PHYSICAL AND CHEMICAL CHARACTERISTICS OF SOME SOILS IN A DRY UPLAND FOREST OF NIGERIA AND THEIR IMPLICATION FOR SUSTAINABLE SOIL MANAGEMENT.

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Abstract
The importance of having knowledge on the types and properties of soils has been shown to be critical for making informed decisions with respect to agricultural production and other land use types. This study was carried out to characterize, classify and evaluate some selected soils of Ekiti State for sustainable management. The ancillary data about the area were collected (topographic map, remote sensing imageries, climatic data) to produce digital terrain map and base map for the soil survey. Thirteen mapping units were identified (P1,P2,P3,P4,P5,P6,P7,P8,P9,P10,P11,P12 and P13) and profile pits were dug, described and sampled in each of the units. The soils were moderately acidic to strongly acidic. The soils were generally low in total nitrogen, exchangeable bases and cation exchange capacity. Incorporation of organic manure to improve the texture of the soil; use of improved tillage methods that will cause minimal disturbance of soils; judicious use of inorganic fertilizer based on soil testing; maintaining a level of crop residues mulch on the soil surface in order to improve the aggregate stability of the soil; and construction of contour ridges along with use of vegetative cover crops to conserve the soil against surface runoff by erosion were recommended.

Keywords: Physical and Chemical Characteristics of Soil, Upland Forest of Nigeria

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Introduction

Knowledge of the types and properties of soil is critical for decision making with respect to crop production and other land use types. It is through precise measurement and full understanding of the nature and properties of soils as well as proper management of the nutrient and moisture requirement that one can maximize crop production to the allowable potential limits (Esayas and Debele, 2006, Esu, 2004, Chukwu and Ogbodo, 2012). In order to evaluate quality of our soil resources and their potential to produce food, fodder and fiber for the present and future generation, detailed information on soil properties is required (Lekwa*et al*, 2001). Soil characterization provides the information for our understanding of the physical, chemical, mineralogical and microbiological properties of the soils which we depend on to grow crops, sustain forest, grazing land as well as support homes and structures (Ogunkunle and Ande 2004).

Different soil properties encountered along landscapes will affect pattern of crop production. Soil physical properties such as clay content distribution with depth and sand content have been shown to be highly correlated to soil genesis while soil organic matter has been shown to vary with slope position (Miler *et al*, 1988). The changing situation of our soil properties due to the soil forming process had also been discovered by some research findings (Ewulo, 2012, Nwachokor and Uzu, 2008 and Fasina *et al*., 2015). Therefore, there is need for periodic update on information of our soil quality through survey system. This should be carried out on a much smaller scale ratio to adequately capture the local agrarian communities. Sharu *et al*., (2013) reported that coupling of soil characterization and classification provides a powerful resource

for the benefit of mankind especially in the area of food security and environmental sustainability while Lekwa *et al*., (2004) reiterated that soil characterization provides the basic information necessary to create functional soil classification scheme and assess soil fertility in order to unravel some unique soil problems in an ecosystem.

There is no adequate information about the soils of the study area for land use planning and agricultural production. Also, these soils must have undergone several transformation owing to continental interaction of the soil forming factors over one another. Therefore, this present study examines the physical and chemical characteristics of some selected soils in Ekiti State for sustainable soil management.

Material and Methods

Description of the study area

The study area is Ido/Osi Local Government Area of Ekiti State (Figure 1), located within latitude $7^{0}86^{'}$ and $8^{0}5^{'}$ North and longitudes $4^{0}5^{'}$ and $5^{0}45^{'}$. It covers an area of 332 square kilometers (33,200ha) and is 250m above sea level.

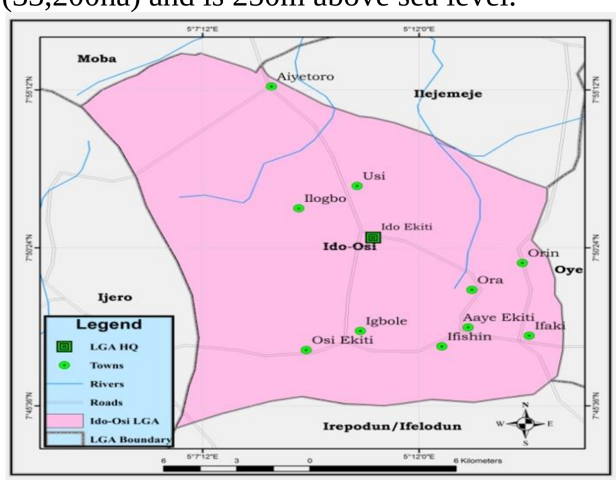

Figure 1: Map of the study area (IdoOsi Local Government) showing the major towns

The climate is of the tropical upland rainforest type with distinct wet and dry seasons. The mean annual rainfall of 1470.1mm and average number of rainy days of 119.3. The mean annual temperature of the area is 25.5^{0}C. The mean monthly relatively humidity is 75 percent (Weather Base, 2018). It lies within the pre-Cambrian of Southwestern Nigeria which is a part of the basement complex of Nigeria and mostly underlain by crystalline rocks ranging from pre-Cambrian to paleozonic (Oyawoye, 1970). Original vegetation characteristic was a semi-deciduous upland rainforest. The original vegetation had been drastically disturbed and in its place are cultivated crops and secondary vegetation successions like bush regrowth, thicket derived savanna and secondary forest. Arable crops mostly cultivated include yam (*Dioscoreaspp*) cassava (*Manihotspp*), maize (*Zea mays*) and vegetables.

