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Characterization, Suitability Evaluation and Soil Quality Assessment of Three Soils of Sedimentary Formation for Sustainable Crop Production

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Authors' contributions

This work was carried out in collaboration between all authors. Author ODA designed the study with inputs from other authors. All authors carried out the field study, handled the laboratory and statistical analysis. Author ODA wrote the protocol and the first draft of the manuscript. Author OAD handled the map production. Author GAO managed the literature searches and read through the draft to make necessary corrections. All authors read and approved the final manuscript.

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ABSTRACT

Inadequate information on the status of agricultural lands can lead to misuse, mismanagement and degradation. Hence, the need for proper assessment methods for effective land management and sustainable production. This study was set out to characterize, conduct suitability evaluation and soil quality assessment of some soils under sedimentary formation.

The study was carried out on agricultural land within Obafemi Owode Local government, Ogun state. The soils were classified; suitability evaluation was carried out for tree (oil palm and cacao) and arable (maize and cassava) crops using parametric approach and soil quality assessed by soil management assessment framework.

Soils encountered at the study site include Ibeshe (Typic Kanhaplustalf), Ipaja (Rhodic Kandiusalf)

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and Agege (Typic Kandiustalf) Series. The soils which have moderate to high quality are marginally to moderately suitable for both tree and arable crops. Limitations to suitability include nutrient availability, nutrient retention, climate and soil physical characteristics.
Despite having high quality, the soils may not be highly sustainable for crop production except with good management. Therefore, there is need for organic matter build up and management for sustainable crop production.

Keywords: Characterization; evaluation; sedimentary; soil quality; sustainability.

1. INTRODUCTION

Soil, a major component of the earth's ecosystem is the mixture of minerals, organic matter, gases, liquids and countless organisms that support plant life. It is considered to be the "Skin of the earth" with interfaces between the lithosphere, hydrosphere atmosphere of earth, and biosphere. Soil is the end product of the influence of the climate, relief, organism and parent materials; and it continually undergoes development by way of numerous physical, chemical and biological processes. It offers plants with physical support, air, water, temperature modulation, nutrient and protection form toxins. Soils provide readily available nutrients to plant and animal by converting dead organic matter into various nutrient forms.

Soil quality is the capacity of the soil to function within ecosystem boundaries and interact positively with the environment external to that ecosystem [1]. The maintenance of soil quality is necessary because the soil provides several vital functions [2]. A number of quantitative studies have been conducted regarding soil quality assessment [3,4]. Land evaluation is the process of assessing the possible uses of land for agriculture, engineering, forestry, recreation, industry and conservation. In the agricultural context, it is the assessment of land for a specific kind of land utilization, e.g. grazing, rainfed farming, irrigation agriculture [5]. Land evaluation methods aim at assessing land qualities or suitability for specific land use, as conditioned by biophysical parameters [6].

Agricultural land use, unlike other uses, is discriminatory. For the fact that not all soils can be used for agricultural purpose, not all crops can be successfully grown on a particular soil type. It is often found that a soil type suitable for a particular crop may not be suitable for another crop because crops are different in their requirements – in terms of nutrients composition and physical quality. Inadequate information on the status of agricultural lands can lead to misuse, mismanagement and degradation. Therefore, there is a need to put in place proper assessment method for effective land management, meaningful research and sustainable production. So, every soil type should be assessed as a matter of necessity to determine its suitability to produce a kind of crop.

Sedimentary soils are soils that are formed from particles (mineral or organic) that are deposited by the action of wind, water, or glacial ice. These sediments can eventually form sedimentary rocks, the disintegration of which will result into sedimentary soils. There is need to have adequate information on these soils to prevent trial and error approach to the use, misuse, underutilization, mismanagement and soil degradation.

The aim of this study is to evaluate some soils of sedimentary formation for sustainable use and management.

2. MATERIALS AND METHODS

2.1 Study Site

The site covers an area of about 17 ha at Ogbe-Eruku village, via Owode, Obafemi Owode Local Government, along Abeokuta-Sagamu express way, Ogun state, Nigeria within latitudes 6^{o} 80' N and 7^{o} 20' N and longitudes 3^{o} 20' E and 3^{o} 55' E (Fig. 1). It is about 15 minutes drive from Abeokuta, Ogun state capital.

