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CRYSTALLINE AND AMORPHOUS FORMS OF IRON (Fe) OXIDES IN HYDROMORPHIC SOILS OF DADIN KOWA, GOMBE STATE, NIGERIA

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ABSTRACT

The content and distribution of different forms of Iron oxides are important indicators used in describing soils. This study was conducted with the aim of evaluating the crystalline and the amorphous forms of Iron oxides distribution in hydromorphic soils across five different land uses (amaranth, millet, mango, rice and tomato) at Dadin Kowa, Gombe State. Two soil profile pits were dug in each of the identified land uses, and soil samples collected from identified genetic horizons. All soil samples collected were analyzed using standard laboratory procedures. The textural classes of the soils revealed loamy sand to sandy loam. Bulk density, particle density, total porosity and silt/clay ratio varied between 1.60 to1.67 g/cm^3, 2.57 to 2.71 g/cm^3, 35.82 to 40.41% and 0.92 to 1.86, respectively. The soil reaction was slightly acidic to neutral (pH 6.39 – 6.68). Soil electrical conductivity (EC) for all the soil mapping units was below the critical limits of 4 d/Sm EC, an indication of the non-saline nature of the studied soils. The values for OC, TN and AP contents of the soils across land use and horizons was substantial > 10 g/kg, and is rated medium to high, 1.1 to 1.40 g/kg, rated low to medium and 8.03 to 9.35 mg/kg, rated low, respectively, while the exchangeable bases were generally rated medium to high. The mean distribution of forms of Fe oxides, extracted by different extracting reagents revealed the dominance of diotonite extractable iron (Fed) over oxalate extractable iron (Feox) and pyrophosphate extractable iron (Fep), while the active iron ratios was generally <0.4 but > 0.1, confirming a moderate stage of soil development, and the dominance of crystalline forms of Fe oxide as against the amorphous forms across the study area. The direction of soil development with age followed the trend; amaranth < mango < millet < tomato <rice.

Keywords: Active iron ratio, Amorphous, Crystalline, Hydromorphic, Iron

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INTRODUCTION

Content and distribution of the different forms of iron oxides in soils are important indicators used in describing soils, not just the direction, but also the intensity of weathering or soil development. A larger proportion of irons in soils exist as oxides. These oxides are found as iron concretions as well as coatings on the soil minerals or bind the different soil particles (Akinbola *et al.*, 2013). Particle size with free iron oxides has been exclusively studied at both small and large scales (Agbenin, 2003). Their distribution and amount in the soil are known to influence some soil properties such as anion adsorption, surface charges, specific surface area, nutrient transformation, swelling and aggregate formation and pollutant retention in soils (Enya *et al.*, 2011). Percentages of free iron have long been used as aids in distinguishing soil types, differentiating soil horizons and determining soil age or degree of soil development (Akinbola *et al.*, 2013).

According to Walker (1983), the origin of free iron oxides in soils is free iron released during weathering of rocks. The released free irons are subsequently precipitated as crystalline and amorphous forms of iron oxides. Ogunkunle and Onasanya (1992) indicated that the crystalline form of iron and aluminum oxides are the dominant oxy-hydroxides in the basement complex soils of western Nigeria. The predominance of the crystalline forms of sesquioxides represents a more advanced stage of soil development than the presence of amorphous forms that is mobile in the soil and could be associated with organic matter (Ogunkunle and Onasanya, 1992). Ojanuga (1985) also reported that the crystalline forms of Fe were goethite and hematite and occur either singly or in association within the hard nodules and concretions in the soil environment. The level of the crystalline form of Fe can thus serve as an estimate of the degree of soil development and formation of hard nodules and concretions. Obi *et al.* (2009) concluded that the dominance of higher proportion of the crystalline form of Fe will lead to structural distortions with implication for anion retention which affects the surface area and leads to hardness of the soil. Higher crystalline Fe content will affect both the physical and chemical properties of soils as well as their management and land use. This study is important because the study area covers a large expanse of irrigable land in Gombe State. Therefore, this research was conducted with the aim of evaluating the disposition of both crystalline and amorphous forms of iron oxides in hydromorphic soils of Dadin Kowa, Gombe State, Nigeria.

MATERIALS AND METHODS

The Study Area

The study area is at Dadin Kowa in Yamaltu Deba Local Government Area of Gombe State. It is located between latitudes, 10° 29' 00" N and latitude 10° 30' 12" E and longitude 11° 50' 35" N and latitude 11° 53' 07" E, within the Northern Guinea Savannah ecological zone of the country (Klinkenberg and Higgins, 1968). It lies at an elevation ranging from 184-351m above sea level (Ikusemoran *et al.*, 2016), situated about 40 km along Gombe – Biu road in the Northern Guinea Savanna Zone of Nigeria. According to Ikusemoran *et al.*, (2018), the geological succession of the Dadin Kowa area, is underlain by the upper cretaceous rocks of marine sediments. The sediments are predominantly argillaceous and consist of alternating shale and limestone with sandy mudstones, siltstones and sandstones respectively (Ikusemoran *et al.*, 2018). The remnants of these included materials form the major components of the resultant soils. These inclusions are either decreased or increased with depths or are uniformly distributed. The climate of the area is that of the semi-arid type characterized by wide seasonal and diurnal temperature ranges with two main seasons: rainy season (April-October) and dry season (November to March) (Abubakar, 2013). Average annual rainfall is put at about 1000 mm, with the greater part falling between July and October (UBRDA, 2018). April is usually the hottest month (maximum temperature being 39°C) while December and January have the lowest temperature, averaging 16°C (UBRDA, 2018).

Field Methods

Five (5) extensively cultivated farms/

orchards were identified and mapped as soil mapping units; they are tomato (TMT), amaranth (AMR), mango (MNG), millet (MLT) and rice (RCE). To achieve the objectives of the study, two soil profile pits were dug on each of the 5 mapping units identified, and soil samples from each recognizable pedogenic horizon from each of the dug profile pits were collected, stored, and tagged in polythene bags for laboratory analysis.