Soil Survey and Sampling

Reconnaissance survey was conducted to know vegetation, cropping pattern and the rural landscape of the study area. A free-soil survey procedure was adopted to identified soil types and thirteen pedons were identified. Profile pit were dug in each pedon, described and sampled for soil laboratory analysis following the procedure described by Soil Survey Staff Division (2017). The location of the pedons were georeferenced with global positioning system (GPS) (GerminiEtrex). At each pedon positions, the local relief, soil erosion or deposition hazards, rock outcrops, surface characteristics, vegetation and land use were recorded.

Laboratory Analysis

The soil samples were air-dried and sieved for the laboratory determinations of soil physical and chemical properties using the IITA (1979) procedure for soil analysis. The following were determined: percent gravel, particle size analysis, bulk density, particle density, total porosity, moisture content, soil pH, organic carbon, total nitrogen, available phosphorus, exchangeable cations (exchangeable K, Na, Ca, and Mg), exchangeable acidity, effective cation exchange capacity (ECEC), base saturation (BS) percentage, electrical conductivity, micro nutrients (Mn, Fe, Cu and Zn), and calcium carbonate ($CaCO_3$).

Results and Discussion

Soil Physical Properties

The soil physical properties are presented in Table 1.

The distribution of soil particle sizes (sand, silt and clay) determines the soil texture. Percentage gravel content of the surface horizons ranged from 8.7% to 59.9%. Lowest gravel content was recorded at pedon 7 (8.7%) while the highest gravel content was recorded at pedon 9 (59.9%). Higher percentage gravel content of most of the pedons of the study area might be due to the formation of the soils in situ (Adekayode, 2008). Percentage sand contents are high and are predominantly coarse textured ranging from 52.9% to 86%. The total sand fraction is higher than that of other fractions (clay and silt) in each of the pedons of the study area. This can be due to the parent material, type of weathering and the downward translocation of clay (Babalola, 2017). The profile distribution of clay content shows irregular increase with depth in most of the pedons. This may be as a result of eluviation – illuviation process, as well as the contribution of the underlying decaying parent materials by biological and / or agricultural activities, clay migration or surface erosion by runoff or a combination of all these (Malgwi*et al.*, 2000). The silt fraction is generally low in all the pedons of the study area ranging from 3.3% to 19.3%. Soils derived from the basement complex rocks had been reported to be low in silt (Babalola, 2017).

Bulk density of the surface horizon ranged between 1.48g/cm^3 to 1.65g/cm^{3}while the bulk density of the subsurface horizons of the pedons in the study area ranged between 1.33g/cm^3 to 1.64g/cm^3. The bulk density showed a variation among and within the soil pedons. The variation indicates the difference in mineralogy, clay content and structural development (Malgwi*et al.*, 2000). The argillic horizons had the lowest bulk density values possibly due to the presence of the lighter clay size minerals and also the good structural development. The Bulk density within the rooting zones (that is upper one meter) of the soils were optimal for good crop growth. Particle density ranged from 2.10g/cm^3 and 2.99g/cm^3 in the surface horizon of the study area and 2.0g/cm^3 and 2.84g/cm^3 for the subsurface horizon of the study area indicating that perhaps quartz, feldspars, mica and other colloidal silicate which have densities between the range of 2.50g/cm^3 and 2.70g/cm^3 made up the major portions in the soils (Ayolagha and Opene, 2012). Total porosity for surface horizons ranged from 51% to 76.8% while for subsurface horizon total porosity ranged between 35.32% and 86.12%. According to Spositol (1991), soils having porosity of over 50% and 40% of their volume are good agricultural soils. The result from this study showed that most of the horizons studied appear to be well aerated and have free water movement at the surface horizon.

The moisture content of the surface horizons ranged between 5.1% and 18.7% and for the subsurface horizons it ranged between 6.3% and 24.7%. The pattern of change of soil moisture

content in the study areas might be influenced by organic matter (Waniyo*et al*., 2015). It was reported that moisture increased with increased organic carbon (Sial, *et al*., 2007). The water holding capacity ranged between 26.57% and 67.44% in the surface horizons and the subsurface horizons values ranged between 26.20% and 62.24%. Water holding capacity was higher in pedons with highest clay contents compared to pedons of lower clay content and in most case increased with depth in general terms that may be attributed to dominance of their micropores resulting from clay accumulation (Abagyeh*et al*., 2017). Incorporation of organic matter in the soils will lower the soil bulk density, further raise porosity and enhance water holding capacity.

Soil Chemical Properties

The soil chemical properties are presented in Table 2 and 3.
The surface horizons of all the pedons have the highest values of pHboth in water and calcium chloride ranging from 4.0 to 7.3 (pH water) and 3.8 to 7.2 (pH $CaCl_2$). The soil pH ranged between moderately acidic and neutral in most of the pedons except in pedon 7 (Ipokin farm, Osi Ekiti) and pedon 9 (Ifishin Ekiti) that are strongly acidic. The subsurface horizons ranged from 4.1 to 6.6 (pH water) and 3.7 to 6.7 (pH $CaCl_2$). The pH values of most of the pedons except pedon 7 and pedon 9 soils are above the critical soil pH (>5.0) for Nigerian soils. Bessah *et al*. (2016) reported that crop yields are usually high in soils with pH values between 6.0 and 7.5 indicating that the soils of most of the pedons are good agricultural lands.

