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Classification and Spatial Variability Assessment of Selected Soil Properties along a Toposequence of an Agricultural Landscape in Nigeria

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Abstract

This study characterize, classify and evaluates the function of topography on spatial variability of some selected soil properties to assist in designing land management that support uniform agricultural production. The study site, an agricultural land, was part of the derived savanna zone in southwest Nigeria. Four soil profile pits each were established along two delineated toposequence and described following the FAO/UNESCO guidelines. Samples were collected from the identified genetic horizons. Properties of four soil series developed on different positions of the two delineated Toposequence viz upper, middle, lower slopes and valley bottom positions respectively were studied. The soil samples were analysed for selected physical and chemical properties and data generated were subjected to descriptive and inferential statistics. The results showed that soil colour, depth and texture varied in response to changes in slope position and drainage condition. The sand content ranged from 61 to 90% while the bulk density ranged between 1.06 g cm^{-3} to 1.68 g cm^{-3}. The soils were neutral to very strongly acid with low total exchangeable bases. Available phosphorus value were low while the extractable micronutrient concentration varied from low to medium. Soils of Asejire and Iwo series mapped in the study area were classified as Typic isohyperthermic paleustult, Apomu series as Plinthic iso-hyperthermic paleustult and Jago series as Aquic psamment (USDA Soil Taxonomy). These soils were correlated as Lixisol, Plinthic Lixisol and Fluvisol (World Reference Based), respectively. Major agronomic constraints of the soils associations mapped in the study area were nutrient availability, nutrient retention, slope, drainage, texture, high bulk density and shallow depth. The study concluded that the soils were not homogenous, shows moderate spatial variation across the slope, had varying potentials for sustainable agricultural practices, and thus, the agronomic constraints should be carefully addressed and managed for precision agriculture.

Key Words: delineated, taxonomy, paleustults, aquic, horizons

Introduction

Landscapes evolve in response to external forces, such as tectonics and climate, which influence surface processes of erosion and weathering (Dixon et al. 2009). It has been reported Smyth and Montgomery (1962) that on a landscape context, the soil properties reflect a combination of characteristics inherited during erosional evolution of the landscape.

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This is as a result of pedological processes acting on the present surface. The relative importance of these processes was considered to vary within the same landscape segments because different soil types have been noticed to be associated with different part of the landscape due to different exposure to pedogenetic processes such as eluviation, illuviation, deposition, cementation of pedisediments, and multiple stratification (Ande 2011). Soil is a dynamic and heterogeneous material that changes continuously both in time and space. This is due to the soil forming factors and processes that operate at different intensities and to soil management practices (Oyedele and Amusan 2000). Quantitative evaluation of soil resources and their responses to management practices require reliable information on the genesis, spatial and temporal variability of soil properties.

Spatial variations of soil properties refer to the variation in soil over horizontal distance as a result of various factors which are Bed/ parent rock, parent materials, climate, vegetation, topography/ relief as well as from human activities (Olorunlana 2014). With growing interest in the landscape perspective to address diverse environmental, ecological and agricultural issues, an adequate understanding of soil variability as a function of space and time becomes essential (Lin et al. 2005).

Characterisation and Classification based on the assessment of spatial distribution of soil properties are important drivers in the advancement of land use planning of a farm (Brevik et al. 2016). It serves as effective tools in site specific nutrient management (Vasu et al. 2017), reclamation of salinity and boron toxicity (Sürücü et al. 2013; Budak and Günal 2015). It supports best management decisions such as selection of the appropriate fertilizer dose, application methods and frequency, improvement of soil drainage (Mali et al. 2016; Rosemary et al. 2017) and monitoring of soil quality changes in time (Paz-Ferreiro and Fu 2016).

The soils in the semi-arid regions of West Africa are highly weathered, well-drained and low in soil nutrients and organic matter (Zougmoré 2003). Increasing pressure on land has necessitated continuous cropping, which has exposed the soils to nutrient deficiencies (Bationo et al. 2003). Consequently, increasing crop production on these soils is only possible with appropriate soil amendment and crop management practices. To date, studies on soil property variability in general which could assist in designing land management that seeks to reduce the extremes of land productivity and support more uniform agricultural production and, especially, the extent to which this variability can be spatially correlated are scanty in SW Nigeria, leaving the study area with no reliable information about the soils property variability despite been agrarian community with greater prospect in food production to alleviate hunger in the region. The objective of the study therefore, is to characterize, classify and assess the variability of some selected soil properties from an agricultural land (farm Settlement) in the derived savanna zone of southwest Nigeria with a view to assist in designing land management that support uniform and sustainable agricultural production over a long period.

Materials and Methods

Description of the study area

The study site is approximately 3.0 ha in Ilora agricultural settlement of Afijio Local Government area of Oyo State (Fig. 1). A part of the region underlain by the Precambrian Basement complex rocks in Southwestern Nigeria (Rahaman 1988), located approximately at 7°48'00"N 3°54'00"E within the derived savanna agro ecological zone. Agriculture is the main land use in the area, and the major agricultural crops are cacao, maize, cassava, yam, water melon and varieties of pepper. The area is characterized by equatorial climate with dry and wet seasons and relatively high humidity. Average daily atmospheric temperature ranges between 25°C and 35°C almost throughout the year. The peak of the

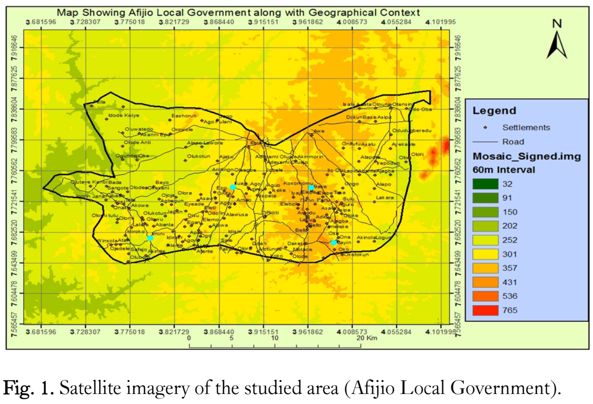

Fig. 1. Satellite imagery of the studied area (Afijio Local Government).

maximum is usually between February and March (33.8/35.0°C) just before the onset of rains while the lowest minimum temperatures are between July and August (25.0/27.9°C) during the peak period of rainfall (FMANR 1990) (Fig. 2).

