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CHARACTERIZATION AND CLASSIFICATION OF RICE-GROWING SOILS ON IMO CLAY SHALE RESIDUA IN EASTERN NIGERIA AND CURRENT SUITABILITY FOR RICE PRODUCTION II: ANAKU AND IGBARIAM AGRARIAN COMMUNITIES

***[1]Asadu C.L.A., [1]Umeugokwe C.P., [1]Eze F., [1]Asadu C.A. and [2]Onyeme E.**

[1]Department of Soil Science, University of Nigeria, Nsukka, Nigeria
[2]Neland Consultants, Government Residential Area (GRA), Enugu, Nigeria

*Corresponding author's email: charles.asadu@unn.edu.ng

ABSTRACT

The soils on Imo Clay Shale residua were sampled at Anaku and Igbariam in Anambra state, Nigeria to characterize, classify and evaluate their current suitability for rice production following standard scientific procedures. After several auger borings, modal profiles were sited, dug, described, and sampled. The soils generally belong to loamy textural classes or finer, especially in the subsoil layers. The morphological and physical properties of soils showed that the soils were poorly drained, favouring high water retention due to low hydraulic conductivity and slow permeability. All these conditions favour good rice performance. Though the soils contained high levels of exchangeable bases, exchangeable acidity was equally high leading to low base saturation (< 35%). Thus, the soils were classified as Typic Kanhaplaquults (Soil Taxonomy) and correlated to Gleyic Cambisols (World Reference Base for Soil Resources). Due to fertility inadequacies, the current suit- ability unit of the soils for rice production is suitability class 2 with fertility constraints (S2f). This implies that for sustainable rice production supplementary nutrients especially P_2O_5 from triple superphosphate or rock phosphate need to be applied. Based on the soil chemical results the following recommendations were made for optimum rice production: 100.00-120.00 kg ha^{-1} urea, 60.00 kg ha^{-1} P_2O_5 from triple superphosphate and 15.00 kg ha^{-1} K_2O (muriate of potash).

Key words: soil characteristics, Typic Kanhaplaquults, Gleyic Cambisols, suitability for rice production

INTRODUCTION

The characterization and classification of soils are necessary to predict their use-values (Yaalon and Arnold, 2000). A review of the future of soil science (Blum, 2006) showed that in countries with food deficiencies especially in Africa, Asia, South, and Central America, soil science would mainly target soil fertility in its largest sense as long as these deficits existed while in countries with sufficient food supply, soil science would increasingly target environmental and cultural issues, such as protection of the food chain against contamination, protection of groundwater resources, protection of the air and of human health as well as protection of soil as a cultural and natural heritage. The latter scenario stems from the fact that clean food, water, and air are the basis for a healthy environment which guarantees long life expectancy of people.

Characterization and classification of soils in countries like Nigeria with insufficient food supplies should be accompanied by land suitability evaluation for making the research more relevant to local users of soil information especially farmers while satisfying the interest of soil researchers. However, earlier characterization and classification of landscape soils in Nigeria (Akamigbo and Asadu, 1983; Akamigbo and Asadu, 1986; Asadu, 1990) as well as detailed information on the relationships between soil properties (Asadu and Akamigbo, 1990; Asadu *et al.*, 1997) still remain valid in evaluating such soils for their use in agricultural production. Generally, land use types differ from one location to another depending on the immediate needs of the government, communities or individuals concerned but in Nigeria land is used for agriculture, urban development, industrial and commercial purposes in that order of decreasing importance (FDALR, 1982).

In order to assess the suitability of soils for crop production accurately, soil characteristics and crop requirements must be known and understood within the context of limitations imposed by landform and other features which do not form a part of the soil but may have a significant influence on use that can be made of the soil (FAO, 1995). Thus, soil suitability evaluation needs a specification of the respective crop requirements and calibrating them with the terrain and soil parameters (Dent and Young, 1981). In most cases, agricultural lands in Nigeria have been utilized intensively for certain purposes at the expense of their suitability capabilities thereby resulting in land degradation and altering of the natural ecological conservatory balances in the landscape (Senjobi, 2007).

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Land evaluation provides a clue to sustainable land use since the land will be used according to its capability. For any given crop species and variety, the yield in terms of harvestable produce (agricultural yield) is affected by soil depth and structure, soil moisture capacity, soil air, soil slope and stoniness, soil reaction, atmospheric and soil temperature, intensity and duration of sunshine, atmospheric humidity, plant pests and diseases, hazards of floods and violent winds as well as good cultural practices (Asadu, 1995). It is the complex interactions between the crops and those several factors and conditions in their environment that determine the performance of any crop. It has been established that Nigeria has all it takes to feed her citizens and place petroleum (crude oil) behind agriculture as a foreign exchange earner if land resources including soils are properly utilized (Asadu *et al*., 2012; Asadu, 2018).

The dynamic nature of swampy soils used for rice production continuously demands that such soils be characterized and evaluated regularly to ensure sustainability. This applies more when the sources of water are from streams or rivers passing through several kilometers before their point of use for swamp rice production. Rice is one of the major staple crops grown in Nigeria especially in swamps as sole crop but sometimes between raised mounds and ridges used to grow such crops as yam, cassava, and maize (Asadu *et al*., 2019). The importance of rice is increasing in Nigeria as it has become part of the everyday diet of an average Nigerian household and local production needs to be encouraged through appropriate land use recommendations. The wide range of rice-growing conditions suggests an equally wide variety of soils on which rice is grown and the most important suborders of soil taxa identified globally in rice-growing areas are Aquents, Aquepts, Ochrepts, Tropepts, Aqualfs, Aquults and Uderts (Moormann, 1978). Generally, clayey textures are significantly better than sandy textures in rice production due to their water and nutrient retention capabilities (Dou *et al*., 2016). Paddy soils are usually medium-to fine-textured; clay to clay loams, silt loams, and silty clay loams because prevention of excessive percolation is a necessity for efficient rice production (Moormann, 1978). Many agrarian communities in Anambra state of Nigeria are well known for rice production (Asadu e*t al.,* 2019).

This study characterized the soils found on Imo Clay Shales that have been used for continuous swamp rice production for over five years, classified them and assessed their current suitability for rice production.

MATERIALS AND METHODS

Brief Description of the Study Areas

The study was carried out in two locations; Anaku – latitude 6°29' 29.52" N, longitude 6°55' 11.58" E and Igbariam – latitude 6°23' 50.88" N, longitude 6°57' 11.88" E, both in Anambra East Local Government Area, Anambra State, Nigeria (Figure 1).

