Quest Journals
Journal of Research in Agriculture and Animal Science
Volume 9 ~ Issue 12 (2022) pp: 12-21
ISSN(Online) : 2321-9459
www.questjournals.org

Research Paper

Soil Characterization, Classification and Land Suitability Evaluation for Cocoa Production in Ijaka-Isale, Yewa North, Ogun State, Nigeria

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Abstract: *Sustainable crop production necessitates that potential and the nutrients level of the soils to be used should be evaluated. 20 acres of land was evaluated for cocoa production in Yewa North local government, Ogun state and the soils were classified according to the criteria of USDA Soil Taxonomy system and correlated with FAO World Reference Base for Soil Resources. Four soil mapping unit identified were classified as Alfisols and correlate as Lixisols. The surface horizons were slightly acidic in reaction while the sub soils were strongly acidic. The soils are deficient in macro and micro elements, their values were below the critical level required for optimum cocoa production. Suitability evaluation of the soils was carried out using parametric approach and the result showed that presently, the soils of mapping units A, B and C are marginally suitable (S3) while mapping unit D is presently not suitable for cocoa production. With the appropriate fertility management, the soils would be classified as moderately suitable (S2) for cocoa production.*
Keywords: *Cocoa production, land evaluation, soil classification*

R*eceived 24 Nov., 2022;* ***R****evised 05 Dec., 2022;* ***A****ccepted 07 Dec., 2022 © The author(s) 2022.*
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I. INTRODUCTION

Soil is one of the world's greatest valuable assets. It is an essential natural resource that sustains most of the planet's life, directly or indirectly and it is a fundamental need for civilizations to thrive, therefore needs to be treasured. Healthy soil is vital to blossoming agriculture. Hence, one of the tactics to accomplish sustainable agriculture in a sustainable environment is to examine soil properties and in particular through soil characterization and land evaluation for several land utilization types [1]. Pedological characterization provides valuable information and knowledge on soil characteristics and gives clear understanding of soil genesis, morphology, classification and spatial distribution of soils in an area [2]. The information gathered through pedological characterization is needed by soil fertility specialists to carry out fertilizer trials and establish meaningful fertilizer recommendations [3].

To solve the problem of food insecurity, modern agriculture demands that farmers have direct or indirect information on the potential and nutrients level of the soils to be used. Such knowledge assists the farmer to make informed selections of crops and/ or livestock to be reared that are precisely reasonable. This has given rise to the need for land suitability assessment before cultivation and other agricultural practices [4]. [5] stated that land suitability assessment (LSA) is the examination of a piece of land for its capability to sustain a specific agricultural use. Generally, LSA for agricultural purposes includes characterization of the biophysical and ecological characteristics of a location according to the agricultural potentials of the land. Basically, it encompasses accounting for the features of the land and matching them with the crop requirements in order to develop land - crop production suitability index in a spatially explicit manner. LSA encompasses evaluating the relative edaphic-ecological requirements of the crops with the spatial edaphic-ecological conditions of a particular location. The locations where the edaphic-ecological conditions amalgamate with the crop requirements will be acknowledged as suitable [6]. In order to have useful soil database allowing proper decisions for assessing the potentials and constraints of the soils for different uses and land management options such as fertilizer application, improved tillage methods as well as crops management systems, pedological characterization of the study area was carried out. The objectives of this study were to characterize, classify the soils of the study area and assess their suitability for cocoa production.

II. MATERIALS AND METHODS

2.1. Description of the study area

The study area is located in Fayena village, via Owode Ketu, Ijaka Isale, Yewa North Local Government, about 29 km from Igbogila town; within the tropical rainforest region of southwestern Ogun state, Nigeria. The mean annual rainfall recorded in the study area in the last 11 years is about 1636 mm, the mean minimum and maximum temperature is 15 and 33^{o} C respectively. Relative humidity, wind speed and wind direction are 86 %, 1.34 m/s and 214^{o} respectively [7]. Geographically, it lies approximately between latitude 7^{o} 8$'$57.8$''$N and longitude 2^{o} 55$'$58.5$''$E, on an altitude of 87.20 meters above sea level. The soil moisture regime is ustic while soil temperature regime of southwesthern Nigeria is iso-hyperthermic [8]. Figure 1 shows the location map of the study area.

