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MINERALOGICAL COMPOSITION AND DISTRIBUTION IN SELECTED FLOODPLAIN SOILS OF SOUTHEASTERN NIGERIA: IMPLICATIONS FOR ARABLE CROP PRODUCTION

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Abstract

Floodplain soils are found on low-area of land where flood water periodically spreads when a river or stream overflow its banks. Floodplain soils of Mgbo-Abaja, Obokofia and Mbutu in Southeastern Nigeria formed under alluvium parent material were investigated and characterized in terms of their physical, chemical and mineralogical properties. Six profile pits (> 150 cm depths) were dug, two each in Mgbo-Abaja (Abakaliki), Obokofia (Egbema) and Mbutu (Owerrinta) study sites. The pits were geo-referenced using handheld GPS receiver, described and sampled from genetic horizons. Soil samples collected were air-dried, sieved and analyzed in the laboratory to determine their physico-chemical properties using standard methods, and mineralogical analysis using x-ray diffractometer. Results indicated that pedons were sandy in nature with low contents of organic carbon, pH, basic cations, cation exchange capacity and base saturation. Minerals in soils showed strong peak values at different intensities: Abakaliki site was dominated with quartz, zircon, magnetite and anatase with percentage abundance of 70 %, 7 %, 8 % and 15 % respectively; Egbema site recorded a percentage abundance of 69 % and 31 % for quartz and microcline respectively; and Owerrinta site had 86 %, 12 % and 2 % abundance in quartz, kaolinite and rutile respectively. Quartz minerals contribute to good soil structure, drainage and growing environment for crops. Zircon mineral (Mgbo-Abaja site) releases trace elements like zirconium which support various physiological processes in plants. Magnetite mineral (Mgbo-Abaja site) can be utilized for soil mapping and monitoring purposes, contributing indirectly to efficient soil management practices. Rutile and Anatase (Mbutu and Mgbo-Abaja sites respectively) can influence some soil properties such as water-holding capacity, nutrient retention, soil acidity and alkalinity which affect crop growth. Microcline (Obokofia site) which contains feldspar minerals releases K+ ions and can contribute to soil fertility, supporting crop productivity. Kaolinite (Mbutu site) has high water-holding capacity that aids in retaining moisture for plants during dry periods, but low in CEC and nutrient-holding capacity, which result in reduced nutrient availability for plants.

Keywords: Floodplain soils, mineralogy, genetic horizons, pedons

Introduction

Floodplain soils occupy an area of approximately 65,783 km^2 or 7.3 % landmass of Nigeria with Southeastern region constituting about 22,859 km^2 or 2.56 % (Chukwu *et al*., 2009). They are part of the ecosystems with environmental and agricultural importance for the maintenance of fauna and flora species (Ojanuga *et al*., 2003; Nnabuihe *et al*., 2021a). They are known for their great potentials to improve food production because of their natural fertility, which is as a result of frequent inundation and deposition of nutrient rich sediments from surrounding watersheds (Nnabuihe *et al*., 2022). These deposited sediments contain minerals which play different roles in soil fertility and sustainable crop production (Ojanuga *et al*., 2003; Achimota *et al*., 2021).

The soils of the floodplains also vary in minerals due to the influence of floodwater flow rate, transportation and deposition of sediments with little pedogenesis thereafter. Their high-water table and/or saturated conditions often influence the soil minerals through slow weathering process forming young soils (inceptisols), such that these weatherable minerals still persist in soils after a long period. Characterizing these soils to determine their dominant minerals is appropriate for large scale farming and management, and requires better understanding of these minerals (Nkwopara *et al*., 2016). The knowledge of soil minerals is important especially in nutrient management, weathering rates of materials, age of soils and sediments, mechanism of soil formation and proffering solutions on efficient use and management of the soil. Mineralogical analysis of soils is done using either a single or several analytical techniques. The x-ray diffraction (XRD) method is a vital approach amongst the commonly used methods (Deng *et al*., 2009). Soil types are generally influenced by the mineralogical properties of parent materials. Their chemical compositions determine the nature of their reactions and resultant fertility which also affect the potentials for agriculture and other uses (Shobayo *et al.*, 2019).