Sampling procedures

Guided by the base map, the free method of soil survey, taking into account the geological and geomorphological parameters was used on the field for the identification of the soil units (Fig. 3). Observations were based on soil-landscape relationship as established by Smyth and Montgomery (1962). Eight (8) standard profile pits were established along two toposequence in line with the number of soil units and physiographic positions observed at the location using the procedures outlined by Agyare (2004). Detailed morphological descriptions of the identified genetic horizons of each soil profile pit was carried out following the FAO/UNESCO (2006) guidelines to support the mapping of the spatial distribution. Soil samples were collected from the identified genetic horizons from each of the established soil profile pits. The soil samples collected were bagged, labelled and taken to the laboratory for processing and analysis using standard procedures for soil analysis. Samples were also collected with the use of soil core sampler for bulk density determination (Blake and Hartge 1986). Data generated from the analyses were subjected to descriptive and inferential statistics. The relationship between soil parameters was explored using spearman correlation coefficient.

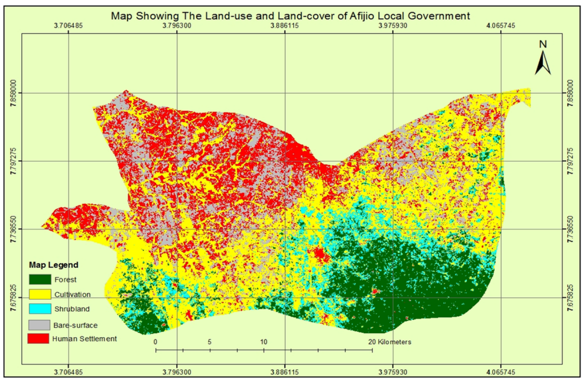

Fig. 2. Unsupervised land use and land cover classification of the studied area.

Results and Discussion

Soil morphology and landform relationship in the study area

The summary of the important morphological characteristics of the soils identified at the various landscape positions on the toposequences is presented in Table 1. The soils along the toposequences in the area were derived from coarse-grained granite, gneisses and pegmatites which are very extensive in southwestern Nigeria, with associated soils grouped as Iwo Association (Smyth and Montgomery 1962). Soil series along the toposequences established were Asejire (upper slope), Iwo (mid slope), Apomu (lower slope) and Jago series (valley bottom).

The colour and texture of the soils changed in response to changes in slope position and drainage condition down to Jago series in the location. The soils that occupied the higher topographical sites were well drained with sandy loam topsoil overlying sandy clay loam to sandy clay subsoil. This is a phenomenon that is applicable to virtually all the pedons under investigation.

The reddish hue of the sub-soils of the Pedons at the up-

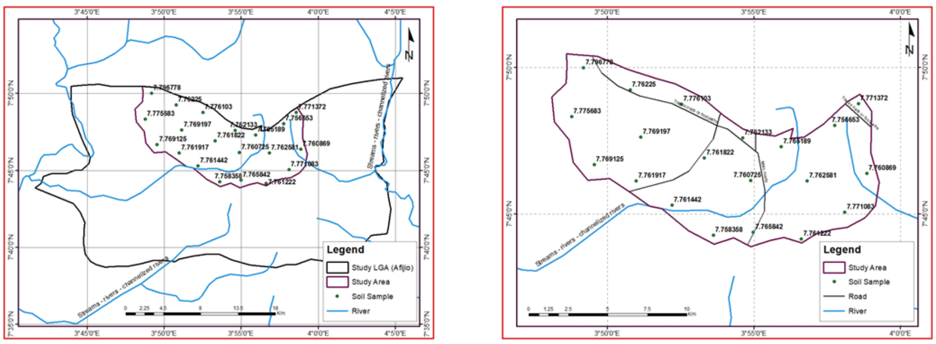

Fig. 3. Clipped shape file of the study site showing sampling points.

Table 1. Morphological description of the soils along a toposequence in the studied area

Horizon	Depth (cm)	Colour moist	Texture[t]	Structure[x]	Consistence[y]	Concretions[b]	Boundary[z]	Notes
				Profile 01 (Upper slope) Asejire series				
Ap	0-25	2.5 YR 3/2	SL	2 msbk	Mnstnplvfr	Vfgr	Irb	Abundant very fine, fine, and few medium roots
AB	25-45	2.5 YR 4/4	SCL	2 mcsbk	Mnstnplvfr	Frstgr	Cs	Abundant fine, medium roots and few coarse roots
Bt1	45-90	10 R 4/4	SC	2 msbk	Fmsstfrspl	Frstgr	Gw	Few fine and medium roots
Bt2	90-130	5 YR 4/8	SC	3 psbk	Sstsplfr	Frstgr	Cs	Very few fine roots
BC	130-185	10 YR 6/8	SC	3 psbk	Msstsplfr	Frstgr	Cs	Devoid of roots
				Profile 02 (Mid slope) Iwo series				
Ap	0-20	10 R 4/3	SL	2 cmsbk	Mnstnplfr	Vfst	Cw	Abundant fine, medium to coarse roots
AB	20-60	2.5 YR 4/6	SCL	2 mcrsbk	Mnstnplfr	Vfrgrvfst	Cs	Common fine and very fine and few medium roots
Bt	60-95	2.5 YR 5/6	SC	2 msbk	Msstsplfr	Vfgr	Cs	Few fine roots
BC	95-160	10 YR 6/8	SC	2 mp	Msstspl	Vfrgrfst	Cs	Few gravels devoid of roots
				Profile 03 (Lower slope) Apomu series				
Ap	0-15	5 YR 4/2	SCL	2 msbk	Mnstnplfr	Vfst	Cs	Common coarse fine to medium roots
AB	15-50	7.5 YR 4/2	SCL	2 m1sbk	Mnstnplfr	Vfst	Ds	Abundant very fine and few coarse and medium roots
Bt	50-90	5 YR 4/3	SC	2 msbk	Mfrsstspl	Frgr	Ds	Common medium and coarse roots
BC	90-160	5 YR 5/6	SC	2 msbk	Mvfrvstspl	Vfgrrd	Ds	Medium to fine prominent mottles, weathered quartz stones with few patchy cutans
				Profile 04 (Valley bottom) Jago series				
Ap	0-11	7.5 YR 2/0	SCL	2 mcrsbk	Sstnp	-	Cw	Common medium frequent fine roots
AB	11-35	7.5 YR 2/2	SC	2 msbk	Sstspl	Fgr	As	Common medium frequent fine roots
Btg	35-60	10 YR 6/4	SC	1 msbk	Fmstpl	Fgr	Gw	Frequent medium and few fine roots
				Profile 05 (Upper slope) Asejire series				
Ap	0-11	7.5 YR 4/4	SL	2 msbk	Mnstnplvfr	Vfgr	Irb	Abundant very fine, fine, and few medium roots
B1	11-50	5 YR 4/4	SCL	2 mcsbk	Mnstnplvfr	Vfgr	Cs	Abundant fine, medium roots and few coarse roots
B2	50-95	7.5 YR 6/8	SC	2 msbk	Fmsstfrspl	Frstgr	Gw	Few fine and medium roots
BC	95-170	10 YR 6/8	SC	3 psbk	Sstsplfr	Frstgr	Cs	Very few fine roots
				Profile 06 (Mid slope) Iwo series				
Ap	0-20	5 YR 3/3	SL	2 cmsbk	Mnstnplfr	Vfst	Cw	Abundant fine, medium to coarse roots
B1	20-60	5 YR 4/3	SCL	2 mcrsbk	Mnstnplfr	Vfrgrvfst	Cs	Common fine and very fine and few medium roots
Bt	60-95	5 YR 4/6	SC	2 msbk	Msstsplfr	Vfgr	Cs	Few fine roots
BC	95-160	10 YR 6/8	SC	2 mp	Msstspl	Vfrgrfst	Cs	Few gravels devoid of roots