Laboratory Analysis

Particle-size fractions were determined using the Bouyoucos hydrometer method (Gee and Bauder, 1986). Soil pH was determined in 1:2 water ratio using a glass electrode pH metre (Page *et al.*, 1982). Determination of Organic carbon, and Total nitrogen were done by the wet oxidation method and regular micro-kjeldal method respectively. Available phosphorus was determined using the Bray 1 method. Extraction of DCB extractable Fe (Fed) was carried out according to the procedure of Mehra and Jacson (1960) while the oxalate extractable iron (Feox) were extracted with Oxalic acid according to the procedure of Mckeague (1966).

Data Analysis

The data obtained from the study were subjected to descriptive statistics to assess the soil properties. Mean differences in properties between soils developed across different land use systems (LUS) and between horizons were analyzed using two-way analysis of variance (ANOVA).

RESULTS AND DISCUSSION

Physical Properties

The total mean sand content across LUS and depths ranged from 73.38-84.8%, and is the predominant soil particle (Table 1). This observation of sand fraction predominance in this study is consistent with the findings of Askira *et al.* (2019). Onweremadu *et al.* (2011) attributed the high sand content to the nature of parent material. The highly significant ($p<0.01$) variation in mean sand distribution across land use could be related to the secondary products of weathering (Brady and Weil, 2013).

The significantly ($p<0.01$) higher variation in mean sand fraction in the surface soil over the subsurface soil might be attributed to pedogenic processes such as lessivage, eluviations and illuviation (Ojetade *et al.*, 2014). Silt particle mean values ranged from 7.8-14.04% across the different LUS and depths (Table 1). A notable feature in all the soils studied is their high silt content. Nsor and Uhie (2016) and Askira *et al.* (2019) reported higher silt content in their various studies. The high silt content obtained in this study could be attributed to the nature of parent material and stage of soil development (Maniyunda, 1999). There was a highly significant ($p<0.001$) difference in silt content between the different land uses. The high mean content of silt recorded in soils under rice, tomato and amaranth, could be attributed to the received fine colluvial and alluvial sediments from the upper slope positions through erosion and deposition (Maniyunda and Gwari, 2014). There was no significant ($P>0.05$) variation in mean silt content with depth. Clay mean content ranged from 6.58-9.91% across LUS and depths. The result for particle size distribution showed that percentage clay content was lowest when compared to sand and silt, in all the studied soils. Such low values of clay content as obtained in this study, agrees with the findings of Akintoye *et al.* (2012) and Akpan *et al.* (2017), from similar soils. The value of mean clay content differed significantly ($p<0.05$) across

Table 1: Physical properties of soils across the different land uses and horizons

	Sand (%)	Silt (%)	Clay (%)	Soil Texture	BD (g/cm^3)	PD (g/cm^3)	TP (g/cm^3)	Silt/ Clay (%)
Land Uses								
Amaranth	77.36^{bc}	14.00^{a}	8.64^{ab}	Sandy loam	1.61^{b}	2.71^{a}	40.41^{a}	1.66^{a}
Millet	83.12^{ab}	7.80^{b}	9.07^{a}	Loamy sand	1.61^{b}	2.57^{ab}	37.14^{ab}	0.92^{b}
Mango	84.80^{a}	8.62^{b}	6.58^{c}	Loamy sand	1.67^{a}	2.64^{a}	36.76^{ab}	1.45^{a}
Rice	73.38^{c}	16.70^{a}	9.91^{a}	Sandy loam	1.60^{b}	2.48^{b}	35.82^{b}	1.68^{a}
Tomato	78.36^{bc}	14.04^{a}	7.60^{ab}	Loamy sand	1.63^{b}	2.66^{a}	38.70^{ab}	1.86^{a}
LSD ($p<0.05$)	5.23	4.07	1.95		0.04	0.12	2.72	0.46
LOS	**	***	*		*	*	*	**
Soil Horizon								
Surface	81.78^{a}	11.04	7.18^{b}	Loamy sand	1.64^{a}	2.61	37.03	1.54
Subsurface	77.03^{b}	13.42	9.54^{a}	Sandy loam	1.60^{b}	2.61	38.50	1.49
LSD ($p<0.05$)	3.31	2.57	1.23		0.02	0.08	1.72	0.29
LOS	**	NS	***		**	NS	NS	NS

LOS (Level of significant) (p): NS (Not Significant) > 0.05, * < 0.05, ** < 0.01, *** < 0.001, BD= bulk density, PD= particle density, TP= total porosity
Note: Means followed by the same letters in the column are not significantly different at 5% LOS

the different land uses (Table 1). The significant variation in clay distribution obtained could be related to the pedogenic processes such as lessivage, eluviations and illuviation (Ojetade *et al.*, 2014).