2.2 Geology and Geomorphology

The site is part of the Western Nigeria low land area described as being relatively flat to very gently undulating plain developed on sedimentary parent rock and Littoral deposits [7]. The dominant slope of the topography is 0 - 2% on the crest and 1 – 2% on the sides. The sedimentary upland is underlain by tertiary and cretaceous sedimentary rocks (mainly sandstone and shale).

2.3 Climate

The major community (Obafemi-Owode) in the area enjoys a hot and humid tropic climate like the rest of south western Nigeria. The climate is characterized by seasonal rainfall, high temperatures and high humidity. The environment is noted for two distinct seasons of rainy and dry periods in a year. The dominance of the seasons is primarily controlled by two major air masses or wind currents. The southwest trade wind dominates the area bringing about rainy season between March and November, while the Northeast trade wind has greater influence between December and February, imposing dryness in the area. The southwest monsoon wind originates from the Atlantic Ocean; hence it is moisture laden and warm, bringing rains, while the northeast wind is cold, dry and dusty. Its chilly influence in the months of December/January is often referred to as harmattan. The occurrence of these winds is controlled primarily by the North-South migration of the zone of demarcation between them, known as the Inter-Tropical Discontinuity (ITD). The movement, though usually gradual, is steady and consistent; hence, the regular pattern of rainfall and dry periods in the year. It directly and indirectly controls other climatic parameters like temperature, relative humidity, cloud cover, wind direction and speed, etc. The area is thus located in the humid zone, characterized by bimodal wet season, having a growing season of between 240 and 300 days [7,8].

2.4 Vegetation and Land-Use

The site is a forest zone characterized by areas with secondary forest, farm fallows and arable farm-lands. Farming activities are going on in area identified as arable farm-lands. Cassava and guinea corn occupy this land unit being 15% of the site. The unit forms a mosaic of land with farm fallow in the south-eastern and north-western part of the site. In the farm fallow area, the plant species were of 1 – 5 years of age. They are made up of the previous farm shrubs and influx of oil palm trees. The secondary forest unit takes about two-third (2/3) of the land and it is composed of woody trees and shrubs.

2.5 Terrain Analysis

With the aid of the existing perimeter and topographic maps of the site, coupled with other information, a general picture of the nature of the terrain was established. The dominant slope of the topography is 0 - 2% on the crest and 1 – 2% on the sides.

On the spot visual identification and assessment of the physical features of the site were made by traversing the entire land area through transects, footpaths and trunk C roads. The topographic/ contour map served as the base map for the establishment of the terrain features like nature of slopes, erosion features, landuse types/ landcover types and characteristics, existing man-made features etc.

Estimated locations of these features were indicated on the base map, while the exact coordinates of such features were recorded with the aid of Geographical Positioning System (GPS).

2.6 Soil Survey and Mapping

A reconnaissance survey of the site was carried out to establish the reference transects. Five transects were establish with varied lengths. Using global positioning system (GPS) to determine the coordinates of each sampling point, Dutch Soil Auger and Munsell Soil Colour Chart, the morphological characteristics of the soils were examined from the soil surface to a depth of 120 cm at interval of 20 m along each transect. The morphological and physical characteristics of the soils were examined and recorded appropriately for each of the sampling points at 0-15, 15-30, 30-60, 60-90 and 90-120 cm depths.

Thus, as movements were made along the footpaths and transects, incursions were also made into the land to examine the soil for identification of soil types, characterization, classification and soil type boundary placement. Changes in vegetation cover, land use, physiography, soil surface form and stoniness, micro-relief, etc. were noted and also used as clues to arrive at changes in soil types and establishment of soil boundaries. The information was recorded on the Base Map (topographical map), field notebook and proforma. These were done in line with the international guideline for field soil survey and mapping [9].

100 soil auger examination holes were made and used for the identification, characterization and classification of the soil types. Placements of boundaries were achieved by grouping similar

auger examination points. Modal soil profile pits were dug based on the most representative auger examination points; for each of the identified soil types. On the whole, three (3) major soil types were identified. All necessary environmental information relating to the site characteristics and the soil morphology were recorded on the proforma. The soil profiles were described according to the FAO guideline [9] and soil samples were taken for microbial, chemical and physical analysis.

2.7 Soil Classification, Evaluation and Soil Quality Asssessment

The soil samples collected were processed and taken to the laboratory for analysis of the different land and soil quality indicators using standard procedures. From the results of the analysis, soil types were identified characterized and classified using Key to Soil Taxonomy by [10]. The soils were also classified at the series local level using the approach of [11].