The electrical conductivity of surface horizon ranged between 0.18mmhos and 0.79mmhos while the subsurface horizons values ranged from 0.02mmhos to 0.19mmhos. All the soils are rated as non-saline as the values recorded in them are below the critical value of 4.00mmhos rated for saline soils (Brady and Weil, 2005). Low salinity soil below 0.2mmhos is corrosive and tends to leach surface soil free of soluble minerals (especially). This affects soil aggregates and structure (James, 2010). Soil organic carbon values ranged in the surface horizon from 0.7% to 8.0% and the values ranged in the subsurface horizon from 0.2% to 1.1%. the organic carbon of the soils of all the pedons are rated low since the values are less than 10% (Esu*et al*., 2014). The organic carbon contents of the surface horizons are higher than that of the subsurface horizons. This is due to the presence of more decomposable, photocycling and enhanced activities of soil microbes; and also due to better aeration and moisture regime (Olayinka, 2009). According to Greenland *et al*., (1975), it is impossible to obtain potential crop yield where soil organic carbon is less or equal to 1% whereas soils with organic carbon at 2% are characterized by lack of cohesion and stability.

Soil organic matter values are higher at the surface horizons of all the pedons ranging between 1.2% and 13.8%. The organic matter values for the subsurface horizon ranged between 0.3% and 19%. Organic matter content decreases irregularly with soil depth. The high organic matter values obtained at surface horizon is as a result of increased litters inputs and its decomposition as observed by Groenendijk*et al*., (2002), while the lower organic matter values in the underlying horizons might be attributed to decreased faunal activities with soil depth. The total nitrogen values ranged between 0.08% and 0.22% at surface horizons while the value of corresponding subsurface horizon ranged between 0.07% and 0.14%. The higher values of total nitrogen in the surface horizon reflects the higher organic matter status of the surface horizon which were enhanced by nutrient cycling through litter fall (Onyekwere*et al*., 2005) and also the decrease with soil depth could be attributed to influence of continuous cultivation, a common practice on Nigerian soils caused by crop residue removal (Noma*et al*., 2011). The values in many of the pedons are below the critical value of 0.2% in the surface horizon and

are even lower in the subsurface horizon. The total nitrogen was relatively higher in forest lands (pedons 1, 3, 9 and 10), followed by tree crops (pedons 2 and 13) while arable land and fallow were both low in total nitrogen fractions which could be as a result of the farming activities in both areas. Such result is expected since most soil nitrogen is bound in organic carbon. However, studies have shown that total nitrogen is not significantly varied with land uses (Moyes and Holden, 2008). The high total nitrogen observed in the forest and tree crops than that of the arable land and fallow could be associated with the relatively high organic carbon which in turn resulted from plant and root biomass as well as residues being returned to the soil system. It has been observed that the main cause nitrogen deficiency in tropical soils is intense leaching and erosion due to high tropical rainfall (Isirimah *et al.*, 2010; Fasina *et al*., (2007).

The surface horizons values of available phosphorus ranged from 1.4mg/kg to 58.5mg/kg while the values at the subsurface horizons ranged from 0.53 to 45.50mg/kg. These values are mostly considered low as they were below or slightly above the 10mg/kg critical level recommended for most crops in the area (Aduayi*et al*., 2002; Obigbesan, 2009). Low values of available phosphorus have similarly been reported in some Nigerian soils and attributed to their fixation in acidic or alkaline soil environments (Esu, 1989). Available phosphorus values of pedon 10 (Ora Ekiti) were relatively high due to location of a paddock close to the area with addition of animal faecal material in the area.

The surface horizon values of calcium ranged between 1.13 and 9.68cmol/kg and the corresponding subsurface horizon exchange calcium ranged between 0.10cmol/kg and 4.69cmol/kg. There is higher accumulation of exchangeable Ca^{2+} at the surface horizons and this can be attributed to continuous recharge by mobile constituent liberated by decomposition of organic residue, irrespective of its exposure to leaching and runoff. The exchangeable calcium recorded according to the ratings of FAO (2004) are low for soils derived from basement complex rocks. The exchangeable calcium dominates the exchange sites in all the soils of the study area. This agrees with the findings of Amalu and Antigha (1999) that calcium has higher absorptive power than other cations in the soil.

The values of Exchangeable Magnesium in all the pedons were found to be low with irregular reduction in values with increase in depth. The values ranged from 0.46cmol/kg to 17.92cmol/kg on the surface horizons and 0.13cmol/kg to 12.71cmol/kg in the subsurface horizons. Higher values were recorded in the surface horizons in all the pedons except pedon 5 (OkeIdo, Ido Ekiti) that recorded higher values at the subsurface horizon. Low level of Ca, Mg and K, have however been reported for most Nigerian soils (Akinnride and Obigbesan, 2000) and could be attributed to leaching losses by the high tropical rainfall as well as low content in the parent rock (Denton *et al*., 2017). Exchangeable Mg values are low to medium.

The value of Exchangeable K ranged between 0.08cmol/kg and 1.03cmol/kg in the surface horizons and 0.03cmol/kg to 0.36cmol/kg in the subsurface horizons. Exchangeable K content generally decreases irregularly with depth. These values are low to moderate according to FAO (2004). Isirimah*et al.*, (2010) reported critical values between 0.16cmol/kg and 2.0cmol/kg for different land uses in Nigeria. There is likelihood of K deficiency in the soils of the area. The values of exchangeable sodium at the surface horizons ranged from 0.01cmol/kg to 0.04cmol/kg and the values at subsurface horizons ranged between 0.01 and 0.04cmol/kg.

