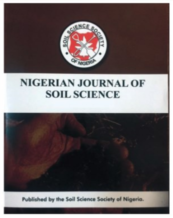
DOI: https://doi.org/10.67042/njss.2020.qbrphk19 **Obasi *et al*,** *NJSS 30 (2) 2020 113-122*

Nigerian Journal of Soil Science

Journal homepage:www.soilsjournalnigeria.com



Fertility capability classification of soils supporting rice production in Ebonyi State, southeastern Nigeria

Obasi S. N.[1], & Obasi C. C.[2]

1. *Department of Crop & Soil Science National Open University of Nigeria, Kaduna Campus.*
2. *Department of Crop Science and Horticulture, Nnamdi Azikiwe University, Awka, Nigeria*

ARTICLE INFO

Article history:
Received April 15, 2020
Received in revised form June 10, 2020
Accepted August 12, 2020
Available online September 4, 2020

Keywords:

Limitations
Modifiers
Soil Characterization
Soil Classification
Soil Fertility

Corresponding Author's E-mail Address:

nobasi@noun.edu.ng +2348034499155

njss.2020.300214

ISSN-1597-4488

ABSTRACT

This research was carried out to characterized and classify fertility capability to enhance the productivity of rice in Ebonyi soils. Ebonyi state was grouped into three zones according to their agricultural zones namely; Ebonyi north, Ebonyi central and Ebonyi south, representing Abakaliki, Ikwo and Ivo locations, respectively. Major rice growing areas of the soils were located and two profile pits were sunk in each of the studied zones, from which soils were characterized, classified and fertility capability classification (FCC) developed. Soil classification was done using United State Department of Agriculture (USDA) Soil Taxonomy and correlated with World Reference Base for soil resources while Fertility capability classification (FCC) system, version 4 was used to classify the fertility capability of the studied soils. Results obtained classified Abakaliki 1 and Abakaliki 2 as Typic Fluvaquents (Ochric Fluvisols). Ikwo 1 was classified as Vertic Eutrudepts (Eutric Vertisols) while Ikwo 2 was classified as Typic Eutrudepts (Eutric Cambisols). Ivo 1 and Ivo 2 were both classified as Aquic Eutrudepts (Gleyic Leptosols). Fertility capability classification revealed that all studied soils had mostly loamy top soils and sub soils except Ikwo 1 with clayey top soil. Limitations encountered in the studied soils include; dryness (d), low ECEC (e), low nutrient capital reserve (k) and water logging/ anaerobic condition (gley). Thus; FCC classifications were *Ldek* for Abakaliki 1 and 2, *Ckv* for Ikwo 1, *LCk* for Ikwo 2 while Ivo 1 and Ivo 2 were *Legk* and *Lgk,* respectively. Information provided by this study will guide users in choosing the right practices for the classified soil.

I.0. Introduction

Ebonyi State is one of the States with highest rice production in Nigeria. According to Umahi (2016), the state achieved 190,000 metric tons of rice per annum, engaging over 10,000 farmers with about 30,000 acres of land. The state hopes to achieve more, having projected the production of 600,000 tons within the nearest future. In addition to that impressive effort, both the International Fund for Agricultural Development (IFAD), funded by the United Nations (UN), and the Federal Government Rural Agricultural Development Project (FADAMA III) also played a welcome role by assisting paddy farmers to put 6,000 hectares and 2,000 hectares of land, respectively, into rice cultivation in the 2016 wet season in Ebonyi State.

Soil characterization provides information on the physical, chemical, mineralogical and microbiological properties of the soils, crop production and sustains forests. Soil classification, on the other hand, helps to organize knowledge, facilitates the transfer of technology for better management and understanding of the soil. Soil fertility capability classification (FCC) is a technical system which groups the soils according to kinds of problems they present for management. The soil fertility related challenges can be identified without testing for soil nutrients thereby seeking for a means of creating a link between pedology and soil fertility (Vasu *et al.,* 2016). Soil fertility capability classification (FCC) system was developed for interpretative purposes using soil taxonomy and some other additional soil characteristics information that are directly useful to plant growth (Buol *et al.*, 1975)., (Sanchez *et al.,* 1982).

FCC places soils in groups depending on the kinds of problems they present for management of their physical and chemical properties (Sanchez *et al.,* 2003). The FCC system is made up of three major levels namely; type (texture of surface soil), sub strata type (texture of subsurface soil) and modifiers with respect to their behavior within the 50 cm depth of soil. Initially, researchers were not very comfortable with it, however it is now widely used all over the world especially with the development of the fourth revision (Tabi *et al.,* 2013). The FCC attributes can be positive or negative, depending on land use as well as temporal and spatial scales in question.

Tabi *et al.,* (2013) stated that FCC is a technical system of sorting soils with related limitations, and management problems as it concerns the nutrient yielding capacity of the soils. FCC is presented as a code (such as Lek, a soil which is loamy for topsoil and subsoil, having high leaching potential and low nutrient capital reserves). The fertility constraints are high leaching potential (e) of its exchangeable cations, and low nutrient capital reserves (k). The interpretation of the code provides information guiding users in choosing the right practices for the classified soil.

The criteria used in the Fertility-Capability Classification of (Buol, *et al.,* 1975) are so defined that soils can be grouped from their existing taxonomic placement in the soil taxonomy (Soil Survey Staff, 1975) and from most other soil classification systems. However, it is anticipated that the primary use of the FCC will be by soil fertility specialists in extrapolating their results from one field to another, an attempt has been made to provide guidelines that can be determined either in the field or with a minimum of laboratory work. Since it is obvious that many of the criteria are mutually exclusive, it should be pointed out that it is impractical to expect that all of the criteria will need to be tested at each site.

The objectives of this research were to characterize, classify and develop fertility capability of soils of Ebonyi State thereby providing information that will guide users in choosing the right practices for the classified soil.

2.0. Materials and Methods

2.1. Location of the study area

Ebonyi state is located in the southeastern Nigeria and lies approximately between latitudes 5o 40' and 6o 45' N and longitudes 7o 30' and 8o 30' E. It has a land mass of approximately 5,952 square kilometers and a population of 2.1 million people (Edeh *et al.,* 2011,–Ahukaemere and Obasi 2018). The vegetation of the state is a mixture of savanna and semi-tropical forest located in Southeastern Nigerian. The study was carried out in three major locations namely; Abakaliki, Ikwo and Ivo Local Government Areas (LGAs) representing three key rice zones of the state, vis; Ebonyi north, Ebonyi central and Ebonyi south, respectively. The geological coordinates and location map of the studied soils are shown in Table 1.

2.2 Geology and Geomorphology

Parent materials consist of shale inter-bedded with sand and limestone (Edeh *et al.,* 2011). The geology is mainly shale (Nkporo) and–sandstone (Afikpo) which spreads through Abakaliki region and dislocation of the Anambra platform and Afikpo region (Ahukaemere and Obasi, 2018; Obi, 2001). The study area has a fairly uniform landform of low relief, dominated with plains of upland and lowland. These plains exhibit a gently rolling toposequence with a characteristic physiographic differentiation of an undulating slope usually below 100 m above sea level (Orajaka, 1975). The lowlands are usually hydromorphic soils, whose morphology is influenced by seasonal waterlogging caused by underlying impervious shale. Most of the inland valleys are usually subjected to swamp rice cultivation.