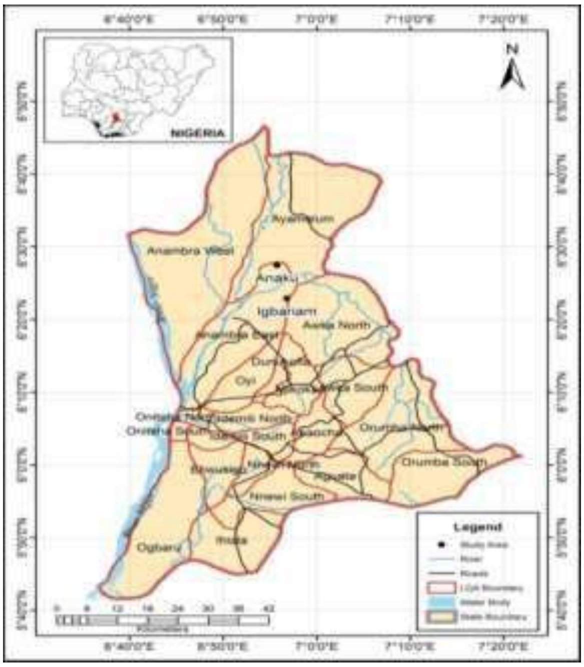

Figure 1: Map of Anambra State showing the study areas

Climatic Information

Generally, all the locations belong to the Kopen classification, an "Awi" climate which is a tropical rainy climate with distinct dry and wet seasons. The average annual rainfall amounts to ca. 1730.00 mm in about 110 rain days and in recent years, the rain days seem to be increasing in number (Akamigbo, 1991).

The wet season lasts from mid-March till November, with maximum rainfall during June/July and another in September. There is a minor dry season in August. The onset of the rains, the rainfall distribution pattern over the year and the rainfall intensity are rather irregular. At the beginning of the wet season, the rainfall takes the form of downpours of high intensity. The dry season lasts from November to early April. It is severe and prolonged. The total dry season rainfall from November to February is ≈ 250.00 mm.

The mean monthly temperature, calculated from averaged maximum and minimum temperatures, varies between 25°C in August and 30°C at the end of the dry season. The absolute maximum is 38°C and the absolute minimum is 12°C, both occurring during the dry season. Diurnal variations seldom exceed 11°C. The relative humidity is high in the rainy season; it drops during the dry season, especially during the occurrence of a north-easterly dry wind "harmattan" which blows intermittently between December and March. According to Akamigbo (1991) during the wet months the rainfall is sufficient for a wet season crop. Crop failure due to excessive precipitation will likely occur in areas with poor drainage conditions and along the depressions and stream valleys. During the dry season annual crops can only be grown under irrigation and vegetables can be grown in the depressions and moist valleys.

Geology and Geomorphology

Detailed descriptions of the geology and geomorphology of areas under study could be found in Ofomata (1965) and they belong mainly to the Imo Clay Shales and the evolution of the present landscape began in the tertiary times. The project areas are underlain by Imo Clay Shales (Palaeocene) which form the parent materials for a greater proportion of the soils (Akamigbo, 1991).

The general relief of the area is very gently undulating to nearly level and the drainage is poor. The greater proportion of the area carries stagnating surface water during the rains as a result of slow percolation of rain water into the soil.

Vegetation and Present Land Use

The general vegetation appears to belong to the Derived Savannah zone (Keay, 1949) due to the absence of forests that characterise virgin land occupied by tall and large trees. It is believed that this savannah zone owes its existence to biotic disturbance due to forest clearing for cultivation and subsequent control by bush fire. Many of the trees existing now are fire-resistant species leading to small patches of forest in some places sandwiched by a variety of scrub grassland. Among the variety of tree species available in the area are West African copal tree (*Daniellia oliveri*), dwarf red ironwood (*Lophira lanceolata)*, guinea peach (*Nauclea latifolia*), oil *palms* (*Elaeis guineensis)*, borassus palms or palmyra palm (*Borassus akeassii*) and some fruit trees such as mangoes (*Mangifera indica*) and oranges (*Citrus* sp.).

General land use is mainly agricultural but rice cultivation dominates over other crops such as maize, sugar cane, yams, cassava, pigeon pea especially in depressions and floodplains (Asadu *et al*., 2019). The farmers depend on seasonal rainfalls which most often cause floods which damage crops grown in depressions and floodplains.

Method of Survey Adopted

The field survey was carried out in two locations (Anaku and Igbariam) from July 22 to 29, 2017. The location of the sampling points was guided by topographic maps and their precise locations were captured with the help of global positioning system (GPS) equipment etrex-Legend. After the preliminary soil examination by free survey technique using auger samples, soil samples were collected from both selected auger points and four modal profile pits though two are presented for the two locations.

The modal profile pits were dug and described in selected locations to represent the major map units. Water table did not allow digging beyond 56.00 cm in all the locations but screw auger was used to collect soil samples up 120.00 cm depth. The profile pits were studied and sampled according to the procedure set out in USDA and FAO/UNESCO guidelines for soil profile study as summarized in Schoeneberger *et al.* (2002). Soil samples were collected from identified pedogenic horizons after macromorphological characterization. Also, undisturbed core samples were collected from 0.00-20.00 cm and 20.00-40.00 cm depths using metallic core samplers for hydraulic conductivity, pore size distribution and bulk density determinations near the profile pits and carefully selected auger point locations.

The soil properties from the auger points and topsoils of the modal profiles were summarized and used for the current suitability evaluation of the soils for rice cultivation while those from the modal profile pits were used to characterize and classify the soils.

Laboratory Determinations and Theoretical Crop Requirements

All the soil analyses were carried out at the Department of Soil Science Laboratory, University of Nigeria, Nsukka following standard laboratory procedures: soil bulk density was determined by the undisturbed core sampling method (Blake, 1965) after drying the soil samples in an oven at 105°C for 24 hrs. Pore size distribution was determined using the water retention data as follows: macroporosity from the volume of water drained at 60.00 cm of tension/volume of bulk soil; microporosity from volume of water retained at 60.00 cm of tension per volume of bulk soil; and total porosity from the sum of macroporosity and microporosity (Brady and Weil, 2002). After air-drying the loose samples and gentle crushing, they were sieved with 2.00 mm sieve. Soil particle size distribution was determined by the Bouyoucous hydrometer method (Van Reeuwijk, 1992) using sodium hydroxides (NaOH) as a dispersing agent. Soil pH was measured in water and dilute potassium chloride (0.1N KCl) suspension in a 1:2.5 (soil: liquid ratio) potentiometrically using a Beckman's zeromatic glass electrode pH meter (McLean, 1982). Available P was extracted with Bray II solution (Bray and Kurtz, 1945) and measured using a colorimeter. Soil organic carbon content was determined using Walkley-Black's titration method (Jackson, 1973). Total N was determined using Kjeldahl digestion, distillation, and titration method using concentrated sulphuric acid (0.1N H_2SO_4) as the oxidizing agent (Bremner, 1965). Cation exchange capacity (CEC) and exchangeable bases (Ca, Mg, K and Na) were determined after extracting with ammonium acetate solution (1N NH_4OAc) at pH 7.0. Exchangeable Na and K in the extracts were determined by flame photometry (Rhoades, 1982) while Exchangeable Ca and Mg in the extracts were determined by the titration method using 0.1N EDTA (Chapman, 1965). The CEC was thereafter estimated titrimetrically using 0.1N NaOH (Chapman, 1965). Exchangeable acidity (EA) was determined by saturating samples with potassium chloride solution (1N KCl) and titrated with sodium hydroxide as described by Mclean (1965). Percentage base saturation was determined by calculation thus:

$$\%BS = TEB/CEC \times 100;$$

where %BS is percentage base saturation, TEB is total exchangeable bases, and CEC is cation exchange capacity. Exchangeable sodium percentage (ESP) was calculated as exchangeable Na × 100/CEC.