The suitability of each pedon for each land use type was also assessed by parametric approach using the land qualities for each land use type. This is a method that assesses the suitability of the land on a continuous scale instead of discreet classes. To assess a particular pedon, the relevant land characteristics/qualities for the land use type was used to estimate the overall limitation effect. Each pedon was placed in suitability class by matching its characteristics with the requirements. The aggregate suitability index was obtained by rating all the land qualities considered. In this study, six land quality groups: climate(c), topography (t), soil physical properties (s), wetness (w), nutrient retention (n) and nutrient availability (f) were considered.

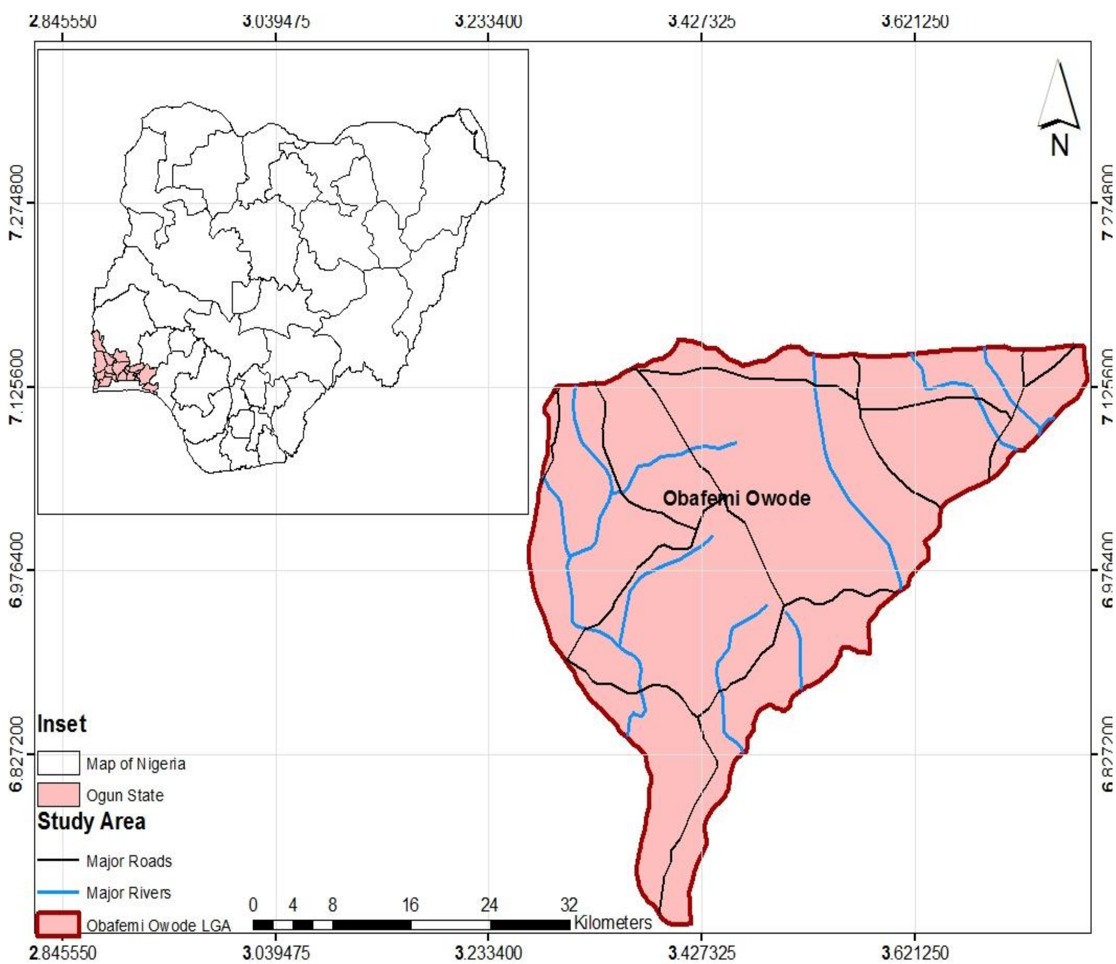

Fig. 1. Map of Nigeria showing the study area

Soil quality assessment was carried out using the framework for evaluating indicators of soil quality by [12] called Soil Management Assessment Framework (SMAF). This technique uses the principle that soil quality can only be assessed by a combination of different properties or indicators (i.e. no single indicator can represent the condition of the soil). The combination was based on the critical values of the indicators in relation to soil processes that are relevant to crop productivity.