Zone	Study Location	Longitude	Latitude	Altitude (m)	Land uses
Ebonyi north	Abakaliki 1	8^{o}11’45”E	6^{o}15’8” N	53	Rice cultivation
Ebonyi north	Abakaliki 2	8^{o}11’46”E	6^{o}15’8” N	58	Rice cultivation
Ebonyi central	Ikwo 1	8^{o}5’50”E	6^{o}2’28”N	31	Rice cultivation
Ebonyi central	Ikwo 2	8^{o}5’51”E	6^{o}2’28”N	31	Rice cultivation
Ebonyi south	Ivo 1	7^{o}34’0”E	5^{o}53’16” N	49	Rice cultivation
Ebonyi south	Ivo 2	7^{o}34’5”E	5^{o}57’2” N	49	Rice cultivation

The soil texture ranges from loamy to clay, with fairly to poorly drained subsoil in some locations, especially the uplands adjacent to lowland areas. The soils of this class are usually pale-colored and in some cases mottled in the sub-soil (Ekpe *et al.,* 2005). The area consists of undulating ridges landforms having wide shallow valleys where rice is a major crop (Oformata 1975). The parent materials of the studied soils are shown in table 2.

2.3 Climate

The climate of Ebonyi State is humid tropics having Ustic moisture regime, suggesting that soil in the moisture control section is dry in some or all parts for 90 or more cumulative days in a normal year (Soil Survey Staff, 2003). Rainfall duration is experienced mostly between April to November with highest intensities occurring between June -September and receives a mean annual rainfall of be-

Table 2: Parent materials of studied soils

Zone	Location	Parent material	Description of the Parent Material	Land use type
Ebonyi north	Abakaliki 1	Shale and limestone	Soils formed in colluvial/limestone soil materials	Rice cultivation
Ebonyi north	Abakaliki 2	Shale and limestone	Soils formed in colluvial/limestone soil materials	Rice cultivation
Ebonyi central	Ikwo 1	Shale	Soils formed in colluvial/alluvial soil materials	Rice cultivation
Ebonyi central	Ikwo 2	Shale	Soils formed in colluvial/alluvial soil materials	Rice cultivation
Ebonyi south	Ivo 1	Shale, sandstone	Formed from alluvial materials brought down from upland region	Rice cultivation
Ebonyi south	Ivo 2	Shale, sandstone	The soils derived from alluvial and sandstone.	Rice cultivation

tween 2250 mm in the South and 1500 mm in the northern part of the zone, average annual temperature of about 27oC with relative humidity of 85% (Nwakpu, 2003). Two main seasons prevail in the area; the rainy season, which spans from late April to early November, usually with two peaks which occur at July and September; and, the short dry period (August break) which is usually experienced during the month of August. The dry season, lasts from late November to early April.

2.4 Field Work

A reconnaissance visit was carried out with the aid of a location map of the study area to identify three major rice zones in the state and each of the three rice zones was mapped out. Each of the rice zones comprise of over 700 km2 area of lowland soils. Two profile pits were considered from each of the rice zones representing Ebonyi north, central and south, respectively. A total of six profile pits were considered from where soils were characterized, classified and fertility capability classification was estimated using identified soil physical and chemical parameters.

2.5 Soil Analysis

Generally, routine soil analysis was carried out on fine soil. Particle size analysis was done using pipette method (Pauwels 1992), pH was measured both in water and KCl (1:2.5 soil/water mixture) using a glass electrode pH meter. Part of the fine soil was ball-milled for organic carbon (OC) and Kjeldahl-N analysis (Pauwels 1992). Soil available P (Olsen P) was determined using the method of Olsen and Sommers (Okalebo 1993), exchangeable cations were determined by extracting with 1N ammonium acetate at pH 7, K and Na in the extract were determined using flame photometer and Mg and Ca determined by complex metric titration. Exchangeable acidity (EA) was extracted with 1M KCl followed by quantification of Al and H by titration (Pauwels 1992). Effective cation exchange capacity (ECEC) was determined as sum of bases and Exchangeable Acidity.

FCC was done according to USDA fertility capability classification system modified by Sanchez *et al.,* (1982). Fertility capability classification Version 4 (Table 3) was used to identify soil fertility limitations and classify soils into FCC units. The FCC system consists of two categorical levels. The first (type/substrata type), describes topsoil and subsoil texture and is expressed in capital letters (e.g. S - sandy throughout; SC - sandy (S) topsoil underlain by clayey (C) subsoil). The second (condition modifier) has about 17 modifiers displayed to circumscribe key soil behaviors which influence plant growth with measurable boundaries. Each condition modifier is presented as a lower case letter. Superscripts + or - indicate greater or lesser expression of the modifier. Whenever appropriate, estimates of mean values of soil properties were calculated at 50 cm soil depth. Respective profile pits were assigned FCC units based on the laboratory analysis of soil properties and thresholds or limits specified in the FCC guide.

3.0. Result and Discussion

The studied soils of Abakaliki were investigated as follows; profile pits were deep enough for rice production (> 50 cm) (Sanchez *et al.,* 1982). Soil color was determined under moist condition, and ranged from very pale brown (7.5 YR 7/3) to yellow (10 YR 8/6) in AbP1 and from light yellowish brown (10 YR 6/4) to very pale brown (10 YR 8/4) in AbP2. The predominant yellowish color matrix at the subsoil may be due to hydrated ferric oxide. The soils were well drained and mottles ranged from few, faint and medium to very many coarse and prominent mottles in the AbP1 and was few, coarse and faint in AbP2. Ikwo mapping units were located in Igweledoha, Agubia Ikwo

