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Classification and Suitability Assessment of Soils on a Fine Grained Biotite Schist Toposequence for Maize and Cassava Production in Ife Area, Southwestern Nigeria

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Results showed that the colour, depth and texture of the soils varied in response to changes in slope position and drainage condition. Soil colour ranged from reddish brown to dusky red (5YR 3/2-2.5YR 3/2) in the surface and yellowish red (5YR 4/8) to reddish yellow (7.5YR 6/6) in the subsoil. Texturally, the soils were sandy clay loam in the surface to sandy clay in the subsoil. The solum was moderately acidic to neutral (5.20 – 6.70) at the surface and strongly acidic to moderately acidic (4.40 - 5.70) in the sub soils. They are characterized by low exchangeable bases which were in the order Ca> Mg> Na> K irrespective of slope position with low to moderate organic matter. The effective cation exchange capacity of the soils was positively correlated with pH (0.52**), organic carbon (0.96**) and available P (0.64**). Bedrock thin section confirmed that the soils were derived from the weathering of the fine grained biotite gneisses and mica schist.

Soils along the toposequemce were described as ultisols (Order), ustult suborder and as Typic Kanhaplustults (Family level) soil taxonomy. The FAO-UNESCO soil legend equates all the soils under consideration as Luvisols.

The results of the actual (a) suitability evaluation showed that the soils are not presently suitable (NS) for commercial cultivation of maize, and cassava in their current condition. However, potential suitability of the soils were ranked moderately suitable (S2) for maize and soils of Olorunda and Oba series were rated marginally suitable for cassava while others still remain (NS) for cassava.

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.

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I. Introduction

Soil is a valuable non-renewable resource that exists throughout the World in a broad diversity. Different types of soil exhibit diverse behaviour and physical properties, provide essential support to ecosystems, human life and society (FAO, 2015). All activities that constitute the cycle of life including procreation and extinction, and adverse environmental events one way or the other relate to it. Therefore, it is important to maintain soil functions and qualities to sustain the ecosystem and the human being (De Groot *et al*., 2002; European Commission, 2006).

Knowledge about soil is fundamental to its utilization and management and therefore to the ecology and economy as a whole (Nkwunonwo and Okeke, 2013). Knowing the soil can be said to involve obtaining information about it, mapping and describing its varied features to suit different uses the resource is put to. It has been recognized that the quality of land suitability assessment and the reliability of land use decisions depend largely on the quality of soil information used to derive them (Salehi *et al*., 2003; Ziadat, 2007). However, studies have shown that there remain only a few landscapes on Earth which are currently in their natural state (Opeyemi, 2008). Due to anthropogenic activities, the Earth' surface is being significantly altered and the presence on the Earth of man and his use of land has had a profound effect upon the natural environment (Briney, 2008). As a result, vast transformations have occurred in the land use and land cover patterns as evidenced by persistent expansion in cultivated land, decrease in natural woodland and grassland in the world (Sumner and Miller, 1996). In the same vein, competition for land is becoming intense with the continuous rise in human population and urbanization with continuous use of land for agricultural activities year after year (Agyarko, *et al.,* 2014).

In recognition of the current global food crises, Nigeria currently pursues policy of expanding the land area under cultivation as well as intensifying crop productions by continuous cropping system of which certain arable crops due to their importance globally are included. Therefore, adoption of more sustainable strategies for the maintenance of soil fertility under such conditions becomes imperative to sustain crop yield.

The area under investigation falls under tropical rainforest zones of southwestern Nigeria and is characterized with a prolonged rainy season, resulting in high annual rainfall above 1400mm, thereby ensuring an adequate supply of water and promoting perennial tree growth. Of all the zones it contains the most valuable species of vegetation, economic cash crops and some principal staple food crops that include the selected crops Cassava and Maize. This zone therefore is very important in terms of food production and timber for construction and cabinet making (Oyenuga, 1967). In the same vein, the food sub-sector of Nigerian agriculture parades a large array of staple crops, made possible by the diversity of agro-ecological production systems, out of which Maize (*Zea mays*) and Cassava (*Manihot esculenta*) are among the most important food crops playing dominant roles in the rural economy of Southwestern (SW) Nigeria where the study area is located.

Maize is one of the most important cereal crop in Sub-Saharan Africa because of its usage that cuts across both human and livestock importance that thus, necessitated the need to improve on its production in Nigeria

Cassava belongs to the family of *Euphorbiaceae* and the genus *Manihot* and is an important root crop popularly grown in Sub-Saharan Africa more especially in the humid tropics. It requires a good amount of rainfall and humid climate with a temperature range of 25ºC to 29ºC. Cassava can grow in all types of soil but best grown in a well-drained sandy loam soil of average fertility. In Nigeria, there is an ongoing campaign for the use of cassava flour as a substitute for wheat flour in baking and bread- making in order to reduce reliance on wheat flour importation and therefore, increase dependence on local raw material. Increased production of the crop can only be enhanced when there is greater improvement on the understanding of the suitability of the area used for production. Therefore, a sound knowledge of the prevailing cropping systems and soil suitability potential in any agro ecological zone is pertinent to the generation of agricultural and food security policies for the country.

The present study is aimed at dwelling on the taxonomic classification, suitability evaluation, land use planning and managements of the soils occurring in the study areas for optimum production of the selected arable crops (Maize and Cassava) employing the use of parametric approach. The information obtained can further be extrapolated to many of those soils closely related in genesis, classification and geography.