The soils of the study sites were formed from coastal plain sands parent material formed under humid tropics, and are highly weathered as a result of high temperature and rainfall (Akamigbo, 2001). The inadequate information on mineralogy of soils of the study sites and the limitations in the traditional analytical techniques necessitated this study. Soil mineralogical studies aside its usefulness in fertility and other physical properties of soils is a functional parameter for soil classification systems such as the USDA soil taxonomy for categorization and classification of different soil types. The objectives of this study were to characterize the floodplain soils of Mgbo-Abaja, Obokofia and Mbutu study sites and determine their dominant minerals.

Materials and Methods

The study sites consisted of the floodplain soils of Mgbo-Abaja in Abakaliki of Ebonyi state (Lat. 06° 20' 63" N and Long. 08° 07' 07" E), Obokofia in Egbema of Imo state (Lat. 05° 32' 25" N and Long. 06° 47' 60" E) and Mbutu in Owerrinta of Abia state (Lat. 05° 18' 30" N and Long. 07° 12' 20" E) (Fig.1). The soils of the area were generally derived from alluvium (Asadu, 1990; Eshett, 1993, Madueke *et al*., 2021a). These geological formations usually give rise to sandy soils (Akamigbo 2001). These soils show strong mottling of gray and red colour due to periodic water logging. The dominance of sandy materials is due to the nature of their alluvial parent materials (Ofomata, 1975; Ogbodo 2011). The study sites belong to the lowland area of southeastern Nigeria (Ofomata, 1975). A greater proportion of the land surface is of flat topography (Onweremadu *et al.*, 2006, Chukwu *et al*., 2009). The area generally occupies a flat to gently undulating plains and lowland of a fairly uniform landform of low relief. The area continuously receives deposits of alluvial materials due to the slope configuration (Ofomata, 1975, Chukwu *et al*., 2009).

The soils of the study sites vary in fertility and support most agricultural crops; it has natural forests having enough nutrient reserves. There is seasonal flooding and deposition of new materials (recent alluvium) on areas closer to the watershed. The hydrology of the area is characterized by series of flowing rivers with tributaries from Imo, Orashi, Eziosu, Ogochie, Owerrinta (Imo and Abia states), Asu and Onu Ebonyi (Ebonyi state) which serve as a source of water for the people (Ofomata, 1975; Ogbodo, 2011). The area is in the humid tropics characterized by two distinct seasons – wet and dry; with high humidity, atmospheric temperature (during dry season) and rainfall (during wet season). The mean annual atmospheric temperature ranges from 28 ^{0}C to 35^{0}C with February and April as the hottest period (Monanu, 1975; Nigeria Meteorological Agency, 2021). Mean annual rainfall range from 2500mm-3000mm (Nigeria Meteorological Agency, 2021). The rainy season usually starts from early March and ends in November and is characterized by clouds driven by light winds from the ocean (Inyang, 1975; Obi and Salako, 1995).

The vegetation stretches from mangrove swamp in the coast through rainforest to derived savanna in the interior, which is that of secondary forests-savannah mosaic, as anthropogenic activities have reduced the density of these forests (Chukwu *et al*., 2009). Some of the economic plants conspicuously growing in the area include: oil palm (*Elaeis guineensis*), raffia palm (*Raphia hokeri*), mango (*Magnifera indica*), Avocado (*Persea americana*), kola (*Kola nitida*), etc. Cultivated crops in the area include maize (*Zea mays*), Rice (*Oryza sativa*), Yam (*Dioscorea spp*), cassava (*Manihot esculenta*), fluted pumpkin (*Telfairia occidentalis*), pumpkin (*cucurbita spp*) amongst others. Socioeconomic activities of the study sites include farming especially food crops like yam, cassava, maize, plantain and vegetables amongst others at both the subsistence and commercial scales. Other activities include fishing, trading, artisan and sand mining.

Sampling methods

Sampling points were geo-referenced using handheld GPS receiver and two profile pits each were dug in Mgbo-Abaja, Obokofia and Mbutu study sites for soil sampling, analysis and description according to the procedure outlined by FAO for profile description (FAO, 2006). After careful delineation of horizon boundaries, samples were collected from the genetic horizons using appropriate labelled black polythene bags. Soil samples were air-dried for one week, crushed and sieved with 2mm mesh sieve, re-bagged, labelled and stored for laboratory analysis.