Generally, the soils of the surface horizons of the study area fall into very low values of exchangeable Na (<0.2cmol/kg). The value of exchangeable acidity values ranged from 0.44cmol/kg to 2.60cmol/kg in the surface horizon and increased irregularly with depth. The subsurface values ranged between 0.40cmol/kg and 3.44cmol/kg. Exchangeable acidity values obtained are generally low except for pedon 9 (Ifishin Ekiti) where considerable high values were obtained. The latter can be related to Exchangeable Al^{3+}status, and this is considered to be an indication of acid weathering which is characteristic of heavy rainfall areas of the tropics. The values of cation exchange capacity (CEC) showed that the surface horizons value ranged from 1.69 to 26.83cmol/kg and tends to decrease irregularly with depth. The CEC values for the subsurface horizons ranged between 0.30cmol/kg and 15.85cmol/kg. The cation exchange capacity values (CEC) are low to moderate. In most soil profiles higher values are obtained from the topsoil and again from lower depth. The higher CEC values of A-horizons can be attributed to the influence of the organic matter contents while slight increases lower in the profile are caused by increase in clay content. The low to moderate content of the exchangeable cations could be a limitation to the soil which will need to be ameliorated to obtain optimum agricultural productivity.

The base saturation values at the surface horizons ranged between 43.85% and 98.10% and the subsurface horizon values ranged between 12.90% and 90.43%. The Base Saturation of soils of the study areas are rated moderate to high except for soils of pedon9 (Ifishin Ekiti) (FAO, 2004).

The surface horizon calcium carbonate ($CaCO_3$) values ranged between 2.73% and 23.38% and between 0.24% and 11.33% for the surface and subsurface horizons. There are higher values of $CaCO_3$at the surface horizons than the subsurface horizons and it decreases down the depth. According to Fasina (2008) rating of $CaCO_3$ status as one of other soil characteristics for irrigation suitability, these soils $CaCO_3$ contents fell mostly within <0.3% and 0.3-10% and were rated to be 90-95% suitable for gravity, and drip localized irrigation. Pedon 10 (Ora Ekiti) soil recorded $CaCO_3$ contents higher than 10% and this could make it unsuitable for irrigation. The SAR values of the surface horizons ranged from 0.018 to 0.137 and tend to increase with depth in all the profile except in pedon 13 (Ifaki Ekiti) where higher SAR values were obtained at the surface horizons. The SAR values for the subsurface horizons ranged between 0.020 and 0.243. The exchangeable sodium percentage (ESP) for the surface horizon ranged between 1.099% and 7.407% and the subsurface horizon values ranged between 1.052% and 22.22% the ESP values is generally lower at the surface horizons and tend to increase with depths in all the profiles. The value of ESP in all the profiles in this study were below the critical level of 15% (Brady and Weil, 2005) except in 'B_2' horizon of pedon 9 (Ifishin Ekiti) where a value of 22.22% was recorded. Therefore, the ESP values are not able to cause sufficient structural breakdown through dispersion and swelling to affect permeability of soils, indicating that the soils are not sodic.

The values of aluminum saturation on the surface soil ranged between 0.96% at pedon 10 (Ora Ekiti) and 10.03% at pedon 9 (Ifishin Ekiti). The Al^{3+} saturation generally increased irregularly with depth. The subsurface values of Al^{3+} saturation ranged between 1.33% at pedon 5 (OkeIdo, Ido Ekiti) and 10.95% at pedon 9 (Ifishin Ekiti). It was observed that Al^{3+} saturation values recorded high value at pedon 9, where very strong soil acidity was recorded (pH H_2O of between 4.0 and 4.3 and pH $CaCl_2$ of between 3.8 and 4.5). This shows that Al^{3+} contributed to the soil acidity. The values of the Extractable Mn ranged from 36.1mg/kg (pedon 11) and 425mg/kg at pedon 3 in the surface horizons and the values decreased with depth in all the profiles. According to the rating of Esu (1991), the Mn values in the soil of the study area is very high. Extractable Fe^{2+} values ranged from 0.6mg/kg at pedon 11 (Orin Ekiti) to 48mg/kg at pedon 9 (Ifishin Ekiti) where the values decrease with depth. High values of Fe^{2+} were recorded in soil of pedon 9. The Fe^{2+} values in the soil of the study area rated between low and medium (Esu, 1991). Extractable Zn and Cu in these soils are also medium to high based on the rating of Esu (1991).