Table 1. Contiuned

Horizon	Depth (cm)	Colour moist	Texture[t]	Structure[x]	Consistence[y]	Concretions[b]	Boundary[z]	Notes
Profile 07 (Lower slope) Apomu series								
Ap	0-15	5 YR 4/2	SCL	2 msbk	Mnstnplfr	Vfst	Cs	Common coarse fine to medium roots
AB	15-50	7.5 YR 4/2	SCL	2 m1sbk	Mnstnplfr	Vfst	Ds	Abundant very fine and few coarse and medium roots
Bt1	50-90	5 YR 4/3	SC	2 msbk	Mfrsstspl	Frgr	Ds	Common medium and coarse roots
Bt2	90-160	5 YR 5/6	SC	2 msbk	Mvfrvstspl	Vfgrrd	Ds	Medium to fine prominent mottles, weathered quartz stones with few patchy cutans
Profile 08 (Valley bottom) Jago series								
Ap	0-15	10 YR 4/3	SCL	2 mcrsbk	Sstnp	-	Gw	Common medium frequent fine roots
AB	15-60	2.5 YR 4/4	SCL	2 msbk	Sstspl	Fgr	Gw	Common medium frequent fine roots
Bt1	60-100	2.5 YR 5/6	SC	1 msbk	Fmstpl	Fgr	Gw	Frequent medium and few fine roots
Btg	100-120	10 YR 7/4	SC	1 m	Fmvstvpl	Nd	-	Common medium roots merging into a water saturated layers

Texture[t]: SC, sandy clay; SL, sandy loam; SCL, sandy clay loam; L, loamy; LS, loamy sand; C, clay; CL, clay loam. Structure[x]: 1, weak; 2, moderate; 3, strong; cr, crumb; sbk, subangular blocky; abk, angular blocky; p, platy; vf, very fine; f, fine; m, medium; c, coarse. Consistence[y]: m, moist; w, wet; vfr, very friable; fr, friable; fm, firm; vfm, very firm; nst, non sticky; sst, slightly sticky; vst, very sticky; st, sticky; npl, non plastic; spl, slightly plastic; pl, plastic; vpl, very plastic. Boundary[z]: a, abrupt; c, clear; g, gradual; d, diffuse; s, smooth; w, wavy; ir, irregular; b, broken; ND, not determined. Concretions[b]: vf, very few; f, few; fr, frequent; gr, gravel; st, stone; rd, rounded; bd, boulder.

per slope, mid-slope and the lower slope areas of the toposequences which is an indication of good drainage, may be due to the presence of hematite (Kantor and Schwertmann 1974; Day et al. 1987; Schwertmann 1993). As moisture condition increases and drainage becomes poorer down the landscape, hue becomes yellower. Similar colour changes from upper slope to valley bottom were reported by Fagbami (1981), and Okusami and Oyediran (1985). The decrease in redness of poorly drained soils can be attributed to increasing hydration of iron (Torrent and Barrón 1993). The soils were clayey in nature and this could be ascribed to the nature of the parent rock and their susceptibility to weathering (Smyth and Montgomery 1962; Ojanuga 1975). The Pedons were moderately deep with horizon boundaries that were not easily discernable being either diffuse or gradual and either irregular or wavy. These indicated a good degree of relationship between one horizon and the next and an evidence of advanced weathering. The sub-soils have probably passed through a process of re-organization, homogenization and illuviation which resulted into the formation of stronger structure and well expressed B-horizon with associated characteristics like clay skin (Ojanuga 1978). The soils have moderate, medium granular or sub-angular blocky structure in the surface horizons and weak, coarse, blocky to moderate medium sub-angular blocky structure in sub-surface horizons.

Ogunwale et al. (1975) noted that the presence of iron stone gravels *in-situ* in residual upland soils as observed in some of the profiles suggested that there had at one time been conditions favourable for the segregations of iron possibly in the form of plinthites. This process requires an adequate supply of iron, alternating wet and dry seasons, a relatively flat land surface with seasonally wet soils such as occur in the study area.