There was a highly significant ($p<0.001$) difference in mean clay content between the horizons, which increased with increasing depth. This trend was in conformity with earlier reports of Ojetade *et al.* (2014) and Fekadu, *et al.* (2018), Brady and Weil (2013) attributed the increase in clay content with depth, to the fact that some of the clay particles in the top soil may have been removed by run-offs, and some still move downwards through other processes such as illuviation or a combination of both processes while Yitbarek *et al.* (2016) and Kebede *et al.* (2017) noted that higher clay content in the B horizon of soils is as a result of predominant in situ pedogenetic formation of clay in the subsoil, and destruction of clay in the surface horizon. Soil texture across mapping units revealed occurrence of loamy sand and sandy loam particles, which corroborated earlier report by Salem *et al.* (2017). Soil texture is an important soil physical property which affects water holding capacity, nutrient retention capacity, organic matter content and soil aeration (Kefas *et al.*, 2016). Several researches have linked soil texture to the nature of parent materials from which the soils were derived and also to the rate and nature of some weathering processes (Ahukaemere *et al.*, 2012). The mean data in bulk density (BD) values across the different land use systems (LUS) and depths ranged from 1.60-1.67 g/cm^3. The values for bulk density obtained in this study are within the range reported in earlier studies by Ande *et al.* (2016) with values of 1.11 to 1.98 g/cm^3 from floodplain soils in Southern Guinea Savanna of North Central Nigeria. There was an observed significant variation ($p<0.05$) in mean bulk density values, between the land uses (Table 1). The highest value for BD recorded for soils under mango cultivation could be attributed to high intensity of livestock grazing (Raji *et al.*, 1996). There was also a highly significant variation ($p<0.01$) across soil depths, with the surface horizons having a higher value. Findings by Zata *et al.* (2010) following a detailed soil survey and characterization of some Usterts in Northeastern Nigeria, also corroborate this finding. The relatively high mean values of the bulk density on the surface horizon could be attributed to compaction due to high intensity of livestock grazing (Raji *et al.*, 1996). The mean BD values obtained in these studies are considered to be generally safe for plants' root penetration as this might be hindered in soils having a bulk density value >1.75 g/cm^3 (Ashenafi *et al.*, 2010). Donahue *et al.* (1990) pointed out that plant growth is best at soil bulk densities below 1.40 g/cm^3 for Clay, and 1.60 g/cm^3 for Sandy soils. Results (Table 1) show that mean particle density (PD) values ranged from 2.57 -2.71 g/cm^3 indicating that quartz, feldspar, micas and the colloidal silicates with densities between 2.60- 2.75 g/cm^3 forms the major portion of minerals in the study area (Brady and Weil, 2013). The mean value of PD differed significantly ($p<0.05$) across the different land uses, while there was no significant ($p>0.05$) difference in mean particle density with depth. Generally, the values of particle density recorded in this study (< 2.75 g/cm^3) were considered satisfactory (Kachinskii, 1965) for plant growth. The mean value for Total Porosity (TP) values of the studied soils across land uses and depths ranged from 35.82 to 40.41%, indicating that the values recorded are low. Similar low porosity values were reported by Ogban and Utin (2015) and Akpan *et al.* (2017) for some soils while working on wetland and coastal plain soils, respectively, in Calabar, Cross River State, Nigeria. Therefore, porosity is a limiting factor in the present study (Kachinskii, 1965). There was a significant ($p<0.05$) variation in mean porosity values with respect to land use. The significantly ($p<0.05$) higher mean porosity value recorded for the Amaranth land use may be attributed to loosening of soil materials by plant roots and during cultivation of the soil (Ahukaemere and Akpan, 2012). Brady and Weil (2008) stated that optimum total pore space value for crop production is >50%. The subsurface horizon (38.50%) is not significantly ($p>0.05$) different from the surface horizon (37.03%). Incorporation of organic manure to the soils will decrease the soil bulk density and ultimately increase the percentage pore distribution, thereby enhancing the soil physical condition for optimum crop production and food security (Hassan and Shuaibu, 2006). The mean range in values for silt to clay ratio across LUS and depths ranged from 0.92-1.86 in the studied soils. The silt/clay ratio (SCR) is an index for extent of weathering as noted by Olehge and Chokor, (2014). "Old" parent materials usually have a silt/clay ratio below 0.15 while silt/clay ratios above 0.15 are indicative of "young" parent materials (Van Wambeke, 1962). Results in this study show that, all the soils have silt/clay ratio above 0.15 indicating that the soils are relatively young with high weathering potential, which is similar to reports by Ajiboye *et al.* (2015) and Osujieke, *et al.* (2017). There was a highly significant ($p<0.01$) variation in mean silt/clay ratios across land uses. The land under millet cultivation recorded the lowest value of 0.92, which is an indication that the soil is older, compared to other land uses. There was no significant ($p>0.05$) variation in mean Silt/clay ratio across soil depths.

Chemical properties

Generally, soil pH is a major driver of soil fertility (Brady and Weil, 2013). The mean soil pH values determined in water [pH (H_2O)] across land uses and horizons ranged from 6.39 to 6.68 (Table 2) which is rated as slightly acidic to neutral in reaction (Malgwi, 2007). The low pH values recorded in this study are similar to those earlier reported (Abagyeh *et al.*, 2017; Okoli *et al.*, 2017; Fekadu *et al.*, 2018). The acidic condition of the soils under study could be attributable to higher leaching process (Brady and Weil, 2013). There was no observed significant ($p>0.05$) variation in mean pH values across the different land uses. However, there was an observed significant ($p<0.05$) variation in mean pH values across depth. The increased pH values with soil depth might be due to less H^+ ions released from low organic matter (OM) decomposition, which is due to decreased OM content with depth (Abay and Sheleme, 2012). However, Akpan *et al.* (2017) attributed this finding to excessive leaching of basic cations from the surface to the subsurface horizons (Table 2). The electrical conductivity (EC) of a soil solution is a good indicator of the degree of salinity of the soil (Brady and Weil, 2013). The mean EC values across LUS and depths ranged from EC 0.12 -0.22 d/sm, which were found to be below the critical limits of 4 d/sm to be described saline soils (FAO, 1993).

Table 1: Physical properties of soils across the different land uses and horizons

	pH (1:2)	EC (d/sm)	OC (g/kg)	TN (g/kg)	AP (mg/kg)	Ca (cmol/kg)	Mg (cmol/kg)	Na (cmol/kg)	K (cmol/kg)
Land Uses									
Amaranth	6.68	0.22[a]	16.02[a]	1.4[a]	9.35[a]	2.79	1.40	0.55[a]	0.52
Millet	6.39	0.12[b]	12.25[b]	1.1[b]	8.86[ab]	2.54	1.23	0.52[a]	0.53
Mango	6.47	0.20[a]	12.57[b]	1.1[b]	8.36[bc]	2.81	1.38	0.49[a]	0.49
Rice	6.53	0.15[ab]	15.20[ab]	1.3[ab]	8.03[c]	3.30	1.71	0.29[b]	0.51
Tomato	6.64	0.18[ab]	13.55[ab]	1.2[ab]	8.43[bc]	2.84	1.31	0.55[a]	0.50
LSD (p<0.05)	0.22	0.05	0.24	0.02	0.50	1.21	0.73	0.14	0.03
LOS	NS	*	*	*	***	NS	NS	**	NS
Soil Horizon									
Surface	6.47[b]	0.16	15.01[a]	1.3[a]	9.03[a]	2.41[b]	1.14[b]	0.50	0.52[a]
Subsurface	6.61[a]	0.19	12.83[b]	1.1[b]	8.19[b]	3.31[a]	1.67[a]	0.47	0.50[b]
LSD (p<0.05)	0.14	0.03	0.15	0.01	0.32	0.77	0.46	0.09	0.02
LOS	*	NS	**	**	***	*	*	NS	*