Laboratory Analyses

Soil samples were analyzed for selected properties: Particle size distribution which was determined using the hydrometer method as modified by (Gee and Or, 2002). Soil pH was determined electrometrically using pH meter and this was done in distilled water and in 0.1 N KCl solution at a soil liquid ratio of 1:2.5 in a glass electrode (Thomas, 1996). Organic carbon was determined by wet digestion method (Nelson and Sommers, 1982). This involved adding 10 ml of 0.1667 $K_2Cr_2O_7$ and 20 ml of conc.H_2SO_4 to weighed out soil sample (5 g) in an Erlenmeyer flask (500 ml) and heated to a temperature of 150 ^{0}C allowing cooling to room temperature. 20 ml of water was added with 4-5 drops of ferroin indicator, titration was done with 0.5 M ferrous sulphate and organic carbon content was calculated thus: Organic C (%) = (meq of $K_2Cr_2O_7$ – meq of $FeSO_4$) x 0.336 /oven-dry soil (g). Cation exchange capacity (CEC) was determined by ammonium acetate (NH_4OAc) of 1.0 M leaching at pH 7.0 (Blackmore *et al*., 1987). Percent base saturation (% BS) was calculated by dividing total exchangeable bases (EBs) by CEC and multiplying by 100,

That is, $(\%\ BS) = \frac{TEB}{CEC} \times \frac{100}{1}$.

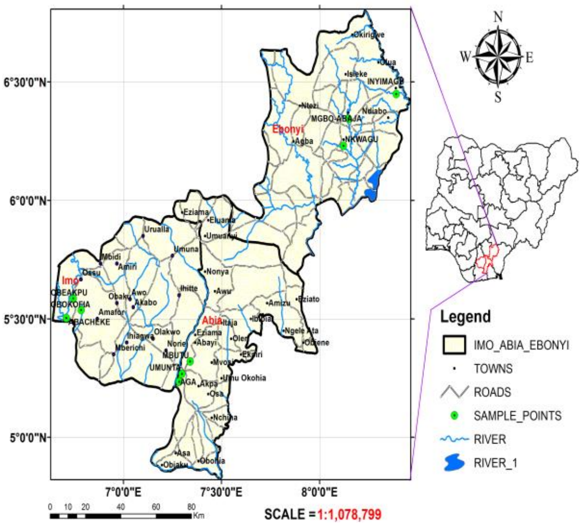

Fig.1: Location map of study sites

Exchangeable bases were extracted with 1N NH_4OAc solution and exchangeable calcium (Ca) and magnesium (Mg) determined using EDTA (Ethylene diamine-tetra acetic acid- 0.01N) complexometric titration. Exchangeable potassium (K) and sodium (Na) was estimated by flame photometry (Jackson, 1962). Mineralogical analysis was carried out using clay fractions of less than two microns (< 2 µm) in size collected from the sub surface horizons of the various profiles. The procedure used was according to the method after Omueti (1980). Samples were prepared by removing exchangeable cations, organic matter, and sesquioxides. Particle size separation was determined by hydrometer method described by Gee and Or (2002). After obtaining the clay fraction, 10 g of the clay fraction was put into a clean test tube with the aid of spatula. Distilled water added to dissolve the samples and subsequently placed inside the centrifuge machine. This was allowed to run at 5 rpm for 5 minutes after which it was removed and the floating material was decanted. Distilled water was added, mixed thoroughly and again placed inside the centrifuge machine and ran the second time maintaining the same time and speed. This process went on for five times to be sure the individual sample went into a clear suspension. After decanting severally, about 3 – 5 drops of 0.6 % Calgon solution was added. At this point, a clear suspension of clay was formed above, while the unwanted settled at the bottom of the test tube. A dropper was used to take some quantity of the suspended clay, saturated with magnesium ions and was applied on a clean labelled glass slide. This was allowed to dry overnight in an oven at 105 ^{0}C, and ready for XRD analysis. The x-ray diffraction (XRD) analysis of the clay sized fraction was carried out to determine the dominant minerals in the soil.