Physical properties of the soils

Table 2 show the particle size distribution and bulk density data of the soils. The soil texture across the toposequence varied from sand to sandy loam for surface horizons. The B and C-horizons have sandy clay loam texture. The sand content ranged from 61 to 90% and decreased with increasing depth except at certain depths where the BC-horizon contained more of sand as in Pedons 03 and 04. Amusan (1991) attributed the higher content of sand in the surface

Table 2. Physical properties of soils (Afijio local government, Ilora farm settlement)

Horizon	Depth (cm)	Total sand (%)	Silt (%)	Clay (%)	Silt/clay ratio	Bulk density (g/cm^3)	Textural class
Profile 01 (Asejire series)							
Ap	0-25	88	08	04	2.00	1.06	Sand
AB	25-45	86	08	06	1.33	1.54	Loamy sand
Bt1	45-90	84	06	10	0.60	1.59	Loamy sand
Bt2	90-130	81	06	13	0.46	1.62	Sand
BC	130-185	73	07	20	0.35	1.65	Sandy clay
Profile 02 (Iwo series)							
Ap	0-20	90	06	04	1.50	1.01	Sand
AB	20-60	76	04	20	0.20	1.57	Sandy loam
Bt	60-95	67	06	27	0.22	1.63	Sandy clay loam
BC	95-160	61	14	25	0.56	1.68	Sandy clay loam
Profile 03 (Apomu series)							
Ap	0-15	90	08	02	4.00	1.34	Sand
AB	15-50	86	10	04	2.50	1.42	Loamy sand
Bt	50-90	90	04	06	0.67	1.45	Sand
BC	90-160	73	03	24	0.13	1.65	Sandy clay loam
Profile 04 (Jago series)							
Ap	0-11	75	19	06	3.17	1.54	Sandy loam
AB	11-35	80	14	06	2.33	1.48	Loamy sand
Btg	35-60	92	06	02	3.00	1.30	Sand
Profile 05 (Asejire series)							
Ap	0-11	88	10	02	5.00	1.04	Sand
B1	11-50	88	08	04	2.00	1.51	Sand
B2	50-95	78	04	18	0.22	1.58	Sandy loam
BC	95-170	65	09	26	0.35	1.58	Sandy clay loam
Profile 06 (Iwo series)							
Ap	0-20	88	08	04	2.00	1.02	Sand
B1	20-60	88	07	05	1.40	1.46	Sandy loam
Bt	60-95	71	05	24	0.21	1.59	Sandy clay loam
BC	95-160	75	10	15	0.67	1.65	Sandy clay loam
Profile 07 (Apomu series)							
Ap	0-15	90	08	02	4.00	1.29	Sand
AB	15-50	88	08	04	2.00	1.34	Loamy sand
Bt1	50-90	86	10	02	5.00	1.41	Sand
Bt2	90-160	86	10	04	2.50	1.58	Sandy clay loam
Profile 08 (Jago series)							
Ap	0-15	86	12	02	6.00	1.51	Sandy loam
AB	15-60	86	10	04	2.50	1.44	Sandy clay loam
Bt1	60-100	82	12	06	2.00	1.43	Sandy clay
Btg	100-120	82	14	04	3.50	1.39	Sandy clay

horizon to the translocation of colloidal clay particles deep into the profile with percolating water and selective erosion and transportation of fine particles to the lower slope position during heavy downpour.

An outstanding feature of these soils irrespective of their location on the topography is their low to moderate silt content at the surface. This characteristic, according to Fasina et al. (2007) distinguished the soils of granite and gneiss rock complex origin from other soils of southwestern Nigeria. The silt content ranged from 03 to 19%, although the value fluctuated within all the pedons with increasing depth. Generally, the silt content was low, a characteristic which the soils shared with most Nigerian soils (Ojanuga 1975). Mbagwu et al. (1983) and Okusami and Oyediran (1985) reported that most of the soils derived from basement complex in southwestern Nigeria had low silt content. The clay content ranged from 02 to 27%. The clay content increased generally with depth to a maximum (probably due to illuviation/eluviation interplay) and then decreased in the BC horizon. The lower clay content in the surface horizon could be attributed to the sorting of soil material by biological and agricultural activities, clay migration or surface erosion by run-off or a combination of these (Malgwi et al. 2000). The subsurface horizons in all the profiles had more clay than the surface horizons and it increased with depth. The trend in particle size distribution as observed followed those of earlier researchers (Akinbola et al. 2006; Udo et al. 2009). Soil bulk density (Table 2) values obtained ranged from 1.06 g cm^{-3} in the Ap horizon to 1.68 g cm^{-3} in the subsoil horizon. Usually, soils with low bulk density are known to be associated with high total porosity, while root penetration becomes a problem when bulk density exceeds 1.6 g cm^{-3} (Payne 1988). Generally, the bulk density value increased with depth to a maximum except at the valley bottom where the trend fluctuates. There is appreciable variation among and within the soils in bulk density value within the studied area and this could be ascribed to differences in mineralogy, clay content and structural development (Fasina et al. 2007). Plants perform best in bulk densities below 1.4 and 1.6 g cm−3 for clayey and sandy soil respectively (Miller and Donahue 1990). Root growth could be inhibited due to high bulk density because of soil resistance to root penetration, poor aeration, slow movement of nutrients and water and build-up of toxic gases as well as root exudates as reported by Odunze (2006). However, the surface soil of the study area do not appear to offer any resistance to root penetration or growth.

Chemical properties of the soils

Table 3a, b show the chemical properties of the pedons studied. The pH of the soils studied fall within the neutral to very strongly acid class (Soil Survey Staff 2006), with pH (H_2O) values ranging from 4.8 to 6.8 and the pH (1M KCl) from 3.5 to 5.3. Generally, the pH decreased with increasing soil depth except in certain occurrences as observed in all the pedons except pedon 06 in transect 2 where sudden increase in pH was observed at the sub soils and followed no definite pattern. The surface horizons of all the pedons were medium to slightly acid (pH 5.1-6.0), while B and C-horizon were strong to very strong acid with pH values ranging from 4.8-5.8.

The pH in 1M KCl was lower than the pH in water (H_2O), thus the difference in soil pH values between the pH in KCl and H_2O (as expressed by $\triangle$pH=pH (KCl)-pH (H_2O)) were all negative ranging from -0.2 to -1.8 in all the pedons investigated. This suggests the dominance of silicate clay minerals over oxides (Van Raij et al. 1972).