3. RESULTS AND DISCUSSION

Tables 1 and 2 show the values of the physical and chemical properties of the soils encountered at the study area. The soil properties serve as both the indicators for soil quality assessment and land characteristics for suitability evaluation. The identified soils are Ibeshe (Typic Kanhaplustalf), Agege (Typic Kandiudalf) and Ipaja (Rhodic Kandiustalf) series (Fig. 2).

Ibeshe series (Typic Kanhaplustalf) is acidic with pH in water ranging from 4.57- 4.73 and increase down the profile. However, exchange acidity is low and this will cushion the effect of acidity on crop production. Organic carbon value is very low ranging from 0.16 – 1.44% with the highest value at the topsoil and decreased down the profile. This is an indication that organic matter build up and management is necessary for sustainable productivity. Total nitrogen values are very low and follow the same pattern with organic carbon. Available phosphorus values are also low and range from 4.80 – 5.40. The values of exchangeable bases are adequate resulting into high base saturation (98.05 – 99.17%). This is an indication that the exchange sites are well occupied by basic cations. Effective cation exchange capacity (ECEC) values are moderately high (6.68 – 13.21). Texture varied as loamy sand to sandy clay loam. The soil is fairly deep and well drained.

Ipaja series (Rhodic Kandiustalf) is moderately acidic with pH ranging from 5.15 - 6.41 and reduce down the profile. Similar to Ibeshe series, exchange acidity is low indicating that acidity cannot necessarily affect crop production. Organic carbon value is very low ranging from 0.19 – 2.17%. Total nitrogen values are also very low and follow the same pattern with organic carbon. Available phosphorus values are also low which range from 5.08 – 8.42 mg/kg. The values of exchangeable bases are adequate resulting into high base saturation (99.30 – 99.56%). This is an indication that the exchange sites will be occupied by basic cations. However, effective cation exchange capacity (ECEC) values are moderate to high (8.59 – 11.48). Texture varied from loamy sand to sandy clay loam. The soil is fairly deep and well drained.

Agege series (Typic Kandiustalf) is moderately acidic with pH ranging from 5.25 - 5.87 and decrease down the profile. Exchange acidity value is also low here indicating that acidity will not affect crop production. Organic carbon value is low ranging from 0.09 – 1.12% and decreased down the profile. Total nitrogen values are also very low and follow the same pattern as organic carbon. Available phosphorus values are also low and range from 1.22– 3.18 mg/kg indicating need for phosphorus rich fertilizer. The values of exchangeable bases are adequate resulting into high base saturation (99.15 – 99.34%). This is an indication that the exchange sites will be occupied by basic cations. Effective cation exchange capacity (ECEC) values are moderate to high (10.57 – 12.12). Texture varied form loamy sand to sandy clay loam. The soil is fairly deep and well drained.

Table 3 shows the aggregate soil quality indices of the soils. They have moderate to high soil quality with values of indices ranging from 69.1 to 74.9 %. The suitability indices of the soils for tree (cacao and oil palm) and arable (maize and cassava) crops are shown on Tables 4 and 5. The soils are marginally to moderately suitable for both tree and arable crops production. Limitations to suitability include nutrient availability, nutrient retention, climate and soil physical characteristics.

The three soil types are sandy at the top, so there is need to protect the topsoil from agents of erosion. This is because most of the nutrients in the soils are concentrated on the topsoil and loss of topsoil is an indication of loss of nutrients. Organic matter management is a good way of protecting the soil against erosion. [13] submitted that the most effective way to maintain soil quality is to provide enough soil organic matter, or soil organic carbon pool in the soil. Planting of cover crops or green manuring is a way of protecting and improving organic matter in the soil. Cover crops usually provide a canopy for seasonal soil protection from erosion and improvement of soil fertility for the production of main crops. They have the potential for recycling nutrients which otherwise would be lost through leaching during off-season periods. Cover crops

