Profile characteristics and agricultural potential of soils under different land use types in Umuahia area of South east, Nigeria

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Abstract

The study was carried out at Mbom, Umuahia North Local Government Area, Abia State, Nigeria, to assess the potentials of soils under different land use types (continuously cultivated land, forest land, fallow land and oil palm plantation) for sustainable crop production. Modal profile pits were established in the identified land use types and morphological attributes described. Soil samples taken from genetic horizons of the soil profile pits were analysed for their physical and chemical properties. Geo-spatial technique was used to estimate the spatial distribution of the soil fertility constraints. The findings revealed variability in soil properties. Soil drainage ranged between poorly drained and well drained conditions. Texture showed sandy loam overlying sandy clay loam. Soils were strongly - moderately acid (4.19 - 6.12) with organic carbon in the surface relatively low to high (10.50 - 22.60 gkg^{-1}). Available phosphorus was moderate (7.11-17.81 mgkg^{-1}). There were generally low exchangeable bases and cations exchange capacity values ranging from 3.28 - 5.19 cmolkg-^{1}. Assessment of the soils' potentials with respect to fertility capability classification (FCC) placed the soils into three FCC units: LCeghk, Lek and Lehkm covering 19.23, 43.63 and 37.14 % of the study area respectively. The findings identified problems and potentials of the soils and recommends the FCC units spatial maps generated as an advisory tool to farmers and soil scientists to make informed decisions on the appropriate fertility management for sustainable use of the soil.

Keywords: Soil properties, potentials, fertility constraints, sustainable crop production

Introduction

The comprehensive analysis of the potentials of natural resources such as climate, soil, topography and hydrology is very pivotal to decision making on land use planning. Land evaluation is very important in this direction as it provides information on the potentials and constraints for a defined land use type in terms of crop performance as affected by the physical environment (Senjobi and Ogunkunle, 2011; Ahukaemere *et al.*, 2012). Heterogeneity of soil and the potentials observed from one location to another are the interplay of soil-forming factors (parent material, climate, organisms, topography and time) which give rise to distinct soil types observed on a landscape (Ojanuga *et al.*, 2003; Esu *et al.*, 2008; Amhakhian and Achimugu, 2011).

Land evaluation (soil survey interpretation) precedes land use planning as the soil resource data provide several information, which may facilitate in predicting soils' behaviour towards different land uses *viz.* crop cultivation, plantation, forest or other usage (Prasad, 2000).

However, utility of the generated data can be significantly enhanced if the taxonomic units are grouped into management units, which can indicate the potential and constraints of an area in terms of its fertility (Akinbola *et al.*, 2009).

Fertility capability classification (FCC) system (a system of land evaluation) has been described as a technical soil classification system that focuses quantitatively on the physical and chemical properties of the soil that are important towards soil fertility management (Sanchez *et al.*, 1982). It is primarily developed for interpreting soil taxonomy and additional soil attributes in a way that is directly relevant to plant growth (Sanchez *et al.*, 2003). Pedological information are very important for general land use planning however, the interest of the farmer lies in the interpretation of the soil surveys, otherwise known as land evaluation (Udoh *et al.*, 2013; Fasina and Adeyanju, 2006). Fertility capability classification identifies the most limiting land qualities and provides a good basis for advising farmers on the appropriate management practice for optimum production in an area. FCC also simplifies information about the profile and analysis of soils for the benefit of those who are not familiar with soil classification system. It appears to be a suitable framework for agronomic soil taxonomy, which is acceptable to both pedologists and agronomists (Udoh *et al.*, 2013).

Little information is currently available to farmers and extension workers with regard to soil fertility management in an agrarian community of Umuahia area of Abia State. In this respect, the research work was carried out to characterize and assess the fertility potentials of soils under selected land use types for sustainable production of different crops.

Materials and methods

Study area

The study was conducted in Mbom, Umuahia North Local Government Area of Abia state, South-eastern Nigeria (Figure 1). The mean annual rainfall of the area is 2201.92 mm and bimodal with annual temperature ranges from 25 – 27 °C (Nigeria Meteorological Agency, 2017). The soil is underlain by coastal plain sands (Chukwu, 2013). Land clearing is by slash-and-burn technique while soil fertility regeneration is by bush fallowing which the length has decreased due to anthropogenic activities.