Generally, there was higher accumulation of bases in the surface horizon of the soils 2.39-2.85 cmol (+) kg^{-1} and the total exchangeable bases decreased with soil depth except in some cases owing to nutrient biocycling and could also be due to differential weathering that had taken place or as a result of plant uptake and leaching losses. Like in most tropical soils, the exchangeable sites of the soils studied were dominated by exchangeable calcium and sodium.

The exchangeable calcium of the soils of Asejire series varied from 1.19 to 1.90 cmol/kg, Iwo series from 1.41 to 1.90 cmol/kg. In Oba series, calcium varied from 1.43-2.60 cmol/kg while in Jago series, it varied from 1.22-2.38 cmol/kg. The calcium and magnesium content fluctuated irregularly with soil depth and across the slope. Exchangeable sodium (Na^+) and potassium (K^+) are low (Table 3a, b) with values ranging from 0.20 to 0.72 cmol (+) kg^{-1} and 0.02 to 0.38 cmol (+) kg^{-1} respectively. These low values indicated that the soils under investigation developed from materials that are either low in K^+ and Na^+ content or have been exhausted by plant uptake or leaching due to their mobility within the soil. The higher values obtained at the surface

Table 3a. Chemical properties of soils along transect 1 (Afijio Local Government, Ilora farm settlement)

Horizon	Depth (cm)	pH H_2O	pH KCl	ΔpH	EC (dS/m)	Ca^{2+}	Mg^{2+}	K^+	Na^+	OM (%)	Al^{3+}	H^+	TEB	ECEC	Base sat.	Al.sat.	Total N	Avail.P	Mn	Co	Fe	Cu	Zn
						(cmol/kg^{-1})					(cmol/kg^{-1})				(%)				(mg/kg)				
Profile 01 (Upper slope) Asejire series																							
Ap	0-25	5.9	4.1	-1.8	1.19	1.43	0.38	0.11	0.47	0.67	0.4	0.2	2.39	2.79	85	1	0.13	17.58	0.30	11.92	280.00	4.40	0.48
AB	25-45	6.1	4.8	-1.3	0.40	1.90	0.43	0.13	0.43	0.34	0.2	0.3	2.89	3.09	94	6	0.09	20.45	0.40	11.66	254.00	4.60	0.36
Bt1	45-90	6.1	4.8	-1.3	0.56	1.19	0.77	0.19	0.72	0.6	0.3	0.3	2.87	3.17	90	9	0.09	21.97	0.50	12.32	292.00	3.30	0.38
Bt2	90-130	5.9	4.8	-1.1	1.00	1.43	0.28	0.19	0.47	0.4	0.7	0.3	2.37	3.07	77	23	0.05	19.60	4.20	11.75	310.00	0.90	0.51
BC	130-185	5.8	4.7	-1.1	1.41	1.66	0.36	0.23	0.47	0.4	1.4	0.6	2.72	4.12	66	34	0.05	18.08	7.20	12.01	272.00	0.40	0.44
Profile 02 (Mid slope) Iwo series																							
Ap	0-20	5.1	4.1	-1.0	1.05	1.43	0.48	0.19	0.54	1.68	0.4	0.2	2.64	3.04	87	13	0.09	22.47	3.10	12.49	300.00	5.20	1.31
AB	20-60	4.8	3.5	-1.3	0.63	1.67	0.39	0.15	0.47	1.41	0.4	0.3	2.68	3.08	87	13	0.10	20.79	2.40	2.05	278.00	2.60	0.39
Bt	60-95	4.8	3.6	-1.2	1.44	1.90	0.05	0.21	0.47	1.27	0.1	0.4	2.63	2.73	96	4	0.06	25.18	3.70	2.22	278.00	0.80	0.42
BC	95-160	5.2	3.6	-1.6	0.38	1.67	0.36	0.09	0.40	1.41	0.4	0.3	2.52	2.92	86	14	0.05	17.07	5.70	3.27	328.00	4.50	0.37
Profile 03 (Lower slope) Apomu series																							
Ap	0-15	5.8	5.2	-0.6	0.62	1.67	0.36	0.09	0.40	2.01	0.4	0.3	2.52	2.92	86	14	0.08	22.31	0.70	1.82	292.00	6.00	0.86
AB	15-50	5.5	5.0	-0.5	0.44	2.60	0.54	0.15	0.43	2.01	0.3	0.3	3.72	4.02	93	8	0.07	31.77	0.50	3.87	294.00	5.40	0.59
Bt	50-90	6.0	5.0	-1.0	0.52	2.14	0.70	0.27	0.47	1.34	0.2	0.2	3.58	3.78	95	5	0.05	20.28	9.50	2.97	294.00	3.20	0.43
BC	90-160	5.1	4.3	-0.8	0.99	1.43	0.49	0.11	0.47	1.01	0.2	0.3	2.50	2.70	93	7	0.06	21.46	6.70	3.67	322.00	3.70	0.39
Profile 04 (Valley bottom) Jago series																							
Ap	0-11	5.1	4.9	-0.2	0.41	1.66	0.34	0.07	0.40	2.68	0.3	0.2	2.47	2.67	93	7	0.11	18.93	4.80	4.03	542.00	6.30	1.07
AB	11-35	5.6	4.8	-0.8	0.54	1.66	0.43	0.15	0.47	1.27	0.3	0.2	2.71	2.91	93	7	0.09	19.60	11.70	4.23	390.00	7.10	0.37
Btg	35-60	5.4	4.9	-0.5	0.93	1.44	0.39	0.11	0.40	1.01	0.5	0.3	2.34	2.54	92	8	0.05	18.59	5.00	5.08	364.00	7.00	0.31

Table 3b. Chemical properties of soils along transect 2 (Afijio Local Government, Ilora farm settlement)

