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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: I. OMASI-AGU AND OMOR AGRARIAN COMMUNITIES

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ABSTRACT

The soils on Imo clay shale residua at Omasi-Agu and Omor areas in Anambra State, Nigeria were sampled in order to characterize classify and evaluate their current suitability for rice production following standard scientific procedures. 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 retentivity due to low hydraulic conductivity and slow permeability. All these soil conditions support good rice performance. Though the soils at Omasi-Agu contained high levels of exchangeable bases, exchangeable acidity was equally high leading to low base saturation of < 35% but at Omor the base saturation was > 35%. Thus, the soils were, respectively, classified as Typic Kandiaquults (Soil Taxonomy) correlated with Gleyic Cambisols of the World Reference Base for Soil Resources (WRBSR) and Typic Kandiaqualfs (Soil Taxonomy) correlated with Gleyic Cambisols (WRBSR). Even though the soils of Omor appeared to be generally more fertile than Omasi-Agu soils, both have similar constraints to rice production, that is, insufficiency of nutrients (f) and possibility of erosion by flooding (e) in limited areas (< 25%). Therefore, the current suitability of the soils for rice production is suitability class 2 with fertility constraints (S2fe). For sustainable rice production, supplementary addition of nutrients especially P_2O_5 from triple superphosphate and some minor levelling and bunding are required to control erosion due to flooding in the limited areas.

Key words: Typic Kandiaquults, Typic Kandiaqualfs, Gleyic Cambisols, sustainability, 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 food 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 the long-life expectancy of people.

Characterization and classification of soils in countries like Nigeria with insufficient food supplies should be accompanied with 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) remain valid in evaluating such soils for use in agricultural production. Generally, land use types differ from one location to another depending on the immediate needs of the government, the communities or the 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 influence the 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 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 would 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 crops and those several factors and conditions in the environment that determine the performance of any crop. 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. 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 better than sandy textures in rice production due to the former's 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). The northern Anambra State of Nigeria is made up many agrarian communities well known for rice production (Asadu *et al.,* 2019). In this study, the soils on Imo Clay Shale residua in northern Anambra State (Omasi-Agu and Omor) were characterized, classified and evaluated for their suitability for rice production.

MATERIALS AND METHODS

Description of Study Areas

The study was carried out in two locations in the northernmost part of Anambra State of Nigeria; Omasi-Agu (6° 42.05" N, 6° 59.45" E) and Omor (6° 30.67" N, 6° 55.48" E), both in Ayamelum Local Government Area of the State (Figure 1).

Figure 1: Map of Anambra State showing the study areas

Climatic Information

Both study sites belong to the Kopen classification, an "Awi" climate which is a tropical rainy climate with distinct dry and wet seasons. The average annual rainfall is 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 often referred to as August break or little dry season (Asadu, 2002) leading to bimodal rainfall pattern. The total rainfall amount, from November to February, during the dry season is ca. 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 (Akamigbo, 1991).

Geology and Geomorphology

Detailed descriptions of the geology and geomorphology of areas under study (Ofomata, 1965) indicate that they belong mainly to the Imo Clay Shales and the evolution of the present landscape began in the Tertiary times. This Imo Clay Shales (Palaeocene) form the parent materials for a greater proportion of the soils (Akamigbo, 1991). The general relief 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 (Akamigbo, 1991; Asadu, 1996).

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 characterize 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 (*Naucleadi derrichii*), oil *palms* (*Elaeis guineensis)*, borassus palms or palmyra palm (*Borassus akeassii*) and some fruit trees such as mangoes (*Mangifera indica*) and oranges (*Citrus* sp.).

Omasi-Agu and Omor are agrarian communities known for the production of many cash and catch crops. The 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 some depressions and floodplains.

Method of Survey Adopted

The field survey was carried out 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 etrex-Legend global positioning system (GPS) equipment. 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 the properties of one in each location were presented.