2.2. Vegetation and Land use

The vegetation is presently mosaic of farmland and secondary forest regrowth. Generally, the study area was divided into four mapping unit based on the vegetation. Mapping unit A is presently being used for arable crop cultivation cassava (*Manihot spp*), Mapping unit B was characterized by scattered cocoa (*Theobroma cocoa*) and cashew (*Anarcadium occidentale*), Mapping unit C was uncultivated, part of it was gradually transforming to secondary forest, the rest was characterized with bush regrowth while Mapping unit D supported scattered mango, grapes and cassava.

2.3. Field study

Four profile pits were established on 20 acres of land assessed for cocoa production. The study area was divided into four mapping units (A, B, C, and D) based on the vegetation of the land and one profile pit was established on each mapping unit. The topography of the land is slightly undulating. The profile pits established were characterized according to the [9] procedures for soil profile description. The profile pits were described and documented on the field (Table 2). Soil samples were collected from the 15 identified genetic horizons. Multiple sub-sampling method was employed to guarantee representative of the samples. Soil samples collected were bagged, labeled and taken to the laboratory for physical and chemical analyses. The location of individual soil profile pit was recorded using geographical positioning system (GPS) device as in Table 1.

Map of Nigeria showing Ogun state Map of Ogun State showing Yewa North Local government