Soil Classification and Suitability Evaluation

The soil classification systems used was the Soil Taxonomy (Soil Survey Staff, 2014) correlated to the World Reference Base for Soil Resources (WRBSR) (IUSS Working Group WRB, 2015). The land and soil requirements for rice production (Dent and Ridgway, 1986) adopted are shown in Table 1. The FAO (1976) suitability classification was used to evaluate the land for suitability in rice cultivation to place them into any of the five suitability classes ranging from "unsuitable" to "highly suitable" using the principle of limiting condition by matching the soil characteristics with the requirements of the crops, then the suitability classes and units determined based on constraints to rice production from the study (FAO, 1995). These are described in Tables 1 and 2.

Statistical Analysis

The soil data were analyzed using descriptive statistics to show the relationship of the variables in the study location. The mean was used to determine the average distribution of the variables.

RESULTS AND DISCUSSION

Morphological Properties of Modal Profiles at Anaku and Igbariam

The soils of the two locations have a mixture of Imo Clay Shale residua and fluvial materials as parent materials, and on gentle slopes found between 36.00 and 45.00 m above sea level (Table 3). The drainage of the areas was generally very poor. The topsoils of Anaku had dull reddish brown (5YR4/3) colour with reddish brown (5YR4/8) mottles whereas Igbariam topsoils had brown gray (10YR6/1) colour with dull reddish brown (5YR4/3) mottles. In the subsurface layers, there were prominent mottles in both soils indicating imperfect drainage (Table 3), which is a characteristic that helps the soil to retain water and support good rice performance (Asadu, 1996).

Soil Physical Properties at the Study Areas

Particle size distribution

The contents of clay, silt and fine sand in both soils (Tables 4 and 5) were very high compared to most soils of eastern Nigeria (Akamigbo, 1984). However, the parent material of the soils, Imo Clay Shale residua and fluvial materials are fine in nature and must have influenced the content of these fine materials as reported earlier (Akamigbo and Asadu, 1983). In addition, occasional flooding of the areas from the surrounding rivers could have contributed additional fine materials in the soils. The general increase in clay fraction with depth indicates the accumulation of this fraction in the subsoil or B-horizon and can be used to predict eluviation/illuviation process of lessivage in the soils. These three fractions; clay, silt and fine sand which clearly dominated over coarse sand favour high soil water storage capacity.

Both soils were dominated by medium to fine textures with loamy textures dominating the top layers and more clayey textures the subsoil layers (Tables 4 and 5). The dominance of these textures is a reflection of the characteristic of soils formed from Imo Clay Shale residua (Akamigbo and Asadu, 1983). All the textures would not impede or restrict root growth to arable crops including rice (FAO, 1988). The implication of the particle size distribution and textural classes of these soils is that high water retention is favoured and permeability is not rapid. These conditions favour adequate water availability, whether from rainfall or irrigation, for rice production.

Table 1: Land and soil requirement for rice

Land qualities	Land characteristics	Limiting values for land characteristics			
		S1	S2	S3	N
Sufficiency of energy	Mean annual temperature (°C)	> 24.00	21.00-24.00	18.00-21.00	< 18.00
	Elevation (m)	0.00-600.00	600.00-1200.00	1200.00-1800.00	> 1800.00
	75% probability rainfall (mm)	> 1300.00	900.00-1300.00	500.00-900.00	< 500.00
Sufficiency of water	Soil drainage class	Poorly drained	Imperfectly drained	Moderately well drained	Excessively drained
	Soil texture	C, SiC, SiCL, L	SC, SCL, SiL, Si	SL	S, LS
	Soil depth (cm)	> 80.00	60.00-80.00	40.00-60.00	< 40.00
Sufficiency of nutrients	pH of flooded soil	6.00-7.00	5.00-6.00 7.00-8.00	4.50-5.00 8.00-8.50	< 4.50 > 8.50
Salinity hazard	ECe (mS cm^{-1})	< 3.00	3.00-5.00	5.00-7.00	> 7.00
Ease of water control	Slope angle (degrees)	< 1.00	1.00-2.00	2.00-6.00	> 6.00
Ease of cultivation	Stones and rock outcrops (%)	nil	1.00-5.00	5.00-10.00	> 10.00

Source: Dent and Ridgway (1986); S1 - suitability class 1, S2 - suitability class 2, S3 - suitability class 3, N - suitability order “not suitable”, ECe - electrical conductivity; C - clay, SiC - silty clay, SiCL - silty clay loam, L - loam, SC - sandy clay, SCL - sandy clay loam, SiL- silt loam, Si - silt, SL - sandy loam, S - sand, LS - loamy sand

Table 2: Suitability classes and their description

Suitability class	Description
Class S1: highly suitable	Land having no significant limitations to sustained application of a given use, or only minor limitations that will not significantly reduce productivity or benefits and will not raise inputs above an acceptable level.
Class S2: moderately suitable	Land having limitations which in aggregate are moderately severe for sustained application of a given use; the limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use, although still attractive, will be appreciably inferior to that expected on Class S1 land.
Class S3: marginally suitable	Land having limitations which in aggregate are severe for sustained application of a given use and will so reduce productivity or benefits, or increase required inputs, that this expenditure will be only marginally justified.
Class N1: currently not suitable	Land having limitations which may be surmountable in time but which cannot be corrected with existing knowledge at currently acceptable cost; the limitations are so severe as to preclude successful sustained use of the land in the given manner.
Class N2: permanently not suitable	Land having limitations which appear as severe as to preclude any possibilities of successful sustained use of the land in the given manner.