The profile pits were dug to permissible water table (≤ 56.00 cm) 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 Soil Survey Staff of USDA and FAO/UNESCO guidelines for soil profile study as summarized in Schoeneberger *et al*. (2002). Soil samples were collected from identifies pedogenic horizons after macro-morphological characterization. Undisturbed core samples were collected from 0.00-20.00 cm and 20.00-40.00 cm depths using metallic core samplers near the profile pits and at carefully selected points for hydraulic conductivity, pore-size distribution and bulk density determinations. The soil properties from the auger points and top-soils of the modal profiles were used to assess the current suitability of the soils for rice cultivation while those from the modal profile pits were used for the characterization and classification of the soils.

Laboratory Determinations and Theoretical Crop Requirements

All the soil analyses were carried out at the Laboratory of the Department of Soil Science, 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 h. 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 divided by the volume of bulk soil; microporosity from volume of water retained at 60.00 cm of tension divided by the 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 hydrometric 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 1:2.50 (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) and converted to soil organic matter (SOM) by multiplying with the factor 1.723. Soil content of total N was determined by the Kjeldahl digestion, distillation, and titration method (Bremner, 1965).

Cation exchange capacity (CEC) and exchangeable bases (Ca, Mg, K and Na) were determined from ammonium acetate extracts (1.00N 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 (1.00 N KCl) and titrating with sodium hydroxide (Mclean, 1965). Percentage base saturation was determined by calculation as follows:

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

where %BS is percentage base saturation of the soil, TEB is total exchangeable bases, and CEC is cation exchange capacity of the soil. 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 system was used to evaluate the suitability of the land for rice cultivation. The suitability orders N (unsuitable) and S (suitable) first employed using the principle of limiting conditions 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.

RESULTS AND DISCUSSION

Morphological Properties of Modal Profiles at Omasi-Agu and Omor

Table 3 shows that the soils of the two locations (Omasi-Agu and Omor) had mixed parent materials of Imo Shale residua and fluvial materials, and on gentle slopes found between 31 and 43 m asl. Drainage was generally very poor in both locations. At Omasi-Agu the top soil was dark reddish brown (5YR3/4) with reddish brown (5YR4/8) mottles while at Omor the colour was very dark brown (7.5YR3/2) with no mottles. In the subsurface layers there were prominent mottles in both soils (Table 3) indicating imperfect drainage, typical of soils that normally support rice production as it aids water retention (Asadu, 1996). The soils of Omasi-Agu had low base saturation (< 35%) with Bt horizon and aquic moisture regime and were therefore classified as Typic Kandiaquults (Soil Taxonomy) correlated to Gleyic Cambisols (WRBSR). The soils of Omor had base saturation of > 35%) with Bt horizon and aquic moisture regime and were classified as Typic Kandiaqualfs (Soil Taxonomy) and correlated to Gleyic Cambisols (WRBSR).

Physical Properties of Soils

Particle size distribution and texture

The clay, silt and fine sand contents in both soils (Tables 4 and 5) were very high compared to most soils of eastern Nigeria (Akamigbo, 1984). The fine of the parent material of the soils, Imo Shale residua, must have influenced the content of these fine materials (Akamigbo and Asadu, 1983). In addition, occasional flooding of the areas from the surrounding rivers could have contributed to addition of fine materials in the soils. Even though total sand fractions dominated over clay and silt fractions, fine sand dominated over coarse sand. The general increase in clay fraction with depth showing the accumulation of this fraction in the subsoil layers or B-horizon can be used to predict eluviation/ illuviation process or lessivage in the soils.

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 in both soils is a characteristic of soils formed from shale residua (Akamigbo and Asadu, 1983). All the textures would not offer restricted root growth to arable crops including rice (FAO, 1988). The implication of particle size distribution and textural classes obtained is that permeability would be slow and water retention high; these conditions favour water availability for rice production in both soils whether from rainfall or irrigation.

Table 1: Land and soil requirement for rice

Land qualities	Land characteristic	Limiting values for land characteristics			
		S1	S2	S3	N
Sufficiency of energy	Mean annual temperature (°C)	> 24	21-24	18-21	< 18
	Elevation (m)	0.00-600.00	600.00-1200.00	1200.00-1800.00	> 1800.00
Sufficiency of water	75% probability rainfall (mm)	> 1300.00	900.00-1300.00	500.00-900.00	< 500.00
	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	4.50-5.00	< 4.50
			7.00-8.00	8.00-8.50	> 8.50
Salinity hazard	EC_e (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	1-5	5-10	> 10

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 descriptions

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.