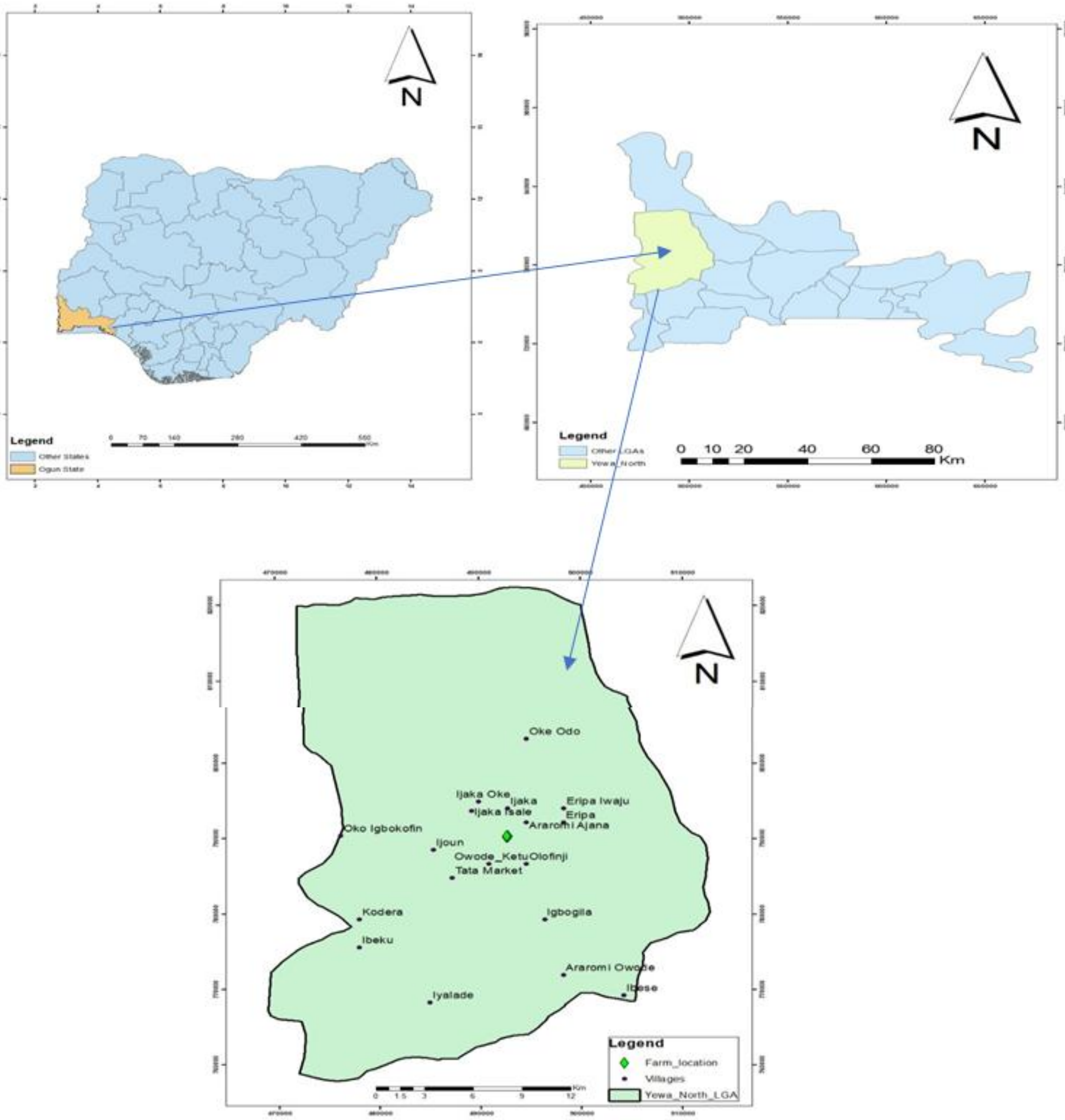

Figure 1: Location Map of the study area.

Table 1: Profile pit points and coordinates

Profile pit	Latitude	Longitude	Elevation
A	7° 8′56.3″N	2° 55′58.2″E	94.86 m
B	7° 8′57.7″N	2° 56′1.7″E	85.86 m
C	7° 9′0.9″N	2° 56′1.8″E	60.80 m
D	7° 8′1.3″N	2° 55′57.5″E	93.02 m

2.4. Laboratory analysis and soil classification

Soil samples collected were analyzed following the standard method. Soil texture was determined using the Bouyoucos hydrometer method [10]. Soil pH was determined in distilled water and 1.0 M KCl [11]. The cations (Ca, Mg, K, Na, Cu, Zn, Fe and Mn) were extracted with 1.0 M ammonium acetate (NH_4OAc) solution at pH 7.0. Exchangeable Ca and Mg Cu, Zn, Fe and Mn in the leachate were determined by atomic absorption spectrophotometer while exchangeable K^+ and Na^+ were determined by flame photometer. The organic carbon was determined by [12] method. The exchangeable acidity was determined by extraction with 1.0 M KCl solution and titrated with NaoH and HCl solutions to measure total acidity [13]. Available phosphorus was determined by Bray-1 method [14]. Total nitrogen by Kjeldahl method [15]. Soil classification was carried out according to the procedure of soil taxonomy [16] and correlates with World Reference Base for soil resources.

2.5. Suitability evaluation

The FAO framework for soil suitability evaluation was used for the study [17]. Land characteristics recognized on the field were combined with those determined in the laboratory to make the preferred land qualities which were used as basis for the land assessment. A numerical rating of the land characteristics in a normal scale from a maximum (normally 100) to a minimum value (20) was employed. If a land characteristic was optimal for the considered land utilization type, the maximal rating of 100 was attributed; if the land characteristic was unfavorable, a minimal rating of 20 was applied. The index of suitability (actual and potential) was calculated using the square root method:

$IP = A \times \sqrt{((B/100) \times (C/100) \times \ldots \times (F/100))}$.

Where:

IP = land index

A =overall lowest characteristic rating

B, C…F = lowest characteristics ratings for each land quality group [18].

III. RESULTS AND DISCUSSIONS

3.1. Morphological characteristics of the soil

The morphological characteristics of the soils of the study area is summarized and presented in the Table 2. The topography is gently sloping on 2-4 % slope gradient. Depth to water table were not encountered at any profile depth. Likewise, soil erosion hazard was not encountered at any part of the study area.

The soils of mapping unit A are very deep and well drained, depth to impenetrable layer and groundwater was not encountered at 160 cm. The colour of the soils ranges between brown (7.5YR 4/2) at the surface to reddish gray (5YR 5/6) at subsoil. The texture of the surface soils was silty loam and silty clay at sub soil. The soil structure included moderate to weak angular blocky. The soils are very friable when moist, slightly sticky and non-plastic when wet. The outline of the profile ranges from clear wavy to clear smooth boundary. Very few coarse roots are common at the surface soil and very fine common, very few, very fine roots at subsoil.

The colour of the soils of mapping unit B were dark reddish gray (5YR 4/2) at the surface and pinkish gray (7.5YR 7/2) to pink (7.5YR 8/4) at the subsurface layers. The texture of the surface soil was loam silty and silty clay at the subsoil while the soil structure is moderate to weak fine angular blocky. The soils are well drained and deep (128 cm).