ABLE 1: PHYSICAL PROPERTIES OF SOIL

HORIZON DEPTH (CM)	HORIZON DESIGNATION	GRAVEL %	SAND %	CLAY %	SILT %	BULK DENSITY g/cm^3	PARTICLE DENSITY g/cm^3	MOISTURE CONTENT %	WA HO CA %
PEDON ONE, OKE IGI FARM, AYETORO EKITI									
0 – 15	A1	24.8	81.1	4.8	14	1.65	2.99	17.5	57.7
15 – 29	A2	25.4	73.1	10.9	16	1.52	2.72	16.7	60.8
29 – 70	B1	35.7	65.1	24.9	10	1.45	2.39	24.7	55.5
70 – 170	B2	36.7	68.4	20.3	11.3	1.47	2.48	17.7	58.5
PEDON TWO, AISABA FARM, AYETORO EKITI									
0 – 10	A1	31.3	84.4	6.2	9.4	1.63	2.49	18.7	33.0
10 – 25	A2	42.3	82.6	8.2	9.3	1.59	2.69	11.3	38.5
25 – 40	A3	44.3	74.4	17.4	8.2	1.51	2.52	11.5	39.3
40 – 70	B1	56.0	68.4	22.3	11.3	1.54	2.51	13.4	39.3
70 – 135	B2	55.9	74.6	22.2	3.3	1.49	2.84	14.8	52.9
PEDON THREE, USI EKITI									
0 – 11	A1	21.9	83.1	6.9	10	1.65	2.83	14.2	67.4
11 – 50	A2	72.0	78.6	8.2	13.2	1.59	2.74	8.2	47.8
50 – 95	B1	66.9	74.6	18.2	7.2	1.47	2.41	9.5	46.0
95 – 125	B2	63.9	80.6	14.2	5.2	1.52	2.52	12.5	43.5
125 – 160	B3	55.8	73.8	18.9	7.3	1.48	2.46	13.6	44.9
PEDON FOUR, ILOGBO EKITI									
0 – 16	A1	21.9	74.6	10.2	15.2	1.57	2.72	15.1	44.7
16 – 33	A2	41.6	76.4	8.2	15.4	1.60	2.59	9.3	41.7
33 – 51	B1	44.3	63	24.2	12.8	1.37	2.11	8.9	46.5
51 – 130	B2	38.0	76.4	10.2	13.4	1.52	2.53	14.5	47.8
PEDON FIVE, OKE IDO, IDO EKITI									
0 – 24	A1	28.2	82.4	12.3	5.3	1.51	2.36	15.4	37.14
24 – 52	A2	44.3	64.9	24.2	12.9	1.45	2.31	14.8	46.68
52 – 95	B1	47.2	63	22.2	14.8	1.44	2.35	8.6	50.61
95 – 150	B2	51.3	66.6	24.2	9.2	1.46	2.42	6.3	54.89
PEDON SIX, IGBOLE EKITI									
0 – 18	A1	50.8	82.6	8.2	9.2	1.59	2.70	11.3	46.93
18 – 31	A2	64.6	86.6	6.2	7.3	1.61	2.56	12.5	41.42
31 – 75	B1	73.5	54.4	36.2	9.4	1.36	2.30	13.5	57.38
75 – 160	B2	84.9	68.4	21.4	10.2	1.42	2.46	14.8	60.46
160 – 200	B3	55.8	66.6	28.2	5.2	1.40	2.39	18.0	62.24
PEDON SEVEN, IPOKIN FARM, OSI EKITI									
0 – 18	A1	8.71	78.4	6.3	15.3	1.65	2.59	16.7	37.9
18 – 32	A2	28.1	75.1	16.9	8	1.54	2.56	13.9	35.1
32 – 111	B1	17.9	58.7	38.2	3.3	1.33	2.20	12.8	48.7
111 – 155	B2	19.1	52.9	36.2	10.9	1.35	2.35	16.8	57.4
PEDON EIGHT, ODO OKO FARM, OSI EKITI									
0 – 25	A1	8.9	86.4	6.2	7.4	1.63	2.59	9.3	41.9

25 – 46	A2	28.1	82.4	10.3	7.3	1.50	2.15	9.4	26.5
46 – 70	B1	36.9	69.1	22.9	8	1.44	2.31	16.3	45.0
70 – 90	B2	29	82.4	14.3	3.3	1.58	2.48	16.8	36.0
PEDON NINE, IFISHIN EKITI									
0 – 18	A	59.9	76.4	12.2	11.4	1.57	2.69	8.8	44.4
18 – 49	B1	68.7	63	24.2	7.4	1.39	2.31	13.9	49.9
49 – 91	B2	66.9	57	32.2	10.9	1.35	2.28	17.8	56.9
91 – 168	B3	43.2	63.8	16.9	19.3	1.48	2.41	17.0	51.5
PEDON TEN, ORA EKITI									
0 – 14	A1	18.9	85.8	6.9	7.3	1.63	2.72	5.1	51.0
14 – 33	A2	25.7	76.6	12.2	11.3	1.52	2.51	18.6	43.8
33 – 91	B1	22.2	75.0	12.2	12.9	1.55	2.09	14.8	35.7
91 – 140	B2	51.5	63.8	32.9	3.3	1.45	2.36	15.2	54.0
PEDON ELEVEN, ORIN EKITI									
0 – 12	A1	20.6	70.4	16.3	13.2	1.48	2.10	9.5	26.5
12 – 28	A2	35.4	79.1	8.9	12.0	1.56	2.31	10.3	28.9
28 – 60	B1	51.6	62.4	30.2	7.4	1.40	2.31	18.2	50.3
60 – 102	B2	49.3	58.6	30.2	11.3	1.38	2.25	18.2	51.0
102 – 200	B3	34.5	75	14.2	10.9	1.47	2.48	19.3	52.0
PEDON TWELVE, FARM SETTLEMENT, ORIN EKITI									
0 – 10	A	55.2	82.4	8.3	9.3	1.61	2.64	11.1	54.9
10 – 50	B1	38.1	80.6	14.2	5.3	1.52	2.31	12.9	26.2
50 – 70	B2	5.9	81.8	6.9	11.3	1.64	2.53	17.1	26.8
PEDON THIRTEEN, IFAKI EKITI									
0 – 20	A1	17.9	79.0	6.2	14.8	1.65	2.49	8.9	32.1
20 – 35	A2	20.4	80.6	8.2	11.2	1.62	2.41	8.5	27.0
35 – 90	B1	18.0	59.1	32.9	8	1.37	2.21	9.1	46.1
90 – 175	B2	37.9	58.4	34.2	7.4	1.36	2.53	9.1	49.0