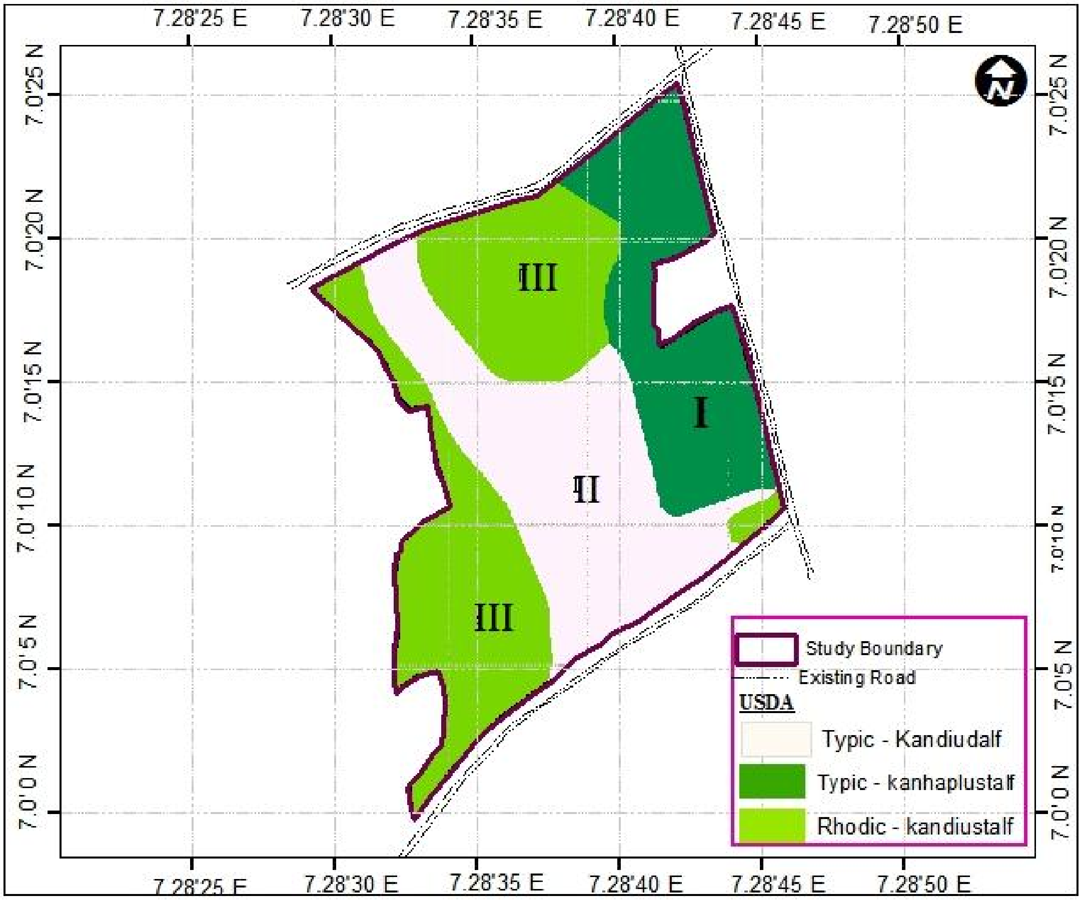

Fig. 2. Soil map of the site

with shallow fibrous root systems, such as many grasses, rapidly build soil aggregation in the surface layer. Cover crops with deep roots can help break-up compacted layers, and bring nutrients from deeper soil layers to make them available for the following crop. Leguminous cover crops have the additional benefit of fixing atmospheric nitrogen for the benefit of crop that follows [14,15]. Other benefits from cover crops include protection of the soil from water and wind erosion, improved soil tilth and suppression of soil-borne pathogens [16]. [17] also submitted that vegetative cover crop is necessary to protect the soil surface from raindrop impact, runoff, erosion and rapid desiccation. Another way of soil protection or organic matter build-up is by plantation crops in form of agroforestry where food crops are grown with permanent tree crops before the canopy is closed up. The resilience of tropical soils is limited due to the fragile nature of the soils coupled with the high erosivity of rainfall [18,19], the need to mimic the natural rainforest condition in tropical farming system, to maintain soil quality, is therefore imperative.