Table 2: Soils morphological description

Horizon	Depth (cm)	Colour (moist)	Texture[a]	Structure[b]	Consistence[c] (moist/wet)	Boundary[d]	Root distribution
Profile pit A							
Ap	0-30	7.5YR 4/2	Sil	1fgr	m vfr w sst npl	cw	coarse, very fine very common roots
AB	30-50	7.5YR 6/2	Sil	1fabk	m fr w sst npl	dw	few coarse, very fine common roots
B2	50-76	5YR 5/4	Sicl	2msbk	m vfr w st npl	cd	very few, very coarse, very fine roots
Bt1	76-117	5YR 5/8	Sicl	1fabk	m vfr w st spl	cs	very few very fine roots
Bt2	117-160	5YR 5/6	Sicl	1fabk	m vfr w sst npl	ND	very few, very fine roots
Profile pit B							
Ap	0-14	5YR 4/2	lSi	1fcr	m fm w st pl	cs	very common, very coarse, very fine roots
AB	14-48	7.5YR 7/2	lSi	2mabk	m vfr w sst spl	wd	very few, few coarse, fine roots
Bt1	48-95	7.5YR 7/4	Sicl	2fabk	m vfr w sst npl	cs	very few very fine roots
Bt2	95-128	7.5YR 8/4	Sicl	1fsbk	m vfr w nst npl	ND	very few fine roots and few mottles

			Profile pit C			
Ap	0-21	7.5 YR 4/2	lSi	2mgr	m fm w sst spl	wd
common very fine, fine, very coarse roots						
AB	21-69	5YR 6/2	lSi	2msbk	m fm w sst spl	cw
very few very fine and coarse roots						
Bt	69-126	7.5YR 7/2	Sicl	1fcr	m fm w nst npl	ND
none						
			Profile pit D			
Ap	0-32	5YR 4/4	scl	2msbk	m fm w sst npl	aw
common very fine, medium and coarse roots						
Btv1	32-62	2.5YR 3/6	grsc	3cssl	m vfr w vst pl	gi
very few fine roots,						
Btv2	62-86	2.5YR 4/8	grsc	3cssl	m vfm w st npl	ND
None						

[a]Texture: sc = sandy clay, gr = gravelly, c = clay, Sicl = silty clay, Sil = silty loam, lSi= loam silty; scl= sandy clay loam
[b]Structure: 1 = weak, 2 = moderate, 3 = strong, cr = crumb, sbk = subangular blocky, abk = angular blocky, vf = very fine, f = fine, m = medium; gr = granular, ssl = structureless;
[c]Consistence: 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;
[d]Boundary: a = abrupt, c = clear, g = gradual, d = diffuse, s = smooth, w = wavy, i = irregular, ND = not determined

The soils of mapping unit C were characterized by brown (7.5YR 4/2), loam silt on soil surface, down to (5YR 6/2) and finally to pinkish gray (7.5 YR 7/2) at the deeper subsurface. Water table not encountered at 126 cm. The structural type of the profile pit is moderate to weak, medium crumb and sub-angular blocky. Very few coarse roots and few mottles were present in the profile pit.

The soils of mapping unit D are moderate to well drained, characterized by reddish brown 5YR (4/4), clay loam at the surface horizon and dark red (2.5YR 4/8) gravelly sandy clay in the subsoil. The soil is shallow (86 cm) and characterized with gravel. The soil structure is moderate at the surface and strong at subsurface. Common very fine, medium and coarse roots were present.

Generally, the soils are very fine and very friable devoid of quartz and stones (except profile pit D), display little change in horizons. The brown colour of the surface soils indicates the presence of organic matter. The dark colour impacted on the surface horizons by the soil organic matter makes the boundaries between horizon A and B to be clear [19]. The brighter colour of subsurface soils is an indicative of well-drainage [20]. Roots concentration was common in the surface horizons of all the profile pits examined and decreased with soil profile depth.

