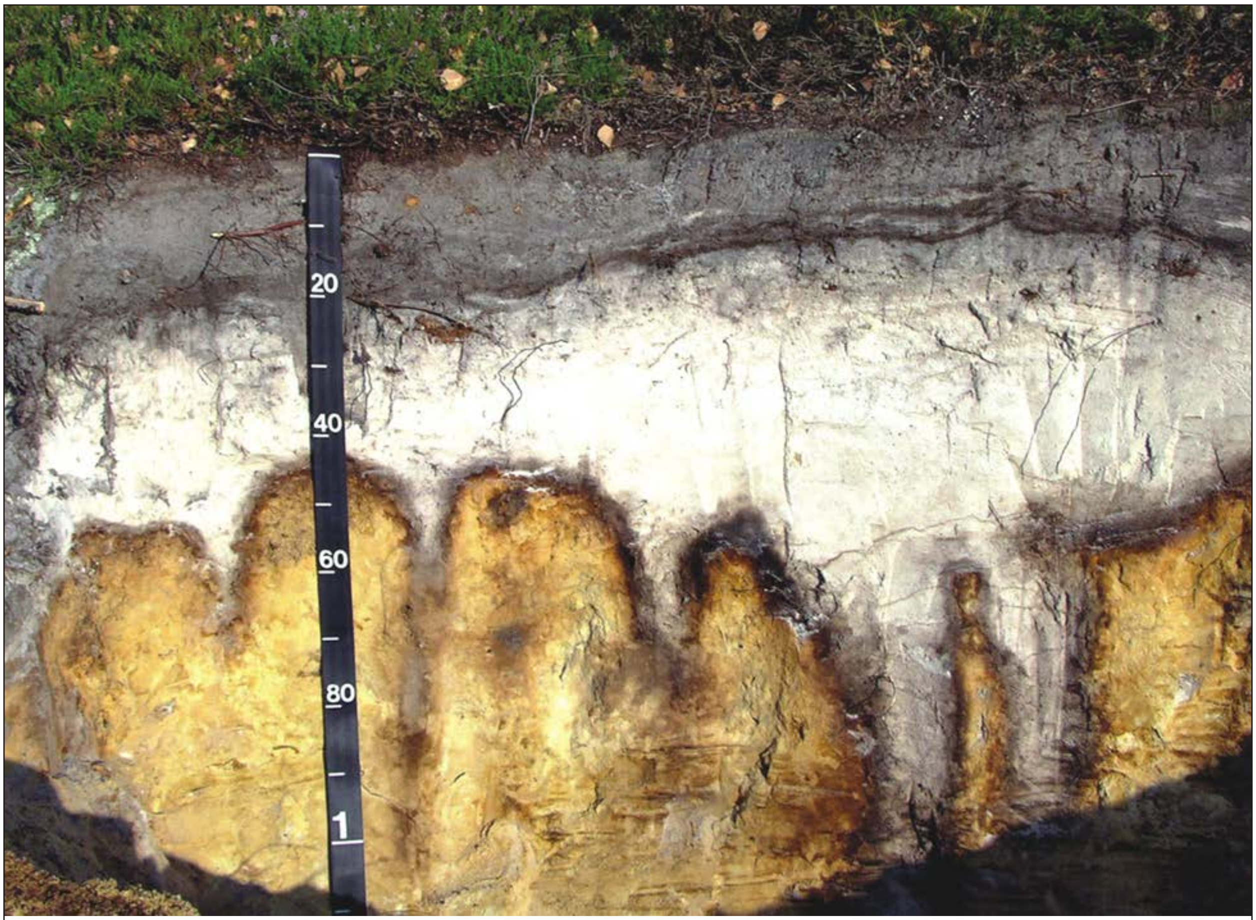

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Effect of Land Use Types on Vulnerability Potential and Degradation Rate of Soils of Similar Lithology in a Tropical Soil of Owerri, Southeastern Nigeria