LOS (Level of significant) (p): NS (Not Significant) > 0.05, * < 0.05, ** < 0.01, *** < 0.001, EC=electrical conductivity, OC=organic carbon, TN=total nitrogen, AP=available phosphorus, Ca=calcium, Mg=magnesium, Na=sodium, K=potassium
Note: Means followed by the same letters in the column are not significantly different at 5% LOS

The entire soil mapping units recorded low EC values which are an indication of the non-saline nature of the studied soils (Malgwi, 2007). Such low EC values obtained in this study is in line with the earlier findings by Egwu *et al.* (2018) and Imadojemu *et al.* (2018). The low electrical conductivity (EC) values recorded in the study area might be attributed to the sandy nature of the parent materials (Imadojemu *et al.*, 2018). The EC mean values recorded for the studied soils indicated that soils under amaranth and mango cultivation had significantly ($p<0.05$) higher values compared to the other land uses. However, there was no significant ($p>0.05$) variation between the soil horizons. The mean organic carbon (OC) content across LUS and soil horizons ranged from 12.25-16.02 g/kg (Table 2). The mean values of the OC content of soils across land use and horizons is substantial (> 10g/kg) and is rated medium to high (Malgwi, 2007). This finding is contrary to earlier report of low OC content for soils in the Savanna zones of Nigeria (Salem, *et al.*, 2018). Soils under amaranth cultivation, in comparisons to others was observed to be statistically ($p<0.05$) higher in mean OC content. The high content of organic matter in the soil mapping unit of amaranth may be attributed to short growing season and regular addition of farm yard manure which causes a relative accumulation of organic matter, reduced microbial activities and less frequent and less severe translocation of mineralized products at the start of the rains (Esu, 1982). The organic carbon content of soils obtained across horizons was highly ($p<0.01$) different indicating a consistent decrease with increased soil depth. This trend corroborates earlier findings of (Abagyeh *et al.* (2017) and Fekadu *et al.* (2018). The decrease in OC content with soil depth may be attributed to immobilization of organic matter by the clay in the surface horizons in forms of organo-clay-complexes (Shobayo, 2010). The mean total nitrogen values for the studied soils, across the various land uses and horizons ranged from 1.1 to 1.4 g/kg (Table 2) and are rated low to medium in accordance with Malgwi (2007). Similar values have been reported for soils in the Northern Guinea Savanna Zone of Nigeria (Egwu *et al.*, 2018). Also, low total nitrogen (TN) in soils has been reported by Salem *et al.* (2017). The low to medium level of TN obtained in this study could be attributed to its' mobile nature in soils. As a result its losses through various mechanism like ammonia volatilization, succeeding denitrification, chemical and microbial fixation, leaching and runoffs, all result in low residual/available N in soils (Awanish *et al.*, 2014 and Akpan *et al.*, 2017). Soils under amaranth cultivation was significantly ($p<0.05$) higher in mean TN content compared to other land uses and this may be related to the higher level of OC in the land use system. Lawal *et al.* (2012) had reported that organic matter content accounts for between 90 and 98 % of soil nitrogen. There was also a significant ($p<0.01$) higher TN at the surface than the subsurface horizons. Such finding was similar to earlier reports of Abagyeh *et al.* (2017), Okoli *et al.* (2017) and Fekadu *et al.* (2018). The higher TN recorded in the surface soil of the floodplain may be related to the relatively higher organic carbon content on the surface in the studied soils. The mean available phosphorus (AP) content of the soils across land uses and profile depths, ranged from 8.03 to 9.35 mg/kg and was substantially found to be low (Malgwi, 2007). Such low AP values were earlier reported by Osujieke *et al.*, (2017) and could be due to fixation, as a result of the acidic condition of the soils under study (Fekadu *et al.*, 2018). The mean value of AP recorded for the soil under amaranth cultivation was highly significantly higher ($p<0.001$) than under millet, mango, rice and tomato cultivations. The higher AP values recorded for the soil under amaranth cultivation could be attributed to addition of phosphorous containing fertilizers to boost crop yields and high organic matter that subsequently accrue to the soil (Sai Kumar *et al.*, 2013). The exchangeable bases in the soils occurred in the order Ca>Mg>Na>K (Table 2), which is in line with earlier reports for soils under irrigation (Esu, 1982). The mean values of calcium (Ca) across the different sampling units and depth ranged from 2.41 to 3.31 cmol (+)/kg and is rated medium to high according to Malgwi, (2007) rating scale. This rating may be attributed to the inherent Ca content of the soil dictated by the parent material (Havlin *et al.*, 1999). Even though, there was no significant ($p>0.05$) difference in mean Ca content between the different land uses, the subsurface horizon recorded a significantly ($p<0.05$) higher value than the surface horizon; this result was similar to the earlier findings of Shobayo (2010). Fekadu, *et al.* (2018) attributed the accumulation of Ca with soil depth to leaching and might also be attributed to mining of Ca by plants from the rooting zone. Magnesium (Mg) is the second most dominant extractable cation on the exchange complex of the studied profiles. The mean values of exchangeable Mg content in the soils across the various sampling units and depth ranged from 1.14 to 1.71 cmol (+)/kg soil, and was rated medium to high (Malgwi, 2007). Ogbodo, (2011), also encountered high Mg soil content in his assessment of some soil fertility characteristics of Abakaliki Urban Floodplains in South-Eastern Nigeria. The seeming medium to high value of Mg content could be related to the calcareous nature of the parent material (Havlin *et al.*, 1999). The soils in the study area showed no significant ($p>0.05$) difference in Mg content across the different land uses. However, the subsurface horizon was significantly ($p<0.05$) higher in mean Mg content, which might be due to higher leaching losses from this horizon (Brady and Weil, 2013). The mean values for exchangeable sodium (Na) in the soils ranged from 0.29 to 0.55 cmol (+)/kg soil and were substantially rated high as per rating scale by Malgwi (2007). Similar values had earlier been reported by Ogbodo (2011) who also, attributed this high value to deposition of salts on the soil as the flood water receded, leaving salt crusts and crystals upon evaporation. Babalola *et al.* (2011) however, attributed it to the nature of parent material (colluvia and alluvia) and use of low quality water for irrigation. Soils under rice cultivation recorded a highly significantly ($p<0.01$) lower Na content which could be attributed to higher leaching losses. However, there was no significant ($p>0.05$) variation in mean sodium content across the soil depth. The mean exchangeable potassium (K) values between sampling units and soil horizons ranged from 0.49 to 0.53 cmol (+)/kg and were rated high (Malgwi, 2007). Salem, *et al.* (2018) also reported high K values while assessing variations in the soil exchangeable bases along toposequences, in Gombe State, Nigeria. There was no observed significant ($p>0.05$) difference in mean K content between the various land uses. However, the surface horizon recorded a significantly ($p<0.05$) higher mean K content across depth which was similar to the findings of Adisa *et al.* (2016), and attributed to more intense weathering, release of labile K from organic residue and application of chemical fertilizers containing K (Sai Kumar *et al.*, 2013).