3.2. Soils physical properties

Physical properties of the soils are presented in Table 3. The texture of the surface soils ranged from sand to loamy sand. The sand particles seemed to be the most dominant size fraction with a range of 70.4 to 93.2%. The silt particles ranged from 2 to 20 % while clay was the least with a range of 4.8 to 13.4% in the soils. The predominance of sand in the surface horizon could be attributed to the removal of clay and silt by water erosion. Silt/clay ratio shows the degree of pedogenic weathering in soil, also reflects the weathering stage of soil parent materials and shows the erodibility potential of the soils [21] and [22]. The silt/clay ratios of 0.40 to 3.30, 0.30 to 1.30, 1.0 to 2.70 and 1.20 to 1.30 were observed in mapping unit A, B, C and D respectively. Mapping unit B was more weathered than others because of the lower silt/clay ratios of subsoil.

3.3. Soils chemical properties

3.3.1. Soil pH

The chemical properties of the soils studied are presented in Table 4. The pH of the soils was slightly acidic to neutral and it varied from 5.37 to 6.92 and 4.86 to 6.59 in water and 1N KCl solution, respectively. The surface horizons were slightly acidic in reaction while the sub soils were strongly acidic. In the surface horizons, the pH ranged from 6.27 to 6.92 and 5.69 to 6.59 in distilled water and 1 M KCl solution, respectively. The pH values were above 6.00 recommended as good for cocoa soil [23]. The low pH of the soils could be as a result of high rainfall in the area which made the soils to be fragile and susceptible to leaching. Generally, the soil pH decreased with the soil depth.

3.3.2. Soil Organic carbon, Total Nitrogen and Available Phosphorus

The soil organic carbon (SOC) contents ranged from 0.01 to 1.02% corresponding to 0.02 to 1.75% soil organic matter (SOM) which was rated low. The values decreased with profile depth. The values were below the critical value of 3 % stated to be the best for cocoa production in Nigeria [23]. The low SOC might have ensued from the high mineralization rate and cropping history of the area. The organic matter of these soils need to be greatly increased through the use of leguminous plants and better plant residue management. Total nitrogen (TN) content varied from 0.01 to 0.09%. The values were within low soil nitrogen fertility class range. The soil N content was generally below critical level of 0.09%. The lower content of nitrogen observed may be attributed to continue nutrient mining by plants. Thus, addition of N based fertilizer would be required in the study area for optimal production of cocoa. The soil available phosphorus (P) content were low. Generally, the values were not adequate for cocoa production since the values obtained were below the critical value of 10 mg/kg [23]. This implies that application of P supplying fertilizers is needed.

3.3.3. The exchangeable cations

Relatively low amounts of exchangeable bases were present in all the profile pits examined. The exchangeable calcium for the soil varied from 0.59 to 2.12 cmol/kg. The soil Ca^{2+} values for each profile pit were less than the critical value of 5.0 cmol/kg for ideal cocoa production [23]. Application of Ca^{2+} containing fertilizer is required to achieve ideal cocoa yields. The exchangeable magnesium (Mg^{2+}) content varied from 0.17 to 0.72 cmol/kg soil. The soils examined had their exchangeable Mg content lower than 0.9 cmol/kg which is the critical value for Mg in cocoa production [23]. Exchangeable potassium (K) contents ranged between 0.04 and 0.92 cmol/kg. The soil K levels were lower than the critical level of 0.3 cmol/kg soil. This indicates that the soils were very low in K content and would therefore need the use of K supplying fertilizer to meet the need. The sodium content ranged from 0.20 – 0.42 cmol/kg. [24] reported that when the value of Na content is <1 cmol/kg, it cannot be detrimental to the roots of the plants.

Table 3: Soils physical properties

Horizon	Depth (cm)	Sand	Silt	Clay	Silt/Clay	Textural Class
		←	(%)	→		
			Profile pit A			
Ap	0-30	93.2	2	4.8	0.4	Sand
AB	30-50	79.2	16	4.8	3.3	loamy sand
B	50-76	83.2	10	6.8	1.5	loamy sand
Bt1	76-117	75.2	16	8.8	1.8	sandy loam
Bt2	117-160	70.4	20	9.6	2.1	sandy clay loam
			Profile pit B			
Ap	0-14	83.2	9.4	7.4	1.3	loamy sand
AB	14-48	81.2	5.4	13.4	0.4	sandy loam
B1	48-95	85.2	7.4	7.4	1.0	loamy sand
B2	95-125	86.4	2.8	10.8	0.3	loamy sand
			Profile pit C			
Ap	0-21	89.2	5.4	5.4	1.0	sand
AB	21-69	79.8	14.8	5.4	2.7	loamy sand
B	69-126	87.8	6.8	5.4	1.3	sand
			Profile pit D			
Ap	0-32	87.8	6.8	5.4	1.3	Sand
Btv1	32-62	84.8	8.4	6.8	1.2	loamy sand
Btv2	62-86	78.6	11.8	9.6	1.2	sandy loam