II. Materials and Methods

a) The study area

The study area is located approximately between latitudes 7º 32´N and 7º 33´N and longitudes 4º 39´E and 4º 40´E. The site is about 2.5 km away from Kajola village, a suburb of the Obafemi Awolowo University (O.A.U.) Teaching and Research Farm (T&R-F) which is located within the schist belt of southwestern Nigeria (Rahaman, 1988). The site is in the same ecological zone (tropical rainforest) as Ile-Ife with hot, humid tropical climate having distinct dry and bimodal rainy seasons. The mean annual rainfall is about 1527mm and the mean monthly air temperature is approximately 31ºC. The wet season starts from mid-March to late October, and the bimodal rainfall pattern has peak periods in June/July and September/October. The dry season runs from early November to early March. The influence of the north-east trade wind, is felt in the study area as 'harmattan' (cold dry wind) between late December and early January (FMANR, 1990). Atmospheric temperature is moderately high throughout the year, with a low range between the monthly mean minimum and maximum temperatures. The peak of the maximum is usually between February and March (34.3-33.8ºC) just before the onset of rains while the lowest minimum temperatures are between July and August (27.1 - 27.9ºC) during the peak periods of rainfall. The area also records the following average monthly data: humidity 73.8%, and sunshine 6.6 hours. The wind speed was 114.6 km d^{-1} while potential evaporation is 4.36 mm d^{-1} (Meterological data bank, T&R-F, O.A.U., Ile-Ife, 2016). The mean monthly soil temperature at 50 cm depth in Ile-Ife, for June, July and August is 27.7ºC and for December, January and February is 29.4ºC. Since these differ by less than 5ºC, the soil temperature regime in the study area is isohyperthermic (Soil Survey Staff, 2006).

b) Vegetation and land use in the study area

The native vegetation was originally rainforest characterized by very tall, big trees and thick shrubs. However, as a result of human interferences, the vegetation now consists of admixture of bush regrowth, arable crop farms and tree crop plantations. In the study area, the crest (summit) and the shoulder are presently being used for arable crop cultivation (cassava (*Manihot spp)*; yam (*Discorea spp*); maize (*Zea mays*) and scattered banana/ plantain (*Musa spp.*). The upper slope area was cultivated to cocoa (*Theobroma cacao*), but was unkept and gradually transforming into secondary forest. The mid slope area was under bush fallow with mostly *Chromolaena odorata* and scattered oil palm (*Elaeis guinensis)*. The lower slope supported cocoa plantation inter-planted with cassava (*Manihot* *spp.*) and banana/ plantain (*Musa spp.*), while plantain/ banana (*Musa spp.*) and cocoa (*Theobroma cacao*) were grown in the valley bottom area.

c) The geology of the area under study

The study area is underlain by the Precambrian rocks which are part of what is collectively referred to as the basement complex of southwestern Nigeria (Smyth and Montgomery, 1962). The rocks of the area can be divided into two major groups: migmatite-gneiss-quartz complex and the Ife-Ilesa schist belt (Rahaman 1988), the study area was within the latter. The most important rock types in the schist belt are the mica schist, amphibolites, amphibole schist, and metamorphosed mafic to ultramafic rocks (Rahaman, 1988). Previous studies indicated the underlying rock in the study area as mica schist.

d) Field study

Guided by the geological map of the study area produced by the Department of Geology, O.A.U. Ile-Ife, a toposequence underlain by mica schist was selected for the study. The toposequence is slightly undulating with relatively flat top and is approximately 2.5 km southeast of Kajola village with an elevation of 295.9 m above mean sea level (amsl) at the crest and 268.6 m amsl at the valley bottom. The other physiographic positions were clearly identified and the upper slope, sedentary and hill-wash areas were 293.6 m, 283.5 m and 276.9 m amsl respectively.

Five (5) soil profile pits were established along the toposequence at different physiographic positions. All the pedons were described following the procedures in the guidelines for soil profile description (F.A.O. 2001) and horizon designations of the Soil Survey Staff (2006). Soil samples were collected from each of the identified genetic horizons for physical and chemical analyses in the laboratory. Undisturbed core soil samples were collected and used for bulk density determination.

e) Laboratory analyses

The soil samples meant for physical and chemical analysis were air dried, gently crushed in ceramic mortal with pestle and passed through 2-mm sieve to separate materials that were greater than 2-mm which was used for the laboratory analyses other than the bulk density determination

f) Physical analyses

The bulk density was determined by the core method as reported by (Blake and Hartge, 1986). The core samples were oven dried at 105°C in the laboratory and weighed at interval until constant weight was attained. Then the ratio of the mass of dried solid to the bulk volume of the soil that is, volume of the solid and pore spaces was determined as the bulk density.

The particle size distribution was evaluated by the modified Bouyoucos hydrometer method as reported by (Gee and Or., 2002) using 5% w/v sodium hexametaphosphate (calgon) as the dispersing agent.

g) Chemical analyses

The soil pH was determined both in distilled water and 1.0 M KCl (1:1 soil: solution ratio) using glass electrode pH meter (Kent model 720) after equilibration for 30 minutes (Thomas, 1996). The exchangeable bases (Ca, Mg, K and Na) were extracted with 1.0 M ammonium acetate (NH_4OAC) solution at pH 7.0 (Thomas and Throp, 1985). Calcium, Ca^{2+}, sodium, Na^+, and potassium, K^+ ions in the extract were determined with the use of flame photometer (Gallenkamp Model FH 500), while magnesium (Mg^{2+}) ion in the extract was determined by titration.

The exchangeable acidity was determined by extraction with 1.0 M KCl solution and titrated with NaOH and HCl solutions to measure total acidity (Al^{3+} and H^+) concentrations respectively (McLean, 1965) as reported by (Bertsch and Bloom, 1996). Effective cation exchange capacity (ECEC) was computed as the summation of NH_4OAC extractable bases (Ca^{2+}, Mg^{2+}, Na^+ and K^+) and KCl extractable aluminium (Al^{3+}) (Soil Survey Staff, 2008). The organic carbon was determined by the Walkley Black method as reported by (Nelson and Sommers, 1996), and the available phosphorous by Bray No. 1 method as reported by (Kuo, 1996).

h) Statistical analyses

Correlation coefficients and simple regression analysis between the selected soil properties were calculated. All statistical analyses were carried out using SAS 9.1 version (2002-2004) software programme.

i) Land suitability evaluation

The aim was to evaluate the land and soil resources of the study area with particular reference to genesis, ecological and agronomic aspects, which was carried out using parametric approach. Land characteristics recognizable on the field were combined with those determined in the laboratory and were rated according to their importance to make the preferred land qualities used as the basis of assessment for each crop. The land characteristics that were selected for the rating were those that have been found to contribute to the growth and yield of maize and cassava.

j) Land qualities/ characteristics

The following land qualities/characteristics were used as basis for assessment in the parametric approach for maize and cassava suitability.