Horizon	Depth (cm)	pH H_2O	pH KCl	ΔpH	EC (dS/m)	Exchangeable bases Ca^{2+} (cmol/kg)	Mg^{2+}	K^+	Na^+	OM (%)	Exchangeable acidity Al^{3+} (cmol/kg)	H^+	Sum of bases	ECEC	Base sat.(%)	Al.sat. (%)	Total N (%)	Avail.P	Extractable micronutrients Mn (mg/kg)	Co	Fe	Cu	Zn
Profile 05 (Upper slope) Asejire series																							
Ap	0-11	5.8	4.9	-0.9	0.67	1.66	0.36	0.17	0.47	0.87	0.4	0.2	2.66	3.06	87	13	0.14	20.45	1.50	5.38	386.00	5.70	0.69
B1	11-50	5.8	4.6	-1.2	0.90	1.90	0.59	0.17	0.47	0.94	0.2	0.3	3.13	3.33	94	6	0.10	21.29	1.60	5.74	386.00	2.50	0.51
B2	50-95	5.6	3.9	-1.7	0.54	1.90	0.57	0.38	0.47	0.94	0.3	0.3	3.32	3.62	92	8	0.10	26.87	6.40	5.36	548.00	3.20	0.37
BC	95-170	5.6	3.9	-1.7	0.35	1.90	0.46	0.17	0.40	1.01	0.7	0.3	2.93	3.63	81	19	0.07	21.80	1.60	4.80	396.00	3.00	0.40
Profile 06 (Mid slope) Iwo series																							
Ap	0-20	6.0	5.3	-0.7	0.43	1.66	0.51	0.13	0.43	1.93	0.4	0.2	2.73	3.13	87	13	0.13	19.94	2.20	5.83	512.00	2.20	1.06
B1	20-60	5.6	4.7	-0.9	0.96	1.43	0.43	0.13	0.40	1.27	0.4	0.3	2.39	2.79	86	14	0.10	23.32	15.00	6.47	368.00	2.90	0.59
Bt	60-95	5.3	4.1	-1.2	0.91	1.43	0.34	0.07	0.43	2.15	0.1	0.4	2.27	2.37	96	4	0.10	37.69	5.10	7.85	346.00	2.20	0.33
BC	95-160	5.2	4.1	-1.1	0.41	1.41	0.34	0.06	0.26	1.22	0.4	0.3	2.07	2.47	84	16	0.06	24.45	8.14	6.70	356.00	2.10	0.44
Profile 07 (Lower slope) Apomu series																							
Ap	0-15	5.9	4.8	-1.1	1.17	1.90	0.33	0.15	0.47	1.88	0.4	0.3	2.85	3.25	88	12	0.14	28.54	5.00	6.49	338.00	1.00	0.71
AB	15-50	4.8	3.6	-1.2	0.48	1.66	0.56	0.17	0.43	1.07	0.3	0.3	2.82	3.12	90	10	0.10	34.98	11.50	7.43	350.00	1.20	0.22
Bt1	50-90	5.3	3.6	-1.7	0.62	1.43	0.51	0.13	0.40	0.95	0.3	0.2	2.47	2.67	93	15	0.10	26.34	11.50	8.43	354.00	1.20	0.28
Bt2	90-160	5.1	3.6	-1.5	1.06	1.43	0.49	0.14	0.20	1.54	0.3	0.3	2.26	2.46	92	8	0.05	21.45	11.60	6.34	346.00	1.10	0.24
Profile 08 (Valley bottom) Jago series																							
Ap	0-15	5.7	4.5	-1.2	0.60	1.66	0.31	0.13	0.40	0.94	0.7	0.4	2.50	2.70	93	7	0.13	21.33	1.50	9.49	482.00	0.50	1.05
AB	15-60	5.7	4.3	-1.6	0.35	1.43	0.34	0.11	0.43	0.74	0.8	0.3	2.31	2.51	92	8	0.10	23.32	5.80	11.19	430.00	0.60	0.37
Bt1	60-100	5.8	4.1	-2.0	0.49	2.38	0.31	0.21	0.36	1.01	0.7	0.2	3.26	3.46	94	6	0.06	29.24	6.50	9.89	444.00	1.50	0.42
Btg	100-120	5.8	4.5	-2.3	0.52	1.22	0.46	0.38	0.36	0.54	0.9	0.4	2.42	2.72	89	1	0.05	18.25	1.00	10.43	534.00	0.20	0.30

horizon of the pedons could be attributed to higher organic matter content. However, the values fluctuated irregularly down the soil profile. The exchangeable bases of the soil are generally low. Similar results have been reported by Fasina et al. (2007). The values of Exchangeable Sodium Percentage (ESP) in all the soils are generally low ($<15\%$), the critical limit for sodicity (Brady and Weil 2004). The soils are therefore not sodic.

The soil organic matter (SOM) content ranged from 0.67 to 2.68% in the surface horizon of the soils under investigation and decreased generally with increasing soil depth. The SOM of the subsurface horizons were from 0.34 to 2.15%. Sobulo and Adepetu (1987) classified percentage SOM into low (0-1.5%), medium (1.5-2.5%) and high ($>2.5\%$). The SOM content was higher in the soil surface than the subsoil, possibly as a result of more decomposable plant materials on the surface soil (Akinbola et al. 2006), and that the surface horizons are the points where decomposition and humification of organic materials take place. The organic matter content of the entire soils studied was generally low, mostly less than 2% except in some instances where higher values were obtained probably due to effect of pedoturbation in the subsoil and movement of the organic materials from one section of the topography to another part that lead to eventual deposition by erosion at the valley bottom. The low organic matter obtained may be partly due to the effect of high temperature and relative humidity which favour rapid mineralization of organic matter (Fashina et al. 2007). It might also not be unconnected with the degradative effect of cultivation and other land use and management activities that tend to destroy much of the organic materials that could have been added to the soil.

Exchangeable acidity values ranged from 0.1 to 1.4 cmol (+) kg^{-1} soil. All the pedons examined showed little variation in the exchangeable acidity (Al^{3+} and H^{+}) and the values were almost uniform with soil depth. Exchangeable Al^{3+} accounted for a greater percentage of the total acidity which implies that if the soil is not properly managed, further increase in Al^{3+} will lead to aluminium toxicity which will eventually hindered nutrients availability to plant.

Effective cations exchange capacity (ECEC) was generally low with values ranging from 2.37 to 4.12 cmol (+) kg^{-1} soil. There were higher values in most of the surface horizons of all the soils examined than in the sub-soil, probably due to the influence of organic carbon on the exchange sites of the soils. However, in those profiles where higher values were noticed in the sub-soil, it could be due to the process of pedoturbation either by fauna or flora. Kadeba and Benjaminsen (1976) observed that low ECEC values were consistent with low organic carbon content of soils especially in the B-horizons and probably with the kaolinitic nature of the soils clay. In most of the pedons examined, the ECEC values decreased with increasing soil depth. Effective cation exchange capacity (ECEC) of the soil are generally from low to medium according to Esu (1987) rating of <6=low, 6-12 medium and >12=high. The low ECEC values indicate that the soil have low potential for retaining plant nutrients, hence the necessity for adequate soil management.