3.3.4. Exchangeable acidity and effective cation exchange capacity

The soil exchangeable acidity (Al^{3+}+H^{+}) ranged from 0.06 - 0.13 cmol/kg. The effective cation exchange capacity (ECEC) of the soils ranged from 1.30 -3.75 cmol/kg. The values were below the minimum standard of 4.0cmol/kg recommended for ideal production of tree crops [25]. Therefore, the study area needs to be properly managed by applying appropriate fertilizer for optimum cocoa yield.

3.3.5. Soil micronutrients

Availability of most of the micronutrients in soils depend on soil pH and OC [26]. [27] also stated that clay fraction and OC of the soils are the mainstay of micronutrients in the soils. The soil micronutrient contents of the studied soils, Mn ranged from 1.85 – 45.4 mg/kg. The values are at sufficiency level only at the surface horizons. Fe content ranged from 2.30 to 50.85 mg/kg, the values are below the critical value of 161 mg/kg reported by [28] and [29] as ideal for tree crops. Copper content ranged from 0.44 – 0.98 mg/kg soil, the values are also below the critical level of 1.2 – 2.0 mg/kg soil. The Zn ranged from 0.07– 1.06 mg/kg soil, the values are also below the critical value of 3.0 to 3.45 mg/kg. Those nutrients elements that are below the critical levels need to be supplied through proper fertilizer application to build their level up in the soil.

Table 4: Soils chemical properties

Horizon	Depth	pH		Exchangeable bases				Al+H	ECEC	BS	TN	OC	Avail. P	Mn	Fe	Cu	Zn
		H_2O	KCl	Ca	Mg	K	Na										
	(cm)					← (cmol/kg) →				← (%) →				← (mg/kg) →			
								Profile Pit A									
Ap	0-30	6.92	6.59	1.64	0.72	0.91	0.42	0.06	3.75	98.40	0.06	0.70	10.22	45.4	29.8	0.72	1.06
AB	30-50	5.76	5.09	0.59	0.28	0.07	0.24	0.12	1.30	90.76	0.03	0.10	8.23	13.9	7.20	0.61	0.23
B2	50-76	5.43	4.86	0.76	0.43	0.08	0.28	0.11	1.66	93.38	0.02	0.01	5.27	11.4	12.60	0.72	0.22
Bt1	76-117	5.37	4.76	0.62	0.29	0.06	0.32	0.13	1.42	90.83	0.03	0.07	3.70	9.25	16.95	0.56	0.09
Bt2	117-160	5.87	4.79	0.70	0.26	0.07	0.20	0.11	1.34	91.78	0.03	0.02	2.54	4.10	20.05	0.68	0.07
								Profile pit B									
Ap	0-14	6.30	5.89	1.90	0.66	0.31	0.42	0.08	3.37	97.63	0.08	0.92	5.18	22.05	50.85	0.78	0.85
AB	14-48	5.93	5.34	0.99	0.28	0.14	0.27	0.10	1.65	93.95	0.01	0.09	2.04	12.15	18.65	0.53	0.20
B1	48-95	6.20	5.43	0.61	0.17	0.92	0.35	0.07	1.29	94.58	0.01	0.03	1.53	4.65	18.8	0.59	0.29
B2	95-125	6.25	5.84	0.95	0.31	0.04	0.25	0.07	1.62	95.67	0.02	0.04	3.33	3.15	15.9	0.91	0.36
								Profile pit C									
Ap	0-21	6.28	5.77	1.72	0.54	0.15	0.28	0.09	2.78	96.76	0.07	0.98	5.74	8.25	36.15	0.98	0.78
AB	21-69	5.59	4.88	1.41	0.28	0.12	0.35	0.12	2.28	94.74	0.04	0.24	4.02	3.50	14.9	0.44	0.33
B1	69-126	6.19	5.97	1.20	0.33	0.04	0.24	0.08	1.89	95.76	0.03	0.03	3.89	1.85	2.30	0.48	0.28
								Profile pit D									
Ap	0-32	6.27	5.69	1.88	0.70	0.14	0.36	0.06	3.14	98.09	0.04	0.54	8.88	32.05	36.75	0.56	0.89
Btv1	32-62	5.70	4.86	2.12	0.66	0.09	0.29	0.13	3.29	96.05	0.02	0.34	12.58	16.25	36.5	0.53	0.48
Btv2	62-86	5.69	4.79	1.75	0.64	0.08	0.32	0.12	2.91	95.88	0.09	1.02	18.13	10.25	18.7	0.79	0.53