FAO (1976)

Table 3: Morphological properties of modal profiles at Anaku and Igbariam

S/N	General information		
		Anaku soils	Igbariam soils
1	Profile Number	1	1
2	Describer	Charles Asadu	Charles Asadu
3	Date	August 24, 2017	August 28, 2017
4	Village	Anaku in Ayamelum Local Government Area (LGA), Anambra State	Igbariam in Anambra East LGA, Anambra State
5	Location	Lat. 6° 29' 29.52° N, Long. 6° 55' 11.58" E	Lat. 6°23' 50.88" N, Long. 6° 57' 11.88" E
6	Parent materials	Weathered Imo Clay Shale with fluvial materials	Weathered Imo Clay Shale with fluvial materials
7	Land form/topography/relief	Gentle slope to almost flat land (2-5% slope)	Gentle slope to almost flat land (2-5% slope) at the central part but sloping (8-10%) at the periphery
8	Elevation	26.00 m above sea level (asl)	45.00 m asl
9	Direction of slope	South to north direction	South to north direction
10	Drainage		
	a. Run-off	Ponded	Very slow
	b. Permeability	Slow	Slow
	c. Internal drainage	Very slow	Very slow
	d. soil drainage class	Very poor	Very poor
11	Stoniness	0%	0%
12	Rockiness	0%	0%
13	Erosion	Slight interrill	Slight interrill
14	Higher categorical classification	Typic Kanhaplaquults (Soil Taxonomy) correlated with Gleyic Cambisols (WRBSR)	Typic Kanhaplaquults (Soil Taxonomy) correlated with Gleyic Cambisols (WRBSR)
15	Land use	Mixed grass fallow and shrubs with water lily underneath in some ponded areas, rice in central portions of ponded areas; yam and cassava in raised mounds in surrounding areas of the flood plain.	Grass fallow with some old mounds grown to cocoyam and telferia in ponded areas; maize, cassava, in raised mounds in surrounding areas.

Horizon description

Anaku soils			Igbariam soils		
Designation	Depth (cm)	Description (colours were moist)	Designation	Depth (cm)	Description (colours were moist)
Ap	0.00-17.00	Dull reddish brown (5YR4/3); loam; moderate, fine, granular; firm, slightly hard, slightly sticky, non-plastic; dull reddish brown (5YR4/3), faint common fine mottles; deep penetrable; few, fine grass roots; common, fine pores; clear smooth boundary.	Ap	0.00-16.00	Brownish gray (10YR6/1); sandy clay loam; moderate, fine, granular; firm, slightly hard, slightly sticky, non-plastic; dull reddish brown (5YR4/3), faint few fine mottles; deep penetrable; few, fine grass roots; common, fine pores; clear smooth boundary.
Bt1	17.00-51.00	Grayish brown (7.5YR6/2); clay; strong, medium, angular blocky; firm, hard, sticky, plastic; deep penetrable; grayish brown (5YR4/2), distinct, few, fine mottles; few, fine grass roots; few, very fine pores; clear smooth boundary.	Bt1	16.00-56.00	Grayish yellow brown (10YR6/2); sandy clay loam; strong, medium, angular blocky; firm, hard, sticky, plastic; deep penetrable; grayish brown (5YR4/2), distinct, few, fine mottles; few, fine grass roots; few, very fine pores; clear smooth boundary.
Bt2	51.00-71.00	Grayish brown (7.5YR5/2); clay; very firm, very hard, very sticky, very plastic; deep penetrable; dark reddish brown (5YR3/6), distinct, common, medium mottles; diffuse irregular boundary.	Bt2	56.00-76.00	Grayish brown (7.5YR5/2); clay; very firm, very hard, very sticky, very plastic; deep penetrable; dark reddish brown (5YR3/6), distinct, common, medium mottles; diffuse irregular boundary.
BC	71.00+	Grayish brown (7.5YR5/2); clay; very firm, very hard, very sticky, very plastic; deep penetrable; dark reddish brown (5YR3/6), prominent, many, medium mottles; diffuse irregular boundary.	BC	76.00+	Greyish brown (7.5YR5/2); clay; very firm, very hard, very sticky, very plastic; deep penetrable; dark reddish brown (5YR3/6), prominent, many, medium mottles; diffuse irregular boundary.

Interpreted characteristics of the soil/ remarks

The soils were very poorly drained with ponded water on the lower portions of the field for more than two months in a year' the soils can therefore support swamp rice. Rice can be grown year-round with supplementary irrigation. Very high mounds of up to 1m are required for growing other arable crops such as yam, cassava, maize during the rainy seasons within the flood plains.	The soils of the flood plain were very poorly drained with ponded water on the lower portions of the field for more than three months in a year; the soil is therefore suitable for swamp rice. Rice can be grown year-round with supplementary irrigation if the stream flowing through a section of the farm is properly channelled. Very high mounds of up to 1m are required for growing other arable crops such as yam, cassava, maize during the rainy seasons within the flood plains.

Table 4: Particle size distribution and soil textures at Anaku

Profile number/Horizon	Depth (cm)	Clay	Silt	Fine sand	Coarse sand	Total sand	Textural class
				g kg^{-1}			
Ap	0.00-17.00	180.00	540.00	180.00	100.00	280.00	L
Bt1	17.00-51.00	420.00	360.00	60.00	160.00	220.00	C
Bt2	51.00-71.00	440.00	280.00	320.00	60.00	380.00	C
BC	71.00+	440.00	320.00	190.00	50.00	240.00	C
Auger position 1 topsoil	0.00-20.00	240.00	420.00	250.00	90.00	340.00	L
Subsoil layer 1	20.00-40.00	320.00	360.00	250.00	70.00	320.00	CL
Subsoil layer 2	40.00-60.00	380.00	320.00	240.00	60.00	300.00	CL
Position 2 topsoil	0.00-20.00	260.00	300.00	300.00	140.00	440.00	CL
Subsoil layer 1	20.00-40.00	260.00	280.00	480.00	80.00	560.00	SCL
Subsoil layer 2	40.00-60.00	400.00	300.00	220.00	80.00	300.00	C
Position 3 topsoil	0.00-20.00	300.00	420.00	250.00	90.00	340.00	CL
Subsoil layer 1	20.00-40.00	300.00	400.00	200.00	100.00	300.00	CL
Subsoil layer 2	40.00-60.00	460.00	360.00	140.00	60.00	200.00	C

L - loam, S - sandy, C - clay

Table 5: Particle size distribution and soil textures at Igbariam

Profile/auger points	Depth (cm)	Clay	Silt	Fine sand	Coarse sand	Total sand	Textural class
				g kg^{-1}			
Ap	0.00-16.00	300.00	160.00	140.00	400.00	540.00	SCL
Bt1	16.00-56.00	320.00	120.00	180.00	360.00	540.00	SCL
Bt2	56.00-76.00	440.00	260.00	240.00	60.00	300.00	C
BC	76.00+	400.00	300.00	220.00	80.00	300.00	C
Auger position 1 topsoil	0.00-20.00	260.00	240.00	250.00	220.00	470.00	SCL
Subsoil layer 1	20.00-40.00	320.00	360.00	250.00	70.00	320.00	SCL
Subsoil layer 2	40.00-60.00	380.00	320.00	240.00	60.00	300.00	CL
Position 2 topsoil	0.00-20.00	240.00	240.00	300.00	220.00	520.00	SCL
Subsoil layer 1	20.00-40.00	280.00	240.00	230.00	250.00	480.00	SCL
Subsoil layer 2	40.00-60.00	280.00	200.00	220.00	300.00	520.00	SCL
Position 3 topsoil	0.00-20.00	240.00	360.00	300.00	100.00	400.00	SCL
Subsoil layer 1	20.00-40.00	260.00	320.00	310.00	110.00	420.00	CL
Subsoil layer 2	40.00-60.00	400.00	220.00	280.00	100.00	380.00	C

L - loam, S - sandy, C – clay

Bulk density, pore size distribution and hydraulic conductivity

The mean values of some structural and hydraulic properties of the top- and subsoils are shown (Table 6). The range of values for soil bulk density was 1.17 to 1.56 Mg m^{-3} at Anaku and 1.05 to 1.62 Mg m^{-3} at Igbariam with the overall mean in both soils and layers < 1.41 Mg m^{-3}. Thus, the values of soil bulk density obtained could be considered not restrictive to the roots of crop plants including rice roots because soil bulk density is considered root-restrictive only if it is above the threshold value of 1.60 Mg m^{-3} (Vespraskas, 1987).