Source: FAO (1976)

Table 3: Morphological properties of modal profiles at Omasi-Agu and Omor

S/N	General Information		
		Omasi-Agu soils	Omor soils
1	Profile number	1	1
2	Describer	Charles Asadu	Charles Asadu
3	Date	August 25, 2017	August 25, 2017
4	Village	Omasi-Agu in Ayamelum Local Government Area (LGA), Anambra State	Omor in Ayamelum LGA, Anambra State
5	Location	Latitudes 6° 43.176" N, longitudes 6° 59.271" E	Latitude 6° 30.670" N, longitude 6° 55.486"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 (4-5% slope)
8	Elevation	43.00 m above sea level (asl)	31.00 m asl
9	Direction of slope	South to north direction	East to west direction
10	Drainage		
	Runoff	Very slow	Ponded
	Permeability	Slow	Slow
	Internal drainage	Very slow	Very slow
	Soil drainage class	Very poor	Very poor
11	Stoniness	0%	0%
12	Rockiness	0%	0%
13	Erosion	Slight inter-rill	Slight inter-rill
14	Higher categorical classification	Typic Kandiaquults (Soil Taxonomy) correlated to Gleyic Cambisols (WRBSR)	Typic Kandiaqualfs (Soil Taxonomy) correlated to Gleyic Cambisols (WRBSR)
15	Land use	Grass fallow in ponded areas, maize, cassava + *Cajanus cajan* in raised mounds in surrounding areas susceptible to flooding	Rice grown in ponded areas, maize, cassava, *Cajanus cajan* in raised mounds within the flood plain and in surrounding areas

Horizon description

Omasi-Agu soils			Omor soils		
Designation	Depth (cm)	Description (all colours are moist colours)	Designation	Depth (cm)	Description (all colours are moist colours)
Ap	0.00-16.00	Dark reddish brown (5YR3/4); loam; moderate, fine, granular; firm, hard, slightly sticky, plastic; deep penetrable; reddish brown (5YR4/8), faint, few, fine mottles; many, very fine grass roots; common, very fine pores; clear smooth boundary	Ap	0.00-18.00	Very dark brown (7.5YR3/2); clay loam; moderate, fine, granular; firm, slightly hard, slightly sticky, slightly plastic; deep penetrable; few, fine grass roots; common, fine pores; clear smooth boundary
AB	16.00-37.00	Dull brown (7.5YR5/3); sandy clay loam; strong, medium, granular; firm, very hard, sticky, plastic; deep penetrable; brownish gray (7.5YR5/4), distinct, common, medium mottles; few, very fine grass roots; common, very fine pores; clear smooth boundary	Bt1	18.00-49.00	Brownish black (2.5YR3/2); clay; strong, medium, granular; firm, hard, sticky, plastic; deep penetrable; brown (10YR4/6), distinct, common, fine mottles; few, fine grass roots; few, fine pores; clear smooth boundary.
Bt	37.00-57.00	Dull brown (7.5YR5/3); sandy clay loam; very firm, very hard, sticky, plastic; deep penetrable; brownish gray (7.5YR5/4), distinct, common, medium mottles; diffuse irregular boundary	Bt2	49.00-69.00	Brownish black (2.5YR3/2); clay; very firm, very hard, very sticky, very plastic; deep penetrable; brown (10YR4/6), prominent, many, medium mottles; diffuse irregular boundary
B	57.00+	Grayfish brown (7.5YR5/2); sandy clay loam; very firm, very hard, sticky, plastic; deep penetrable; bright brown (7.5YR5/6), prominent, common, medium mottles; diffuse irregular boundary	BC	69.00+	Brownish black (2.5YR3/2); clay; very firm, very hard, very sticky, very plastic; deep penetrable; brown (10YR4/6), prominent, many, medium mottles; diffuse irregular boundary

Interpreted characteristics of the soil/remarks

Soil can hold water for a very long time because of very poor drainage; therefore, it is good for swamp rice. Rice can be grown year-round with subsidiary irrigation from the Obina River. Very high mounds of up to 1 m are required for growing other arable crops such as yam, cassava, maize during the rains within the floodplains.	Soil can hold water for a very long time because of very poor drainage, therefore, it good for swamp rice. Rice can be grown year-round with subsidiary irrigation. Very high mounds of up to 1 m are required for growing other arable crops such as yam, cassava, maize during the rains within the floodplains.