Results and Discussion

Results of the selected physico-chemical properties of soils are presented in Table 1. Sand fraction ranged from 585 g/kg – 745 g/kg with Obokofia having highest value of 745 g/kg. Silt fraction varied from 71 g/kg – 193 g/kg with highest value of 193 g/kg recorded in Mgbo-Abaja, and clay fraction ranges from 180 g/kg to 222 g/kg with highest value of 222 g/kg obtained in Mgbo-Abaja. Textural class ranged from sandy loam (SL) to sandy clay loam (SCL). pH values of soils were 5.89, 5.54 and 5.38 in Mgbo-Abaja, Obokofia and Mbutu respectively. In Mgbo-Abaja, Obokofia and Mbutu, the values of organic carbon were 3.57, 6.74 and 7.81 g/kg respectively.

Table 1: Mean values of selected soil properties of the study sites

Soil property	Mgbo-Abaja (Abakaliki) Lat. 06° 20' 63" and Long. 08° 07' 07"	Obokofia (Egbema) Lat. 05° 32' 25" and Long. 06° 47' 21"	Mbutu (Owerrinta) Lat. 05° 18' 30" and Long. 07° 12' 20"
Sand g/kg	585	745	744
Silt g/kg	193	75	71
Clay g/kg	222	180	185
Texture	SCL	SL	SL
pH (H_2O)	5.89	5.54	5.38
Organic carbon g/kg	3.57	6.74	7.81
CEC (cmol/kg)	11.22	9.25	8.98
Base saturation (%)	26.23	36.99	41.02
Ca (cmol/kg)	1.35	1.93	2.42
Mg (cmol/kg)	0.92	1.18	1.12
K (cmol/kg)	0.20	0.15	0.03
Na (cmol/kg)	0.46	0.15	0.03

Key: SCL = sandy clay loam, SL = sandy loam, pH (H_2O) = pH in water, CEC = cation exchange capacity

Cation exchange capacity (CEC) ranged from 8.98 – 11.22 cmol/kg. The percent base saturation ranged from 26.23 – 41.02 % with highest value of 41.02 % obtained at Mbutu site. In Mbutu and Obokofia, the values of Ex. Ca and Mg were 2.42 cmol/kg and 1.18 cmol/kg respectively, and Ex. K and Na had highest values of 0.20 cmol/kg and 0.40 cmol/kg respectively in Mbutu site. From above results, sand dominated other fractions as soils were generally sandy as a result of their parent material (Akamigbo, 2001; Nnabuihe *et* *al*., 2021a; Madueke *et al*., 2021b; Nnabuihe *et al*., 2022). Soils were slightly to moderately acidic with Mbutu being the most acidic, which could be due to the leaching of basic cations, high-water saturation and slow decomposition of organic materials and as reported by Ogg *et al*. (2017) and Nnabuihe *et al*. (2023). Organic carbon content was generally low (< 15 g/kg) and fell below critical level for tropical soils (Landon, 1991). Cation exchange capacity (CEC) values of soils were low (6 - 12 cmol/kg) (FDALR, 1990), as result of inherent clay minerals and parent materials (Akamigbo, 2001). Base saturation of pedons was rated low to moderate since they ranged from 20 - 60 % (FDALR. 1990). These values are indicative of low nutrient reserve of these soils due to low activity clays (Akamigbo, 2001; Obi. 2003). Exchangeable Ca^{2+} dominated the exchange site, but was below critical limit of 4 cmol/kg (Kyuma *et al*., 1986); Mg^{2+} (0.92 – 1.18 cmol/kg) and K^{+1} (0.03 – 0.20 cmol/kg) were rated low (Enwezor *et al*., 1989), and Na^{+} (0.03 – 0.46 cmol/kg) was low to moderate (Kyuma *et al*., 1986).

The x-ray diffractograms (XRD) of clay fractions of the soils of Mgbo-Abaja, Obokofia and Mbutu are shown in Figures 2, 3 and 4 respectively, and the pie-charts inside each of the diagram showed the percentage abundance of minerals in the clay size fractions. X-ray diffractograms (XRD) of clay fraction in Mgbo-Abaja (Fig. 2) revealed that four major minerals (quartz, zircon, magnetite and anatase) dominated the mineralogy of the soils. This result was confirmed by the various peaks against corresponding 2 Theta (2θ) Braggs angles, which indicated that quartz had 75 % dominance and ranged from 21 ° 2θ to 65 ° 2θ with strong peak recorded at 27 ° 2θ at 100 % intensity. Zircon had 15 % abundance with peak at 69 ° 2θ, magnetite was 8 % with a reflection peak of 36 ° 2θ while anatase abundance was 7 % at a peak of 26 ° 2θ.