(i) Climate: annual rainfall, mean temperature (c)
(ii) Soil physical characteristics: soil depth, texture, clay content (s)
(iii) Wetness: drainage (w)
(iv) Topography: slope percent (t)
(v) Nutrient availability (f): pH, N, P, K, Mn, Fe, Cu, Zn

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(vi) Nutrient retention capacity (n): organic matter, base status and effective cation exchange capacity (ECEC).

Maize and cassava were put into suitability classes based on their respective land requirements in relation to their land characteristics and qualities.

k) Application of the ratings

The land characteristics (LC) for each soil type was matched with the land use requirements for maize and cassava. Suitability classes were then derived from the matching.

Land indices were calculated before converting them to suitability classes using the equation as developed by Storie (1978):

$$S_i = A \times \frac{B}{100} \times \frac{C}{100} \ldots \frac{n}{100}$$

Where;

S_i = Index of suitability

A = Index of the most limiting characteristic

B = Index of topography

C = Index of moisture availability

n = Index of nth characteristic

The index of suitability (S_i) would then be converted to suitability class using Sys (1978) conversion table.

Index 75-100 = S1 (Highly suitable)

50-75 = S2 (Moderately suitable)

25-50 = S3 (Marginally suitable)

<25 = NS (Non suitable)

Table 1a: Land requirements and suitability classes for rainfed maize production

Land characteristics	SI1 100	SI2 95	S2 85	S3 60	N1 40	N2 25
Topography (t)						
(a) Slope (%)	0-2	2-4	4-8	8-16	16-20	>20
(b) Slope (%)	0-4	4-8	8-16	>16	-	-
Moisture availability (c)						
Total rainfall during the growing season (mm)	800-1200	700-800	600-700	500-600	<500	-
Oxygen availability (w)						
Drainage	Good	Moderate	imperfect/rapid	poor/very excess	poor but drainable	poor but not drainable
Nutrient availability (0-20cm) (f)						
Total N (%)	>0.15	0.08-0.15	0.08-0.04	0.02-0.04	<0.02	any less
Avail P (mg/kg)	>22	13-22	6-13	3-6	<3	any less
Extractable K (meq/100g soil)	>0.5	0.3-0.5	0.2-0.3	0.1-0.2	<0.1	Any
Mn (mg/kg)	>20	15-20	12-15	5-12	<5	Any
Zn (mg/kg)	>15	12-15	8-12	3-8	<3	Any
Cu (mg/kg)	>10	6-10	4-6	1-4	<1	Any
Nutrient retention capacity (n)						
(c) ECEC (meq/100g soil)	>15	10-15	5-10	3-5	<3	Any
(d) ECEC (meq/100g clay)	>24	16-24	8-16	<8	-	-
Base saturation						
(c) (%)	>80	30-50	35-50	20-50	<20	-
(d) (%)	>70	50-70	35-70	<35	-	-
Organic matter						
(c) (%)	>3	1-3	0.8-1	0.4-0.8	<0.4	-
Physical soil characteristics						
Texture/structure Gravel	CL	SC, SCL, L	SL, LS	LS, fS	Cm, S, cS	-
(ac) (%)	<15	15-40	40-60	60-75	75-90	>90
(b) (%)	<40	40-75	75-80	80-90	>90	-
(e) (%)	<20	20-40	40-75	>75	-	-
Soil depth (cm)	>90	50-90	30-50	20-30	10-20	<10
Bulk density (g/cm^3)	<1.0	1.0-1.21	1.22-1.51	1.51-1.63	1.63-2	>2

a = mechanized; b = non-mechanized; c = AP or A horizon, d = B or sub horizon; CL = clayloam; S = sand; SC = sandy clay; SCL = sandy clay loam; L = loam; cS = coarse sand; SL = sandy loam; LS = loamy sand; fS = fine sand; Cm = massive clay. Source: Oluwatosin and Ogunkunle (1991)

Table 1b: Land requirements and suitability classes for cassava production

Land qualities	Sl1 100	Sl2 95	S2 85	S3 60	N1 40	N2 25
Climate (c)						
Annual rainfall (mm)	>1000	900-1000	800-900	600-800	500-600	<500
Temperature (°C)	>25	22-25	20-22	18-20	16-18	<16
Topography (t)						
Slope (%)	<2	2-4	4-8	8-16	16-20	>20
Drainage (w)						
Wetness	WD	MWD	MD	ID	PD	PD
Soil physical properties (s)						
Texture	L	LS	SCL	SC	S	-
Gravel (%)	<10	10-20	20-30	30-40	>40	-
Soil depth (m)	>100	80-100	60-80	50-60	35-50	<35
Nutrient availability (f)						
Ph	>8	7-8	4.5-7	3.5-4.5	<3.5	-
Total N (%)	>0.15	0.08-0.15	0.04-0.08	0.02-0.04	<0.02	-
Avail P (mg/kg)	>15	10-15	8-10	5-8	3-5	-
Extract. K (cmol/kg)	>0.25	0.20-0.25	0.15-0.20	0.10-0.15	<0.10	-
Cu (mg/kg)	>5	1-5	0.3-1	0.1-0.3	<0.1	-
Mn (mg/kg)	>250	100-250	10-100	5-10	<5	-
Fe (mg/kg)	>120	100-120	10-100	1-10	<10	-
Zn (mg/kg)	>50	5-50	1-5	0.5-1	<0.5	-
Nutrient retention (n)						
Organic matter (%)	>4	3-4	2-3	1-2	<1	-
ECEC (cmol/kg)	>15	10-15	5-10	3-5	<3	-
Base saturation (%)	>80	50-80	35-50	20-35	<20	-

WD = Well Drained; MWD; = Moderately Well Drained; ID = Imperfectly Drained; PD = Poorly Drained; L = Loamy; SC= Sandy clay; LS =Loamy sand; S = sand; SCL =Sandy Clay Loam.