Table 4: Particle size distribution and soil textures at Omasi-Agu modal profile pit and auger samples

Profile/auger points	Depth (cm)	Clay	Silt	Fine sand	Coarse sand	Total sand	Textural class
				(g kg^{-1})			
Ap	0.00-16.00	260.00	420.00	210.00	110.00	320.00	L
AB	16.00-37.00	260.00	280.00	480.00	80.00	560.00	SCL
Bt	37.00-57.00	300.00	220.00	400.00	80.00	480.00	SCL
BC	57.00+	300.00	220.00	400.00	80.00	480.00	SCL
Auger position 1 topsoil	0.00-20.00	260.00	420.00	210.00	110.00	320.00	L
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	300.00	220.00	400.00	80.00	480.00	SCL
Position 2 topsoil	0.00-20.00	180.00	280.00	360.00	180.00	540.00	SL
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	260.00	300.00	300.00	140.00	440.00	CL
Position 3 topsoil	0.00-20.00	200.00	320.00	280.00	200.00	480.00	L
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	400.00	300.00	220.00	80.00	300.00	C

L - loam, S - sand or sandy, C - clay

Table 5: Particle size distribution and soil textures at Omor modal profile pit and auger samples

Profile/auger points	Depth (cm)	Clay	Silt	Fine sand	Coarse sand	Total sand	Textural class
				(g kg^{-1})			
Ap	0.00-18.00	320.00	360.00	160.00	160.00	360.00	CL
Bt1	18.00-49.00	440.00	220.00	200.00	140.00	340.00	C
Bt2	49.00-69.00	480.00	220.00	200.00	100.00	300.00	C
BC	69.00+	480.00	220.00	120.00	100.00	220.00	C
Position 1 topsoil	0.00-20.00	140.00	140.00	120.00	600.00	720.00	SL
Subsoil layer 1	20.00-40.00	180.00	140.00	200.00	480.00	680.00	SL
Subsoil layer 2	40.00-60.00	200.00	100.00	160.00	540.00	700.00	SCL
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	220.00	160.00	160.00	460.00	620.00	SL
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	400.00	300.00	220.00	80.00	300.00	C

L – loam, S – sand or sandy, C – clay

Bulk density, pore size distribution and hydraulic conductivity

The values of bulk density (Table 6) indicate that at Omasi-Agu the range was 1.02-1.54 Mg m^{-3} and at Omor it was 1.18-1.46 Mg m^{-3} with the overall mean in both soils and layers < 1.30 Mg m^{-3}. Thus, the bulk density values obtained could be considered not restrictive to rice roots because soil bulk density is considered root-restrictive if it is above the threshold value of 1.60 Mg m^{-3} (Vespraskas, 1987). Although high soil bulk densities are undesirable, such low values as 1.02 Mg m^{-3} obtained at Omasi-Agu may pose problems as a study on a sandy loam soil found a decline in yield of lowland rice when the soil bulk density dropped below a critical value of 1.05 Mg m^{-3} but it can be ameliorated if the soil is well puddled before planting because soils with appreciable clay content, once puddled, initially show a decrease in bulk density which slowly increases over the season (Nwite *et al.,* 2016).