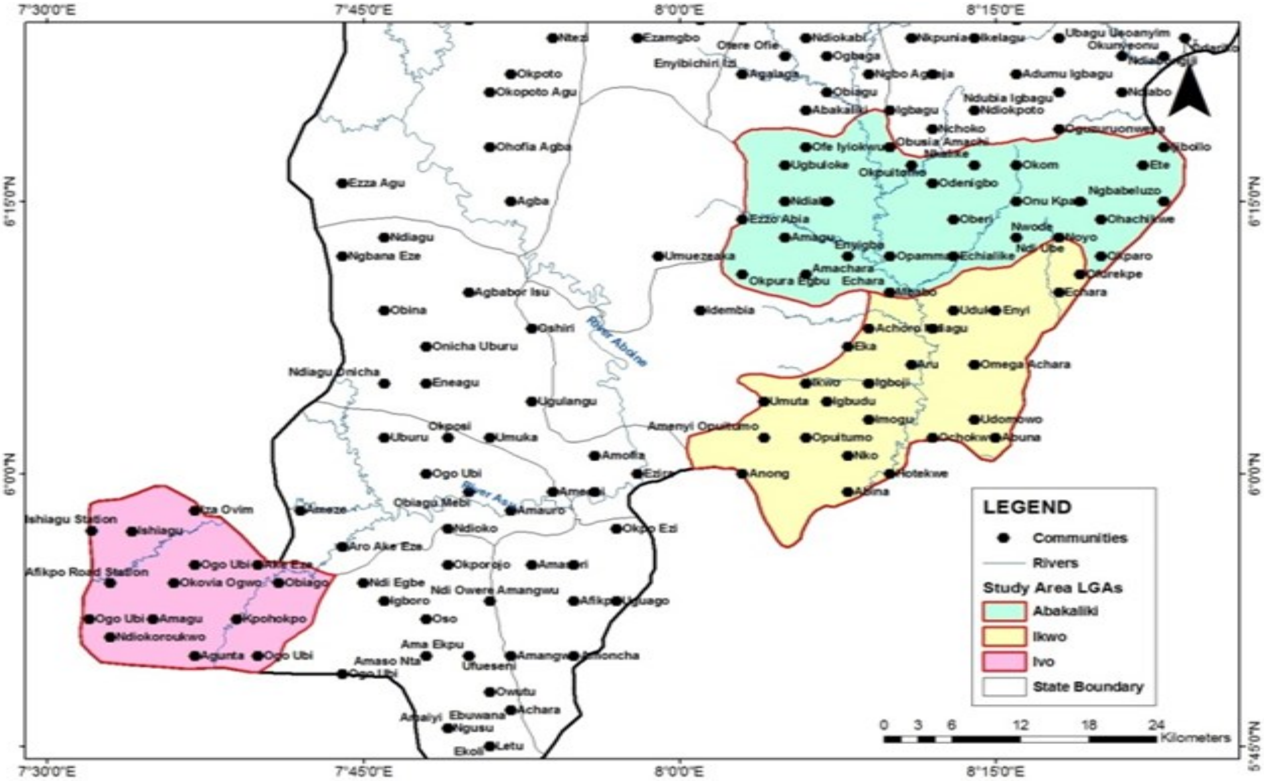


Fig. 1: Map of Ebonyi State showing study areas, the major zones in the study area, rivers and communities
Source: Obasi *et al.,* (2016)

Table 3: Fertility Capability Soil Classification System: Version 4

FCC class and short description	Symbols	Definitions and some interpretations
Type: texture is the average of plough layer or 0 to 20 cm depth, whichever is shallower	S	Sandy topsoil: loamy sands and sands
	L	Loamy topsoil: < 35% clay
	C	Clayey topsoil: > 35% clay
	O	Organic soil: >12% organic C to a depth of 50 cm or more (Histosols and histic groups)
Substrata type: used if textural change is encountered within top 50 cm	S	Sandy subsoil: texture as in type
	L	Loamy subsoil: texture as in type
	C	Clayey subsoil: texture as in type
	R	Rock or other hard root-restricting layer within 50 cm
	R-	As above, but layer can be ripped, plowed or blasted to increase rooting depth
Condition	Modifiers	Identifying criteria (if more than one, they are listed in decreasing desirability)
Modifiers related to soil physical properties Waterlogging (gley): anaerobic condition, chemical reduction, denitrification; N2O and CH4 emissions	G	Aquic soil moisture regime; mottles < 2 chroma within 50 cm for surface and below all A horizons or soil saturated with water for > 60 days in most years
	g+	Prolonged waterlogging; soil saturated with water either naturally or by irrigation for > 200 days/year with no evidence of mottles indicative of Fe3+ compounds in the top 50 cm; includes paddy rice soils in which an aerobic rice crop cannot be grown without drainage; continuous chemical reduction can result in slower soil N- mineralization and Zn deficiencies in rice
Strong dry season (dry): Limits year-round cropping, interrupts pest cycles, Birch effect	D	Ustic or Xeric soil moisture regime: dry > 60 consecutive days/year but moist >180 cumulative days/year within 20 cm to 60 cm depth
	d+	Aridic or torric soil moisture regime: too dry to grow a crop without irrigation
Low Soil temperature	T	Cryic and frigid (< 8°C mean annual), non iso-soil temperature regimes, where management practices can help warm top soils for short-term cereal production
	t+	Permafrost within 50 cm gelisols; no cropping possible
Gravel	r+	r + = 10-35%
	r++	r + + > = 35% (by volume) of gravel size coarse fragments (2 cm to 25 cm in diameter) anywhere in the top 50 cm of the soil
	r+++	More than 15% rock outcroppings
Slope		Where desirable place range in % slope (that is, 0% to 15%; 15% to 30%; > 305)
High erosion risk	SC, LC, CR, LR, SR, >30%	Soils with high erodibility due to sharp textural contrasts (SC, LC), shallow depth (R) or steep (> 30%) slope
Modifiers related to soil reaction Sulfidic (cat clays)	C	pH < 3.5 after drying; jarosite mottles with hues 2.5Y or yellower and chromas 6 or more within 60 cm sulfaquents, sulfaquepts, sulfudepts
Aluminium toxicity for most common crops	A	When > 60% Al saturation within 50 cm, or < 33% base saturation of CEC (BS 7) determined by sum of cations at pH 7 within 50cm, or pH < 5.5 except in organic soils (O)
	a -	10 to 60% Al saturation within 50 cm for extremely acid-sensitive crops such as cotton and alfalfa
No major chemical limitations (includes former h modifier)	No symbol	When < 60% Al saturation of ECEC within 50 cm and pH between 5.5 and 7.2
Calcareous (basic reaction): common Fe and Zn deficiencies common Fe and Zn deficiencies	B	Free CaCO3 within 50 cm (fizzing with HCL), or pH > 7.3
Salinity	S	When > 0.4 sm-1 of saturated extract at 25°C within 1 m; salic groups; solonchaks
	s -	0.2-0.4 s m -1 of saturated extract at 25°C within 1m (incipient alkalinity)
Alkalinity	N	When > 15% Na saturation of ECEC within 50 cm; most solonetz
	n -	6% to 15% Na saturation of ECEC within 50 cm (incipient alkalinity)
Modifiers related to soil mineralogy		
Low nutrient capital reserves (K deficiencies)	K	When < 10% weatherable minerals in silt and sand fractions within 50 cm, or siliceous mineralogy, or exchangeable K < 0.20 c mole kg -1 soil, or exchangeable K < 2% of sum of bases, if sum of bases is < 10 cmolc kg – 1 soil
High P fixation by Fe and Al oxides (> 10 mg kg – 1 P added to achieve adequate soil test levels); Ci soils have excellent structure but low water holding capacity; Ci sub soils retain nitrates	I	Dithionate-extractable free R2 O3: clay ratio > 0.2, or > 4% citrate dithionate – extractable Fe in of topsoil, or oxisols and oxic groups with C type, or hues redder than 5YR and granular structure
	i -	As above, but soils have been recapitalized with P fertilizers to supply long- term P to crops; soil test > 10 mg Kg – 1 P by Olsen method
	i+	as above; potential Fe toxicity if soils waterlogged for long time (g +) or adjacent uplands have I modifier
Amorphous volcanic (X-ray amorphous); high P fixation by allophone (> 200 mg Kg -1 P added to achieve adequate soil test levels); low N mineralization rates	X	Within 50 cm pH > 10 (in 1 M NaF) or positive to field NaFtest , or andisols and andic subgroups, other indirect evidences of allophone dominance in the clay size fraction, or > 90% P retention.
	x-	P retention between 30% and 90% ; medium P fixers
Cracking clays (vertic properties): very sticky plastic clay, severe topsoil shrinking and swelling v	V	> 35% clay and > 50% of 2:1 expanding clays, or coefficient of linear expansibility > 0.09 or vertisols and vertic groups
High leaching potential (low buffering capacity, low ECEC)	E	< 4 c mole kg – 1 soil as ECEC, or < 7 c mole kg – 1 soil by sum of cations at pH 7, or < 10 c mole kg – 1 soil by sum of cations + Al3+ +H+ AT pH 8.2
Modifier related to soil biological properties (new)		
Low organic carbon saturation (soil organic matter depletion, C sequestration potential)	M	80% total organic C saturation in the topsoil compared with a nearby undisturbed or productive site the same soil, which is equal to 100% OR < 80% 333 Mm KMnO4-extractable topsoil organic carbon saturation compared with a nearby undisturbed or productive site of the same soil which is equal to 100%