The soil total nitrogen level is critically low with all the values less than 1 g/kg. The total nitrogen of the surface soils were from 0.08 to 0.14%, and subsurface soils were from 0.05 to 0.10%. Sobulo and Adepetu (1987) classified percentage total Nitrogen into low ($<0.10\%$), medium (0.10-0.20%) and high ($>0.20\%$). The probable reasons for low value of nitrogen in the soils may be due to rapid rate of soil organic matter decomposition, high rate of leaching and loss to soil erosion (Solarin and Ayolagha 2006). Similar results of very low to low N values have been reported by Fasina et al. (2007) for some soils in southwestern Nigeria. The total nitrogen values of the soils in the area changed irregularly with depth and this could be attributed to influence of continuous cultivation, a common practice on Nigerian soils caused by crop residues removal (Noma et al. 2011).

The Extractable Micronutrients contents of the soils indicated that Copper (Cu) was 0.2 to 7.1 mg/kg, Iron (Fe) was 257.0 to 548.0 mg/kg, Zinc (Zn) was 0.22 to 1.31 mg/kg, Cobalt (Co) was 1.82 to 12.49 mg/kg and Manganese (Mn) was 0.30 to 15.00 mg/kg. The distribution of these elements down the soil profiles was irregular as observed from the two transect. The concentration of Fe and Cu was found to be higher in all the profiles examined, this could either be due to the mineral composition of the underlying rock and/or of the transported materials, uptake of essential nutrients by plant, leaching of exchangeable cations through heavy rainfall or by erosion or a combination of these factors. The higher values observed could be responsible

Table 4. Pearson correlation coefficients of the soils' physical and chemical properties at the studied area

	Sand	Silt	Clay	pH_1	pH_2	Ca^{2+}	Mg^{2+}	K^+	Na^+	OM	Al^{3+}	H^+	TEB	ECEC	Base sat.	Al.sat.	TN	Mn	Co	Fe	Cu	Zn	Ec
Sand																							
Silt	-0.11																						
Clay	-0.91**	-0.31																					
pH_1	-0.08	-0.24	0.17																				
pH_2	0.45**	0.01	-0.42*	-0.14																			
Ca^{2+}	-0.05	0.15	-0.01	0.14	0.12																		
Mg^{2+}	0.33	-0.21	-0.23	0.21	0.17	-0.01																	
K^+	-0.03	-0.31	0.16	0.55**	-0.04	0.17	0.28																
Na^+	-0.05	-0.37	0.20	0.09	0.24	-0.05	0.33	0.21															
OM	-0.03	0.27	-0.08	0.10	0.11	0.22	-0.08	-0.40**	-0.19														
Al^{3+}	-0.10	0.11	0.06	-0.08	0.11	-0.12	-0.21	0.27	-0.11	-0.45*													
H^+	-0.37*	-0.29	0.45**	0.11	-0.09	-0.12	-0.27	0.19	-0.03	-0.27	0.50**												
TEB	-0.06	-0.09	-0.02	0.31	0.20	0.83**	0.47**	0.48**	0.33	0.03	-0.14	-0.16											
ECEC	-0.06	-0.15	0.11	0.26	0.24	0.68**	0.36*	0.49**	0.83	-0.12	0.27	0.12	0.85**										
Base sat.	0.13	0.12	-0.18	0.08	0.09	0.22	0.15	-0.06	-0.04	0.29	-0.71**	-0.40*	0.21	0.34									
Al.sat.	-0.16	-0.07	0.18	0.07	0.06	-0.09	-0.11	-0.06	0.02	-0.15	0.56**	0.34	-0.12	-0.37*	0.86**								
TN	0.29	0.11	-0.33	0.10	0.16	-0.15	0.01	-0.23	0.27	0.20	-0.22	-0.32	-0.22	-0.11	0.16	-0.17							
Mn	0.03	0.14	-0.10	0.05	-0.28	-0.13	0.08	-0.04	-0.34	0.05	-0.08	-0.08	-0.16	-0.16	0.04	0.15	-0.20						
Co	0.24	-0.02	-0.22	-0.07	0.03	-0.36*	0.06	0.15	0.22	-0.56**	0.47**	0.17	-0.19	-0.02	-0.29	0.13	0.09	-0.13					
Fe	-0.02	0.38*	-0.14	0.40*	0.09	-0.04	0.02	0.27	-0.27	0.14	0.18	-0.15	-0.03	-0.14	0.21	-0.23	0.26	0.03	-0.03				
Cu	0.13	0.17	-0.18	0.02	0.37*	0.11	0.15	-0.30	0.18	0.33	-0.38*	-0.48**	0.12	0.01	0.17	-0.17	0.07	-0.17	-0.36*	-0.11			
Zn	0.26	0.15	-0.30	-0.10	0.43*	0.05	-0.13	-0.19	0.15	0.48**	0.02	-0.23	-0.01	0.03	-0.09	0.10	0.45**	-0.34	0.02	0.23	0.24		
Ec	-0.02	-0.40*	0.19	-0.11	-0.09	-0.20	-0.34	0.43	0.14	-0.09	0.07	0.39*	-0.24	-0.06	-0.27	0.17	-0.06	0.08	0.14	-0.43**	-0.20	0.02	

Significant at $*p \leq 0.05$, $**p \leq 0.01$.

OM, organic matter; TEB, total exchangeable bases; ECEC, effective cation exchange capacity; TN, total nitrogen; EC, electrical conductivity.

for the occlusion of some of the plants nutrient like phosphorus, thereby making it unavailable for plant uptake and could also be responsible for the lower exchangeable cations recorded from the soils under examination. With adequate soil management system, this can be taken care of. Apart from these two elements, the soil is presumed to have adequate level of other micronutrients for plant growth.