3.1 Soil Quality Indices

The percentage aggregate soil quality indices are moderate to high with values ranging from 69.1% to 74.8% (Table 3). This is resulting from the values of the soil quality indicators. For instance organic matter which is a very crucial indicator of soil quality is moderate and this will affect the levels of other indicators. However, for soil quality to be maintained and/or improved there is need for organic matter build-up and management. This is because of the sandy nature of the soils which make them vulnerable to erosion and resultant degradation. If organic matter is improve, it will positively influence aggregate stability, water holding capacity and reduce compaction and erosion. [20]. [21,22] also reported that the change in organic matter content of the surface soil significantly influenced other key soil properties. Soil organic matter play key roles in soil function determining soil nutrient status, water holding capacity and stability of soil to degradation [23,24]. Soil organic matter may serve as a source of sink to atmospheric Co2 [25] and an increase in the soil carbon content is indicated by a higher microbial biomass and elevated respiration [26]. It is also the principal reserve of nutrients such as N in the soil and some tropical soil may contain large quantity of mineral N in the top 2 m depth [27].

3.2 Land Suitability for Cacao and Oil Palm

The actual suitability indices of the study site for both tree and arable crops are marginally suitable (S3) (Tables 4 and 5). The limitations to suitability for the two land use types are soil physical characteristics (s), nutrient availability (f), nutrient retention (n) and climatic characteristics (c). Potentially, the soils ranged from marginally suitable (S3) to moderately suitable (S2) for both tree and arable crop production. The most limiting land quality common to all the soil type is nutrient retention (n), nutrient availability (f), climate (c) and soil physical characteristics (S). Nutrient availability is not expected to be a limiting factor in basement complex soils. However, the nature of tropical soils does not encourage organic matter build-up, hence; low organic matter content can lower the level of other nutrient characteristics. This is in line with the submission of [20] and [28] that organic matter plays an important role in nutrient availability and retention, affect soil aggregate stability, water retention and lots of other indicators. Therefore, management of organic matter for nutrient retention to reduce susceptibility to run-off and erosion is required for sustainable crop production. Nutrient availability a limiting land quality is considered to be critical because it affects both tree and arable crops. [29] also found that nutrient availability was a major limitation to the suitability of oil palm growth. Another limiting land quality is climate and it also cut across all the soil types. [30] discovered that climate is a major land quality that affects the suitability of cocoa in Nigeria. Soil physical characteristic (s) is another limiting land quality. The extent of land quality 's' will greatly influence suitability of land use because the characteristics does not respond to change easily. Therefore, even if nutrient retention (n) and nutrient availability (f) are adequate, the suitability indices were still low because s,c and we were suboptimal. Some soil physical characteristics like texture and effective soil depth do not easily change in response to use and management they can be said to be permanent in nature. This is to support the submission of [31] that the textural classes of surface soils did not change in response to burning.

Table 1. Physical properties of the soils

Soil depth	Sand	Clay (g/kg)	Silt	Texture	Bulk density (g cm-3)	Total porosity (%)	WHC	Aggregate stability (%)
Ibeshe Series (Typic Kanhaplustalf)								
0-10 cm	740.6	126.4	133	LS	1.1	58.5	14.1	73.2
10-34 cm	720.6	166.4	113	LS	1.4	47.2	147	75.3
34 -73 cm	680.6	186.4	133	SCL	1.53	42.3	12.5	78.9
73-144 cm	640.6	166.4	193	SCL	1.24	53.2	14.2	74.1
144-166 cm	620.6	206.4	173	SCL	1.26	52.5	14.5	74.7
Ipaja Series (Rhodic Kandiustalf)								
0-19 cm	720.6	126.4	153	LS	1.01	61.9	17.4	68.2
19-33 cm	660.6	166.4	173	SCL	1.04	60.8	14.4	76.3
33-65 cm	640.6	186.4	173	SCL	1.57	40.8	10.6	78.1
65-99 cm	640.6	206.4	153	SCL	1.55	41.5	8.8	78.9
99-135 cm	640.6	186.4	173	SCL	1.37	48.3	12.7	77.2
Agege Series (Typic Kandiustalf)								
0-15 cm	760.6	86.4	153	LS	1.08	59.2	16.4	65.4
15-29 cm	740.6	126.4	133	LS	1.08	59.2	16.4	68.2
29-50 cm	680.6	186.4	133	CS	1.74	34.3	9.0	74.3
50-102 cm	640.6	186.4	173	SCL	1.41	46.8	10.0	74.5
102-140 cm	640.6	206.4	153	SCL	1.72	35.1	11.4	77.5