The total porosity, macro- and micro-porosity values showed that the topsoils were generally more porous than the subsoils in both locations though the differences were not very substantial (Table 6). On the average, the soils have less than 50% of its volume occupied by pores; a value slightly less than the hypothetical 50% expected of agricultural soils that favours rice cultivation (Dent and Ridgway, 1986). However, the higher total porosities in the topsoils compared to the subsoils can be attributed to the finer textures of the latter. Generally, the porosity of the soil is determined by the relationship between texture and organic matter and very often there is always higher organic matter content in the surface layer than the subsurface layers in the tropical soils.

The pore size distribution is disproportionately in favour of microporosity, understandably due to the high to fairly high clay content of the soils. The disproportionately high microporosity implies greater water retention and availability in the soils. However, this situation potentially might cause poor internal drainage which could translate into sub-optimal aeration under field conditions for other arable crops but it is good for rice.

The saturated hydraulic conductivity (K_s) was consistently but slightly higher in the subsoils than the topsoils but all the values are in the class ‘moderately high’ (Schoeneberger *et al.*, 2012) under the permeability class ‘moderate’. This implies that the rate of transmission of water through the soils, as defined by their texture and structure, is intermediate in the soils. With the topsoils being moderately permeable, rainwater and irrigation water would be readily retained in the soil; the intermediately permeable subsurface layers would not allow all such water to be lost to excessive drainage. Again, this is a good attribute of the soils in terms of water retention for rice cultivation.

Table 6: Bulk density, pore size distribution and hydraulic conductivity (K_s)

Position	Depth (cm)	Bulk density (Mg m^{-3})	Total porosity	Macro-porosity	Micro-porosity	K_s (cm h^{-1})
				(%)		
			Anaku			
Number 1	0.00-20.00	1.56	46.48	4.36	42.11	1.98
	20.00-40.00	1.52	39.24	4.80	34.44	2.31
Number 2	0.00-20.00	1.48	51.12	7.24	43.88	2.18
	20.00-40.00	1.36	47.90	5.49	42.41	2.49
Number 3	0.00-20.00	1.17	45.54	2.56	42.98	0.94
	20.00-40.00	1.48	34.29	2.60	31.69	1.25
Number 4	0.00-20.00	1.42	46.86	7.52	39.34	1.25
	20.00-40.00	1.25	47.18	6.13	41.05	1.65
Mean	0.00-20.00	1.41	47.50	5.42	42.08	1.59
	20.00-40.00	1.40	42.15	4.76	37.40	1.93
			Igbariam			
Number 1	0.00-20.00	1.48	43.05	3.26	39.79	2.81
	20.00-40.00	1.23	51.35	3.18	48.17	3.96
Number 2	0.00-20.00	1.05	42.87	1.96	40.91	2.17
	20.00-40.00	1.35	46.51	4.19	42.32	1.87
Number 3	0.00-20.00	1.54	41.27	1.99	39.28	1.09
	20.00-40.00	1.62	39.52	4.68	34.84	4.05
Mean	0.00-20.00	1.36	42.40	2.40	39.99	2.02
	20.00-40.00	1.40	45.79	4.02	41.78	3.29

Chemical Properties

Soil pH, soil organic matter, and total nitrogen

The values for soil pH, soil organic matter (SOM) and total nitrogen (TN) for the soils of Anaku and Igbariam are shown in Table 7. The pH values ranged from moderately acidic (5.30) to slightly acidic (6.20) at Anaku and extremely acidic (4.30) to moderately acidic (5.60) at Igbariam. Though the average pH values are suitable for most arable crops including rice, care must be taken not apply acid-forming fertilizers.

The SOM values varied from low (9.84 g kg^{-1}) to very high values (41.63 g kg^{-1}) in both locations (Table 7). The high variability in SOM content in the soils may be due to fluctuating soil water conditions over the seasons of the year. The TN values were low (0.42-2.80 g kg^{-1}). The low N content could be attributed to rapid mineralization of SOM following the exposure of soils to high temperatures (Uzoho *et al.*, 2014). This is obvious as SOM is essentially the main source of nitrogen in soils (Osinuga *et al.,* 2020).

Exchangeable bases, acidity, CEC, base saturation and available P

The exchangeable bases and total exchangeable bases were generally high to very high except exchangeable K and Na which were very low (Tables 8 and 9). Exchangeable Ca varied widely at Anaku (1.80-7.40 cmol kg^{-1}) averaging over 3.97 cmol kg^{-1} and at Igbariam (1.60-3.80 cmol kg^{-1}) averaging over 2.29 cmol kg^{-1}. Exchangeable Mg had a wide range (1.00-8.20 cmol kg^{-1}) with a mean of 6.01 cmol kg^{-1} at Anaku but the range was 1.60-4.00 cmol kg^{-1} with a mean of 2.25 cmol kg^{-1} at Igbariam. Also, exchangeable K ranged from 0.04 to 0.14 cmol kg^{-1} at Anaku and 0.05 to 0.14 cmol kg^{-1} at Igbariam with a mean of ≈ 0.01 cmol kg^{-1} for both locations. Both exchangeable Na and exchangeable sodium percentage (ESP) were very low with mean values of 0.19% (Anaku) and 0.26% (Igbariam). Thus, sodicity problems (unstable structure, poor root development among others) are not likely in the soils.

At Anaku, the total exchangeable bases (TEB) values were very high averaging over 10.00 cmol kg^{-1}. The CEC ranged from 13.10 to 84.00 cmol kg^{-1} with a mean of ≈ 27.00 cmol kg^{-1} but with high total exchangeable acidity though exchangeable Al was not detected in one sample. Exchangeable Al averaged 2.50 cmol kg^{-1}, and was much lower than the mean exchangeable H (3.20 cmol kg^{-1}) which was recorded in all the samples. The high total exchangeable acidity reflected the strongly to slightly acid conditions of the soil as shown by the pH values (Table 8). This is also reflected by low base saturation of < 40% on the average though higher values were obtained in samples without exchangeable Al. The available P was generally very low with a mean of < 5.00 mg kg^{-1}.