Field methods

The study area was reconnoitered using footpaths and perimeter survey was conducted. Following free survey method, the area was delineated into four mapping units based on the land use types identified (fallow land, forestland, continuously cultivated land and oil palm plantation) with several auger investigations (depths of 0 - 15, 15 - 30 and 30 – 50 cm). Auger investigations were further carried out at various points across the delineated mapping units for the establishment of modal profile pits. Each profile pit was demarcated into horizons and described for morphological attributes (Soil Survey Staff, 2014). Disturbed and undisturbed (core) soil samples were collected from identified horizons and analyzed for their physical and chemical properties. All sample points (boundary and profile) were geo-referenced using a hand-held (Garmin Etrex) Global Positioning System (GPS) receiver and their coordinates generated for geospatial analysis

Soil analysis

The disturbed soil samples collected were air-dried under laboratory conditions and sieved through a-2 mm wire mesh sieve. The fine earth fractions (< 2 mm) were subjected to routine soil analyses using standard procedures described by Udo *et al.* (2009): Particle size distribution was determined by Bouyoucos hydrometer method using sodium hexametaphosphate as dispersant and selenium tablets as catalysts (Gee and Or, 2002).

Undisturbed soil core samples were oven-dried at 105°C to a constant weight and bulk density was calculated using the formulae:

$$bd = m \div v \quad \ldots\ldots\ldots\ldots\ldots 1$$

Where: bd = bulk density (gcm^{-3}), m = mass of oven dry soil (g), v = volume of core sampler {$v = \pi r^2 h$} {where r and h are radius (m) and height (m) of the core sampler respectively}.

Total porosity was computed as:

$$Tp = 1 - \{Bd \div Pd\} \times 100 \quad \ldots. 2$$

Where: Tp = total porosity, Bd = bulk density, Pd = particle density assumed to be 2.65 mgm^{-3} for tropical soils.

Soil pH was measured potentiometrically in a soil: water suspension (ratio 1:2.5) using a glass electrode pH meter (Thomas, 1996). Organic carbon was determined (from the soil passed through 0.5 mm sieves) by the dichromate wet oxidation method (Udo *et al.*, 2009). Total nitrogen was determined on soil (through 0.5 mm sieve) by the regular micro-Kjeldahl method described by Bremner (1996). Available phosphorus was extracted with Bray number II solution of HF and HCl and the P in the extract was determined spectrophotometrically. The effective cation exchange capacity (ECEC) was determined by summation of all exchangeable cations including exchange acidity (Al^{3+} and H^+). The exchangeable bases were extracted by saturating the soil with neutral 1N KCl. Ca^{2+}, Mg^{2+}, Na^+ and K^+ displaced by $NH4^+$ were measured by Atomic Absorption Spectrometer (AAS) (Udo *et al.*, 2009). Exchangeable acidity was extracted with 1N KCl and estimated in the extract by titration (Udo *et al.*, 2009).

ECEC = Exchangeable acidity +Total exchangeable bases (TEB)………… 3

Base saturation was obtained by expressing the sum of exchangeable bases (Ca^{2+}, Mg^{2+}, Na^+, and K^+) as percentages of the effective cation exchange capacity:

$$\% BS = \frac{TEB}{ECEC} \times 100 \ldots\ldots\ldots\ldots\ldots\ 4$$

Assessment of the potentials of soils in the study area

The potential of the soils for the kinds of problems they present for agronomic management of the chemical and physical properties was assessed using the (FCC) system as outlined in Sanchez et al. (1982) version. The system consists of three categorical levels: 'type' (texture of plough layer or top 20 cm); substrata type' (texture of sub-soils) and 'modifiers' (soil properties or conditions which act as constraints to crop performance). Class designations from the three categorical levels are combined to form a FCC unit.