Pedogenic forms of Iron (Fe) oxides

The values of the amorphous form of iron oxide (Feox) across land uses and horizons ranged from 2.07 to 3.82 g/kg (Table 3). These values were higher than those reported by Maniyunda and Raji, (2017), even though they are generally regarded as low. Osayande *et al.* (2016) attributed low values of Feox in soils to less weathered soils as the parent materials contain very high weatherable minerals. It is also observed in this study that, both land use and soil depth did not significantly (p>0.05) influence the variability of the mean Feox distribution (Table 3). Osodeke *et al.* (2005) also reported similar observation while assessing the Sesquioxides distribution along a toposequence in Umudike area of Southeastern Nigeria. However, the crystalline form of iron oxide (Fed) mean content for the studied soils across land uses and horizons ranged from 10.25 to 13.98 g/kg, which falls within the values earlier reported by Ajiboye *et al.* (2015) and Maniyunda and Raji (2017).

Table 3: Pedological forms of iron oxides, across different land uses and horizons

	Feox (g/kg)	Fed (g/kg)	Fep (g/kg)	Feox/Fed (g/kg)
Land Uses				
Amaranth	3.82	10.84[c]	0.76	0.36
Millet	2.07	10.25[c]	0.76	0.21
Mango	3.29	12.76[b]	0.58	0.26
Rice	2.42	13.98[a]	0.71	0.18
Tomato	3.33	12.77[b]	0.43	0.24
LSD (p<0.05)	*2.23*	*0.88*	*0.30*	*0.19*
LOS	NS	***	NS	NS
Soil Horizon				
Surface	3.32	12.38	0.64	0.28
Subsurface	2.65	11.86	0.65	0.22
LSD (p<0.05)	*1.41*	*0.55*	*0.19*	*0.12*
LOS	NS	NS	NS	NS

LOS (Level of significant) (p): NS (Not Significant) > 0.05, * < 0.05, ** < 0.01, *** < 0.001, Feox=oxalate extractable iron, Fed=diotonite extractable iron, Fep=pyrophosphate extractable iron

Note: Means followed by the same letters in the column are not significantly different at 5% LOS

Soils under rice cultivation recorded a higher (p<0.001) soil content of Fed and this might be attributed to abundance of ferromagnesian minerals (Maniyunda and Raji, 2017) or an advanced stage of pedological process. There was an observed increase in soil mean Fed content with depth which was similar to the trend that was also observed by Ajiboye *et al.* (2015) and Maniyunda and Raji (2017). This trend could be attributed to co - translocation of Fe with clay from surface to subsoil horizons through elluviation-illuviation processes (Jelic *et al.*, 2011). Maniyunda and Raji (2017) had reported a significant positive correlation between Fed and clay which further affirm this process.The values for crystalline form of Fe (Fed) obtained in this study was higher than the amorphous form (Feox) in the studied soils; an observation corroborated by the findings of Osayande *et al.* (2016) and Maniyunda and Raji (2017) while assessing the profile distribution of crystalline and amorphous sesquioxides in their various studies. The higher values of Fed compared to Feox was an indication that a considerable fraction of Fe may be present in crystalline form. According to Seal, *et al.* (2006), high temperature condition and the prolonged dry season as is characteristic of the study area, may be responsible for higher amount of crystalline Fe fraction in soils. The mean values for soil Fep content recorded across land uses and horizons for the studied soils ranged from 0.43 to 0.76 g/kg (Table 3). The values of Fep obtained in this study were lower than the range earlier reported in established forest in the Southern Guinea Savanna zone of Nigeria (Samndi *et al.*, 2006). The general low extractable values of Fep might be attributed to well drained condition of the soils which had been noted to promote strong weathering and crystallization of Fep in soils (Hassan *et al.*, 2004).

Active iron ratio (Feox/Fed)

Active iron ratio is defined as the amorphous form divided by the crystalline form of iron oxide (Feox/Fed), and has been used in evaluating soil development and weathering (Omenihu *et al.*, 1994). It indicates the reactivity of sesquioxides and the relative amounts of the amorphous and the crystalline oxides in a soil (Omenihu *et al.*, 1994) and classifying soils into well drained and poorly drained conditions (Stonehouse and Amaud, 1971). The mean data for active iron ratio across land uses and horizons ranged from 0.18 to 0.36 (Table 3). The values obtained in this study are within the range earlier reported (Camêlo *et al.*, 2017). The obtained range of active iron ratios was found to be low (<0.4) across all the land use systems, an indication that the soils of the study area were generally young soils. According to Mahaney *et al.*, (1991), soils with high ratios were younger soils, whereas low ratios are indicative of older soils. The higher mean active Fe ratio of 0.36 and 0.28 recorded in soils under amaranth production and the surface horizon, respectively, suggest that the soils were relatively less weathered when compared to other land uses and the subsurface horizon. Active iron ratio is also an index used in describing the proportion of the amorphous and crystalline iron contents of soils (Obi *et al.*, 2009). The values of active iron ratios (Feox/Fed) (<0.4) obtained confirmed that most of the Fe in the soils in this study was in the crystalline rather than the amorphous forms. The values further suggest that the degree of crystallinity of the Fe fraction is higher than those reported by Obi *et al.* (2009) for some basement complex soils in Southeastern Nigeria.