The data on porosity parameters (total porosity, macro- and microporosity) of the soil showed that generally the topsoils were more porous than the subsurface layers in both locations though the differences were not very substantial being < 7% at Omasi-Agu and < 11% at Omor (Table 6). However, the higher total porosities in the topsoils compared to the subsurface layers can be attributed to the finer textures of the latter. Generally, the porosity of soils is determined by the interplay between texture and organic matter and very often there is always higher organic matter concentration in the topsoils than the subsurface layers in 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. This implies greater water retention and availability in the soils. On the average, the soils had about 50% and 38% of its volume occupied by pores in topsoil and subsurface layers, respectively; therefore, the porosities meet the hypothetical value that favours rice cultivation (Dent and Ridgway, 1986). The saturated hydraulic conductivity (K_s) values were consistently lower in the subsurface layers than the topsoils. The K_s values of the soil layers were dominated by ‘moderately slow class’ (Schoeneberger *et al*., 2012). By this rating, the K_s values are under the permeability classes ‘moderate’ to ‘very slow’. This implies that the rate of water transmission through the soil, as defined by their texture and structure, would be intermediate and slow in the soils. With the moderate permeability of the topsoils, rainwater and irrigation water would be readily intercepted into the soil; the intermediately permeable subsurface layers would not allow all such water to be lost through excessive drainage. In addition, this is a good attribute of the soils in terms of water retention for rice cultivation.

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

Position	Depth (cm)	Bulk density ($Mg\ m^{-3}$)	Total porosity (%)	Macroporosity (%)	Microporosity (%)	K_s ($cm\ h^{-1}$)
				Omasi-Agu		
Number 1	0.00-20.00	1.02	51.59	5.15	46.44	6.61
	20.00-40.00	1.54	38.16	3.17	35.00	4.07
Number 2	0.00-20.00	1.31	43.50	4.46	39.04	7.06
	20.00-40.00	1.51	36.38	3.08	33.31	3.26
Number 3	0.00-20.00	1.02	46.97	5.64	41.33	10.32
	20.00-40.00	1.14	46.88	5.52	41.36	4.89
Mean	0.00-20.00	1.29	47.35	5.08	42.27	7.15
	20.00-40.00	1.22	40.47	3.92	36.56	4.92
				Omor		
Position 1	0.00-20.00	1.24	55.38	4.61	50.77	0.62
	20.00-40.00	1.46	44.31	3.58	40.74	0.59
Position 2	0.00-20.00	1.30	40.42	4.13	36.29	0.53
	20.00-40.00	1.35	30.58	2.35	28.23	0.47
Position 3	0.00-20.00	1.18	51.98	3.67	48.31	0.94
	20.00-40.00	1.40	38.13	5.37	32.76	1.25
Mean	0.00-20.00	1.24	49.26	4.14	45.12	0.70
	20.00-40.00	1.40	37.67	3.77	33.91	0.77

Chemical Properties

Soil pH, soil organic matter, total nitrogen

Table 7 shows pH, soil organic matter (SOM) and total nitrogen (TN) contents of the soils of both locations. At Omasi-Agu the pH values ranged from strongly acid (4.9) to slightly acid (6.5) but dominated by moderately acid soils (pH > 5.5) while at Omor the pH values ranged from strongly acid (4.7) through moderately acid and slightly acid to neutral (7.3) but dominated by moderately acid soils (pH > 5.6). The dominant pH values obtained from the soils of both locations are suitable for most arable crops including rice.

The SOM values varied from moderately low (9.08 g kg^{-1}) through medium and moderately high to very high values (53.74 g kg^{-1}) in both locations (Table 7). The high variability in SOM content may be due to fluctuating soil water conditions over the seasons during the year because of non-uniformity in SOM decomposition over the field. The TN contents generally followed the same trend as SOM varying from moderately low (0.42 g kg^{-1}) through medium to very high values (29.40 g kg^{-1}) even though the highest and lowest values were obtained from soils of Omasi-Agu (Table 7). The low TN content in the soils could be attributed to rapid mineralization of SOM resulting from the exposure of soils to high temperatures (Uzoho *et al*., 2014). This is obvious as SOM is essentially the main source of nitrogen in soil (Osinuga *et al.,* 2020).