Table 7: Soil pH, soil organic matter and total nitrogen

Horizon/auger point	Depth (cm)	pH		SOM	TN	Depth (cm)	pH		SOM	TN
		H_2O	KCl	(g kg^{-1})			H_2O	KCl	(g kg^{-1})	
		Anaku location					Igbariam location			
Ap	0.00-17.00	5.30	4.40	26.49	0.98	0.00-16.00	5.10	4.00	41.63	0.84
Bt1	17.00-51.00	5.40	4.20	11.35	0.56	16.00-56.00	4.30	3.20	36.30	1.54
Bt2	51.00-71.00	5.40	4.20	9.84	0.42	56.00-76.00	4.70	3.60	10.60	0.84
BC	71.00+	5.30	4.20	5.30	0.84	76.00+	5.10	4.00	18.16	1.54
Point 1 topsoil	0.00-20.00	5.60	4.30	21.95	0.70	0.00-20.00	5.60	4.40	28.00	0.42
Subsoil layer 1	20.00-40.00	5.80	4.20	12.87	0.42	20.00-40.00	4.70	3.60	13.62	1.12
Subsoil layer 2	40.00-60.00	5.40	4.30	12.87	0.42	40.00-60.00	4.30	3.20	36.30	1.54
Point 2 topsoil	0.00-20.00	5.90	4.80	40.09	1.12	0.00-20.00	4.90	4.00	31.03	2.80
Subsoil layer 1	20.00-40.00	6.20	5.00	26.49	0.56	20.00-40.00	5.10	4.00	41.63	0.84
Subsoil layer 2	40.00-60.00	5.50	4.50	15.89	0.42	40.00-60.00	5.10	4.00	20.43	0.98
Point 3 topsoil	0.00-20.00	5.60	4.40	12.11	1.26	0.00-20.00	5.10	4.00	18.16	1.54
Subsoil layer 1	20.00-40.00	5.70	4.10	15.89	0.42	20.00-40.00	4.90	3.70	25.37	0.84
Subsoil layer 2	40.00-60.00	5.20	4.00	15.89	0.56	40.00-60.00	4.70	3.60	10.60	0.84

SOM - soil organic matter, TN - total nitrogen

At Igbariam, the TEB ranged from 4.12 to 6.11cmol kg^{-1} with a mean of approximately 4.80 cmol kg^{-1}. The CEC was also high ranging from 10.40 to 30.80 cmol kg^{-1} with a mean of approximately 22.40 cmol kg^{-1}. Although exchangeable Al was not detected in one sample it was high in the others. The mean exchangeable H was slightly lower (approximately 2.10 cmol kg^{-1}) than that of Al. The total exchangeable acidity reflected the strongly to slightly acid conditions of the soil as shown by the pH values (Table 9). The values are also reflected by low base saturation of < 23% on the average. The inconsistent trends in the exchangeable cations in the soils tended to reflect mixed mineralogy often associated with modes of the formation of the geological materials which formed the parent materials of the soils. X-ray diffraction studies carried out on soils of Imo Clay Shales at Okada, Edo State, showed the presence of vermiculite, montmorillonite and glauconite peaks, occurring as a mixed layer with traces of chlorite and low amounts of illite (Osadebe *et al.,* 2011). The soils of the residua of Igbaku sandstones which overlie the Imo Clay Shales (Akamigbo, 1991) in Ifite-Ogwari Anambra state gave similar inconsistent values of exchangeable cations (Asadu and Onyeme, 2021).

The available P ranged from low (3.73 mg kg^{-1}) to moderate (11.19 mg kg^{-1}) with a mean of approximately 8.00 mg kg^{-1}. The low available phosphorus values recorded in both soils corroborate the findings of Amhakhian *et al.* (2012) that tropical soils are generally low in available P due to low apatite content of the soil forming materials.

Soil Classification

Based on the observed morphological, physical and chemical properties of the modal profile pits, the soils of Anaku and Igbariam were classified as Typic Kanhaplaquults (Soil Survey Staff, 2014) which correlated with Gleyic Cambisols (IUSS Working Group WRB, 2015).

Current Suitability for Rice Production

The two locations had similar constraints to rice production, that is, insufficiency of nutrients (*f*) and possibility of erosion by flooding (*e*) in small depressions within the fields. The physical fertility of the soils of both locations would place them in suitability class, highly suitable (S1) but the chemical fertility would place them in the class, moderately suitable (S2f) for rice production. Thus,

Table 8: Exchangeable bases, acidity, CEC, base saturation, exchangeable sodium percentage and available P at Anaku

Profile number/ Horizon	Depth (cm)	Exchangeable Bases				TEB	CEC	BS %	Ex. acidity		ESP %	Available P
		Ca	Mg	K	Na				Al	H		
Profile 1		(cmol kg^{-1})							(cmol kg^{-1})			(mg kg^{-1})
Ap	0.00-17.00	2.40	3.20	0.08	0.05	5.73	28.65	20.00	1.20	1.40	0.17	4.66
Bt1	17.00-51.00	3.00	3.40	0.04	0.02	6.46	19.70	32.80	0.80	6.60	0.10	0.93
Bt2	51.00-71.00	4.80	5.60	0.04	0.02	10.46	22.94	45.60	3.40	4.00	0.09	5.60
BC	71.00+	4.80	6.40	0.04	0.02	11.26	29.63	38.00	2.40	4.20	0.07	0.93
Aug Point 1 topsoil	0.00-20.00	2.60	1.00	0.08	0.05	3.73	13.13	28.40	2.20	1.80	0.38	3.73
Subsoil layer 1	20.00-40.00	2.80	2.60	0.07	0.03	5.50	14.32	38.40	3.20	3.00	0.21	5.60
Subsoil layer 2	40.00-60.00	3.80	4.00	0.09	0.04	7.93	20.61	38.40	3.60	3.60	0.19	4.66
Aug Point 2 topsoil	0.00-20.00	6.00	8.20	0.14	0.08	14.42	46.81	30.80	0.20	2.20	0.17	7.46
Subsoil layer 1	20.00-40.00	7.40	1.52	0.10	0.06	22.76	42.46	53.60	trace	1.80	0.09	9.33
Subsoil layer 2	40.00-60.00	6.80	1.96	0.09	0.04	26.53	83.96	31.60	0.40	2.20	0.05	3.73
Aug Point 3 topsoil	0.00-20.00	4.00	4.00	0.07	0.03	8.10	20.88	38.80	1.80	2.20	0.14	8.39
Subsoil layer 1	20.00-40.00	1.60	2.80	0.10	0.04	4.54	14.37	31.60	4.20	4.20	0.28	1.87
Subsoil layer 2	40.00-60.00	1.80	3.00	0.09	0.04	4.93	14.67	33.60	4.40	4.60	0.27	3.73
Mean		3.97	6.01	0.08	0.06	10.10	27.24	36.21	2.53	3.15	0.19	4.83