Geo-spatial analysis

A detailed geo-spatial analysis involving the use of Geographic Information System (GIS) was carried out to describe the variability and spatial distribution patterns of the (FCC) units. Kriging method was used in ArcGIS 10.3 environment to generate spatial maps of the identified FCC units

Results and discussion

Land qualities/characteristics of the land use types in the study area

The soils (Table 1) were generally deep (> 160 cm), non-concretionary and well drained except oil palm plantation which was poorly drained. The bright and mottle-free soil horizons are indicative of good surface drainage as evidenced by the soil chroma (strength of lightness) colour notation greater than 2. This may be attributed to perhaps, presence of sesquioxides in hydrated form, especially the goethite (Idoga and Azagaku, 2005). However, the poor drainage condition of soil of oil palm plantation may be attributed to its lower position on the terrain. The crumb structure and friable (moist) consistence of the surface soils observed will enhance good tillage operation and easy penetration of plant roots (Ogba and Ibia, 2006). The high sand fraction (620.00 – 825.00 gkg^{-1}) in the soils could be attributed to the coasted plain sands geology of the area and the progressive increase in the clay content down the depth could be consequent upon eluviations - a pedogenic process (Ojanuga *et al*., 2003; Chukwu, 2013). Bulk density values ranged between 1.29 and 1.69 gcm^{-3}. These are within the acceptable values (1.0 - 1.6 mgm^{-3}) for agronomic activities in most mineral soils (Chude *et al.*, 2011; Chaudhari *et al*., 2013). The higher bulk density observed under continuously cultivated land compared to other land use types may be attributed to the mechanical disruption of the pore arrangements by tillage activities (Celik, 2005; Cerda and Jurgensen, 2008; Oguike and Mbagwu, 2009) and its increase down the pedal depth could be attributed to a decrease in organic matter down the depth (Sakin *et al.*, 2011). Soil weathering potential, assessed by the silt/clay ratio revealed that the soils are relatively young with high degree of weathering as reported by Ayolagha and Opene (2012) that soils with silt/clay ratio more than 0.25 are of low degree of weathering.

The pH (H_2O) values across the land use types ranged from moderately acid (5.54 - 6.12) surface to strongly acid (4.19 – 5.32) sub-surface soil (Table 2). The acid nature of the soil can be adduced to high amount of rainfall in the area and the coarse texture of the soils resulting to leaching of some basic cations and dominance of acidic cations on the exchange complex of the soil (Chude *et al*., 2011; Nkwopara *et al.*, 2019). Thus, the soils would need to be limed to reduce its acidity and make nutrient elements readily available for absorption by plant roots. Organic carbon was low in soils under 3-year fallow and continuously cultivated land (10.5 and 12.5 gkg^{-1}) and high under forest land and oil palm plantation (18.7 - 22.6 gkg^{-1}) (Enwezor *et al.*, 1990). The low levels of organic carbon in the fallow and continuously cultivated land use types could be attributed to management practices involving bush burning, continuous farming and reduction in the fallow period (Akinrinde and Obigbesan, 2000).

Agricultural potential of soils of the study area

Soil coding and systematic placement of the soils into FCC units (Table 3) clearly indicates that soil individuals in a single FCC unit do not necessarily belong to the same mapping unit (land use type). Fallow, forest and continuously cultivated land were associated with loamy top and sub soils (L) while oil palm plantation showed loamy top (L) and clay sub (C) soils. Soil of the forest land was grouped into FCC unit Lek due to low CEC (e) and exchangeable K (k) while soils under fallow and continuously cultivated land were further classified into FCC unit Lehkm due to additional criteria of low organic matter (m) and high acidity (h). However, soil under oil palm land use type was further associated with poor drainage conditions (g modifier) representative of aquic moisture regime, low cation exchange capacity (e), high acid reaction (h) and low K reserves (k) thus, was classified into FCC unit LCghk (Fig. 2).

Conclusion

The study estimated the soil properties of Mbom, Umuahia North Local Government Area of Abia State and assessed their potentials for sustainable crop production. The finding revealed variability in soil properties and their potentials for sustained crop production. The soils are acidic and generally low in exchangeable bases. The soils' potentials identified three FCC units; LCeghk, Lek and Lehkm.

Recommendation

The finding recommends that FCC system is an important tool to evaluate the problems and potentials of varied soils. Thus, the FCC units spatial maps generated is a helpful tool to farmers and soil scientists to make informed decisions on the appropriate fertility management technique to be deployed for sustained use of the soils in the study area.