As for drainage condition, the soils under amaranth cultivation with 0.36 active iron ratio is classified as poorly drained, while soils under mango, tomato, millet and rice cultivation which recorded 0.26, 0.24, 0.21 and 0.18 active iron ratios, respectively are well drained. According to Stonehouse and Amaud (1971), soils with active iron ratio of higher than 0.35 are poorly drained, while well drained soils have values lower than 0.35.

CONCLUSION AND RECOMMENDATIONS

Based on the above results the silt/clay ratio, different forms of iron oxides, Feox/Fed and the disposition of crystalline and amorphous forms of Fe all gave a consistent information on the the stage of development of the studied soils. The higher values of Fed as compared to Feox and Fep and the generally low active iron ratios of (<0.4) obtained is an indication of the predominance of the crystalline forms as against the amorphous forms of Fe, which is indicative of an early stage of development of the soils, while the direction of soil development with increase in age followed the trend; amaranth < mango < millet < tomato <rice. The general agronomic constraints of the soils were low nutrient reserve, acidic reaction and high P fixation conditions. Effective management practices such as periodic monitoring of soil quality, addition of organic manure and guided inorganic fertilizer use are recommended for sustainable agricultural productivity of the soils.

REFERENCES

Abagyeh, S. O. L., Wuese, S. T., Ezenwa, M. I. S. 2017. Characterization, Classification and Management of Integrated Landscapes in the Middle Benue Valley of Benue State. *Nigerian Journal of Soil Science* 27:267-281.

Abay, A., Sheleme, B. 2012. Characterization of soils at Angacha district in southern Ethiopia. *Journal of Biology, Agriculture and Healthcare* 2(1): 6-16.

Abubakar, B. Y. 2013. North-east economic summit: Up-scaling agricultural-business in the North-east through innovative value and agricultural clusters. A paper presented by the Executive Secretary, Agricultural Research Council of Nigeria at a workshop organized by the Agricultural Research Council of Nigeria at Mabushi Abuja on 3rd - 4th December. 2013.

Agbenin, J.O. 2003. Extractable iron and aluminum effects on phosphate sorption in savannah alfisol. *Soil Science Society of America Journal* 67: 589-593.

Ahukaemere, C.M., Akpan, E. L. 2012. Fertility Status and Characterization of Paddy Soils of Amasiri, Ebonyi State, Southeastern Nigeria. *Journal of Production Agriculture Technology* 8(2): 159-168

Ajiboye, G. A., Ogunwale, J. A., Aduloju, M. O. 2015. Profile Distribution of Crystalline and Amorphous Sesquioxides in Talc Overburden Soils of Southern Guinea Savanna Ecology in Nigeria. *Nigerian Journal of Soil Science* 25: 58-69.

Akinbola, G. E., Adigun, M.O., Aduroja, O. 2013. Dithionite and oxalate extraction of iron and manganese in some basement complex soils of Southwestern Nigeria. *Journal of Experimental Sciences* 4(2): 22-26.

Akintoye, O. A., Ukata, S. U., Esomonye, H. I. 2012. The Effects of Landuse on the Infiltration Capacity of Coastal Plain Soils of Calabar, Nigeria. *International Journal of Applied Science and Technology* 2 (2): 81-84

Akpan, J. F., Aki, E.E., Isong, I.A. 2017. Comparative Assessment of Wetland and Coastal plain Soils in Calabar, Cross River State. *Global Journal of Agricultural Sciences* 16:17-30

Ande, O.T., Are, K.S., Adeyolanu, O.D. Ojo, O.A., Oke, A.O., Adelana, A.O., Adetayo, A.O., Oluwatosin, G.A. 2016. Characterization of floodplain soils in Southern Guinea Savanna of North Central Nigeria. *Catena* 139: 19–27

Ashenafi, A., Abayneh, E., Sheleme, B.

2010. Characterizing soils of Delbo Wegene watershed, Wolaita Zone, Southern Ethiopia for planning appropriate land management. *Journal of Soil Science and Environmental Management* 1: 184-199.

Askira, M. S., Musa, H., Salem, A. 2019. Fertility Evaluation under different Management Practices in Fufore Local Government Area of Adamawa state, Nigeria. *Biological and Environmental Sciences Journal for the Tropics* 16(1): 27 - 32

Awanish, K., Mishra,V. N., Srivastav, L. K., Rakesh B. 2014. Evaluations of Soil Fertility Status of Available Major Nutrients (N,P & K) and MicroNutrients (Fe, Mn, Cu & Zn) in Vertisol of Kabeerdham District of Chhattisgarh, India. *International Journal of Interdisciplinary and Multidisciplinary Studies (IJIMS)* 1(10): 72-79. Retrieved from http://www.ijims.comISSN: 2348 – 0343

Babalola, T.S., Oso, T., Fasina, A.S., Godonu, K. 2011. Land Evaluation Studies of two Wetland Soils in Nigeria. *International Research Journal of Agricultural Science and Soil Science* (ISSN: 2251-0044) 1(6): 193-204 Available online http://www.interesjournals.org/IRJAS

Bera, R., Bera, A., Seal, M., Banerjee, A. K., Dolui 2005. Nature and profile distribution of iron and aluminum in relation to pedogenic processes in some soils developed under tropical environment in India. *Environmental Geology*. 47:241–245

Brady, N. C., Weil, R. R. 2008. The Nature and Properties of Soils (14th edition). Pearson Prentice Hall, Pearson Education, New Delhi, India. 148pp

Brady, N. C., Weil, R. C. 2013. The Nature and Properties of Soils. 15th Edition. Dorlin Kindersley (India) PVT LTD. Pearson Printice- Hall Inc. India Pp 381-387.

Camêlo Danilo de Lima, João Carlos Ker, Maurício Paulo Ferreira Fontes, Marcelo Metri Corrêa, Antonio Carlos Saraiva da Costa, Vander Freitas Melo 2017. Pedogenic Iron Oxides in Iron-Rich Oxisols Developed from Mafic Rocks. *Revista Brasileira de Ciencia do Solo* 41: 1-16

Donahue, R.L, Raymond, M.W., Schick Line, J.C. 1990. Soils: An introduction to soils and plant growth. Prentice hall of India. 667pp

Egwu, G. N., Okunola, O. J., Ugwoke, K. C. 2018. Evaluation of Some Heavy Metals in Wetland Soils of Uguru, Yobe State, Nigeria. *Journal of Applied Science, Environment and Management* 22(6): 987–992.