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ABSTRACT

A field study was conducted in 2014 to evaluate the effect of three land use types on the vulnerability potential and soil degradation rate of soils of similar lithology in a typic hapludult in Owerri, Southeastern Nigeria. Three land use types namely Fallow Land (FL), Cassava Cultivated Land (CCL) and maize and yam inter crop (MYC), located in three villages in Owerri North Local Government Area of Imo State Nigeria were studied. In each of the village and land use type, three soil samples were collected at the depths of 0-15 and 15-30 cm. Samples were prepared and analyzed using standard methods. Data generated from laboratory analysis were subjected to analysis of variance (ANOVA). Significant treatment means were separated using Least Significant Difference (LSD) while variations among soil properties and relation among soil properties was determined using coefficient of variation and linear correlation, respectively. Results obtained showed that irrespective of the land use, soils of the studied area were strongly acidic with high sand fraction (>70%) resulting to poor physical condition such as poor moisture retention and total porosity. The chemical properties showed moderate organic matter content, total nitrogen and available phosphorus. The exchangeable bases were low and below the critical limits with predominant exchangeable H and Al. Variations existed among soil chemical properties in the three land use types. Soils of the studied area have strong to moderate degradation rate and vulnerability potential. Relationship existed among soil physicochemical properties which positively or negatively interfere with nutrient availability. To reduce the high degradation rate and vulnerability potential of these soils and to improve the fertility status of the soils, it is recommended that farmers should be advised to plant acid tolerant plants. Organic fertilization and liming should be practiced. Cover cropping and conservational tillage should be practiced to reduce erosion and runoff.

Key words: Degradation rate, vulnerability potential, land use, soil variability, epipedon

INTRODUCTION

Decline in soil fertility and land degradation has been considered as some of the major constrains facing agricultural productivity in Southeastern Nigeria (Onwudike *et al*., 2015). Owerri in Imo State, Southeastern Nigeria, is a humid tropical rainforest characterized by high precipitation which causes runoff, leaching of nutrient elements and soil erosion (Onweremadu *et al*., 2011). Soils of these areas have been subjected to anthropogenic activities thereby resulting to variations in soil properties. Pando-Moreno *et al.* (2004) have shown that nutrient mining, absence of fallow periods, use of inappropriate farming practices and frequent changes in land uses (over-cultivation), variation in micro-climate, vegetation and parent material aggravate soil degradation, resulting to constant plummeting of soil fertility levels and productivity. Research has shown that anthropogenic activities on the natural terrestrial ecosystem have resulted to variations in the physical, chemical and biological properties of soil (Conant *et al.*, 2003). Some land use and cropping systems like cultivation, deforestation, overgrazing and mineral fertilization have been reported to cause significant variations in soil properties, terrestrial cycle and reduction of output (Conant *et al.*, 2003; Saraswathy *et al.*, 2007).

Soil degradation is the lowering of soil physical and chemical fertility to a threshold that limits maximization of agricultural productivity (Ezeaku and Davidson, 2008). Soil degradation of similar lithology may be greatly affected by land use types and cropping systems and these play an important role in agriculture and the environmental management, especially with regard to soil fertility and soil quality (Ezeaku, 2013). There is dearth of information on the degradation rate and vulnerability potential of soil qualities in Owerri. Therefore, information on the rate of degradation, vulnerability potential as well as variation among soil physico-chemical properties due to land use types has become essential for practical and experimental agriculture.

MATERIALS AND METHODS

Study area: The study was carried out at Owerri North Local Government Area of Imo State, Southeastern Nigeria. The area lies between Latitude 5°17'N and 5°38' N and Longitude 7°11'E and 7°45'E. The area has an average annual rainfall range of 1949-2251 mm and annual temperature range of 27-30°C with average relative humidity of 78%. The geological material of soil in the study area is an ultisol and classified as Typic Hapludtult (FDALR., 1985), derived from Coastal Plain Sands (Benin formation) of the Oligocene-Miocene geological era and are characterized by low cation exchange capacity, low organic matter with high leaching of nutrient elements (Onweremadu *et al.*, 2011). Tropical rainforest is the dominant vegetation of the area, though with remarkable ecological diversity caused by anthropogenic activities, especially farming and deforestation resulting into depleted vegetation as a result of demographic pressure. More than 50% of people in the area are subsistence farmers. Soil fertility restoration in the area is by bush fallow and application of inorganic and organic fertilizers.

Soil sampling and experimental design: Soil samples were collected from three land use types in three villages in Owerri North local Government Area, Imo State, Southeastern Nigeria. A reconnaissance visit was made to the study locations to locate the sampling sites and to obtain information from the owners about the study sites. The villages were Ishiuzor village, Ofeuzor village and Umuayalu village. The three locations have similar lithological property (parent material) which is coastal plain sand and this guided the sampling locations. Fallow land (four years fallow) (FL), Cassava Cultivated Land (CCL) and maize and yam intercrop (MYC) were studied. Three soil samples were collected from each of the land use at each location which had similar history and agronomic practices. The three sampling points acted as replications while the land use types were used as treatments. Samples were collected at the root zones of 0-15 and 15-30 cm using soil auger and core samplers for bulk density determination. Each sample was air dried, passed through a 2 mm screen and the coarse fraction (>2 mm) separated. The <2 mm soil fractions were then subjected to laboratory analysis using standard procedures.