In Obokofia site (Fig. 3), the two major minerals that dominated the clay fraction of soils were quartz and microcline. The result was confirmed by the corresponding peaks against 2 Theta (θ) Braggs angles as quartz had the strongest peak for percentage abundance of 69 % at 27 ° 2θ, while microcline had a reflection peak of 28 ° 2θ for 31 % abundance. Mbutu soils (Fig. 4) had three major minerals namely: quartz, kaolinite and rutile present at 86 %, 12 % and 2 % abundance respectively. The result showed strong peak of quartz at 27 ° 2θ, while kaolinite and rutile had weak peaks at 35 ° 2θ and 28 ° 2θ respectively. From the above XRD results, quartz (SiO_2) being a common silicate mineral (tectosilicate) was more abundant or had high concentration (over 60 % composition/abundance) than the other minerals, and the most resistant to weathering. It provides stability to soil aggregates, improving soil structure and water infiltration (Hurlbut and Klein, 1993, Heaney, 1994). Proper soil structure is essential for providing a favourable growing environment for crops. Quartz has low pH and CEC, which are the promoters of fertility status of soils. Their presence and persistence in the clay-sized minerals is due to their resistance to both physical and chemical weathering (Deer *et al*., 2013). Zircon ($ZrSiO_4$) belongs to the group of minerals called nesosilicates, highly resistant to weathering, commonly found in igneous and metamorphic rocks. It contains trace elements like zirconium, hafnium, and thorium which can have positive effects on plant growth when released slowly over time (Hanchar and Hoskin, 2003, Corfu and Andersen, 2010).