Exchangeable bases/acidity, CEC, base saturation, ESP and available P at Omasi-Agu

The exchangeable Ca and Mg obtained in Omasi-Agu soils were generally high to very high, while the exchangeable K, Na and total exchangeable bases were low (Table 8). Exchangeable Ca ranged from 1.80 to 3.40 cmol kg^{-1} with a mean of 2.50 cmol kg^{-1}, while exchangeable Mg ranged from 1.40 to 4.80 cmol kg^{-1} with a mean of 3.10 cmol kg^{-1}. Exchangeable K ranged from 0.04 to 0.19 cmol kg^{-1} with a mean of about 0.10 cmol kg^{-1}. Both exchangeable Na and exchangeable sodium percentage (ESP) were very low with their respective mean values as 0.05 cmol $kg^{-1}$and ≈ 0.2 %. These values suggest that sodicity problems (unstable structure, poor root development etc) are not likely in the soils.

The values of total exchangeable bases (TEB) ranged from 4.10 to 8.40 cmol kg^{-1} with a mean of over 6.00 cmol kg^{-1}. The CEC values were relatively high ranging from 13.60 to 54.00 cmol kg^{-1} with a mean of 21.00 cmol kg^{-1}, but with high values of exchangeable acidity. Exchangeable Al was very high, ranging from 0.40 to 2.80 cmol kg^{-1} with a mean of 1.40 cmol kg^{-1}. The mean exchangeable H was slightly lower (≈ 1.20 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 7). The values contributed to the low mean base saturation of < 25%. The available P was 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 H_2O	pH KCl	SOM ($g\ kg^{-1}$)	TN ($g\ kg^{-1}$)	Depth (cm)	pH H_2O	pH KCl	SOM ($g\ kg^{-1}$)	TN ($g\ kg^{-1}$)
	Omasi-Agu					Omor				
Ap	0.00-16.00	6.50	5.30	36.33	2.94	0.00-18.00	7.30	6.10	37.08	1.26
AB/Bt1	16.00-37.00	5.80	4.60	14.38	0.42	18.00-49.00	6.60	5.40	18.92	0.56
Bt2	37.00-57.00	5.50	4.20	24.98	0.84	49.00-69.00	6.40	5.20	16.65	0.70
BC	57.00+	6.20	5.00	11.35	0.98	69.00+	5.90	4.60	12.87	0.84
Point 1 topsoil	0.00-20.00	5.60	4.40	9.08	0.42	0.00-20.00	4.70	3.50	30.27	0.70
Subsoil layer 1	20.00-40.00	5.50	4.20	24.98	0.84	20.00-40.00	4.90	4.20	21.19	0.84
Subsoil layer 2	40.00-60.00	4.90	4.20	16.65	0.98	40.00-60.00	4.70	3.50	22.71	0.70
Point 2 topsoil	0.00-20.00	5.60	4.50	24.98	0.42	0.00-20.00	5.50	4.40	31.03	0.84
Subsoil layer 1	20.00-40.00	6.50	5.30	36.33	2.94	20.00-40.00	4.90	4.20	21.19	0.84
Subsoil layer 2	40.00-60.00	5.80	4.60	14.38	0.42	40.00-60.00	4.70	3.50	22.71	0.70
Point 3 topsoil	0.00-20.00	5.40	4.20	15.89	0.15	0.00-20.00	5.50	4.40	31.03	0.84
Subsoil layer 1	20.00-40.00	5.50	4.30	53.74	0.24	20.00-40.00	5.50	4.20	19.68	0.56
Subsoil layer 2	40.00-60.00	6.20	5.00	11.35	0.98	40.00-60.00	5.40	4.10	16.65	0.42

