surface area.

Base on the result of the study, Akure sites (AKR 1 and AKR 2) had peculiar characteristics among the locations. Akure sites were higher than other location in all the soil fertility parameters under investigation and hence affected the overall result. The result from Akure may be as a result of few reasons which include geological fertilization, fertilizer application and vegetation. Akure is located in the southwest of Nigeria with thick forest. According to Issaka *et al.,* (1996), in the equatorial forest zone, base-rich sediments of Tertiary-Quaternary, relating to volcanic activities may account for the presence of soils rich in exchangeable cations, phosphorus, high pH and other fertility parameters found in Akure sites. Further research is intended to ascertain the reason (s) for this variation.

The general low level of soil fertility parameters found in the study areas is due to the high level of weathering. As reported in Table 2, the CIA values of the soils revealed that *sawah* soils in Nigeria fall within intermediated (CIA 60-80) to extreme weathering rate (CIA>80) which may result in high level of leaching. Extreme degree of weathering leads to rapid loss of mobile species such as base cations. The role of climate cannot also be over emphasised. Climate seems to exert a great effect on the availability of organic matter which has a pronounced effect on the amount of TN, TC, avail. P, exchangeable cations and avail. S. High temperature and rainfall of the study area as shown in Table 1 could aid the rapid decomposition of organic matter. High precipitation coupled with the sandy nature of soils could also lead to high rate of leaching of major nutrients especially exchangeable bases.

## CONCLUSION

This study investigated the physico-chemical and geochemical compositions of the soils under *sawah* in Nigeria. This study has provided useful information needed to improve *sawah* rice production thereby increase rice productivity in Nigeria. The study revealed that soils under *sawah* in Nigeria are majorly sandy loam to sandy clay loam. The study also indicated that soils under *sawah* are acidic and lacking basic fertility parameters such as exchangeable bases, TC, TN, avail. S avail. P and avail. $SiO_2$. The result further revealed that total elemental $SiO_2$, $Al_2O_3$ and $Fe_2O_3$ dominated total elements in soils under *sawah* Nigeria. Soils under *Sawah* exhibited intermediated to extreme weathering rate with majority of the soil sampled falling into the category of extreme weathering rate. With extreme degree of weathering, rapid loss of mobile species such as base cations (Ca, Mg, K and Na) from soil is imminent resulting in low fertility status of soils under *sawah*. Leaching of major nutrients due to high sand proportion in the soil, high rainfall and low level of organic matter also contributed to the low fertility status of the soils.

As soil texture cannot be easily influenced by management practices, to ameliorate the trend of depletion in the fertility, combination of conservative agricultural practices which encourage organic matter accumulation and recycling is recommended. Therefore, effective organic matter management is necessary and a key factor in improving the basic cations of these soils. Poor farm management through removal of crop biomass (such as rice straw) by farmers used for feeding livestock and other purposes should be discouraged while encouraging recycling crop biomass with the soil to increase soil organic matter content. Adoption of leguminous crops in rotation with rice especially after harvest of rice is also recommended as this will increase nitrogen through bacteria fixation and reduce the use of nitrogen fertilizers thereby reducing soil acidification process. Due to the importance of silica in rice production, a detail study which will provide a recommended rate of silica towards improving rice production in Nigeria is needed. Also, a study to ascertain the dynamics of nutrient in lowland in Akure site is recommended.

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