TEB - total exchangeable bases, CEC - cation exchange capacity, BS - base saturation, ESP - exchangeable sodium percentage

Table 9: Exchangeable bases, acidity, CEC, base saturation, exchangeable sodium percentage and available P at Igbariam

Profile Number/ Horizon	Depth (cm)	Exchangeable bases				TEB	CEC	BS (%)	Ex. acidity		ESP (%)	Available P
		Ca	Mg	K	Na				Al	H		
Profile 1		(cmol kg^{-1})							(cmol kg^{-1})			(mg kg^{-1})
Ap	0.00-17.00	2.20	2.20	0.10	0.06	4.56	30.80	14.81	3.00	2.00	0.19	9.33
Bt1	17.00-51.00	2.20	2.20	0.05	0.03	4.48	21.60	20.74	3.60	2.80	0.14	9.33
Bt2	51.00-71.00	1.80	2.40	0.14	0.08	4.42	23.20	19.05	1.60	3.80	0.34	11.19
BC	71.00+	3.80	1.80	0.14	0.08	5.82	21.60	26.94	3.60	1.00	0.37	6.53
Aug Point 1 topsoil	0.00-20.00	2.20	1.60	0.09	0.05	3.94	10.40	37.88	trace	1.20	0.48	8.39
Subsoil layer 1	20.00-40.00	2.20	2.20	0.05	0.03	4.48	21.60	20.74	3.60	2.80	0.14	9.33
Subsoil layer 2	40.00-60.00	1.80	2.40	0.14	0.08	4.42	23.20	19.05	1.60	3.80	0.34	11.19
Aug Point 2 topsoil	0.00-20.00	2.10	2.10	0.08	0.05	4.33	15.40	30.49	2.70	1.80	0.33	6.06
Subsoil layer 1	20.00-40.00	3.80	1.80	0.14	0.08	5.82	21.60	26.94	3.60	1.00	0.37	6.53
Subsoil layer 2	40.00-60.00	2.00	4.00	0.07	0.04	6.11	22.40	27.80	2.00	1.40	0.18	4.66
Aug Point 3 topsoil	0.00-20.00	2.00	2.60	0.07	0.04	4.71	20.40	23.09	2.80	2.40	0.20	3.73
Subsoil layer 1	20.00-40.00	2.00	2.00	0.07	0.05	4.12	22.40	18.39	4.00	2.80	0.22	8.39
Subsoil layer 2	40.00-60.00	1.60	3.80	0.08	0.04	5.51	27.20	20.56	5.60	2.00	0.15	4.66
Mean		2.29	2.25	0.10	0.06	4.84	22.62	22.37	2.92	2.09	0.26	7.89

the soils belong to S2fe unit because of these constraints. This implies that for sustainable rice production, supplementary nutrient elements especially P, Ca and Mg need to be applied and acid forming fertilizers; for example, ammonium nitrate and sulphate of ammonia, should be avoided rather rock phosphates or superphosphates should be applied. Based on the soil chemical results and calculations (Nwille *et al*., undated) the following recommendations were made: 100.00-120.00 kg ha^{-1} urea, 60.00 kg P_2O_5 kg ha^{-1} and 25.00 kg ha^{-1} K_2O. In areas likely to be flooded, some minor levelling and bunding can be done to control erosion.

CONCLUSION

In this study, the soils on Imo clay shale residua at Anaku and Igbariam areas in Anambra State were characterized, classified and evaluated for their current suitability for rice production. The soils were moderately deep, with characteristics indicating high water table and poor drainage such as prominent mottles. The soils were dominated by medium to fine textures with clayey textures especially in the subsurface layers. The morphological and physical properties of soils favour high water retentivity due to moderate hydraulic conductivity and permeability of the soil. The soils of the study areas were classified as Typic Kanhaplaquults (soil taxonomy) which correlated with Gleyic Cambisols (WRBSR). Although, Anaku soils appeared to be more fertile than Igbariam soils, both had similar constraints to rice production; that is, insufficiency of nutrients (*f*) and possibility of erosion by flooding (*e*) in limited areas. Therefore, the current suitability of the soils for rice production is S2fe.

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REFERENCES

Akamigbo F.O.R. (1991). Semi detailed soil survey of lower Anambra flood plains in Anambra State Nigeria, final report. Water and Dams Company, Lagos, 73 pp.

Akamigbo F.O.R. and C.L.A. Asadu, (1983). Influence of parent material on the soils of southeastern Nigeria. *East Afr. Agric. Forest. J.,* **48,** 81-91

Akamigbo F.O.R. and Asadu C.L.A. (1986). The influence of topography on some soil parameters in selected areas of Anambra State Nigeria. *Nig. J. Soil Sci.,* **6,** 35-46

Akamigbo F.O.R. (1984). The accuracy of field textures in a humid tropical environment. *Soil Surv. Land Eval.,* **4,** 63-70

Amhakhian S., Osemwota I. and Oyewole C.I. (2012). Response of maize (*Zea mays* L.) yield and yield components to rates of applied phosphorus fertilizer in the Guinea Savannah soils of Kogi State, Nigeria. *J. Biol. Agric. Healthcare,* **2 (3),** 12-20

Asadu C.L.A. (1990). A Comparative characterization of two foot-slope soils in Nsukka area of Eastern Nigeria. *Soil Sci.,* **150,** 527-534

Asadu C.L.A. (1995). Environmental impact assessment studies on lower Anambra irrigation projects in eastern Nigeria. Technical Report to Water and Dams Limited, Lagos, 64 pp.

Asadu C.L.A. (1996). Soil management for conservation and sustainable rice production in an irrigated area of eastern Nigeria. *Outlook on Agric.,* **25,** 151-156

Asadu C.L.A. (2018). Agricultural policies, programmes and small-holder farming systems *vis-a-vis* food security in Nigeria. University Press Monograph No. 6, University Press, Ibadan, 45 pp.

Asadu C.L.A. and Akamigbo F.O.R. (1990). Relative contributions of organic matter and clay fractions to cation-exchange capacity (CEC) of soils in southeastern Nigeria. *Samaru J. Agric. Res.*, **7,** 17-23

Asadu C.L.A. and Onyeme E. (2021). Characterization and classification of rice-growing soils on Igbaku sandstones residua and current suitability for rice production in Anambra State, Eastern Nigeria. *Nig. J. of Soil Sci.,* **31 (1),** 70-76

Asadu C.L.A., Diels J. and Vanluawe B. (1997). A comparison of the contributions of clay, silt and organic matter to the effective CEC of soils in sub-Saharan Africa. *Soil Sci.,* **162,** 785-794

Asadu C.L.A., Onyeme E. and Asadu A.N. (2019). Comparison of land use practices and their limitations in five agrarian communities in southeastern Nigeria. *Int. J. Trend Sci. Res. Dev.,* **3 (2),** 856-862

Asadu C.L.A., Ucheagwu H. and Asadu A.N. (2012). *The Reality of Man-Made Food Insecurity in Nigeria: A Comprehensive Analysis*. University of Nigeria Press Limited, 78 pp.