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Table 1: Some morphological and physical properties of soils of the study area

Horizons	Depth (cm)	Colour (moist)	Structure	Consistence (moist)	Sand ←	Silt gkg^{-1}	Clay →	SCR	TC	BD mg/m^3	TP %
			Fallow land (3 years)								
Ap	0–17	10YR 3/3	crumb	friable	825.00	43.00	132.00	0.33	SL	1.41	0.47
BA	17–45	10YR 4/3	crumb	friable	780.00	35.00	185.00	0.19	SL	1.45	0.45
Bt1	45–97	10YR 5/3	Sbk	Firm	690.00	50.00	260.00	0.19	SCL	1.63	0.38
Bt2	97–185	10YR 4/3	Sbk	Firm	643.00	47.00	310.00	0.15	SCL	1.68	0.37
			Forest land (40 years)								
Ap	0 –14	10YR 3/3	crumb	friable	780.00	40.00	180.00	0.22	SL	1.29	0.51
AB	14–58	10YR 5/3	crumb	friable	720.0	50.00	230.00	0.22	SL	1.40	0.47
Bt	58–106	10YR 4/3	Sbk	Firm	650.00	40.00	310.00	0.13	SCL	1.51	0.43
Bt2	106-192	10YR 5/8	Sbk	Firm	750.00	30.00	220.00	0.14	SCL	1.68	0.35
			Continuously cultivated land (6 years)								
Ap	0 –21	10YR 3/3	crumb	friable	815.00	23.00	162.00	0.14	SL	1.61	0.39
BA	21–69	10YR 4/3	crumb	friable	750.00	70.00	180.00	0.39	SL	1.59	0.40
BtC	69-164	10YR 5/3	Sbk	firm	730.00	67.00	203.00	0.33	SCL	1.72	0.35
			Oil palm plantation (20 years)								
Ap	0–17	10YR 5/2	crumb	friable	802.00	38.00	I60.00	0.19	SL	1.46	0.45
Bt	17–35	10YR 4/3	Sbk	firm	680.00	60.00	260.00	0.24	SCL	1.51	0.43
Btg	35–70	10YR 5/6	Sbk	firm	620.00	20.00	360.00	0.06	SC	1.68	0.35
Bg	70–161	10YR 5/8	Sbk	firm	684.00	64.00	252.00	0.25	SCL	1.69	0.34

Key: SCR = silt clay ratio, SL = sandy loam, SCL = sandy clay loam, BD = bulk density, TC – textural class, Sbk = sub-angular blocky

Table 2: Some chemical properties of soils of the study area

Horizon	Depth (cm)	pH H_2O	Av. P mg/kg	TN %	OC %	Ca	Mg	K	Na cmolkg^{-1}	Al^{+3}	H^{+}	ECEC	BS %
			Fallow land (3 years)										
Ap	0–17	5.63	10.14	0.14	1.25	1.40	1.16	0.28	0.21	0.61	1.28	4.94	61.74
BA	17–45	5.15	9.88	0.10	1.02	1.31	1.03	0.21	0.12	0.64	1.16	4.47	59.73
Bt1	45–97	4.87	7.35	0.09	0.67	1.23	1.07	0.24	0.21	0.51	1.10	4.36	63.07
Bt2	97–185	4.90	7.92	0.06	0.38	1.19	0.53	0.10	0.10	0.52	1.06	3.50	54.86
			Forest land (40 years)										
Ap	0 –14	6.12	17.81	0.21	2.26	2.10	1.12	0.36	0.21	0.45	0.66	4.90	77.35
AB	14–58	5.82	16.25	0.12	1.24	1.18	1.02	0.30	0.20	0.42	0.90	4.02	67.16
Bt	58–106	5.10	8.47	0.08	0.66	1.03	0.75	0.23	0.17	0.35	0.87	3.40	64.12
BtC	106-192	5.26	7.60	0.03	0.34	1.05	0.67	0.20	0.11	0.43	0.69	3.15	64.44
			Continuously cultivated land (6 years)										
Ap	0 –21	5.54	7.53	0.12	1.05	1.40	1.04	0.24	0.22	0.37	1.70	4.97	58.35
Bt1	21–69	4.79	7.11	0.08	0.76	1.33	0.72	0.18	0.21	0.40	1.24	4.08	59.80
Bt2	69-164	4.68	8.16	0.04	0.31	1.20	0.45	0.08	0.10	0.38	1.30	3.51	52.14
			Oil palm plantation (20 years)										
Ap	0–17	5.71	9.66	0.16	1.87	1.81	1.16	0.32	0.22	0.49	1.19	5.19	67.63
Bt	17–35	5.32	7.31	0.09	1.02	1.18	1.01	0.24	0.17	0.43	1.03	4.06	64.04
Btg	35–70	5.06	8.02	0.04	0.73	1.06	0.97	0.11	0.20	0.45	0.94	3.73	62.73
Bg	70–161	4.19	7.22	0.04	0.24	0.80	0.63	0.15	0.17	0.56	0.97	3.28	53.35