Enya, O. O, Omueti, J. A. I, Akinbola, G. E. 2011. Particle size and free iron oxide distribution along two toposequence in South Western Nigeria. *Wilolud Journals; Continental Journal of Agromony* 5(2):22-31

Esu, I. E. 1982. Evaluation of soils for irrigation in the Kaduna Area of Nigeria. An unpublished Ph.D Thesis submitted to Soil Science Department, Ahmadu Bello University, Zaria.

FAO 1993. Guidelines for land use planning. FAO Development series. FAO Rome, xv 78.

Fekadu, Endalkachew , Kibebew Kibret, Bobe Bedadi, Asmare Melese 2018. Characterization and classification of soils of Yikalo Subwatershed in Lay Gayint District, Northwestern Highlands of Ethiopia. *Eura-*

sian Journal of Soil Science 7(2): 151 – 166

Gee, G. W., Bauder, J. W. 1986. Particle size analysis In: A Klute (Ed). Method of soil analysis 2nd No. ASA Inc. SSSA. Inc. Madison, Washington DC Pp 383-409.

Hassan, A. M., Singh, B. R., Alkali, M. 2004. Profile distribution of Sequeoxides in granite soil in Bauchi, Nigeria. In: Salako, F. K., Adetunji, M. T., Ojanuga, A. G., Arowolo, T. A. and Ojeniyi, S. O. (ed) 2004. Managing Soil Resources for Food Security and Sustainable Environment. Proceeding of the 29th Annual Conference of the Soil Science Society of Nigeria, held at University of Agriculture, Abeokuta, Nigeria December 6-10 2004 pp 93-97.

Hassan, A. M., Shuaibu, M. 2006. Physico-Chemical properties of the soil at Walban-Deba, Gombe State. Proceedings of the 24th annual conference of the Horticultural Society of Nigeria, held at Gombe State University, Gombe. September. 17th to 22nd 2006. pp 163-168.

Havlin, J. L., Beaton, J. D., Tisdale, S. L., Nelson, W. L. 1999. Soil fertility and fertilizers. Pearson education Inc. Singapore pp 499.

Ikusemoran, M., Wanah, B. B., Mbaya, L. A. 2016. Geospatial techniques for terrain analysis of Gombe State,Nigeria. *Journal of Geography, Environment and Earth Science International* 6(1): 1-20

Ikusemoran, Mayomi, Didams, Gideon and Michael, Abashiya 2018. Analysis of the Spatial Distribution of Geology and Pedologic Formations in Gombe State, North Eastern Nigeria. *Journal of Geography and Geology* 10(1): 83-108

Imadojemu, P. E., Osujieke1, D. N., Obasi, S. N., Mbe, J. O., Dibofori, E. G. 2018. Characterization and classification of some soils of Edo state formed under different Parent materials. *Trends in Science and Technology Journal* 3(1): 201 – 206

Jelic, M. Z., Milivojevic, J. Z., Trifunovic, S. R., Dalovic, I. G., Milosev, D. S., Seremesic, S. I. 2011. Distribution of Forms of Iron in the Vertisols of Serbia. *Journal of Serbian Chemical Society* 76(5): 781-794.

Kachinskii, N. A. 1965. Soil Physics, part 1.Vissahyaskhola, Moscow.

Kebede, M., Shimbir, T., Kasa, G., Abera, D., Girma, T. 2017. Description, characterization and classification of the major soils in Jinka Agricultural Research Center, South Western Ethiopia. *Journal of Soil Science and Environmental Management* 8(3): 61-69.

Kefas, P. K., Ukabiala, M. E., Azuka, C. V. 2016. The physical properties and micronutrient status of Mayo-gwoi floodplain soils, in Taraba State, Nigeria. International Journal of Plant and Soil Science. 10(6):1-8.

Klinkenberg, K. and Higgins, G. M. (1968). An outline of Northern Nigerian soils. *Nigerian Journal of Soil Science* 2: 91-115.

Lawal, B. A., Adeboye, M. K. A., Tsado, P. A., Elebiyo, M. G., Nwajoku, C. R. 2012. Properties, classification and agricultural potentials of lateritic soils of Minna in sub-humid agroecological zone, Nigeria. *International Journal of Development and Sustainability* 1(3): 903-911

Mahaney, W. C., Hancock, R.G.V., Sanmugadas, K. 1991. Extractable Fe-Al and geochemistry of late Pleistocene Paleosol in the Dalijia Shan, Western China. *Journal of Southeast Asian Earth Science* 6:75–82

Malgwi W. B. 2007. Soil Survey: Soil Analytical Data Interpretation for Land Management. Paper presented at Training Workshop in Soil Survey and Land Evaluation Methodology for Federal Department of Agriculture and Land Resource Staff in Kaduna.

Maniyunda, L.M. 1999. Pedogensis on Loess and Basement Complex rocks in a sub-humid environment of Nigeria and the suitability of the lands for rain fed cultivation. An unpublished M.Sc Thesis submitted to Soil Science Department, Ahmadu Bello University, Zaria.

Maniyunda L.M., Gwari M.G. (2014). Soils Development on a Toposequence on Loessial Deposit in Northern Guinea Savanna, Nigeria. *Journal of Agricultural and Biological Science* 9(3) ISSN 1990-614. Retrieved fromwww.arpnjournals.com

Maniyunda, L. M., Raji, B. A. 2017. Pedogenetic Evaluation of Forms of Iron and Manganese Oxides of Lithosequence in Kaduna State, Nigeria. *Nigerian Journal of Soil and Environmental Research* 15: 263-273.

McKeague, I. A., Day J. H. 1966. Dithionite and oxalate extractable Fe and Al as aid in differentiating various classes of soils. *Canadian Journal of Soil Science* 46:13-20.