Source: Sanchez et al., (1982), Buol et al., (1975) and designated by IkP1 and IkP2 in two respective pedons used for soils study (Table 4). The profiles were deep enough for rice cultivation and drainage indicated perfectly drained for Ap and AB horizons and poorly drained for Bg and BCg horizons in IkP1 and IkP3, respectively. The color of the soils ranged from yellow (10 YR 7/6) to pale brown (10YR 6/3) in IkP1, and brownish yellow (10 YR 6/6) to yellowish brown (10 YR 5/8) in IkP2. The presence of hydrated ferric oxide may have impacted this dominant color matrix. There were no mottles in IkP1, however, mottles in IkP2 ranged from few, coarse and faint to few, coarse and distinct in Ap and BCg, respectively. Ivo study area was located near the research farm of Federal College of Agriculture Ishiagu. The profiles were deep for rice production (> 50 cm) however, poorly drained because of the high-water table. The color of the soils ranged from light gray (10YR 7/1) to light brownish gray (10 YR 6/2) in IvP1 and IvP2. There were no mottles in most of the horizons except at IvP1 where mottles were few, massive and faint in BCg and ABg, respectively. The dominance color matrix resulted from previous condition of restricted drainage (Akpan-idiok and Esu, 2001).

The particle size distribution, as shown in Fig. 2, revealed that soils of Abakaliki recorded mean sand as 326.7 gkg-1 and 545.3 gkg-1 in AbP 1 and AbP 2, respectively. Also, the trend of silt were 488.6 gkg-1 and 342.7 gkg-1 and that of clay were 184.9 gkg-1 and 111.1 gkg-1 in AbP1 and AbP2, respectively. There was highest sand (545.3 gkg-1) in AbP2 when compared to others investigated rice zones. In Ebonyi central (Ikwo rice soils), sandiness decreased when compared to their Abakaliki and Ivo counterparts. Sand recorded 194.1 gkg-1 and 280.3 gkg-1 in IkP1 and IkP2, respectively. Silt scored 402.9 gkg-1 and 400.2 gkg-1 in IkP1 and IkP2, respectively, while clay yielded 403.1 gkg-1 and 319 gkg-1 in IkP1 and IkP2, respectively. In Ebonyi southern soils, as shown in Fig. 2, IvP1 and IvP2 had 373.1 gkg-1 and 419.8 gkg-1, respectively. Silt also recorded 421.5 gkg-1 and 434.9 gkg-1 in IvP1 and IvP2, respectively, while mean clay contents of IvP1 and IvP2 were 205.3 gkg-1 and 145.3 gkg-1, respectively. The results of particle size obtained in Fig. 2 were the bases for the textural classification of soils as revealed in Table 4.

Table 4: Morphological properties of studied soils

Location/ Horizon	Depth (cm)	Color (moist)	Mottles	Text. Class	Soil Structure	Drainage
Abakaliki 1	AbP 1.	6°15’8” N, 8°11’45”E, Altitude 53m				
Ap	0-12	7.5YR7/3	-	Loamy	1,cr,vc	Well drained
AB	12-27	7.5YR7/4	-	Silty Loam	1,cr,f	Well drained
Bt1	27-58	7.5YR8/2	fe,2,f	Loam	1,cr,m	Well drained
Bt2	58-104	7.5YR8/6	v,3,p	Loam	3,cr,c	Well drained
Abakaliki 2	AbP 2.	6°15’10” N, 8°11’46”E, Altitude 58m				
Ap	0-11	7.5YR6/4	fe,3,f	Loam	3,m,vc	Well drained
AB	11-25	7.5YR7/4	fe,3,f	Loam	2,bk,vc	Well drained
Bt1	25-66	7.5YR8/3	fe,3,f	Loamy	3,m,vc	Well drained
Bt2	66-107	7.5YR8/4	fe,3,f	Silty Loam	3,m,vc	Well drained
Ikwo 1	ILP1.6°2’28”N, 8°5’50”E, Altitude 31m					
Ap	0-17	7.5YR7/6	-	Clay Loam	2,bk,c	Well drained
AB	17-38	7.5YR5/3	-	Silty Loam	2,cr,vc	Well drained
Bg	38-70	7.5YR5/4	-	Clay	3,m,c	Poorly drained
BCg	70-114	7.5YR6/3	-	Clay	3,m,vc	Poorly drained
Ikwo 2	ILP2.6°2’28”N, 8°5’51”E, Altitude 31m					
Ap	0-20	10YR6/6	f,3,f	Loamy	3,bk,c	Well drained
AB	20-39	5YR8/4	f,2,f	Loamy	2,cr,m	Well drained
Bg	39-73	7.5YR6/8	f,2,d	Clay Loam	3,bk,m	Poorly drained
BCg	73-110	7.5YR5/8	f,3,d	Clay Loam	3,bk,vc	Poorly drained
Ivo 1	IvP 1.	5°53’16” N, 7°34’0”E, Altitude 49m				
Ap	0-18	7.5YR7/1	-	Loam	2,m,c	Poorly drained
ABg	18-44	7.5YR7/2	-	Loam	3,bk,c	Poorly drained
BCg	44-88	7.5YR6/2	f,m,f	Clay Loam	3,bk,c	Poorly drained
Ivo 2	IvP 2.	5°57’2” N, 7°34’5”E, Altitude 49m				
Ap	0-15	7.5YR7/1	-	Loam	2,bk,c	Poorly drained
ABg	15-53	7.5YR7/2	-	Loam	2,bk,c	Poorly drained
BCg	53-79	7.5YR6/2	-	Loam	3,m,c	Poorly drained

Mottles: 1= fine, 2= medium, 3= coarse, fe= few, f= faint, c= common, d= distinct, p = prominent, v = very many, Structure: 1= weak, 2= moderate, 3= strong, cr= crumb, f=fine, m= massive, bk= blocky, vc = very coarse, m= medium,

The pH of Abakaliki soils was very strongly acidic according to Foth and Ellis (1997) which stated that very strongly acidic soils ranged from pH 4.5 to 5.5. The pH of AbP1 and AbP2 was less than 4.0. The high acidic content of the Abakaliki soils may lead to aluminum toxicity which occurs in aerobic layers; this implies that the exchange sites of the soil complex may be saturated with alumina. The problem of strongly acid soils can be caused by strong leaching from high rainfall, and mainly from oxidation of sulfidic material (Tabi *et al.,* 2012). However, at Ikwo in Ebonyi central and Ivo in Ebonyi south, mean soil reaction was >5.5 in most soils. This soil pH of slight acidity condition may be due to fluctuating water table common to most rice growing soils. However, this situation favors paddy production as it encourages nutrient release and inhibits incidence of loss exchangeable cations down the profile. Onweremadu *et al.,* (2007) reported similar soil reaction in selected wetland soils of Nigeria.