Source: Ande 2011.

III. Results and Discussion

a) *Soil morphology and landform relationship*

The summary of the important morphological characteristics of the soil types identified on the landscape positions on the toposequence is presented in Table 2. The soils along the toposequence are derived from fined-grained biotite gneisses and schist and are very extensive in southwestern Nigeria, the parent rocks are very easily weathered and give rise to very deep soils. Similar soils overlying same rock types were grouped as Egbeda Association by Smyth and Montgomery (1962). Soils of Egbeda Association are found on gently undulating topography, and the sequence of soils along such topography is Egbeda, Olorunda, Makun, Oba and Jago series from the crestal (upper slope) position to the valley bottom (Smyth and Montgomery, 1962). The colour and texture of the soils changes in response to changes in slope position and drainage condition down to Jago series. The soils that occupied the higher topographical sites were well drained with sandy loam topsoil overlying clay to clay loam subsoil. These are typified by Pedons 01 to 04 of the toposequence and are Egbeda, Olorunda, Makun and Oba series. The colour varies from dark reddish brown (5YR 3/2) moist at the upper soil layers to yellowish red (5YR 4/8) in the subsoil. Roots are concentrated in the upper 50 cm but were found all through the profile in various degree of composition. Iron stones and concretions occur very frequently throughout the pedons.

Table 3: Field morphological description of the soils studied.

Horizon	Depth (cm)	Colour Moist	Texture[t]	Structure[x]	Consistence[y]	Concretions[b]	Boundary	Notes
Profile 01 Egbeda series								
Ap	0-18	5YR 3/2	SL	2mcsbk	Nstnplvfr	Cfrgr	cs	Abundant very fine, fine, and few medium roots
AB	18-24	10YR 4/4	SCL	2msbk	Nplfrnst	Cfrstgr	cs	Abundant fine and medium roots
B	24-51	2.5YR 4/4	SC	2msbk	Sstfrspl	Cfrstgr	gw	Few fine and medium roots
BC	51-70	5YR 4/8	SC	3psbk	Sstsplfr	Cfrstgr	cs	Very few fine roots
Profile 02 Oloronda series								
Ap	0-18	5YR 3/3	SCL	Cmsbk	Sstsplfr	Vfgr	cs	Abundant fine, medium to coarse roots
AB	18-28	2.5YR 4/4	SCL	2mcr	Sstsplfr	vfrgrvfst	ds	Common fine and very fine and few medium roots
B21	28-72	2.5YR 4/8	SC	1msbk	Nstnplfr	Vfgr	s	Frequent fine roots
B22	72-132	2.5YR 4/4	SC	2msbk	Sstspl	vfrgrfst	cs	Few gravels
BC1	132-185	5YR 4/6	SC	3csbk	Fmstpl	-	ds	Thick cutans of clay and iron oxides on ped
BC2	185-210	5YR 6/6	SC	3msbk	Vfr	-	-	Few mottles, frequent pieces of weathered rock, devoid of roots.
Profile 03 Makun series								
Ap	0-18	5YR 4/2	SCL	2msbk	Nstnplfr	-	cs	Common coarse fine to medium roots
BA	18-33	2.5YR 4/2, (5YR 5/6)	CL	2m1sbk	Sstspl	-	ds	Abundant very fine and few coarse and medium roots
B21	33-65	2.5YR 4/6 (5YR 5/6)	SC	2msbk	Frstpl	Frgr	Ds	Common medium and coarse roots
B22	65-120	2.55YR 4/6	SC	2msbk	Sstsplfr	Vfgrrd	Ds	Medium to fine prominent mottles, Weathered quartz stones with few patchy cutans
BC	120-200	5YR 4/6	SC	2msbk	Sstsplfr	Vfgrrd	-	Frequent quartz materials. Devoid of roots
Profile 04 Oba series								
Ap	0-20	7.5YR 4/2	SCL	2fcr	Vfrnstnpl	-	cs	Common medium frequent fine and few coarse roots
BA	20-40	5YR 4/6	SCL	2msbk	Frsstspl	Fst	cs	Few medium, common fine and few very fine roots
B1	40-71	2.5YR 4/6	SC	2msbk	Frsstspl	Vfgrvfst	ds	Few patchy cutans, common fine and medium roots
2BtC1	71-115	2.5YR 4/8	SC	2msbk	Vstspl	Vfgfst	gs	Few patchy cutans with stonelines, few medium to fine roots
2BC2	115-170	5YR 5/8	SC	2msbk	Frstpl	Vfrgfst	-	Few roots with frequent black hard concretions present.
					Profile 05	Jago series		
Ap	0-18	2.5YR 3/2	SCL	2mcr	Sstnp	-	gw	Common medium frequent fine roots
AB	18-40	2.5YR 4/4, (5YR 6/1)	SC	2msbk	Sstspl	Fgr	gw	Common medium frequent fine roots
B	40-60	2.5YR 4/6 (5YR 6/1)	SC	1msbk	Fmstpl	Fgr	gw	Frequent medium and few fine roots
Btg	60-75	7.5YR 6/6	SC	2f	Fmvstvpl	Nd	-	Common medium roots merging into a water saturated layers

The variation in soil colour among the soils was primarily due to differences in physiographic position of each profile and drainage condition of the soils. As moisture condition increases and drainage becomes poorer down the landscape, hues become yellower. Similar colour changes from crest to valley bottom were reported by (Okusami and Oyediran (1985). The soils are clayey in nature, this could be ascribed to the nature of the parent rock and their susceptibility to weathering (Smyth and Montgomery, 1962; Ojanuga, 1978). The pedons have horizon boundaries that are not easily discerned being either diffuse or gradual and either irregular or wavy. This indicates a good degree of relationship between one horizon and the next and an evidence of advanced weathering. 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. Morphologic observation suggested a lithologic break at $2BtC_1$ (71-115 cm) horizon in Pedon 04. This was corroborated by the differences in the sand fraction.