Laboratory analysis: Particle size distribution was determined by hydrometer method according to the procedure of Gee and Or (2002). Bulk density was determined by core methods according to Grossmans and Reinsch (2002). Total Porosity (TP) was calculated from the result of bulk density as:

$$TP = \frac{1 - Bd}{Pd} \times 100 \quad (1)$$

where, Pd = particle density (2.65).

Gravimetric Moisture Content (GMC) was determined by the gravimetric method calculated mathematically as follows:

$$GMC = \frac{W_2 - W_3}{W_3 - W_1} \times 100 \quad (2)$$

Where:

W_1 = Weight of the can
W_2 = Weight of wet sample+can
W_3 = Weight of oven-dried sample+can

Silt/Clay ratio was calculated by dividing the value of the silt fractions by the clay fractions. Soil pH was determined in water and in KCl using pH meter in soil/liquid suspension of 1: 2.5 according to Herdershot *et al.* (1993). Organic carbon was determined using chromic wet oxidation method according to Nelson and Sommers (1982). Total Nitrogen was determined by kjeldahl digestion method using concentrated H_2SO_4 and Sodium copper sulphate catalyst mixture according to Bremner and Yeomans (1988). The C/N ratio was determined by computation of organic carbon and total nitrogen values (Brady and Weil, 1999), while available phosphorus was determined using Bray II solution method according to Nelson and Sommers (1982). Exchangeable Mg and Ca was determined using Ethylene Diamine Tetra Acetic Acid (EDTA) (Thomas, 1982) while exchangeable K and Na was extracted using 1 N Neutral ammonium acetate ($C_2H_7NO_2$) and then determined using flame photometer (Thomas, 1982). Exchangeable Acidity was measured titrimetrically using 1 M KCl against 0.05 M sodium hydroxide (McLean, 1982), while, effective cation exchange capacity was calculated from the summation of all exchangeable bases and total exchangeable acidity. The Ca/Mg ratio was calculated by the value of exchangeable calcium with exchangeable Mg. Percentage Base Saturation (PBS) was calculated by the summation of the total exchangeable bases divided by effective cation exchange capacity and then multiplied by 100.

Soil Vulnerability Potential (SVP) and Soil Degradation Rate (SDR) was estimated using the rating scheme for soil degradation according to Lal (1993). Soil texture, soil pH, soil organic carbon, soil total nitrogen, available phosphorus, effective cation exchange capacity and percentage base saturation was used in the assessment. The vulnerability potentials of these properties were also determined. For SDR, the weighting sequence was as follows: 1 = none, 2 = slight, 3 = moderate, 4 = severe and 5 = extreme. Good soils have the lowest SDR and poor soils have the highest value. For the SVP, the weighting sequence is the reverse of SDR such that: 5 = very low, 4 = low, 3 = medium, 2 = high and 1 = very high according to Lal (1993) and Akpan-Idiok (2012).

Data were subjected to analysis of variance (ANOVA). Significant means among treatments were separated using Least Significant Difference (LSD) at 5% probability level. Variability among soil physical and chemical properties were determined using Coefficient of Variation (CV) and ranked according to Wilding *et al.* (1994) as % CV from 0-15 = low variation, 15-35 = medium variation and above 35 = high variation.

RESULTS AND DISCUSSION

Soil physical properties of the studied locations: Results of the physical properties of soil in the studied locations are presented in Table 1. Texturally, soils at the epipedon were sandy loam while the sub-soils were loamy sand irrespective of the land use. Sand fractions dominated the particle size distribution. The high sand fraction could be attributed to the parent material dominant in the area which is coastal plain sand since the texture of the soil is highly influenced by parent material over time (Oguike and Mbagwu, 2009). This result agreed with Onweremadu (2007) who observed similar textural characteristics on coastal plain soils in Owerri, Southeastern Nigeria. Also, the humid rainfall characteristics that promote illuviation or leaching of silt and clay particles below the epipedon could contribute to the texture of soils in the area.