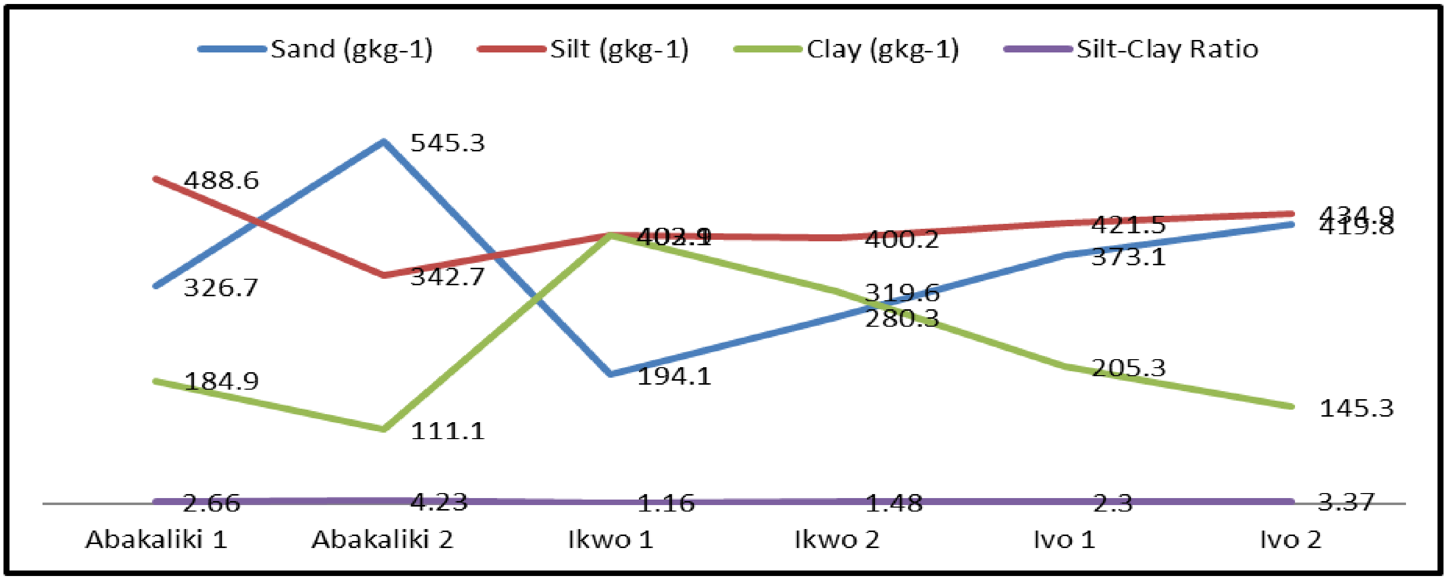


Fig. 2: Particle size distribution of studied soil

The low organic matter in the soil is a reflection of less organic matter recycling in the rice fields as well as loss of oxidized organic matter through drainage. Organic carbon, organic matter and total nitrogen of all the studied soils decreased down the profile. Mean organic carbon was low in AbP2 (<20 gkg-1) moderately distributed (20 – 42 gkg-1) in AbP1, IkP1, IkP2 and high (> 42 gkg-1) in IvP1 and IvP2. High organic matter content of the soils of Ebonyi south in IvP1 and IvP2 soils when compared to soils of other locations could be attributed to huge decomposing litter presence and moisture condition of the soil at the time of sampling.

Organic matter is one of the vital characteristics used in determining soil quality and productivity. Organic matter has significant positive impact on soil pH, cation exchange capacity, color, buffering capacity, base saturation and water holding capacity (Akamigbo, 1999), as well as effective cation exchange capacity (Onasanya 1992). Therefore, due to these numerous benefits of organic matter on agricultural soils, steps should be taken to increase the OM content of the studied soils, thereby improving soils' agronomic performance. This can be achieved by adopting appropriate land use type and constant supply of organic residue to the soil, thereby maintaining optimal soil temperature and biological activities of soil organisms. Available P content of the soil was moderate ranging from 5 – 15 mg/kg (Tabi *et al.,* 2012), with the surface horizon containing the highest amount. The moderate concentration of available P in the soil may be a reflection of soil pH and organic matter content of the soil. Halvin *et al.*, (2005) and Idigbo *et al.,* (2008) opined that P content of most soils is at its peak when soil pH is between 6.0 - 6.5. However, when the critical level of P in soils of southeastern Nigeria was considered (15 mgkg-1) (Enwezor *et al.,* 1990), the soils of Ebonyi were mostly lower than this critical level suggesting the need for phosphate fertilizer application for increase in rice yield.

The calcium (Ca) content of the studied soils (Table 5) showed that Ca was very low (<2.0 gkg-1) in pedons of Abakaliki soils. The means exchangeable Ca were far below optimum as critical levels indicated; very low (<2.0 gkg-1), low (2-5 gkg-1), medium (5-10 gkg-1), high (10-20 gkg-1), and very high (>20 gkg-1) (Tabi *et al.,* 2012). There was irregular distribution of Mg, K and Na in all the pedons of Ebonyi north soils. Mean Mg were 0.91 and 0.28 gkg-1, mean K were 0.06 and 0.06 gkg-1, and mean Na were 0.04 and 0.05 gkg-1 in AbP1 and AbP2, respectively (Table 5). Magnesium, K and Na distribution in these soils were very low as values fell below the optimum critical limits. Critical levels of Mg were; very low (<0.5 gkg-1), low (0.5-1.5 cmol/kg), medium (1.5-3 gkg-1) and high (3-8 gkg-1). K were; very low (<0.1 gkg-1), low (0.1-0.3 gkg-1), medium (0.3-0.6 gkg-1) and high (0.6-1.2 gkg-1). Na were; very low (<0.1), low (0.1-0.3 gkg-1), medium (0.3-0.7 gkg-1) and high (0.7-2.0 gkg-1) (Beernaert and Bitondo 1992). Furthermore, at Ikwo soils in Ebonyi central (Table 5) calcium increased down the profile and very high in IkP1 (20.02 gkg-1) and medium at IkP2 as mean Ca was 5.48 gkg-1.

Mg distribution decreased down the profile in IkP1 and IkP3, having means of 2.05 and 1.35 gkg^{-1} in IkP1 and IkP2, respectively. This distribution indicated that Mg was medium and within range (1.5-3 gkg^{-1}) at IkP1 and low and within the range (0.5-1.5 cmol/kg) at IkP2. The K and Na increased in IkP1 and IkP2. Mean K distribution were 0.27 and 0.07 gkg^{-1}. Mean Na were 0.14 and 0.09 gkg^{-1} in IkP1 and IkP2, respectively. K was low (0.1-0.3 gkg^{-1}) at IkP1 and very low (<0.1 gkg^{-1}) at IkP2. Na was low (0.1 - 0.3 gkg^{-1}) at IkP1 and very low (<0.1 cmol/kg) at IkP2. However, at Ebonyi south soils (Table 4) exchangeable Ca was medium (5-10 cmol/kg) with means of 5.07 and 6.09 gkg^{-1} in IvP1 and IvP2, respectively. Exchangeable Mg was low (0.5-1.5 gkg^{-1}) at IvP1 and IvP2, having means of 0.80 and 0.75 gkg^{-1}, respectively. Exchangeable K and Na were very low (<0.1 gkg^{-1}) and decreased down the profile at IvP1 and IvP2. Means of exchangeable K and Na were 0.10 and 0.06 gkg^{-1}; 0.07 and 0.06 gkg^{-1} in IvP1 and IvP2, respectively.