b) Physical properties of the soils

The soil texture varied from sandy loam to sandy clay loam for surface horizons except in Pedon 05 which has clay texture. The B and C-horizons have clay loam texture except in Pedons 03 and 04 that were more clayey in the B and BC horizons. The sand content ranged from 29 to 67 ±12.83% and decreased with increasing depth except at certain depths where the BC-horizon contained more of sand as in Pedons 03 and 04. The silt content ranged from 11 to 25 ±3.31%, although the value fluctuated within all the pedons with increasing depth. Generally, the silt content is low, a characteristic which the soils shared with most Nigerian soils (Ojanuga, 1978). The clay values ranged from 18 to 59 ±13.98% in the Bt horizons. The clay content increased generally with increasing depth to a maximum (probably due to illuviation/ eluviation interplay or possibly clay migration) and then decreased in the BC horizons. Similar trend was observed by Ojanuga (1978) in soils of Ife and Ondo areas of southwestern Nigeria. The bulk density varied with the structural conditions of the soils particularly those related to packing hence, it is often used as a measure of soil texture and structure (Hamblin *et al.,* 1988). Values obtained ranged from 0.74 g cm^{-3} in the Ap horizons to 1.7 g cm^{-3} in the Bt horizons. The higher values in surface soils are due to compaction (e.g pedons 02 and 03).

c) Chemical properties of the soils

Tables 5 show the chemical properties of the pedons studied. The soils studied fall within the neutral to very strongly acid class (Ojanuga, 1975; Landon, 1991; Soil Survey Staff, 2003), with pH (H_2O) values ranging from 5.6 to 7.0. The pH decreased with increasing soil depth except in Pedon 03 where no definite pattern was observed.

The pH (1M KCl) ranged from 4.4 to 5.7. Generally, the surface horizons of the pedons were medium to slightly acid (pH 5.2 - 5.7), while B and C-horizon were strong to very strong acid with pH values ranging from 4.4 - 5.7. The acid nature of the soil can be ascribed to high rate of leaching of bases which is prevalent in the humid tropics, and the acidic nature of the parent rock (granite-gneiss). The higher pH values observed at the soil surface horizons according to Fasina *et al.* (2005) might be due to liming effect of bush burning and bio cycling of nutrients.

Table 4: Physical properties of the soils on the toposequence that was studied

Horizon	Depth (cm)	Total sand	Silt	Clay	BD (g/cm^3)	Textural class
Profile 01 Egbeda series						
Ap	0-18	49	21	30	1.06	Sandy loam
AB	18-24	47	25	28	1.54	Sandy clay loam
B	24-51	31	11	58	1.62	Sandy clay
BC	51-70	29	13	58	1.59	Sandy clay
Profile 02 Olorunda series						
Ap	0-18	55	17	28	1.01	Sandy clay loam
AB	18-28	51	11	38	1.57	Sandy clay loam
B21	28-72	39	13	48	1.63	Sandy clay
B22	72-132	33	13	54	1.68	Sandy clay
BC1	132-185	35	17	48	1.73	Sandy clay
BC2	185-210	43	15	42	1.48	Sandy clay
Profile 03 Makun series						
Ap	0-18	55	17	28	1.34	Sandy clay loam
BA	18-33	51	15	34	1.42	Clay loam
B21	33-65	34	13	53	1.45	Sandy clay
B22	65-120	30	11	59	1.65	Sandy clay
BC	120-200	39	15	46	1.40	Sandy clay
Profile 04 Oba series						
Ap	0-20	57	15	28	1.54	Sandy clay loam
BA	20-40	39	13	48	1.48	Sandy clay loam
B1	40-71	31	11	58	1.30	Sandy clay
2BtC1	71-115	31	13	56	1.71	Sandy clay
2BC2	115-170	39	13	48	1.40	Sandy clay

Profile 05 Jago series						
Ap	0-18	67	15	18	0.74	Sandy clay
AB	18-40	65	13	22	1.21	Sandy clay
B	40-60	67	11	22	1.31	Sandy clay
Btg	60-75	65	15	20	1.13	Sandy clay