OC = organic carbon, TN = Total nitrogen, Avail. P = available phosphorus, ECEC = effective cation exchange capacity, BS = base saturation

3.4. Soil Classification

All the profile pits were mainly of kandic horizon judging from their textural class (fine-earth fraction) of sand, loamy sand or loamy coarse sand established by the particle size data ((Table 2) and decrease in organic carbon content with increasing depth. There was no consistent increase in clay content with soil depth. They are characterized by high base saturation of >50% by NH_4OAc – pH 7 which is part of the basis for classifying them as Alfisols [16]. This result is similar to the work of [25] who worked in similar environment, in Ogun State, Nigeria. The soils belong to suborder Ustalfs due to its ustic moisture regime. Profile pits 1, 2 and 3 belong to great group Kandiustalfs and consequently classified at subgroup level as Typic isohyperthermic kandiustalf because of its temperature regime [8].

In the FAO World Reference Base for soil Resources (2006) system of soil classification, they were correlated as orthoeutric Lixisols because of an effective base saturation that is > 50% throughout the mineral soil surfaces. Profile pit 4 belong to great group Plinthustalfs due to the presence of concretions and gravels and then classified at subgroup level as Typic Plinthustalfs. In the FAO/UNESCO system, it correlates as Plinthosol. The summary of the soil classification is presented in Table 5.

Table 5: Summary of the soils classification

Profile pits	Order	Suborder	Great group	Subgroup	FAO/UNESCO
A	Alfisol	Ustalfs	Kandiustalfs	Typic kandiustalf	orthoeutric Lixisol
B	Alfisol	Ustalfs	Kandiustalfs	Typic kandiustalf	orthoeutric Lixisol
C	Alfisol	Ustalfs	Kandiustalfs	Typic kandiustalf	orthoeutric Lixisol
D	Alfisol	Ustalfs	Plinthustalfs	Typic Plinthustalfs	Plinthosol

3.5. Suitability evaluation of the soils

The factor rating of land use requirements for cocoa (Table 6) were matched with the soil properties (Table 7). The actual or current suitability of the soils under parametric approach as calculated with the index of productivity for each profile pit [18] showed that profile pit A, B and C are marginally suitable (S3) for cocoa production while profile pit D is presently not suitable (N1) (Table 8). However, in the potential suitability, all the profile pits would be moderately suitable for cocoa production with proper fertility management. The major limitation is fertility status for mapping unit A, B and C while soil depth, coarse fragment and fertility status placed mapping unit D in N1 class (presently not suitable) for cocoa production. [30] in his evaluation of soils of Idoffa within Yewa North Local Government area in Ogun State also reported that soil fertility is the major limitation to the suitability of Nigeria soils.

IV. CONCLUSION

Soils of the studied area were characterized, classified and evaluated for cocoa production. The soils were moderately acidic to neutral. The soils are deficient in macro and micro elements, their values were below the critical level required for optimum cocoa production. Land suitability evaluation result revealed that currently, the soils are marginally suitable for cocoa production. Potentially, that is, with good management practices, the soils would be moderately suitable. Therefore, management practices such as application of appropriate fertilizers, incorporation of crop residues and organic manure should be adopted to correct the major limitations on the studied soils for optimum cocoa production.

ACKNOWLEDGEMENTS

The authors appreciated the Executive Director of Cocoa Research Institut Nigeria for the permission to publish this work.