The effective cation exchange capacity of the soil was subjugated by the exchangeable bases showing the capacity of the soil to make nutrient elements available to crops. Bruce (1999) andHamza (2009), suggested that it is diffi-

Table 5: Abakaliki and Ikwo Soils Chemical Properties

Depth (cm)	pH (H_20)	pH (KCl)	OC ⟵	OM gkg^{-1}	TN ⟶	Av.P Mgkg^{-1}	Ca ⟵	Mg	K	Na	TEB gkg^{-1}	Al ⟶	H	TEA	ECEC ⟶	B. Sat. (%)	Al Sat. (%)
AbP 1	6°15’8” N, 8°11’45”E, Altitude 53m																
0-12	3.54	3.02	25.1	43.3	2.2	6.25	0.88	1.00	0.05	0.02	1.97	1.84	0.24	2.08	4.05	48.64	45.00
12-27	3.69	2.99	12.0	20.6	1.0	10.8	1.23	0.86	0.06	0.06	2.21	2.00	1.04	3.04	5.25	42.10	38.10
27-58	4.10	3.08	08.4	14.4	0.7	12.8	1.44	0.86	0.07	0.05	2.42	1.83	0.97	2.80	5.22	46.36	35.10
58-104	4.61	2.96	07.2	12.4	0.6	11.6	1.68	0.93	0.06	0.04	2.71	0.68	2.12	2.80	5.51	49.18	12.34
Mean	3.99	3.01	13	22.7	1.1	10.4	1.31	0.91	0.06	0.04	2.33	1.59	1.09	2.68	5.01	46.57	32.64
AbP 2	6°15’8” N, 8°11’46”E, Altitude 58m																
0-11	4.75	3.25	15.6	26.8	1.3	6.10	1.21	0.34	0.06	0.03	1.64	1.16	1.20	2.36	4.00	41.00	29.00
11-25	5.14	3.22	10.0	17.2	0.9	7.56	1.02	0.25	0.05	0.04	1.36	0.76	1.12	1.88	3.24	41.98	23.46
25-66	5.34	3.11	06.4	11.0	0.6	8.07	1.41	0.31	0.07	0.04	1.83	1.60	0.40	2.00	3.83	49.09	41.78
66-107	4.68	3.14	05.2	08.9	0.5	12.4	1.18	0.22	0.05	0.07	1.52	0.80	1.68	2.48	4.00	38.00	20.00
Mean	4.98	3.18	09.3	15.0	0.8	8.54	1.21	0.28	0.06	0.05	1.59	1.08	1.10	2.18	3.77	42.52	28.56
IkP1	6°2’28”N, 8°5’50”E, Altitude 31m																
0-17	7.14	5.14	21.2	36.5	1.8	9.93	11.1	2.67	0.09	0.06	13.86	0.01	0.20	0.21	14.07	98.50	0.07
17-38	7.36	6.47	20.0	34.4	1.6	6.71	18.56	1.87	0.13	0.08	20.66	0.01	0.48	0.49	21.15	97.68	0.07
38-70	7.27	6.12	12.0	20.6	1.0	14.8	22.32	2.07	0.20	0.21	24.80	0.01	0.16	0.17	24.97	99.32	0.07
70-114	7.55	6.24	08.4	14.4	0.7	11.6	28.16	1.60	0.25	0.22	30.23	0.01	0.44	0.45	30.68	98.53	0.07
Mean	7.33	5.99	15.4	26.5	1.3	10.7	20.02	2.05	0.17	0.14	22.39	0.01	0.32	0.33	22.72	98.51	0.07
IkP 2	6°2’28”N, 8°5’51”E, Altitude 31m																
0-20	5.04	4.74	18.4	31.6	1.6	5.84	2.64	2.07	0.04	0.09	4.84	2.16	0.44	2.60	7.44	65.05	29.03
20-39	6.35	5.41	13.6	23.4	1.1	7.76	4.00	0.93	0.02	0.04	4.99	0.68	1.64	2.32	7.31	68.26	9.30
39-73	6.44	5.49	08.4	14.4	0.7	8.53	1.36	1.80	0.07	0.07	3.30	0.64	0.56	1.20	4.50	73.33	14.22
73-110	6.57	5.73	08.4	14.4	0.6	15.6	13.93	0.60	0.14	0.14	14.81	0.01	0.48	0.49	15.30	96.80	0.07
Mean	6.10	5.34	12.2	21.0	1.0	9.43	5.48	1.35	0.07	0.09	6.99	0.87	0.78	1.65	8.64	75.86	13.16
IvP1																	
0-18	5.35	4.27	59.8	10.3	5.2	16.56	3.54	0.86	0.13	0.11	4.64	0.81	0.43	1.24	5.88	78.91	13.7
18-44	5.65	4.44	43.1	74.3	3.7	15.78	4.03	0.92	0.07	0.05	5.07	0.64	0.36	1.00	6.07	83.52	10.5
44-88	5.59	4.51	32.8	56.4	2.8	15.69	7.64	0.63	0.11	0.04	8.42	0.14	0.16	0.30	8.72	96.56	1.61
Mean	5.53	4.41	45.2	77.9	3.9	16.01	5.07	0.80	0.10	0.07	6.04	0.53	0.32	0.85	6.89	86.33	8.63
IvP2																	
0-15	5.07	4.13	38.7	66.7	3.3	17.58	3.61	0.74	0.07	0.09	4.51	0.69	0.34	1.03	5.54	81.40	12.45
15-53	5.96	4.69	24.7	42.6	2.1	11.66	6.42	0.67	0.05	0.08	7.22	0.55	0.36	0.91	8.13	88.80	6.77
53-79	5.65	4.57	19.2	33.0	1.7	17.96	8.23	0.83	0.05	0.02	9.13	0.66	0.41	1.07	10.20	89.5	6.47
Mean	5.56	4.40	27.5	47.4	2.4	15.69	6.09	0.75	0.06	0.06	6.95	0.63	0.37	1.00	7.95	86.57	8.56

OC = organic carbon, OM = organic matter, TN = total nitrogen, Av.P = available phosphorus, TEB = total exchangeable bases, TEA = total exchangeable acidity, ECEC = effective cation exchange capacity, B. Sat = base saturation, Al Sat. = aluminum saturation cult to establish critical levels of exchangeable Ca for plant growth that apply across a range of dissimilar soils. Obasi (2015) emphasized the importance of exchangeable Ca in acid soils and suggested that base saturation was more important than the absolute amount of exchangeable Ca. Obasi, (2015) also concluded that the percentage base saturation of soils, and probably the proportion of the various bases present in the exchange complex and in the soil solution, are primary factors which directly influence plant growth on acid soils. This influence on plant growth comes from decreasing H, Al and Mn toxicities and it is only in the absence of these toxicities that Ca saturation becomes a useful measure of Ca availability to the plant (Adams 1984).