SOM - soil organic matter, TN - total nitrogen

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

Profile/auger points		Exchangeable bases				TEB	CEC	BS	Exch. acidity		ESP	Available
Profile	Depth (cm)	Ca	Mg	K	Na			(%)	Al^{3+}	H^{+}	(%)	P
		(cmol (+) kg^{-1})							(cmol (+) kg^{-1})			(mg kg^{-1})
Ap	0.00-16.00	1.80	3.80	0.09	0.05	5.74	54.40	10.55	2.80	1.00	0.10	14.92
Bt1	16.00-37.00	2.00	4.20	0.09	0.04	6.33	42.00	15.07	2.00	0.10	0.25	1.87
Bt2	37.00-57.00	3.20	3.40	0.09	0.05	6.74	46.40	14.53	1.40	0.80	0.11	3.73
BC	57.00+	3.00	3.00	0.08	0.04	6.12	13.60	45.00	0.06	1.00	0.29	2.80
Point 1 topsoil	0.00-20.00	2.60	1.40	0.08	0.04	4.12	14.80	27.84	0.60	1.60	0.27	0.93
Subsoil layer 1	20.00-40.00	2.60	2.60	0.10	0.06	5.36	30.40	17.63	2.00	0.80	0.20	3.73
Subsoil layer 2	40.00-60.00	1.80	2.80	0.09	0.05	4.74	35.20	13.47	2.00	2.40	0.14	2.80
Point 2 topsoil	0.00-20.00	3.40	4.80	0.10	0.06	8.36	35.20	23.75	1.00	1.20	0.17	3.73
Subsoil layer 1	20.00-40	3.20	2.00	0.08	0.04	5.32	18.40	28.91	0.40	1.20	0.22	3.73
Subsoil layer 2	40.00-60.00	3.40	3.00	0.14	0.08	6.62	27.20	24.34	0.40	1.00	0.29	8.39
Point 3 topsoil	0.00-20.00	1.80	3.80	0.09	0.05	5.74	54.40	10.55	2.80	1.00	0.10	14.92
Subsoil layer 1	20.00-40.00	2.00	4.20	0.18	0.10	6.49	42.00	15.44	2.00	0.80	0.25	1.87
Subsoil layer 2	40.00-60.00	3.20	3.40	0.09	0.05	6.74	46.40	14.53	1.40	0.80	0.11	3.73
Mean		2.50	3.13	0.10	0.06	6.14	33.62	21.68	1.38	1.20	0.20	4.99

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

Omor location

The exchangeable Ca and Mg were generally high to very high while the exchangeable K and Na were low. The values of total exchangeable bases were high leading to relatively moderate base saturation (Table 9). Exchangeable Ca ranged from 2.80 to 15.00 cmol kg^{-1} averaging over 6.00 cmol kg^{-1} while exchangeable Mg ranged from 0.60 to 18.30 cmol kg^{-1} with a mean of about 8.00 cmol kg^{-1}. Exchangeable K was low ranging from 0.04 to 0.14 cmol kg^{-1} with a mean of about 0.08 cmol kg^{-1}. Both exchangeable Na and exchangeable sodium percentage (ESP) indicated very low the mean values being 0.055 cmol kg^{-1} and about 0.2%, respectively. These very low values of exchangeable Na and ESP suggest that sodicity problems (unstable structure, poor root development, etc.) are not likely in the soils.

The values of TEB ranged from 5.68 to 34.22 cmol kg^{-1} with a mean of ≈ 15.00 cmol kg^{-1}. The CEC values were high ranging from 19.60 to 74.00 cmol kg^{-1} with a mean of ≈ 36.00 cmol kg^{-1}. Total exchangeable acidity values were dominated by exchangeable H with a mean of 1.27 cmol kg^{-1} compared to 0.70 cmol kg^{-1} for exchangeable Al and exchangeable Al was not detected in some samples while exchangeable H was recorded in all the samples. The total exchangeable acidity reflected the strongly to slightly acid conditions of the soil as shown by the pH values (Table 7). This is also reflected by the base saturation of ≈ 40% on the average though higher values were obtained in samples without exchangeable Al.

The variations in the exchangeable cations of soils of Imo Clay Shales studied tended to reflect mixed mineralogy often associated with the modes of formation of the geological formation. The 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 high and inconsistent values of exchangeable cations (Asadu and Onyeme, 2021).

The available phosphorus (P) contents of the soils were very low with a mean of approximately 12.00 mg kg^{-1}. Thesde low available P 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.