TABLE 2: CHEMICAL PROPERTIES OF SOILS OF IDO-OSI

Depth (cm)	Horizon	P^H H₂O	P^H CaCl₂	EC Dsm	OC %	OM %	TN %	Avail. P mg/kg	K cMol/kg	Na cMol/kg	Ca cMol/kg	M c g
PEDON ONE, OKE IGI FARM, AYETORO EKITI												
0 – 15	A1	6.4	6.5	0.22	3.1	5.4	0.20	4.2	0.25	0.01	4.88	1
15 – 29	A2	5.9	5.4	0.16	1.5	2.5	0.10	2.8	0.15	0.01	3.70	0
29 – 70	B1	5.8	5.4	0.02	0.8	1.4	0.08	1.4	0.13	0.03	3.30	1
70 – 170	B2	5.6	5.2	0.06	0.6	1.0	0.07	1.05	0.13	0.02	2.80	0
PEDON TWO, AISABA FARM, AYETORO EKITI												
0 – 10	A1	6.6	6.3	0.18	2.2	3.7	0.15	1.40	0.24	0.02	4.34	1
10 – 25	A2	6.7	6.2	0.18	1.8	3.2	0.10	0.53	0.13	0.02	3.96	0
25 – 40	A3	6.4	6.1	0.04	1.9	3.2	0.07	0.53	0.09	0.01	2.83	1
40 – 70	B1	6.1	5.5	0.04	1.1	1.9	0.10	2.80	0.36	0.04	0.78	5
70 – 135	B2	5.9	5.7	0.07	0.7	1.2	0.08	1.40	0.17	0.02	2.30	0
PEDON THREE, USI EKITI												
0 – 11	A1	7.3	7.2	0.33	8.0	13.8	0.22	18.20	0.44	0.04	7.50	1
11 – 50	A2	6.4	5.9	0.40	2.5	4.3	0.15	1.40	0.46	0.04	5.73	9
50 – 95	B1	6.4	5.8	0.06	0.9	1.5	0.10	5.60	0.11	0.03	3.01	0
95 – 125	B2	6.5	6.7	0.03	0.4	0.6	0.08	1.40	0.16	0.02	2.34	0
125 – 160	B3	6.6	6.5	0.03	1.0	1.8	0.08	1.40	0.21	0.03	3.78	1
PEDON FOUR, ILOGBO EKITI												
0 – 16	A1	6.0	6.0	0.79	3.0	5.2	0.14	8.40	0.23	0.03	1.22	1
16 – 33	A2	5.2	5.2	0.19	1.7	2.9	0.08	1.40	0.05	0.01	3.25	0
33 – 51	B1	5.5	4.9	0.03	1.0	1.7	0.10	2.80	0.04	0.01	0.71	0
51 – 130	B2	6.0	6.0	0.02	0.3	0.6	0.08	1.40	0.06	0.02	0.33	0
PEDON FIVE, OKE IDO, IDO EKITI												
0 – 24	A1	6.6	6.8	0.45	1.8	3.0	0.10	12.60	0.24	0.02	3.26	0
24 – 52	A2	6.5	6.5	0.30	2.8	4.7	0.11	2.80	0.33	0.04	9.18	1
52 – 95	B1	6.3	6.7	0.07	0.7	1.2	0.10	1.05	0.36	0.09	2.70	1
95 – 150	B2	5.4	6.2	0.06	0.3	0.4	0.07	0.53	0.24	0.02	2.46	1
PEDON SIX, IGBOLE EKITI												
0 – 18	A1	5.6	5.7	0.51	2.2	3.8	0.13	2.80	0.11	0.02	4.66	1
18 – 31	A2	5.9	5.6	0.16	2.1	3.5	0.11	0.70	0.08	0.01	3.06	1
31 – 75	B1	5.0	4.7	0.07	0.9	1.5	0.10	2.80	0.07	0.02	1.35	c
75 – 160	B2	5.2	5	0.03	0.3	0.6	0.07	1.40	0.05	0.03	1.24	0
160 – 200	B3	4.9	4.9	0.03	0.4	0.7	0.07	1.40	0.04	0.03	1.05	0
PEDON SEVEN, IPOKIN FARM, OSI EKITI												
0 – 18	A1	6.3	6.4	0.50	2.9	5.1	0.15	9.10	0.36	0.04	4.08	1
18 – 32	A2	5.1	4.9	0.08	1.0	1.8	0.08	1.05	0.16	0.03	0.99	0
32 – 111	B1	4.01	3.9	0.15	0.6	1.0	0.08	1.40	0.08	0.03	1.15	0
111 – 155	B2	4.7	4.5	0.19	0.4	0.7	0.08	1.05	0.06	0.02	0.81	0
PEDON EIGHT, ODO OKO FARM, OSI EKITI												