3.1 Taxonomic Classification

The taxonomic classification of the studied soil zones using the USDA soil taxonomy and World Reference Base (WRB) for soil recourses were shown in Table 6. Mean annual soil temperatures were higher than 22°C and nearly constant within the study area (Soil Survey Staff 2003). Ochric epipedons were observed in AbP1 and AbP2, while mollic epipedons were observed in IvP1 and IvP2. Diagnostic subsurface horizons were argillic in all investigated pedons except in IkP1 where subsurface horizons were kandic. Two soil orders were identified in the investigated agro-ecological zones which include Entisols (AbP1 and AbP2), Inceptisols (IkP1, IkP2 andIvP1), Organic matter contents and stratification qualified pedons AbP1 and AbP2 as Fluvents; this was as a result of an inconsistent reduction in organic-carbon content (post-pleistocene geologic epoch) between a depth of 25 cm and either a depth of 125 cm below the mineral soil surface. Isohyperthermic soil temperature regime placed IkP1, IkP2 and IvP1 on the suborder Tropepts. A base saturation (by NH4OAc) of more than 60% or more at a depth between 25 cm and 75 cm from the mineral soil surface at IkP1, IkP2,and IvIP1. Pedons AbP1 and AbP2 were classified as Typic Fluvaquents and Ochric Fluvisol (WRB). IkP1 had vertic properties and therefore classified as Vertic Eutrudepts and Eutric Vertisol (WRB). IkP2 was classified as Typic Eutrudepts and Eutric Cambisol (WRB). IvP1 and IvP2 were classified as Aquic Eutrudept and Glyic Leptosol (FAO – WRB).

3.2 Fertility Capability Classification of rice soils

Based on the soil fertility classification guide in Table 3 (Sanchez *et al.,* 1982), soil fertility limitations that characterize lowland rice in three major zones of Ebonyi state (Table 7). Considering Type and Subtrata type of the FCC classification, Abakaliki 1 and Abakaliki 2, Ikwo 2, as well as Ivo 1 and Ivo 2, all had Loamy top soils while Ikwo 1 had a clayey (>35%) top soil. At the substrata type level, Abakaliki 1 and Abakaliki 2; Ivo 1 and Ivo 2 all had Loamy Sub soils while Ikwo 1 and Ikwo 2 soils had clay sub soils. The limitations of the investigated soils revealed that Abakaliki 1 and Abalakili 2 had a limitation of dryness (d) suggesting a situation in which soils experience dry > 60 consecutive days/year but moist >180 cumulative days/year within 20 cm to 60 cm depth. Abakaliki 1 and Abakaliki 2 also had limitations of (e) low exchangeable cations < 7 c mole kg $^{-1}$ soil as ECEC by sum of cations at pH 7 and limitations of (k), suggesting low nutrient capital reserves (K deficiencies). Ikwo 1 and Ikwo 2 soils had limitations of low nutrient capital reserve (k) while Ikwo 1 had limitation of cracking clays (Vertic properties): very sticky plastic clay, severe topsoil shrinking and swelling (v). Ivo 1 and Ivo 2 soils had challenges of low nutrient capital reserve (k) and limitation of gley situation (g), Aquic soil moisture regime; mottles < 2 chroma within 50 cm for surface and below all A horizons or soil saturated with water for > 60 days in most years. Ivo 1 soils also had a limitation of low ECEC (e). Therefore, the fertility capability classification (FCC) of the studied soils are as follows; Abakaliki 1 and Abakaliki 2 were classified as Ldek, Ikwo 1 and Ikwo 2 classified as Ckv and LCk respectively, while Ivo 1 and Ivo 2 were classified as Legk and Lgk, respectively.

Table 6: Taxonomic and WRB Classifications

Study Location	Soil Taxonomy	World Reference Base (WRB)
Abakaliki 1 (AbP1)	Typic Fluvaquents	Ochric Fluvisol
Abakaliki 2 (AbP2)	Typic Fluvaquents	Ochric Fluvisol
Ikwo 1 (IkP1)	Vertic Eutrudepts	Eutric Vertisols
Ikwo 2 (IkP2)	Typic Eutrudepts	Eutric Cambisols
Ivo 1 (IvP1)	Aquic Eutrudepts	Gleyic Leptosols
Ivo 2 (IvP2)	Aquic Eutrudepts	Gleyic Leptosols

Table 7: Soil Fertility Limitations and Fertility Capability Classification Units

ZLocation	Soil Classification	Type	Subtrata type	Modifiers					FCC Classification
				d	e	g	k	v	
Abakaliki 1	Typic Fluvaquents	L	L	+	+	_	+	_	Ldek
Abakaliki 2	Typic Fluvaquents	L	L	+	+	_	+	_	Ldek
Ikwo 1	Vertic Eutrudepts	C	C	_	_	_	+	+	Ckv
Ikwo 2	Typic Eutrudepts	L	C	_	_	_	+	_	LCk
Ivo 1	Aquic Eutrudepts	L	L	_	+	+	+	_	Legk
Ivo 2	Aquic Eutrudepts	L	L	_	_	+	+	_	Lgk

Quang (2011), reported that inorganic fertilizers should not be used in these soils in their natural condition, since soils with low ECEC (e) hardly retains nutrients or has very low capacity to retain nutrients. As a result of this situation, high application of mineral fertilizers may predispose the soil to leaching causing heavy loss of nutrients. Therefore, split applications of nutrients containing N fertilizers should be adopted. Application of organic matter is also crucial as it increases soil cation exchange capacity (Noble *et al.,* 2004).

Potassium fertilizers are highly needed in these soils considering the low nutrient capital reserves (k) challenge, and because soils have low capacity to retain nutrients, exchangeable basic cations added in the form of fertilizers can be easily lost (Nguyễn, 2003). Potassium fertilizers or organic amendments with a significant content of K will need to be applied. Crops should also be constantly monitored for K deficiency symptoms (Moody *et al.,* 2008).

4.0. Conclusion

Rice soils of Ebonyi were classified both with USDA Soil Taxonomy and Fertility Capability Classification (FCC) Systems. The limitations of the studied soils ranged from dryness (d) at the Abakaliki locations 1 and 2 to waterlogged condition in Ivo locations 1 and 2. However, low ECEC (e) and low nutrient capital reserve (k) was widespread in all the studied soils except in Ikwo 1 and 2 and Ivo 2 soils where ECEC (e) was not limiting. FCC classifications were *Ldek* for Abakaliki 1 and 2, *Ckv* for Ikwo 1, *LCk* for Ikwo 2 while Ivo 1 and 2 were *Legk* and *Lgk,* respectively. This study provided information that will guide users in choosing the right practices for the classified soil which will invariably enhance sustainable rice farming in Ebonyi State, Southeastern Nigeria.

References

Adams F. (1984). Crop response to lime in the southern United States. *In*: 'Soil Acidity andLiming'. (Ed. F Adams) 2nd ed. pp. 211-66. Agronomy No. 12, *American Society of Agronomy*: Madison, Wisconsin.

Ahukaemere, C.M. and S. N. Obasi. (2018). Potentials of Soils derived from Asu River Group and Asata Nkporo Shale for Arable Crop Production in Ebonyi State, Nigeria. *Bulgarian Journal of Soil Science. Volume 3, Issue 1. www. Bsss.2018,bg. pp 48 – 62*

Akamigbo, F.O.R. (1999). Influence of land use on soil properties of the humid tropical agroecology of southeastern Nigeria. Niger. Agric. J., 30: 59-76.

Akpan-idiok A.U. and Esu, I. E. (2001). Morphological characteristics and classification of mangrove swamp soils in Cross River state estuary, southeast Nigeria. . Proceedings of the 27th Annual Conference of the Soil Science Society of Nigeria, Calabar, Nigeria

Beernaert D and F, Bitondo. (1992). A Simple and Practical Method to Evaluate Analytical Data of Soil Profiles. CUDs, Soil Science Department. Belgian Cooperation Dschang Cameroon. 1992, 65 p.