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

Profile/auger points		Exchangeable bases				TEB	CEC	BS	Exch. acidity		ESP	Available
Profile	Depth (cm)	Ca	Mg	K	Na			(%)	Al^{3+}	H^{+}	(%)	P
		(cmol (+) kg^{-1})							(cmol (+) kg^{-1})			(mg kg^{-1})
Ap	0.00-18.00	15.80	18.20	014	0.08	34.22	70.40	48.61	trace	1.80	0.11	19.59
AB	18.00-49.00	12.80	17.20	0.09	0.05	30.14	72.00	41.86	trace	1.80	0.01	17.72
Bt	49.00-69.00	11.00	12.40	0.09	0.05	23.54	50.40	46.71	trace	1.20	0.10	13.06
BC	69.00+	8.00	14.00	0.07	0.03	22.10	50.40	43.85	trace	1.60	0.06	13.99
Point 1 topsoil	0.00-20.00	2.80	4.20	1.03	0.06	8.09	26.80	26.73	0.08	0.80	0.22	10.26
Subsoil layer 1	20.00-40.00	3.40	1.20	1.03	0.06	5.68	21.20	22.47	0.16	2.40	0.28	12.12
Subsoil layer 2	40.00-60.00	3.60	3.80	0.90	0.05	8.55	18.80	40.11	0.32	2.80	0.27	7.46
Point 2 topsoil	0.00-20.00	3.40	1.20	1.03	0.06	6.69	21.20	22.47	0.16	2.40	0.28	12.12
Subsoil layer 1	20.00-40.00	3.80	6.00	0.90	0.05	10.85	19.60	54.80	0.18	1.20	0.26	9.33
Subsoil layer 2	40.00-60.00	8.00	1.40	0.70	0.03	10.10	50.40	43.85	trace	0.20	0.06	13.99
Point 3 topsoil	0.00-20.00	2.80	4.20	1.03	0.06	8.09	26.80	26.73	0.08	0.10	0.22	10.26
Subsoil layer 1	20.00-40.00	3.80	6.80	0.90	0.05	11.55	19.60	54.80	1.80	0.10	0.26	9.33
Subsoil layer 2	40.00-60.00	4.20	6.80	0.90	0.05	11.95	21.20	52.55	1.80	0.10	0.24	11.19
Mean		6.01	8.04	0.80	0.05	14.73	36.61	40.43	0.17	1.27	0.18	12.34

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

Current Suitability for Rice Production

Comparatively, the Omor soils could be considered to be generally more fertile than Omasi-Agu soils but both have similar constraints to rice production, that is, insufficiency of nutrients (f) and possibility of erosion by flooding (e) in limited areas (< 25%). 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 (S2) for rice production. Thus, both soils belong to suitability unit with fertility and erosion constraints (S2fe). This implies that for sustainable rice production, supplementary nutrient elements especially NPK, Ca and Mg need to be applied but acid forming fertilizers, for example, ammonium nitrate and sulphate of ammonia, should be avoided rather 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 ha^{-1} P_2O_5 (from triple super phosphate) and 25.00 kg ha^{-1} K_2O. In small areas likely to be flooded, some minor levelling and bunding can be done to control erosion that may result from flooding.

CONCLUSION

The study characterized, classified and evaluated the soils on Imo Clay Shale residua at Omasi-Agu and Omor areas in Anambra state, Nigeria for their current suitability for rice production. The soils were moderately deep, with characteristics indicating high water table and poor drainage especially the presence of prominent mottles. The dominant textures were fine textures belonging to loamy textural classes or finer, especially in the subsoil layers. The morphological and physical properties of soils favour high water retention due to low hydraulic conductivity and slow permeability both of which are soil conditions that support good rice performance. Based on the properties of the modal profiles the soils of Omasi-Agu and Omor were, respectively, classified as Typic Kandiaquults (Soil Taxonomy) correlated to Gleyic Cambisols (WRBSR) and Typic Kandiaqualfs (Soil Taxonomy) correlated to Gleyic Cambisols (WRBSR). Both soils had similar constraints to rice production namely insufficiency of nutrients (f) and possibility of erosion by flooding (e) in limited areas. Therefore, their current suitability for rice production is S2fe. Application of supplementary nutrient especially P_2O_5 from triple superphosphate or rock phosphate and minor levelling or bunding is recommended to ensure sustainable rice production in both locations.

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