Table 5: Chemical properties of the soils studied

Horizon	Depth (cm)	pH (H_2O)	pH KCl	ΔpH	Exchangeable Bases				Exchangeable Acidity		Sum of Bases	ECEC	Base sat. (%)	Al. Sat. (%)	OM (%)	Avail. P (ppm)
					Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Al^{3+}	H^{+}						
Profile 01 Egbeda series																
Ap	0-18	6.9	6.0	-0.9	7.2	4.86	0.21	0.30	0.4	0.2	12.57	12.97	97	3	2.55	11.2
AB	18-24	6.8	5.4	-1.4	6.6	4.86	0.26	0.26	0.2	0.3	11.98	12.18	98	2	1.61	7.4
B	24-51	6.5	5.0	-1.5	6.7	4.10	0.25	0.30	0.3	0.3	11.30	11.60	97	3	1.21	3.4
BC	51-70	6.0	4.6	-1.4	5.8	3.20	0.20	0.24	0.7	0.3	9.44	10.10	93	7	1.07	3.2
Profile 02 Olorunda series																
Ap	0-18	6.5	5.3	-1.2	5.3	4.86	0.19	0.24	0.4	0.2	10.58	10.98	96	4	1.68	6.3
AB	18-28	6.4	5.0	-1.4	4.9	4.05	0.19	0.22	0.4	0.3	9.35	9.75	96	4	1.14	8.2
B21	28-72	6.2	5.0	-1.2	5.5	1.62	0.21	0.28	0.1	0.4	7.69	7.79	99	1	0.87	4.1
B22	72-132	6.1	5.0	-1.1	5.3	5.67	0.19	0.26	0.4	0.3	11.42	11.82	97	3	0.67	3.3
BC1	132-185	5.9	4.9	-1.0	5.3	4.05	0.20	0.26	0.1	0.3	9.81	9.91	99	1	0.60	3.0
BC2	185-210	5.6	4.8	-0.8	5.0	4.86	0.17	0.26	0.2	0.2	10.29	10.49	98	2	0.07	2.6
Profile 03 Makun series																
Ap	0-18	6.8	5.6	-1.2	4.0	7.29	0.14	0.22	0.4	0.3	11.64	12.04	97	3	1.54	8.4
BA	18-33	6.7	5.5	-1.2	4.9	4.05	0.19	0.24	0.3	0.3	9.38	9.68	97	3	0.94	10.5
B21	33-65	6.6	5.5	-1.1	5.3	1.62	0.21	0.30	0.2	0.2	7.44	7.64	97	3	0.94	7.0
B22	65-120	6.4	5.5	-0.9	4.1	6.48	0.14	0.20	0.2	0.3	10.91	11.11	98	2	0.87	5.8
BC	120-200	6.7	5.7	-1.0	3.1	10.53	0.11	0.22	0.3	0.2	13.96	14.26	95	2	0.40	3.2
Profile 04 Oba series																
Ap	0-20	6.4	5.2	-1.2	4.7	4.05	0.23	0.24	0.2	9.22	0.9	9.92	93	7	1.74	7.7
BA	20-40	6.2	4.8	-1.4	3.2	5.67	0.12	0.22	0.2	9.21	0.3	9.31	99	1	0.93	8.4
BC1	40-71	6.0	4.8	-1.2	2.2	5.67	0.08	0.24	0.2	8.19	0.3	8.29	99	1	0.67	5.8
2BtC1	71-115	5.8	4.6	-1.2	2.1	4.05	0.10	0.24	0.3	6.49	0.4	6.59	99	2	0.60	6.2
2BC2	115-170	5.6	4.4	-1.2	2.8	3.24	0.16	0.26	0.2	6.46	0.3	6.56	99	2	0.40	4.5
Profile 05 Jago series																
Ap	0-18	7.0	6.7	-1.3	1.5	4.86	0.08	0.15	0.2	6.59	0.6	6.99	94	6	1.74	6.9
AB	18-40	6.6	5.2	-1.4	1.9	4.86	0.08	0.24	0.3	7.08	0.6	7.38	96	4	0.74	8.9
B	40-60	6.5	5.0	-1.5	0.6	2.43	0.08	0.22	0.2	3.33	0.6	3.73	89	11	0.40	5.4
Btg	60-75	6.3	5.0	-1.3	1.5	2.43	0.08	0.21	0.2	4.22	0.6	4.62	91	9	0.13	5.2

Generally, there was higher accumulation of bases in the surface horizons 6.59 - 12.57 cmol(+)kg^{-1} of the soil, and the total exchangeable bases decreased with soil depth except in some cases owing to nutrient biocycling (Ajiboye and Ogunwale, 2010), and 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 magnesium. The low values K^{+} and Na^{+} 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 horizon of the pedons could be attributed to higher organic matter content (Ano, 1991). However, the values fluctuated irregularly down the soil profile. Exchangeable acidity values ranged from 0.3 to 1.0 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.

Effective cations exchange capacity (ECEC) was generally low with values ranging from 3.73 to 14.26 cmol (+) kg^{-1} soil. There were higher values in 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 as in Pedons 02 (B22) and 03 (BC) with more of clay content, this could be due to the process of pedoturbation either by fauna or flora. In all the pedons examined, the ECEC values decreased with increasing soil depth. The organic matter content of the surface horizons of the pedons under examination ranged from

1.54 to 2.55% and decreased with increasing soil depth. The sub-soil horizons were generally lower in organic carbon than the surface horizons of all the pedons examined. The reasons for this may be due to the fact 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 the surface horizon of Pedon 01. 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.,* 2006). It might also not be unconnected with the degradative effect of cultivation and other land use and management activities. In all the pedons examined, the exchangeable bases, ECEC, percent base saturation and organic matter contents were slightly higher in the surface horizons than in the sub-soils in general. Probable reason is that the surface horizons, although the most exposed to leaching and runoff, are indeed continuously recharged by phytocycling (Amusan and Ashaye, 1991).

Available phosphorous (P) contents of the soils varied from 2.6 to 11.2 ppm in all the horizons in the profiles with the highest values at the surface horizons, The relatively high concentration of the available P and organic carbon in the surface horizons may imply significant organic or biocycled P in the soils and also an indication that organic matter contributes significantly to the available phosphorus in these soils. The available P values are considered low at some horizons as they were below or only slightly above the 10 ppm critical limit recommended for most commonly cultivated crops in the area. The low value of available P might be due to the fixation of phosphorus by iron and aluminum sesquioxides under well drained and acidic conditions of the soils (Onyekwere *et al*., 2001; Uzoho and Oti, 2004).

d) Classification of the soils studied

i. Local system

The soils studied were classified based on the report of the soil survey work carried out by Smyth and Montgomery (1962), taken into considerations the nature of the bedrock, the form of parent material, physiographic position, soil colour, presence or absence of mottles, soil texture and general profile morphology. The soils on the toposequence studied were classified as Egbeda Association (Smyth and Montgomery, (1962). The parent rock is very easily weathered and gives rise to deep soils as observed in the pedons studied. Pedon 01 is classified as Egbeda series. Pedon 02 classified as Olorunda series. Pedon 03 as Makun series. Pedon 04 occupied gently sloping section of the lower slope area of the toposequence and are classified as Oba series and Pedon 05 as Jago series.

ii. Taxonomic classification

All the pedons observed showed increasing trend in clay content with soil depth to a certain level, a kind of trend that was indicative of argillic horizon. Low level of fertility as observed from the organic matter content and other soil mineral composition which are the two most important differentiating characteristics of the Ultisols.