0 – 25	A1	5.6	6.4	0.59	2.4	4.2	0.11	5.95	0.16	0.01	4.19	0.9
25 – 46	A2	6.2	6	0.45	2.3	4.0	0.07	2.80	0.09	0.03	1.93	0.4
46 – 70	B1	5.9	5.3	0.05	0.9	1.5	0.10	1.40	0.09	0.01	2.45	0.8
70 – 90	B2	5.2	5.2	0.03	0.6	1.1	0.10	0.35	0.19	0.03	1.48	0.5
PEDON NINE, IFISHIN EKITI												
0 – 18	A	4.0	3.8	0.78	4.2	7.2	0.20	4.90	0.19	0.02	1.33	0.5
8 – 49	B1	4.1	4.4	0.05	1.2	2.0	0.11	0.70	0.08	0.02	0.23	0.1
49 – 91	B2	4.2	3.7	0.20	0.7	1.2	0.14	0.70	0.07	0.01	0.15	0.1
91 – 168	B3	4.3	4.5	0.03	0.4	0.7	0.13	0.70	0.05	0.02	0.10	0.1
PEDON TEN, ORA EKITI												
0 – 14	A1	7.1	6.9	0.21	4.2	7.2	0.20	43.50	1.03	0.04	9.68	16.
14 – 33	A2	5.9	5.6	0.16	2.0	3.4	0.13	58.50	0.25	0.02	3.68	0.7
33 – 91	B1	6.4	5.5	0.13	1.1	1.8	0.10	45.50	0.10	0.01	4.69	0.4
91 – 140	B2	6.3	6.3	0.02	0.5	0.9	0.08	1.40	0.21	0.02	4.56	0.5
PEDON ELEVEN, ORIN EKITI												
0 – 12	A1	5.6	5.7	0.24	0.7	1.2	0.14	2.80	0.41	0.04	3.08	10.
12 – 28	A2	5.9	5.3	0.12	0.9	1.6	0.10	2.80	0.15	0.04	1.22	0.5
28 – 69	B1	4.7	4.3	0.10	0.7	1.2	0.14	2.80	0.06	0.02	1.06	0.7
69 – 102	B2	4.9	5.0	0.07	0.6	1.0	0.10	1.05	0.05	0.03	1.81	0.7
102 – 200	B3	5.7	5.7	0.02	0.2	0.3	0.08	1.05	0.04	0.02	2.04	0.6
PEDON TWELVE, FARM SETTLEMENT, ORIN EKITI												
0 – 10	A	5.3	5.5	0.36	4.3	7.4	0.11	4.90	0.23	0.02	3.75	1.4
10 – 50	B1	5.3	4.9	0.12	0.5	0.8	0.10	4.20	0.12	0.02	0.74	0.3
50 – 70	B2	5.4	4.5	0.03	0.9	1.5	0.07	2.10	0.03	0.02	0.56	0.3
PEDON 13, IFAKI EKITI												
0 – 20	A1	5.4	5.2	0.22	1.7	3.0	0.13	4.20	0.08	0.02	1.31	0.4
20 – 35	A2	5.8	5.9	0.18	0.8	1.3	0.14	3.50	0.11	0.01	1.28	0.6
35 – 90	B1	4.6	4.5	0.05	1.1	1.8	0.10	1.40	0.04	0.01	1.18	0.4
90 – 175	B2	5.1	4.8	0.03	0.5	0.8	0.07	1.05	0.04	0.02	1.44	0.5

TABLE 3: CHEMICAL PROPERTIES OF SOILS OF IDO-OSI INCLUDING SOME MICRONUTRIENTS

HORIZON DEPTH (CM)	HORIZON DESIGNATION	EXCH. AL^{3+}	EXCH.. H^+	CEC	% BASE SATURATION	% AL^{3+} SATURATION	Mn mg/kg	Fe mg/kg
PEDON 1 OKE IGI FARM, AYETORO EKITI								
0 - 15	A1	0.06	0.74	6.38	88.86	3.57	120	5
15 – 29	A2	0.06	0.5	4.66	89.26	5.11	45.9	11
29 – 70	B1	0.08	0.84	3.53	83.11	5.30	8.8	9
70 – 170	B2	0.06	0.66	3.72	83.78	4.92	10.4	13
PEDON 2 AISABA FARM, AYETORO EKITI								
0 – 10	A1	0.04	0.56	5.62	90.35	2.86	118	4
10 – 25	A2	0.04	0.36	5.09	92.71	3.85	108	2
25 – 40	A3	0.02	0.62	4.23	86.86	1.73	91.8	4
40 – 70	B1	0.04	0.64	6.43	90.43	2.37	49.1	5
70 – 135	B2	0.04	0.64	3.24	82.66	3.40	11.1	5
PEDON 3 USI EKITI								
0 – 11	A1	0.06	0.72	25.90	97.44	1.62	425	0.8
11 – 50	A2	0.06	0.66	15.36	95.52	2.21	104.7	0.5
50 – 95	B1	0.04	0.72	3.83	83.43	3.13	11.6	2
95 – 125	B2	0.02	0.66	3.18	82.27	1.73	12.6	1
125 – 160	B3	0.04	0.6	5.02	88.69	2.96	13.2	2
PEDON 4 ILOGBO EKITI								
0 – 16	A1	0.06	0.86	3.18	77.58	4.07	67.2	5
16 – 33	A2	0.1	2.7	4.11	59.50	3.06	19.5	12
33 – 51	B1	0.04	1.12	1.53	56.93	2.94	18.7	4
51 – 130	B2	0.04	0.64	1.20	63.81	4.62	13.6	10
PEDON 5 OKE IDO, IDO EKITI								
0 – 24	A1	0.04	0.48	4.06	88.65	3.45	41.8	17
24 – 52	A2	0.04	0.64	19.80	96.68	1.33	154.8	5
52 – 95	B1	0.04	0.76	15.85	95.20	1.44	7.2	5
95 – 150	B2	0.04	0.8	4.11	83.02	2.69	1.3	3
PEDON 6 IGBOLE EKITI E								
0 – 18	A1	0.06	0.46	5.88	91.87	4.92	57.7	2
18 – 31	A2	0.02	0.62	4.21	86.79	1.75	36.8	2
31 – 75	B1	0.1	1.14	2.07	62.58	6.56	25.1	6
75 – 160	B2	0.06	0.66	1.85	71.94	6.17	3.9	7
160 – 200	B3	0.06	0.8	1.66	66.37	3.75	5.1	4
PEDON 7 IPOKIN FARM, OSI EKITI E								
0 – 18	A1	0.04	0.52	18.02	96.99	1.47	159.8	4
18 – 32	A2	0.06	0.62	1.88	73.39	5.79	42.5	4
32 – 111	B1	0.34	4.06	1.97	30.92	7.24	25.6	4
111 – 155	B2	0.14	1.94	1.54	42.54	6.06	8	3