LS = Loamy Soil, SCL = Sandy Clay loam

Table 2. Chemical properties of the soils

Soil depth	pH H_2O	pH KCl	Ca	Na	K	H^+	ECEC	B.S	Org. carbon	Total N	Avail. P
			(cmol kg^{-1})						(g/kg)		(mg/kg)
Ibeshe Series (Typic Kanhaplustalf)											
0-10 cm	4.57	3.56	3.89	8.82	0.19	0.11	13.21	991.7	14.4	1.1	5.40
10-34 cm	4.59	3.51	3.42	8.14	0.28	0.12	12.07	990.9	6.0	0.5	9.33
34 -73 cm	4.54	3.52	2.78	7.79	0.26	0.11	11.06	990.1	3.7	0.5	9.53
73-144 cm	4.68	3.66	2.32	7.50	0.29	0.12	10.26	988.3	2.1	0.4	7.90
144-166 cm	4.73	3.67	1.50	4.67	0.26	0.13	6.68	980.5	1.6	0.3	4.80
Ipaja Series (Rhodic Kandiustalf)											
0-19 cm	6.41	5.25	4.53	6.39	0.37	0.05	11.48	995.6	1.7	1.6	5.08
19-33 cm	6.55	5.39	3.81	6.36	0.31	0.05	10.64	995.3	7.4	1.4	4.21
33-65 cm	6.29	4.76	3.24	6.21	0.27	0.04	9.84	995.9	5.4	0.7	5.84
65-99 cm	5.19	3.97	2.62	6.15	0.25	0.07	9.18	992.4	4.4	0.3	6.55
99-135 cm	5.15	3.96	1.96	6.04	0.28	0.06	8.59	993.0	1.9	0.3	8.42
Agege Series (Typic Kandiustalf)											
0-15 cm	5.87	4.76	3.65	7.81	0.34	0.08	12.12	993.4	11.2	1.0	3.18
15-29 cm	5.54	4.46	3.29	7.67	0.27	0.07	11.48	993.9	3.9	0.5	2.30
29-50 cm	5.39	4.16	2.88	7.73	026	0.06	11.17	994.6	3.8	0.4	3.89
50-102 cm	4.97	3.80	2.56	7.19	0.26	0.10	10.35	990.3	2.3	0.3	6.27
102-140 cm	5.25	3.84	2.58	7.40	0.25	0.09	10.57	991.5	0.9	0.2	1.22

Table 3. Aggregate soil quality indices of the three soil types

Soil type	Soil quality indices (%)
Ibeshe (Typic Kanhaplustalf)	74.9%
Ipaja (Rhodic Kandiustalf)	74.8%
Agege (Typic Kandiustalf)	69.1%

Table 4. Suitability for oil palm and cacao

Soil type	Suitability for oil palm		Suitability for cacao	
	Actual	potential	Actual	Potential
Ibeshe	48% S3 (f,n,c,s)	64% S2(f,n ,c,s)	49% S3 (f,n,c,s)	66% S2(c, s)
Agege	43% S3 (f,n,c,s)	59% S3 (f,n,c,s)	44 % S3 (f,n,c,s)	61% S2(c, s)
Ipaja	43% S3 (f,n,c,s)	60% S2(c, s)	48% S3 (f,n,c,s)	64% S2(c, s)

Note: S3 = marginally suitable, S2 = moderately suitable, n = nutrient retention, f= nutrient availability, s = soil physical characteristic, c = climatic characteristics

Table 5. Suitability for maize and cassava

Soil type	Suitability for maize		Suitability for cassava	
	Actual	Potential	Actual	Potential
Ibeshe	42% S3 (f,n,c,s)	51% S3(f,n ,c,s)	41% S3 (f,n,c,s)	63% S2(c, s)
Agege	40% S3 (f,n,c,s)	51% S3 (f,n,c,s)	37 % NS (f,n,c,s)	61% S2(c, s)
Ipaja	40% S3 (f,n,c,s)	50% S3(c, s)	41% S3 (f,n,c,s)	62% S2(c, s)

Note: NS = not suitable, S3 = marginally suitable, S2 = moderately suitable, n = nutrient retention, f= nutrient availability, s = Soil physical characteristic, c = climatic characteristics

4. CONCLUSION

The study was set up to characterise, evaluate and assess soil quality of some soils under sedimentary formation. Three soil types were encountered at the study site and they have low to moderate suitability for crop (both tree and arable) production basically due to soil physical and climatic characteristics. Although, the soils are of moderate to high quality, their suitability for crop production may not be sustainable except with good management strategies. Therefore, there is need for organic matter build up and management on the agricultural land of the study site for sustainable crop production.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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