The pedons studied are mineral soils with ochric epipedon, low in organic matter, high in colour values and chromas. The soils are dry for more than 90 cumulative days but less than 180. The upland soils of southwestern Nigeria is primarily under ustic moisture regime (Periaswamy and Ashaye, 1982), therefore, the soils are in Ustults suborder. Pedon 05 qualifies as Aqults because of the hydromorphic properties right from the soil surface and the gleyed subsurface horizons. The presence of Kandic horizons are established in most pedons because they meet the following requirements: coarse textured surface horizon over vertically continuous sub-surface horizons; ECEC values within the sub-surface B-horizons that are less than 12cmol(+)/kgclay; a regular decrease in organic carbon contents with increasing soil depth (Table 4) (Soil Survey Staff, 2003).

Soils of Pedons 01, 02, 03 and 04 have no evidence of hydromorphic properties within 125 cm of the mineral soil surface but have clay distribution such that the percentage clay decreased from its maximum by 20% or more within 125 cm of the mineral soil surface. These soils therefore, classify as Typic Kanhaplustults, they have ECEC of less than 12 cmol/kg soil. Soils of pedon 05 show evidence of redox depletion within 75 cm of the mineral soil surface and therefore, qualify as Aquic Haplustults. In the FAO-UNESCO soil legend, all the pedons under consideration qualify as Luvisols because of the presence of argillic horizon and humus surface horizon that is separated from the mineral horizon (Bruand *et al.,* 2004), a horizon eluviated of clay minerals and a horizon of at least 5 cm. thick with illuvial clays (Bruand *et al.,* 2004). The soils of pedon 03 and 04 classify as Plinthic Luvisols because of the presence of indurated coherent plinthite within 100 cm of the soil mineral surface. Soil of pedon 05 classifies as Gleyic Luvisols because of evidence of gleyic properties within 100 cm of the soil surface. The soils of pedon 01 and 02 classify as Eutric Luvisols because of the high base saturation (IUSS, 2006).

e) Suitability evaluation using parametric approach

The parametric approach attributes a numerical rating to the limitation as follows no limitation (highly suitable) as 100%, low limitation (highly suitable) as 95%, moderate limitation (moderately suitable) as 85%, severe limitation (marginally suitable) as 60% and very severe limitation (not suitable) as 40%, defined with regards to the type and intensity of the limitations. Soils were placed in classes according to their suitability for the production of selected crop. The determination of the scores for rating involved matching of land characteristics/land qualities and crop requirements to evolve suitability classes for the different mapping units in the area of study.

The assessment of the soils for crop production involved the use of properties that are permanent in nature and that cannot be changed or modified without exorbitant cost. Such properties include soil depth, slope, drainage, texture and amount of coarse fragments. These properties are known to constitute some kind of hindrance to crop production. Chemical properties that are usually considered (e.g. fertility) can be changed by minor improvement (Sys, 1985).

Table 6a: Land characteristics and quality of the study area for maize production

Land characteristics	Egbeda (1)	Olorunda (2)	Makun (3)	Oba (4)	Jago (5)
Topography (t)					
Slope (%)	7	6	4	2	2
Moisture availability (c)					
Rainfall during growing season(mm)	1200	1200	1200	1200	1200
Oxygen availability (w)					
Drainage	Good	Good	Good	Good	Imperfect
Nutrient availability (f)					
Total N (%)	0.12	0.13	0.12	0.10	0.12
Available P (mg/kg)	11.2	6.3	8.4	7.7	6.9
Extract. K (cmol/kg)	0.30	0.24	0.22	0.24	0.15
Mn (mg/kg)	12.60	14.66	12.11	11.89	9.56
Zn (mg/kg)	1.80	0.6	2.00	0.5	0.80
Cu (mg/kg)	393.05	399.82	333.15	383.58	332.36
Nutrient retention capacity (n)					
ECEC (0-20cm) (cmol/kg)	12.97	10.98	12.04	9.92	6.99
Base saturation (0-20) (%)	97	96	97	93	94
Base saturation (20-100) (%)	93	97	98	99	89
Organic matter (0-20) (%)	2.55	1.68	1.54	1.74	1.74
Physical soil characteristics (s)					
Textural class	SL	SCL	SCL	SCL	SC
Gravel (0-20cm) (%)	35	41	43	8	26
Soil depth	70	210	200	170	75

Tables 6b: Land characteristics and quality of the study area for cassava

Land characteristics	Egbeda (1)	Olorunda (2)	Makun (3)	Oba (4)	Jago (5)
Climate (c)					
Annual Rainfall (mm)	1200	1200	1200	1200	1200
Temperature (°C)	28	28	28	28	28
Topography (t)					
Slope (%)	7	6	4	2	2
Drainage (w)					
Wetness	Good	Good	Good	Good	Imperfect
Soil physical properties (s)					
Texture	SL	SCL	SCL	SCL	SC
Gravel (%)	35	41	43	8	26
Soil depth (m)	70	210	200	170	75
Nutrient availability (f)					
pH	6.9	6.5	6.8	6.4	7.0
Total N (%)	0.12	0.13	0.12	0.10	0.12
Avail. P (mg/kg)	11.2	6.3	8.4	7.7	6.9
Extract. K (cmol/kg)s	0.30	0.24	0.22	0.24	0.15
Cu (mg/kg)	393.05	399.82	333.15	383.58	332.36
Mn (mg/kg)	12.60	14.66	12.11	11.89	9.56
Fe (mg/kg)	396.12	523.01	322.64	338.26	257.28
Zn (mg/kg)	1.80	0.6	2.00	0.5	0.80
Nutrient retention (n)					
Organic matter (%)	2.55	1.68	1.54	1.74	1.74
ECEC (cmol/kg)	12.97	10.98	12.04	9.92	6.99
Base sat. (%)	97	96	97	93	94

Table 7a: Suitability evaluation of the soils for maize production using parametric approach