PEDON 8 ODO OKO FARM, OSI EKITI								
0 – 25	A1	0.04	0.4	5.30	92.34	3.55	41.5	1
25 – 46	A2	0.02	0.54	2.51	81.75	2.18	32.6	4
46 – 70	B1	0.08	3.16	3.42	51.35	2.18	5.1	4
70 – 90	B2	0.04	0.68	2.21	75.41	3.51	6.7	4
PEDON 9 IFISHIN EKITI								
0 – 18	A	0.3	2.3	2.03	43.85	10.03	80.6	48
18 – 49	B1	0.44	3.44	0.47	10.78	10.95	7.6	11
49 – 91	B2	0.38	3.06	0.39	10.26	10.69	4.5	5
91 – 168	B3	0.14	1.86	0.30	12.90	6.69	3.3	2
PEDON 10 ORA EKITI E								
0 – 14	A1	0.04	0.48	26.83	98.10	0.96	39.5	9
14 – 33	A2	0.04	0.72	4.64	85.94	2.73	199.2	6
33 – 91	B1	0.04	0.6	5.21	89.06	3.16	36.9	15
91 – 140	B2	0.04	0.72	5.35	87.56	2.68	4.8	4
PEDON 11 ORIN EKITI								
0 – 12	A1	0.04	0.68	14.32	95.21	1.56	36.1	0.6
12 – 28	A2	0.04	0.60	1.90	74.84	3.98	20.6	0.4
28 – 69	B1	0.16	1.64	1.85	50.69	7.80	25	6
69 – 102	B2	0.08	0.76	2.68	76.12	6.77	10.1	4
102 – 200	B3	0.06	0.7	2.78	78.54	5.47	1.7	4
PEDON 12 FARM SETTLEMENT, ORIN EKITI								
0 – 10	A	0.06	0.78	5.48	86.71	5.71	130.2	17
10 – 50	B1	0.08	0.92	1.20	54.53	6.45	48	4
50 – 70	B2	0.06	0.7	0.93	55.14	6.67	13.9	73
PEDON 13 IFAKI EKITI								
0 – 20	A1	0.04	0.56	1.69	73.85	4.62	177.6	3
20 – 35	A2	0.02	0.94	2.03	67.93	1.57	79.2	3
35 – 90	B1	0.12	1.16	1.71	57.26	7.99	76	3
90 – 175	B2	0.04	0.88	2.03	68.84	3.42	30.5	3

Sustainable Soil Management Practices for Ido-Osi Soils

Arising from the evaluation of the physical and chemical properties of pedons, the following limitations were observed and accompany sustainable soil management were suggested**:**

1. Poor soil physical characteristics and low fertility were observed in pedons 1, 2, 3, 4, 5, 6, 7, 11 and 13. Suggested sustainable management area: i) Protection of soil aggregate through the use of minimum soil disturbance and maintaining organic matter cover on the soil. (ii) Minimizing soil disturbance by mechanical tillage to reduce physical soil problems such as compaction. Also planting directly to untilled soil in order to maintain soil organic matter, soil structure and overall soil health.

   (iii) Enhancing and maintaining organic nutrient cover on the soil surface, using crop residues or cover crops. This protects the soil surface, conserves water and nutrient, promote soil biological activity. (iv) Diversification of species (both annual and perennial) in association, sequences and rotations that can include trees, shrubs, pastures and crops. This will also contribute to enhanced crop nutrition and improved crop resilience. (v) Use of well adapted high yielding varieties and good quality seeds. (vi) Enhanced soil nutrition based on soil health. (vii) Integrated soil fertility management. This according to Ogunkunle, 2015 is a set of soil fertility management practices that include the use of fertilizer, organic inputs and improved germplasm with the knowledge to adopt these practices to local conditions, aiming at optimizing agronomic use efficiency of the applied nutrients and improving crop production.
2. Soil acidity and presence of concretions in pedons 8 and 9. (i) Management practices that can be adopted in improving performance of crops on acid soils are liming, gypsum application and the use of an adequate rate of fertilizers and organic manures. (ii) the use of acidity tolerant crop species or cultivars within species is another important strategy in improving crop yields on such soils. (iii) Minimum tillage is recommended because of the presence of concretions in these pedons. Soils with plinthite and concretions must always be under cover to prevent serious erosion.
3. No limitation was observed in pedon 10. Sustainable land management practices should be employed to maintain the present soil quality of this pedon through appropriate management practices that will enable land users to maximize the economic and social benefits from the land while maintaining or enhancing the ecological support functions of the land resources.
4. Wetness (water logging) in pedon 12. The management practices that can be used to ameliorate water logging stress include the use of flood tolerant varieties, adjusting management practices, improving drainage by construction of bunds and ridges.
5. Erosion in pedon 2, 3, 8 and 9. Some of the sustainable land management techniques used with a view to reducing erosion damages are: (i) contouring – this entails making sure that cropping follows contour lines. Soil clods and small hollows must be perpendicular to the slope, so that the eventual runoff sheet is slowed as much as possible. (ii) Contour Ridging – The ridges are set perpendicular to the greatest slope so that the furrows can hold a considerable amount of water containing suspended sandy or loamy solids. (iii) Buffer strip cropping - The strips are effective in the case of light or medium rainstorms and can quickly become water logged under exceptional rainfall. They act as filters slowing down the runoff flow. The leafy plants provide good cover on erosion control strips, particularly natural fallow plants. Also, the presence of pulses with tap root and large, deep rooting

perennial grasses improves infiltration. (iv) Natural or artificial mulching – Preventing destruction of the structure of the surface horizon, according to Ogunkunle (2015) the formation of slaking crusts is some of the achieved by this technique. (v) Cover plants – this is another good way of erosion control on slopes. It slows down the rate of runoff on the slope.

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