Blake G.R. (1965). Bulk density. In: Black C.A. (ed.), *Methods of Soil Analysis, Part I* (pp. 375-390). American Society of Agronomy, Madison-Wisconsin, USA

Blum W.E.H. (2006). The future of soil science. In: Hartemink A.E. (ed.), *The Future of Soil Science* (pp. 176). International Union of Soil Sciences (IUSS), Wageningen, The Netherlands

Brady N.C. and Weil R.R. (2002). *The Nature and Properties of Soils* (13th edn.). Prentice-Hall Inc., New Jersey, USA, p. 960

Bray K.H. and Kurtz L.T. (1945). Determination of total organic and available forms of phosphorus in soils. *Soil Sci*., **59,** 39-45

Bremner J.M. (1965). Total nitrogen. In: Black C.A. (ed.), *Methods of Soil Analysis Part 2* (pp. 1149-1178). Am. Soc. Agron. Monograph No. 9, Madison-Wisconsin

Chapman H.D. (1965). Cation exchange capacity. In: Black C.A., Ensminger L.E. and Clark F.E. (eds.), *Methods of Soil Analysis* (pp. 891-901). Am. Soc. Agron. Monograph No. 9, Madison-Wisconsin

Dent D. and Young A. (1981). *Soil Survey and Land Evaluation*. George Allen and Unwin Limited

Dent D.L. and Ridgway R.B. (1986). *A Land Use Planning Handbook for Sri Lanka*. Land Use Policy Planning Division, Ministry of Lands and Land Development, FD 2, SRL 79/058. Colombo, Sri Lanka, p. 389

Dou F., Soriano J., Tabien R.E. and Chen K. (2016). Soil texture and cultivar effects on rice (*Oryza sativa* L.) grain yield, yield components and water productivity in three water regimes. *PLoS ONE,* **11 (3),** e0150549

FAO (1976). A framework for land evaluation. FAO Soil Bulletin 32 (pp. 72-77), Food and Agriculture Organization (FAO), Rome

FAO (1988). World soil resources report, agro-ecological zone projects (volume 1). Methodology and Results for Africa, Food and Agriculture Organization (FAO), Rome

FAO (1995). Guidelines: land evaluation for rainfall agriculture. FAO Soil Bulletin 52 (p. 237), Soil Resources Management and Conservation Services, Land and Water Development Division, Food and Agriculture Organization (FAO), Rome

FDALR (1982). Land evaluation for agricultural land use in Nigeria. In: *Efficient Use of Nigeria Land Resources* (pp. 38-47). Proc. 1st National Seminar on Agricultural Land Resources, Federal Department of Agricultural Land Resources (FDALR), 13-18 Sep., Kaduna

IUSS Working Group WRB (2015). World reference base for soil resources 2014: Update 2015. International Soil Classification System for Naming Soils and Creating Legends for Soil Maps World Soil Resources Reports No. 106, FAO, Rome

Jackson M.L. (1973). *Soil Chemical Analysis*. Prentice Hall of India Private Limited, New Delhi, p. 498

Keay R.W.J. (1949). *An Outline of Nigerian Vegetation*. Government Printer, South Africa, p. 52

McLean E.O. (1965). Aluminium. In: Black C.A. (ed.), *Methods of Soil Analysis Part II* (pp. 978-998). Am. Soc. Agron. Monograph No. 9, Madison-Wisconsin

McLean E.O. (1982). Soil pH and lime requirement. In: Page A.L. (ed.), *Methods of Soil Analysis Part 2: Chemical and Microbiological Properties* (pp. 199-224). American Society of Agronomy, Soil Science Society of America, Madison-Wisconsin, USA

Moormann F.R. (1978). Morphology and classification of soils on which rice is grown. In: *Soils and Rice* (pp. 255-272). International Rice Research Institute, Los Banos, Philippines

Nwille F.E., Oikeh S.O., Agunbiade T.A., *et al.* (undated). *Growing Lowland Rice: A Production Handbook*. Africa Rice Centre (WARDA) Headquarters, Cotonou, Benin, 45 pp.

Ofomata G.E.K. (1965). Factors of soil erosion in Enugu area of Nigeria. *Nig. Geogr. J.,* **8,** 45-59

Osadebe C.C., Obrike S.E. and Sulymon N.A. (2011). Evaluation of Imo clay shale deposit (paleocene) from Okada, Edo State, southwestern Nigeria, as drilling mud clay. *J. Appl. Technol. Environ. Sanit.,* **1 (4),** 311-316

Osinuga O.A., Aiboni V.U. and Oyegoke C.O. (2020). Classification and suitability evaluation of soils along a toposequence for rice production in Alabata, southwest Nigeria. *Agro-Science*, **19 (4)**, 43-50

Rhoades J.D. (1982). Cation exchange capacity. In: Page A.L. (ed.), *Methods of Soil Analysis Part 2* (pp. 149-157). Am. Soc. Agron. No.9, Madison-Wisconsin

Soil Survey Staff (2014). *Keys to Soil Taxonomy* (12th edn.). USDA Natural Resources Conservation Service, p. 372

Schoeneberger P.J., Wysocki D.A., Benham E.C. and Soil Survey Staff (2012). *Field Book for Describing and Sampling Soils* (3rd edn.). Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE. https://www.nrcs.usda.gov/resources/guides-and-instructions/field-book-for-describing-and-sampling-soils

Schoeneberger P.J., Wysocki D.A., Benham E.C. and Broderson W.D. (2002). *Field Book for Describing and Sampling Soils* (2nd edn.), Natural Resources Conservation Service, National Soil Survey Centre, Lincoln, NE, 298 pp.

Senjobi B.A. (2007). *Comparative Assessment of the Effect of Land Use and Land Type on Soil Degradation and Productivity in Ogun State, Nigeria*. PhD Thesis, Department of Agronomy, University of Ibadan, p. 161

Uzoho B.U., Ekpe I.I., Ahukaemere C.M., Ndukwu B.N., Okoli N.H., Osisi F.A. and Chris-Emenyonu C.M. (2014). Nitrogen status of soils of selected land-uses of two cropping systems in the humid tropical rainforest, southeastern Nigeria. *Adv. Life Sci. Technol.,* **25,** 24-33

Van Reeuwijk L.P. (1992). *Procedures for Soil Analysis* (3rd edn.). International Soil Reference and Information Centre (ISRIC), Wageningen, The Netherlands, p. 34

Vespraskas (1987). Bulk density values diagnostic of restricted root growth in coarse-textured soils. *Soil Sci. Soc. Am. J.,* **52 (4),** 1117-1121

Yaalon D.H. and Arnold R.W. (2000). Attitudes toward soils and their societal relevance: Then and now. *Soil Sci.,* **165,** 5-12