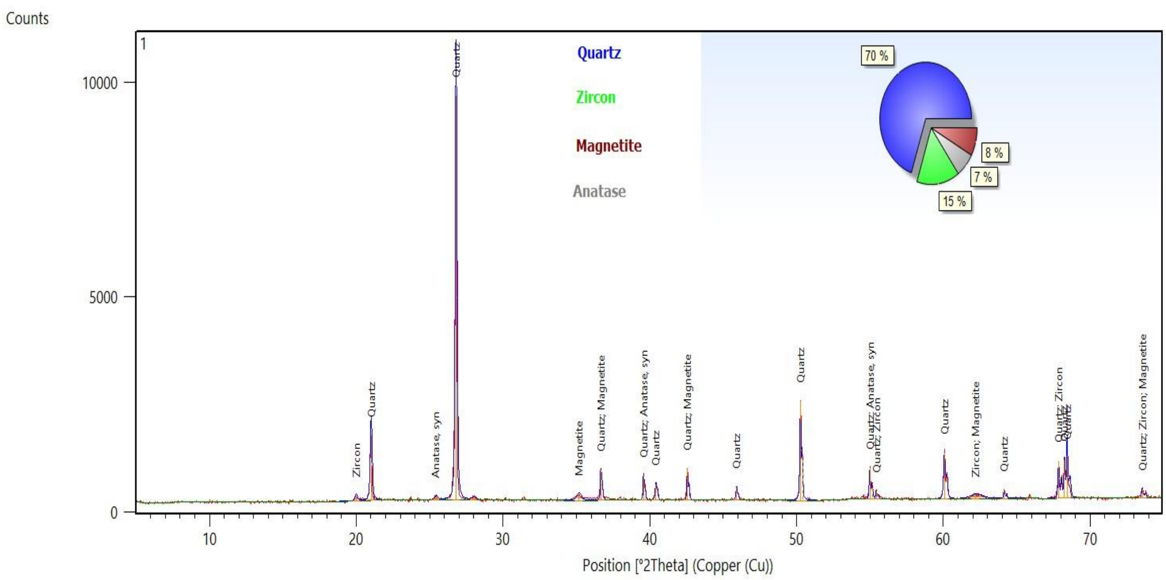

Fig. 2 X-ray diffractograms measurement for soils of Mgbo-Abaja study site

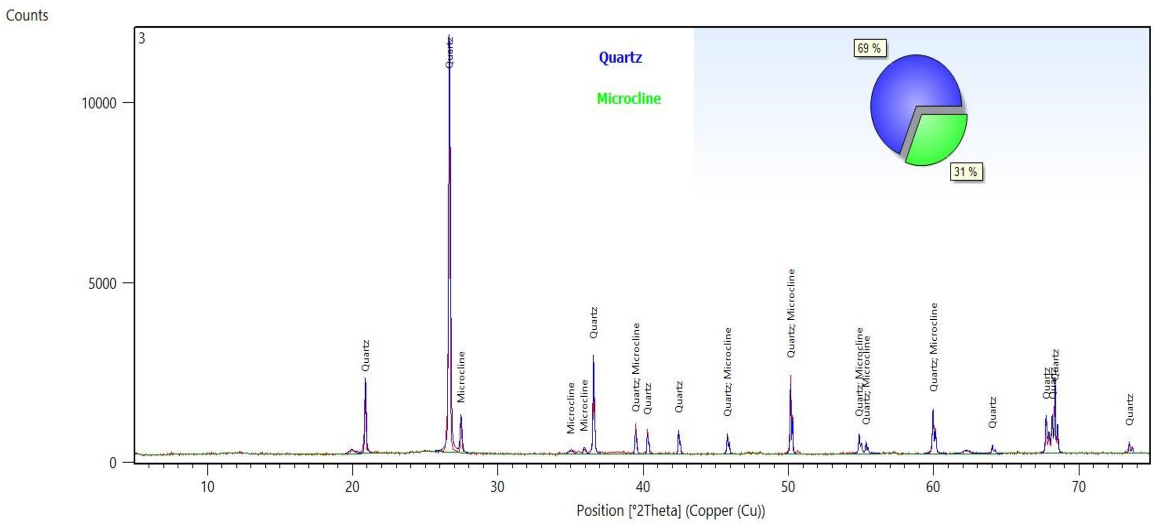

Fig. 3 X-ray diffractograms measurement for soils of Obokofia study site

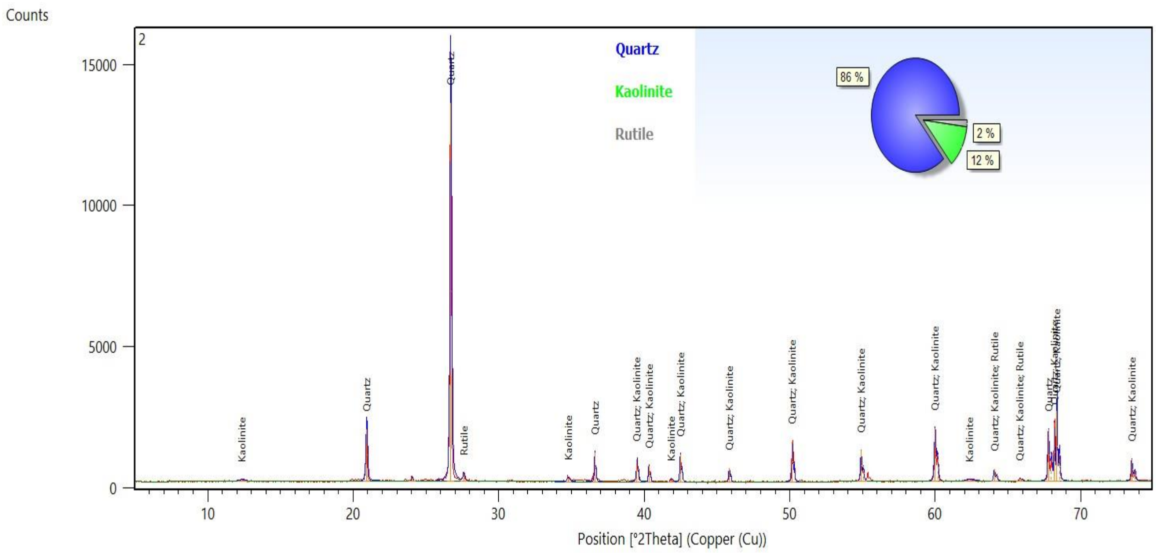

Fig. 4 X-ray diffractograms measurement for soils of Mbutu study site

These trace elements may act as micronutrients and support various physiological processes in plants. However, the availability of these elements depends on several factors such as soil pH and organic matter content (Hoskin and Schaltegger, 2003). Magnetite (Fe_2O_4 or Fe_3O_4) is an iron oxide mineral (Spinel group), moderately resistant to weathering, contains manganese iron oxide ($MnFe_2O_4$), forms secondary minerals due to oxidation processes and their presence in soils also indicated low degree of weathering (Cornell and Schwertmann, 2003). It has minimal direct implications for crop production but its magnetic properties can be utilized for soil mapping and monitoring purposes, which indirectly contributes to efficient soil management practices (Rosenblum and Krinsley, 2008). Rutile is an oxide mineral (Rutile group) composed of titanium dioxide (TiO_2), chemically stable and can withstand the effects of weathering, although it may be susceptible to some alteration over extended periods (Gutzmer and Beukes, 1996). It has limited direct implications for crop production (nutrient cycling or fertility), but contribute to the overall mineral composition and physical properties of the soil (Ribbe, 2010). Anatase is a type of oxide mineral (Rutile group) belonging to the titanium dioxide (TiO_2) group (Frost and Kloprogge, 2000). It is less resistant to weathering compared to quartz, zircon, magnetite, and rutile. It occurs practically undecomposed in the soil due to chemical transformations, formation of secondary minerals and alteration products. Anatase minerals play a crucial role in soil fertility and plant nutrition, including CEC, water holding capacity, and nutrient retention. They can also influence soil pH and contribute to soil acidity or alkalinity (Drits and Tchoubar, 2007). It has low mobility under good environmental conditions, mainly due to the high stability of the insoluble rutile (TiO_2), thus considered to be directly derived from the parent material (Brookins, 1988, Nkwopara *et al*., 2016, Shobayo *et al*., 2019).

Microcline ($KAlSi_3O_8$) is a silicate mineral (feldspar group) relatively susceptible to weathering compared to the minerals mentioned above (Deer *et al.