Key: Av. P = Available phosphorus, OC = Organic carbon, TN = Total nitrogen, ECEC = Effective cation exchange capacity, BS = Base saturation.

Table 3: Fertility capability classification checklist showing type, substrata type and modifiers

Land use type	Type 1 (Topsoil)	Type 2 (Substrata)	a	e	g	h	I	k	M	s	v	FCC unit
			← Condition modifiers →									
Fallow land	L	L	-	+	-	+	-	+	+	-	-	Lehkm
Forest land	L	L	-	+	-	+	-	+	-	-	-	Lek
Continuously cultivated land	L	L	-	+	-	+	-	+	+	-	-	Lehkm
Oil palm	L	C	-	+	+	+	-	+	-	-	-	LCeghk

Key: L = loamy soil; < 35 % clay but not loamy sand or sand, C = clayey soil; > 35 % clay, g = aquic soil moisture regime, v=vertisols (cracking clays), k = low nutrient capital reserves, e = low CEC, a = aluminum toxicity, h = acidic, i = high fixation of P by Fe, s = salinity, m=low organic matter

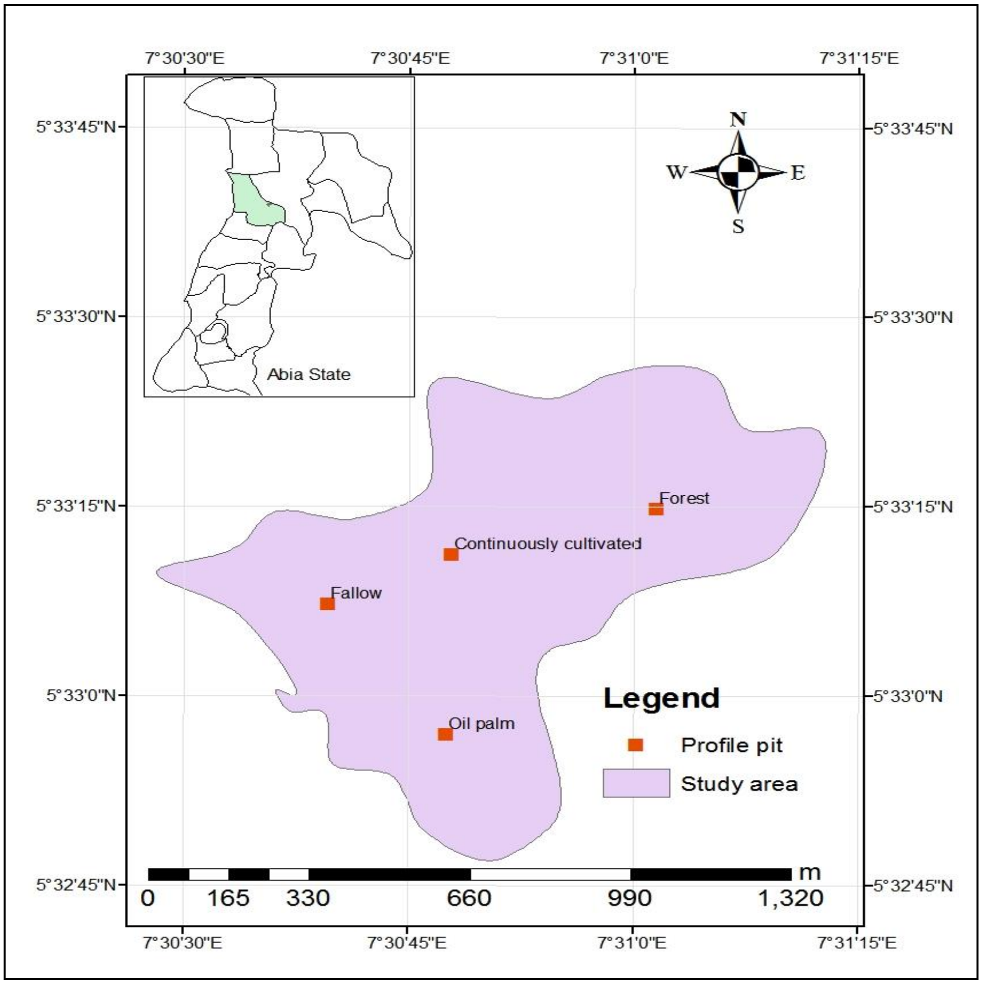

Fig.1: Map showing the location of profile pits in the study area

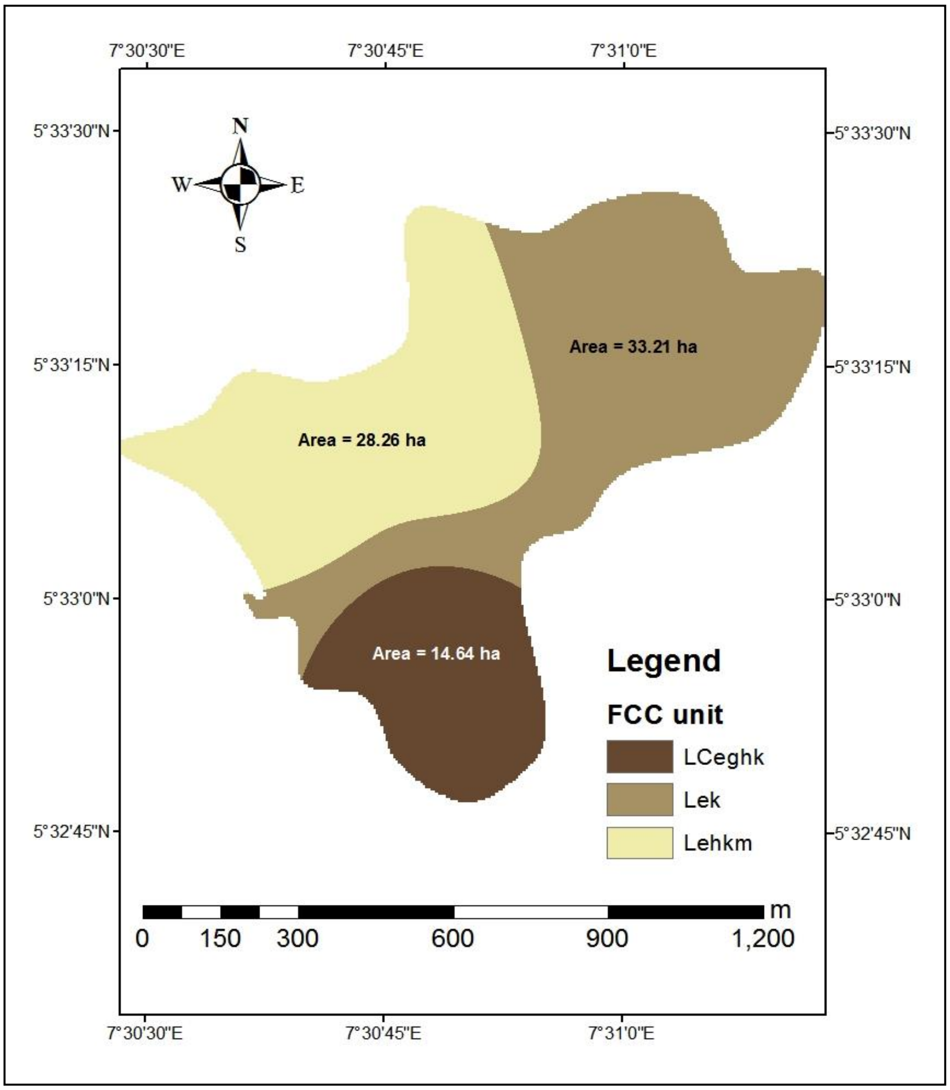

Fig. 2: Fertility capability classification map of the study area