Soil Profile	Soil series name	Topography slope (t)	Drainage (w)	Moisture Avail (m)	Physical soil properties (s) Texture	Gravel	Soil Depth	Nutrient availability (f) N	P	K	Mn	Zn	Cu	Nutrient retention (n) ECEC	Base Sat	Organic Matter	Suitability Index	Class
1	Egbeda	85	100	100	85	95	95	95	85	95	85	40	100	95	100	95	15	NSa
		85	100	100	85	95	95	-	-	-	-	-	-	95	100	95	59	S2p
2	Olorunda	85	100	100	95	85	100	95	85	85	85	40	100	95	100	95	14	NSa
		85	100	100	95	85	100	-	-	-	-	-	-	95	100	95	62	S2p
3	Makun	85	100	100	95	85	100	95	85	85	85	40	100	95	100	95	14	NSa
		85	100	100	95	85	100	-	-	-	-	-	-	95	100	95	62	S2p
4	Oba	95	100	100	95	95	100	95	85	85	60	40	100	85	100	95	11	NSa
		95	100	100	95	95	100	-	-	-	-	-	-	85	100	95	69	S2p
5	Jago	95	85	100	95	95	95	95	85	60	60	40	100	85	100	95	7	NSa
		95	85	100	95	95	95	-	-	-	-	-	-	85	100	95	56	S2p

a = actual suitability when characteristics (f) is not corrected by fertilizer application.
p = potential suitability after the correction of characteristics (f) by fertilizer applicatio

Table 7b: Suitability evaluation of the soils for cassava production using parametric approach

Soil Profile	Soil series name	Topography slope (t)	Drainage (w)	Moisture Avail (m)	Physical soil properties (s)			Nutrient availability (f)							Nutrient retention (n)			Suitability	
					Texture	Gravel	Soil Depth	N	P	K	Fe	Mn	Zn	Cu	ECEC	Base Sat	Organic Matter	Index	Class
1	Egbeda	85	100	100	100	60	85	95	95	100	100	85	85	100	95	100	85	22	NSa
		85	100	100	100	60	85	-	-	-	-	-	-	-	95	100	85	35	S3p
2	Olorunda	85	100	100	85	40	100	95	60	95	100	85	60-	100	95	100	60	5	NSa
		85	100	100	85	40	100	-	-	-	-	-	-	-	95	100	60	16	NSp
3	Makun	95	100	100	85	40	100	95	85	95	100	85	85	100	95	100	60	10	NSa
		95	100	100	85	40	100	-	-	-	-	-	-	-	95	100	60	18	NSp
4	Oba	95	100	100	85	100	100	95	60	95	100	85	60	100	85	100	60	11	NSa
		95	100	100	85	100	100	-	-	-	-	-	-	-	85	100	60	41	S3p
5	Jago	95	60	100	60	85	85	95	60	85	100	60	60	100	85	100	85	3	NSa
		95	60	100	60	85	85	-	-	-	-	-	-	-	85	100	85	18	NSp

a = actual suitability when characteristics (f) is not corrected by fertilizer application.

p = potential suitability after the correction of characteristics (f) by fertilizer application.

The actual suitability implies the suitability of the soils for crop production in its present condition when correctable limitations (i.e. in this case nutrient availability – N. P, K, Mn, Cu, Fe, Zn) are not corrected. Potential suitability (p) assesses performance when fertilizers are added to correct fertility limitations during cropping. This presentation is necessary since the difference between actual and potential suitability is simply a management factor. Soils were placed in classes according to their suitability for the production of the selected crop.

The results of the actual (a) suitability evaluation showed that the soils are not presently suitable (N1) for commercial cultivation of maize, and cassava in their current condition. However, potential suitability of the soils were ranked moderately suitable (S2) for maize and soils of Olorunda and Oba series were rated marginally suitable for cassava while others still remain (N1) for cassava (Tables 7a, and b). The major agronomic constraints of these soils are physical characteristics, nutrient availability, nutrient retention and perhaps the topography in the order of severity.

Management practices that can improve these limitations should be employed. Such management practices are mulching to conserve moisture contents at the upper positions, organic materials or incorporation of plant residues into the soil to improve the soils fertility, vegetation covers to reduce erosion. Soils of Jago series in the study area could be considered for alternative uses.

IV. Conclusion

The study was conducted to assess the suitability of the soils of the study area for the sustainable production of maize and cassava using parametric approach with a view to characterizing the soils, produce their suitability classes for sustainable production of the selected crops and suggest land management strategy for optimum sustainable crop production.

The soil samples collected were subjected to routine analyses. The morphology, physical and chemical characteristics alongside the taxonomic and suitability classifications of the soils were determined to generate valuable information about the soils' properties, their management requirements and their agronomic constraints. The landscape selected for the study depicts a complete toposequence with all the physiographic positions clearly defined namely the crest, the upper slope, mid-slope/ sedentary, hillwash and valley bottom. The soils at the summit, upper, middle and lower slopes of the toposequence are well drained as evidenced by their reddish brown hues in the A-horizon and brighter hues in the subsoil B and C-horizons (2.5YR-10R). The soils at the valley bottom are poorly drained as shown by the water table closer to the soil surface and mottles within the sub-soil horizon.

The soils are predominantly ultisols according to Soil Taxonomy and are placed in ustults suborder. Soils of pedons 03 and 04 further classify as Typic Plinthustults. Pedons 01 and 02 classify as Typic Kanhaplustults while soils of pedon 05 are Aquic Haplustults. The FAO-UNESCO soil legend equates all the pedons under consideration as Luvisols. The soils of pedons 03 and 04 are Plinthic Luvisols, pedons 01 and 02 as Eutric Luvisols. and pedon 05 as Gleyic Luvisols.

The results of the actual (a) suitability evaluation showed that the soils are not presently suitable (N1) for commercial cultivation of maize, and cassava in their current condition. However, potential suitability of the soils were ranked moderately suitable (S2) for maize and soils of Olorunda and Oba series were rated marginally suitable for cassava while others still remain (NS) for cassava.

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 maize, cassava and rice 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.

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