The electrical conductivity (EC) of the soils ranged from 0.35 to 1.44 dS/m. The values for EC were generally less than 2 dS/m in all the soils and this is an indication that the soils are neither saline nor sodic (Brady and Weil 1999). In general, when the soil EC exceeds 2.0 dS/m salt index, many plants experience stress due to salts (Hanlon et al. 1993).

Relationship between the soils' physical and chemical properties

Results from the correlation analyses of the physical and chemical properties of soils in the area (Table 4) showed that the sand content of the soils had negative and significant relationship with the silt, clay content and ECEC (r=-0.91; -0.11; and -0.06) implying that the more sandy the soil is, the lower the silt, clay content and the cation exchange capacity of the soil. The clay content showed a negative and significant relationship with the soils' pH in KCl, organic matter and BS (r=-0.42; -0.08; -0.18), this is an indication that most of the exchangeable basic cations will be adsorb to the surfaces of clay minerals thereby making them available for plant uptake. It also showed a positive relationship with ECEC and EC (r=0.11; 0.19), an indication that clay contributes significantly to the total bases and cation exchange capacity of the soil and its Electrical conductivity. However, the clay content showed a negative correlation with all the micronutrients studied Fe, Mn, Zn, Cu and Co (r=-0.14; -0.10; -0.30; -0.18; -0.22). The soils pH showed a positive relationship with BS (r=0.09), implying that at higher pH, the availability of basic nutrients such as Ca, Mg and K to plant increases with increasing base saturation. Soil pH also showed a positive relationship with ECEC (r=0.24) an indication that the soil pH will affect the availability of some mineral nutrient. ECEC showed a positive and significant relationship with Fe, Cu and Zn (r=0.09; 0.37; and 0.43 respectively). OM also showed a negative and significant relationship with Al^{3+} and Co (r=-0.45; -0.56) but a positive and significant correlation with Zn (r=0.48), this is an indication that these mineral nutrients are present in OM and it will be released upon mineralization. OM showed a positive and significant relationship with TEB, BS, N, Zn and Mn (r=0.72; 0.71; 0.52; 0.46; and 0.47), thus indicated that the more the OM contents in the soils, the more their availability.

Classification of the soils

Local system

The report of the soil survey work carried out by Smyth and Montgomery (1962) in the central western Nigeria was used as a reference for the local classification of the soils studied. The factors taken into consideration were the nature of the bedrock, form of parent material, physiographic position, drainage and soil morphological properties.

The soils in the studied area were derived from coarse grained granite gneisses and pegmatites which are the parent rock of soils of Iwo Association (Smyth and Montgomery 1962). Considering the results of the morphological, physical and chemical analysis together with the drainage condition and their physiographic position along the toposequence, Pedons 01 and 05 are classified as Asejire series, profiles 02 and 06 as Iwo series, profiles 03 and 07 as Apomu series while pedons 04 and 08 are classified as Jago series.

Taxonomic classification

All the pedons studied showed characteristic subsoil clay bulge with reported predominance of low activity clay, low ECEC at depth of 125 cm below the upper boundary of the kandic horizon and slightly acidic subsoil horizon (Soil Survey Staff 2010), thus all the pedons at the study area are placed into order Ultisol.

The profiles were mineral soils with low SOM content, high in colour values and chromas. The soils are dried for more than 90 cumulative days but less than 180. The moisture regime of upland soils of southwestern Nigeria has been classified as being ustic (Periaswamy and Ashaye 1982; Okusami and Oyediran 1985), therefore, the soils are in ustult suborder. Soil temperature regime in southwestern Nigeria has been reported as isohyperthermic (Amusan and Ashaye 1991) while the landscape is an old one that has remained geologically stable with ochric epipedon, hence pale and are typical for the profiles. Profiles 01, 02, 05 and 06 are therefore classified as Typic isohyperthermic paleustult while profiles 03 and 07 with plinthic material within 100 cm of the soil surface qualified as Plinthic isohyperthermic paleustult and profiles 04 and 08 (Jago series) as Aquic psamment in the USDA Soil Taxonomy (Soil Survey Staff 2006). However, in the FAO/UNESCO system of soil classification, profiles 01, 02, 05 and 06 were correlated as Chromic Lixisol due to the presence of argillic B horizon, reported to be low in CEC, base saturation with high chroma. Profiles 03 and 07 with plinthitic material are Plinthic Lixisol and profiles 04 and 08 as Fluvisol respectively.

Conclusion

The study was conducted to understand the genesis of the soils in the study area, characterize and classify the soils and assess the spatial variability of selected soil properties along the toposequaence of an agricultural landscape with a view to suggesting land management strategy for the sustainable production of the crops.

The study thus indicates clearly that the differences in topography, parent material, drainage and age (stage of weathering) have played important roles in the genesis of the soils and consequently their morphological, physical and chemical properties. On the other hand, the elemental compositions of the soils showed very little spatial variations in their chemical compositions which could indicate the fact that they are likely formed from similar parent materials. The small variations as observed were probably attributed to different degrees of weathering of the same parent rock. The major agronomic constraints of the soils of Iwo and Jago associations encountered from the study area in order of their severity were soil physical characteristics (s), nutrients availability (f), nutrient retention (n), slope (t), and the influence of their ecological regions. The major agronomic constraints of the soils of jago series were wetness (w) (poorly drained), texture (sandy loam), high bulk density (1.5 g/cm^3), shallow depth and fertility (low P and K).

In conclusion, the study showed that the soils are closely related but are not homogenous, the soils vary in their potentiality with different physiographic units for crops production. Pedogenesis in the study area was influenced by physiography resulting in different soil types on the landscape. The predominant pedogenetic processes that seem to have evolved the soils are hydrolytic weathering and leaching of bases, with lessivation, mobilization and immobilization of iron and cyclic change of climate as other dominant pedogenetic processes. This study, therefore, provided evidence for the need to adopt different management practices to suit each soil type at the different physiographic positions as indicated by the agronomic constraints to ensure sustainable use of the soil resources. Appropriate organic and inorganic fertilizers can be used to remedy nutrient shortages, other management measures, such as drainage, flood control, cross slope farming, and even subsoiling, might help to alleviate the major constraints to crop production in this location. For the good performance of various arable crops in the area, potassium (K) rich fertilizer and drainage methods should be encouraged as evidenced by the agronomic constraints.

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