Bruce, R.C. (1999) Calcium. *In*: 'Soil Analysis, an Interpretation Manual'. (Eds K.I. Peverill, Sparrow, L.A., Reuter, D.J.) pp. 171-185. CSIRO Publishing, Australia.

Buol, S.W., Sanchez, R.B., Cate, J.R., and Granger M.A. (1975). Soil Fertility Capability Classification: A technical soil classification for fertility management. In Soil Management in Tropical America, North Carolina State University.

Edeh, H.O., Eboh E.C., and Mbah, B.N. (2011). Analysis of Environmental Risk Factors Affecting Rice Farming in Ebonyi State, Southeastern Nigeria. World Journal of Agricultural Sci., 7(1): 100-103)

Ekpe, I.I., Okporie, E.O., Ogbodo E.N., and Nwite, J.N. (2005). Physico-Chemical properties of Four Ultisols Under Different Vegetation Covering Southeastern Nigeria. J. Sci. Agric. Food Tech. Environ., 5: 74-78.

Enwezor, W.O., Ohiri A.C. Opuwahribo, E.E, Udo, E.J. (1990). Literature review on soil fertility investigations in Nigeria Federal Ministry of Agriculture and natural Resources, 281.

Foth, H.D. and Ellis, B.G. (1997). Soil Fertility. CRC Press, Inc., Boca Raton FL.

Halvin, J.I., James, D.B., Samuel, L., (2005). Tisdale and Werner, L.N. Soil fertilityand fertilizer. An introduction to nutrient management. 7th Edition. Prentice,New Jersey Delhi. Pp 515

Hamza, M.A. (2009) Understanding soil analysis data. Department of agriculture and food. Resource management technical report, 327.

Idigbor, C.M., Asawalam D.O., and Agbede O.O. (2008). Phosphorus forms and Psorption Capacity of Fauna Modified Soils of South-Eastern Nigeria. Journal ofAgricultural Production and Technology, 4 (2): 195-210.

Lekwa, G. (1986). Soils of tidal marshes in the Kono-Imo River estuary, Rivers State, Nigeria. *Niger J. Soil Sci.1986,*6:47-56.

Moody, P.W., Legrandl, P.T.J. and Chon, N.Q. (2008). A decision support constraints to upland soils. Soil Use and Management, 24, 148-155.

Nguyễn, H.M. (2003). Soil potassium dynamics under intensive rice cropping. A case study in the Mekong Delta, Vietnam. Ph.D thesis Wageningen University, Netherlands.

Noble, A.D., Ruaysoongnern, S., Penning de Vries, F.W.T., Hartmann, C. and Webb, M.J. (2004). Enhancing the agronomic productivity of degraded soils in northeast Thailand through clay-based Interventions. ACIAR Proceedings, 116, 147-160.

Nwakpu C. (2003). Practical guide to lowland rice production in Nigeria.1 st Edition, SNAAP Press Ltd Enugu, Nigeria.

Obasi S.N. (2017). Petu-Ibikunle M. A., Iwuanyanwu, U. P., Ike S. G. I. Characterization, Classification and selected Micronutrients Status of Soils of Umuagwo – Ohaji, Southeastern Nigeria. JWWM, Vol. 1, Number (4), Pp 105 – 117.

Obasi, S.N., E. U. Onweremadu, N. U. Manuemelula, E. C. (2016). Abbah. Cations Ratios Distribution in Selected Rice Soils of Ebonyi, Southeastern Nigeria. American Journal of Food Science and Nutrition Research. Vol. 4, No. 1, pp. 42-49.

Obasi S.N. (2015). Application of Geographic Information System (GIS) in Investigation of potentials of soils of Ebonyi State for rice production. Unpublished Ph.D Thesis Submitted to the Department of Soil Science, Federal University of Technology Owerri, Nigeria, 258pp.

Obi, G. C., Okogbue, C.O., Nwajide, C.S. (2001). Evolution of the Enugu Cuesta: A tectonically driven erosional process. Global Journal of Pure Applied Sciences, 7, 321–330.

Ofomata G.E.K,. (1975) Hydrology. In: G.E.K. Ofomata (ed.) Nigeria in maps. Eastern States, Benin City: Ethiope Publishing House. Pp.13-15.

Okalebo, J.R., Gathua KW, Woomer PL. (1993) Laboratory Methods of Soil and Plant Analysis: A Working Manual. Tropical Soil biology and Fertility Programme, Nairobi, Kenya, P. 88.

Onasanya, S.O. (1992). The relationship between topographic location, soil propertiesand cultural management and the productivity. Maize-soybean intercrop. A ph.D thesis in the dept. of agronomy. University of Ibadan. Pp 319.

Onweremadu, E.U., Akamigbo, F.O.R. and Igwe, C.A. (2007). Physical shrinkage relationship in soils of dissimilar lithologies in central Southeastern Nigeria. Journal of applied sciences, 7(17): 2495-2499.

Orajaka, S.O. (1975). Geology. In: Ofomata, G.E.K. (ed.). Nigeria in Maps: Eastern States Ethiope Publishing House, Benin City, Pp. 5-7.

Pauwels, J.M.,Van Ranst E, Verloo M, MvondoZe A. (1992). Méthodesd'analyses de sols et de plantes, équipement, gestion de stocks de verrerie et de produitschimiques., A.G. Building. Bruxelles.

Quang V.M. (2011). The rice soil fertility capability classification system. International journal of environmental and rural development.

Sanchez, P.A., Palm, C.A. and Buol, S.W. (2003). Fertility capability soil classification: a tool to help assess soil quality in the tropics. Geoderma, 114, 157-182.

Sanchez, P.A., Couto W, Boul S.W. (1982). The fertility capability classification system: Interpretation, applicability and modification. Geoderma, 27:283-309.

Soil Survey Staff (1975). Soil Taxonomy. A basic system of soil classification for making and interpreting soil surveys. Agric. Handbook No 436, USDA, Washington D.C. pp 869.

Soil Survey Staff, (2003). Keys to Soil Taxonomy: 9th Edition, USDA Natural Resources Conservation Service Washington D. C., U.S.A.

Tabi, F.O., Ngobesing E. S. C., Yinda G. S., Boukong A., Omoko M., Bitondo D., MvondoZe A. D. (2013). Soil fertility capability classification (FCC) for rice production in Cameroon lowlands Vol. 8(119), pp. 1650-1660, DOI: 10.5897/AJAR12.1576

Tabi, F.O., Omoko M, Boukong A, Mvondo Z.A.D., Bitondo D and Fuh C. C. (2012). Evaluation of lowland rice (*Oryza sativa*) production system and management recommendations for Logone and Chari flood plain – Republic of Cameroon. Agricultural Science Research Journals Vol. 2(5); pp. 261-273.

Umahi D. (2016) "How we grew rice production in Ebonyi to 190,000 tonnes this year", a welcome speech by the Ebonyi State Governor, Engineer David Nweze Umahi, during the official visit to the state by the Governor of the Central Bank of Nigeria, theeagleonline.com.ng

Vasu D., S.K. Singh, K. Karthikeyan and V.P. Duraisami (2016). Fertility Capability Classification (FCC): A case study in rainfed soils of semi-arid Deccan plateau. Agropedology 2016, 26 (01), 22-28