*, 2013). It can be altered by chemical weathering processes, leading to the formation of clay minerals or other secondary products. Microcline like rutile have limited direct implication for crop production. Their presence in soils influence factors such as structure, drainage, and nutrient retention (Grew *et al*., 2013). Microcline clay minerals are important constituent of many igneous rock (forming tectosilicate mineral) and are found in metamorphic and sedimentary rocks. It is rich in K alkali type of feldspar and less in Na. Microclines clay minerals in Obokofia site showed that the soil still has considerable amounts of weatherable minerals although feldspar is highly resistant to weathering and is the third after quartz and sixth on the Mohs scale (Juo and Franzluebber, 2003). The abundance of microclines could be due to recent alluvium or deposition of materials which is undergoing less pedogenesis and formation of young soils (inceptisols) in this site. Kaolinite [$AlSi_2O_5(OH)_4$] is a phyllosilicate mineral (clay mineral group) that is highly susceptible to weathering. It is one of the most widespread clay minerals in tropical soils and its formed from the chemical weathering (alteration) of feldspars or other aluminium silicate minerals and also is an important component in many tropical soils (Nkwopara *et al*., 2016; Shobayo *et al*., 2019). The abundance of kaolinite in soils indicates low pH, low activity clay, infertile or old soils which was further explained by preponderance of high sand particles recorded in the study sites.

Conclusion

The soil minerals in the study sites showed that there were variations as reflected in their X-ray diffractograms. Mineralogical properties of these soils indicate mixed mineralogy, quartz has no direct implications on arable crop production in terms of fertility or nutrient availability, but contribute to good structure, drainage and growing environment for crops. Zircon (Abakaliki site) release trace elements like zirconium, hafnium, and thorium which may act as micronutrients and support various physiological processes in plants. Magnetite (Mgbo-Abaja site) has minimal direct implication in crop production, but can be utilized for soil mapping and monitoring purposes, contributing indirectly to efficient soil management practices. Rutile and Anatase (Mgbo-Abaja and Mbutu sites respectively) do not have direct implications for crop production, but can influence some soil properties such as water-holding capacity, nutrient retention, soil acidity and alkalinity, requiring appropriate soil amendments to maintain optimal pH levels for crop growth. Microcline (Obokofia site) does not have direct implications for crop production in terms of nutrient availability, but contains feldspar minerals that weather and release essential elements such as potassium, which is important for plant growth. The weathering of microcline and the release of K can contribute to soil fertility, supporting crop productivity. Kaolinite (Mbutu site) have both positive and negative implications for crop production, it has high water-holding capacity, which can aid in retaining moisture for plants during dry periods, and also has low CEC and nutrient-holding capacity, which result in reduced nutrient availability for plants.

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