Mehra, O. P., Jackson, M. L. 1960. Iron oxide removal from soils and clays by diothionate citrate system buffered with sodium bicarbonate. *Clays and Clay Minerals* 7:317-327

Nsor, M.E., Uhie, O. O. 2016. Characterization and Land Suitability Assessment of Fresh Fish Farming of Wetland Soils along the Floodplains of Imo River, Eastern Nigeria. *Nigerian Journal of Soil Science and Environmental Research* 15:229-239

Obi, J. C., Akinbola, G. E., Anozie, H. F. (2009). Distribution of Dithionate and Oxalate Extractable Iron oxides of a Catena in the basement complex soils of Southwestern Nigeria. *Nigerian Journal of Soil Science* 19 (1):100-108.

Ogban, P. I., Utin, U. E. 2015. Effect of land use on infiltration characteristics of Sandstone-derived soils in Akwa Ibom State, Southeastern Nigeria. *Journal of Applied Agricultural Research* 7: 141-149

Ogbodo, E. N. 2011. Assessment of Some Soil Fertility Characteristics of Abakaliki Urban Flood Plains of South-East Nigeria, for Sustainable Crop Production. *World Journal of Agricultural Sciences* 7(4): 489-495.

Ogunkunle, A. O., Onasanya, O. S. 1992. Soil-Landscape relationship in a Forest Zone in Southwestern Nigeria. *Samaru Journal of Agricultural Research*, 9: 19-33.

Ojanuga, A. G. 1985. Forms of Sesqueoxides in Iwo soils. *Nigerian Agricultural Journal*, 19/20:39-49.

Ojetade, J. O., Adegbenro, R. O., Amusan, A. A. 2014. Influence of Vegetation on Soil Characteristics in Ife Area, Southwestern Nigeria. *Advanced Journal of Agricultural Research* 2 (5): 91-98.

Okoli, N. H., Uzoho, B. U., Onweremadu, E. U., Ahukaemere, C. M., Osisi, A. F., Aliba, E. O. 2017. Status and Available

Micronutrients in Soil Profiles of different Parent Materials in Imo State, Southeastern, Nigeria. *Nigerian Journal of Soil Science* 27:40-52.

Oleghe, E.E., Chokor, J.U. 2014. Effects of gully erosion on soil properties in some soils of Edo state Nigeria. *Nigerian Journal of Soil Science* 24(1): 174 – 182.

Omenihu, A. A., Opuwaribo, E. E., Sutton, P. M. 1994. Forms of extractable iron and aluminum oxides in coastal plain soil of Southeastern Nigeria. The 21st Annual Conference of Soil Science Society of Nigeria. University of Uyo, Nigeria, 30th January-4th February, 1994. Pp. 87-93.

Osayande, P. E., Orhue, E. R., Ovie, S., Obi, E. A., Ogbebor, C. O., Koloche, I. M. 2016. Status and Distribution of Diothionite and Oxalate Extractable Iron and Aluminium Oxides in Ultisols of Nifor Main Station. *Nigerian Journal of Soil and Environmental Research* 14: 51-56.

Osodeke V. E., Nwotiti I. L., Nuga B.O. 2005. Sesquioxides distribution along a toposequence in Umudike area of Southeastern Nigeria. *Electron Journal of Environment Agriculture and Food Chemistry* 4(6): 1117-1124

Osujieke, D. N., Imadojemu, P. E., Igbojionu, J. N. 2017. Characterization and Variability of soils formed on a toposequential floodplain in Uratta, Southeastern Nigeria. *Trends in Science & Technology Journal* 2(1B): 628 – 632

Page, A. L., Miller, R.H., Keeney, D.R. 1982. Methods of soil analysis (Eds) Agron 9, part 2, ASA, Madison Wisconsin

Raji, B.A., Esu, I.E., Chude, V.O., Owonubi, J.J., Kparmwang, T. 1996. Profiles, classification and management implication of soils of Illela sand dunes, NW Nigeria. *Journal of Science Food Agriculture*, 71:425-432.

Sai Kumar R., Satish Kumar, Y.S., Srinivas P. 2013. Characterization, Classification and Evaluation of Chilli Growing Soils Of Khammam District, Andhra Pradesh. *International Journal of Innovative Research and Development* 2(9): 26-33.

Salem, A., Musa, H., Askira, M. S. 2017. The Study of Soil Profile Characteristics Under different Land Use in Fufore Local Government, Adamawa State, Nigeria. *Nigerian Journal of Engineering, Sciences and Technological Research* 3(2): 80-91.

Salem, A., Dedan, N. K., Ibrahim, A. E. 2018. Geospatial Variation in Soil Exchangeable Bases along Toposequences, in Gombe State, Northern Guinea Savanna Zone of Nigeria. *Journal of Agriculture, Food Security and Sustainable Environment* 1(1): 71-78

Samndi, A. M., Raji, B. A., Kparmwang, T. 2006. Long-Term effects of Fast-growing Tree species (Tectona Grandis Linn F.) on the distribution of Pedogenic forms of Fe and Al in some soils of Southern Guinea Savanna of Nigeria. *Samaru Journal of Agriculture* 1(1): 39-45.

Seal, A., Bera, R., Bhattacharyya, P., Mukhopadhyay, K., Giri, R. 2006. Degree of soil development in some Alfisols of Subtropical India with special reference to the nature and distribution of Fe and Al. *International Journal of Agriculture* 1(4): 305-311.

Shobayo, A.B. 2010. A lithosequence of soils developed on basement complex rocks of zaria, the northern guinea savanna, Nigeria. Unpublished MSc. Thesis. Department of Soil Science ABU, Zaria.

Stonehouse, H. B., R. J. St. Arnaud 1971. Distribution of iron, clay and extractable iron and aluminum in some Saskatchewan soils *Canadian Journal of Soil Science* 51: 283-292

UBRBDA 2018. Upper Benue River Basin Development Authority Metrological Unit. Dadin Kowa Sub-station, Gombe State, Nigeria.

Van Wambeke, R.G. 1962. Criteria for Classifying Tropical Soils by Age. John Wiley and Sons Inc. New York

Yitbarek, T., Beyene, S., Kibret, K. 2016. Characterization and classification of soils of Abobo Area, Western Ethiopia. *Applied and Environmental Soil Science* Article ID 4708235.

Zata, A. I. 2010. The Study of Soils Derived from Olivine Basaltic Deposits of Lunguda Plateau (A): Morphological Properties of Vertisols. *Journal of League of Researchers of Nigeria* 11(2):10-18.