Table 6: Factor Ratings of land use requirements for cocoa

Land, soil and climatic characteristics	S1 (100%)	S2 (85%)	S3 (60%)	N1 (40%)	N2 (20%)
Climate (c) Annual rainfall (mm)	1,600-2,500	1,400-1,600	1,200-1,400	-	<1,200
Mean annual temperature (°C)	23-28	28-35	20-25	35-38	>38
Length of dry season (months)	1-2	2-3	3-4	>4	any
Dryest month (%)	40-60	35-65	30-75	Any	-
Relative humidity (%)	40-65	35-75	30-85	Any	-
Topography (t)					
Slope (%)	<8	<16	<30	-	Any
Wetness (w)					
Drainage	Well	Moderate/better	Imperfect/better	Poor/better	Very poor/better
Flooding	No	No	F1	F1	Any
Physical soil condition(s)					
Soil depth (cm)	>150	>100	>50	>50	Any
Coarse fragments (Vol.%)	<15	15-35	35-55	>55	Any
Texture/structure	C-60s to SC	C+60s to SCL	C+60s to LFS	C+60s to LFS	Cm to Cs
Fertility status (f)					
Soil pH (in water)	6.0 -7.0	7.0 – 7.6	5.5 – 6.0	5.5 – 4.0	>7.6
Base saturation (%)	>60	50-35	<20	-	-
Apparent CEC (Meq/ 100 g soil)	>16	12-16	8-12	<8	-
Organic matter (% C, 0-15cm)	>3	2.5-1.5	1.5-0.8	0.6-0.8	<0.6

F1 = Slight, C-60V to L = Clay vertisol structure to loam, C+60s to s = Very fine clay, C+60s to fs = Very fine clay blocky structure to fine sand, C+60s to SCL = Very fine clay blocky structure to sandy clay loam, C+60v to fs = Very fine clay vertisol to fine sand, vertisol structure to sandy soil, CM to SC = Massive clay to sandy clay. S1 = highly suitable, S2 = moderately suitable, S3 = marginally suitable, N1 = presently not suitable, N2 = permanently not suitable.

Source: Modified from Sys et al., (1993).

Table 7: Summary of land characteristics of the land units

Land characteristics	Profile pit A	Profile pit B	Profile pit C	Profile pit D
Annual rainfall (mm)	1636	1636	1636	1636
Mean annual temperature (°C)	33	33	33	33
Length of dry season (months)	4	4	4	4
Relative humidity (%)	86	86	86	86
Slope	<8	<8	<8	<8
Flooding	No	No	No	No
Drainage	well drained	well drained	well drained	well drained
Texture	Sand	loamy sand	Sand	Sand
Coarse fragments	<15	<15	<15	<15
Soil depth (cm)	160	125	124	86
Base saturation (%)	98.40	97.63	96.76	98.09
Soil pH (H_2O)	6.92	6.30	6.28	6.27

Organic matter (% C, 0-15 cm)	0.72	0.92	0.98	0.54

Table 8: Parametric suitability class scores of the study area

Land qualities	**Profile pit A**	**Profile pit B**	**Profile pit C**	**Profile pit D**
Climate (C)				
Annual rainfall (mm)	100 (S1)	100 (S1)	100 (S1)	100 (S1)
Mean annual temperature (°C)	85 (S2)	85 (S2)	85 (S2)	85 (S2)
Topography (T)				
Slope (%)	100 (S1)	100 (S1)	100 (S1)	100 (S1)
Wetness (W)				
Soil drainage	100 (S1	100 (S1	100 (S1	100 (S1
Flooding	100 (S1	100 (S1	100 (S1	100 (S1
Soil Physical condition (S)				
Texture	60 (S3)	60 (S3)	60 (S3)	60 (S3)
Soil depth (cm)	100 (S1)	85 (S2)	85 (S2)	40 (N1)
Coarse fragment (%)	100 (S1)	100 (S1)	100 (S1)	40 (N1)
Fertility status (F)				
Soil pH	100 (S1)	100 (S1)	100 (S1)	100 (S1)
Soil organic carbon	40 (N1)	40 (N1)	40 (N1)	40 (N1)
Base saturation	100 (S1)	100 (S1)	100 (S1)	100 (S1)
Actual suitability	**29 (S3)**	**29 (S3)**	**29 (S3)**	**23 (N1)**
Potential suitability	**71 (S2)**	**71 (S2)**	**71 (S2)**	**58 (S2)**

A = actual/current suitability class, B = potential suitability class (after soil fertility improvement)
Aggregate suitability scores: S1 (75-100); S2 (50-74); S3 (25-49); N1 (12-24); N2 (0-12).

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