The bulk density of the soils increased down the depth in each land use. Fallow Land (FL) recorded the lowest bulk density of 1.05 g cm^{-3} at the epipedon and 1.12 g cm^{-3} at the sub soil. Higher bulk densities were recorded in Cassava Cultivated Land (CCL) and maize and yam inter crop (MYC). This could be attributed to tillage activities since tillage activities could reduce organic matter accumulation which reduces soil bulk density. However, the values of bulk densities were below the critical limit of 1.3 g cm^{-3} recommended for tuber and cereal crops (Lal, 1986). Soil total porosity followed the same sequence with soil bulk density with FL recording the highest value of 60.6% at the epipedon and 57.3% at the sub soil. Increase in soil bulk density resulted to a decrease in soil total porosity which could be attributed to compaction of soil macro and micro pore spaces. The highest gravimetric moisture content was recorded in fallow land with the value of 527 g kg^{-1} at the epipedon. The gravimetric moisture content of the soils was low and could be attributed to the high sand fraction and low porosity which hinders moisture retention. Soils with this property lack adsorption capacity for basic plant nutrient and water retention (Oguike and Mbagwu, 2009).

Soil chemical properties of the studied locations: Results of soil chemical properties of the studied locations are presented in Table 2. Result showed that the soils had a mean pH value

Table 1: Physical properties of the study locations

Location	Depth (cm)	Sand (g kg^{-1})	Silt (g kg^{-1})	Clay (g kg^{-1})	TC	BD (g cm^{-3})	TP (%)	GMC (g kg^{-1})	Silt/clay
MYC	0-15	809	89	101	SL	1.16	56.2	525	0.9
MYC	15-30	767	87	146	SL	1.29	50.9	464	0.6
CCL	0-15	813	78	109	SL	1.13	56.7	519	0.7
CCL	15-30	749	112	139	LS	1.13	57.2	469	0.8
FL	0-15	810	85	105	SL	1.05	60.3	527	0.8
FL	15-30	741	110	149	LS	1.12	57.3	452	0.7
	Mean	782	94	125	SL	1.16	56.0	493	0.8
	$LSD_{(0.05)}$	45.45	24.15	32.65		0.14	5.46	50.9	NS

NS: Not significant, FL: Fallow land, CCL: Cassava cultivated land, MYC: Maize and yam inter crop, TC: Textural class, BD: Bulk density, TP: Total porosity, GMC: Gravimetric moisture content, SL: Sandy loam, LS: Loamy sand

Table 2: Chemical properties of the study locations

Land use	Depth (cm)	pH (H_2O)	pH (KCl)	OC (g kg^{-1})	TN (g kg^{-1})	Avail. P (mg kg^{-1})	Ca	Mg	K	Exch. Na (cmol kg^{-1})	H	Al	ECEC (%)	BS	Ca/ Mg
MYC	0-15	5.6	4.5	16.5	1.5	15.3	2.8	2.2	0.2	0.27	0.5	0.6	6.6	82.9	1.3
MYC	15-30	5.1	4.3	10.9	1.2	11.3	1.5	1.8	0.2	0.39	0.7	0.8	5.4	72.0	0.9
CCL	0-15	5.4	4.4	16.1	1.2	15.5	2.5	1.8	0.3	0.03	0.4	0.5	5.5	84.2	1.4
CCL	15-30	5.3	4.0	12.1	1.1	14.1	1.3	1.6	0.2	0.04	0.6	0.9	4.6	68.3	0.8
FL	0-15	5.8	4.7	18.8	1.6	16.2	3.1	2.7	0.8	0.03	0.5	0.7	7.8	85.0	1.2
FL	15-30	5.5	4.3	13.6	1.4	11.7	2.0	2.1	0.3	0.01	0.8	0.9	6.1	72.2	1.0
	Mean	5.5	4.4	13.0	1.3	14.0	2.2	2.0	0.3	0.12	0.6	0.7	6.0	77.4	1.1
	LSD (0.05)	0.66	0.61	4.24	0.33	2.38	1.0	0.44	0.28	0.02	0.17	0.09	1.42	5.6	0.35

FL: Fallow land, CCL: Cassava cultivated land, MYC: Maize and yam inter crop, Avail. P: Available P, TN: Total nitrogen, ECEC: Effective cation exchange capacity, BS: Base saturation of 5.5 indicating strong acidity according to Esu (1991). The highest soil pH of 5.8 and 5.5 was recorded in the fallow land at the surface and sub-surface soils, respectively when compared to CCL and MYC. This could be attributed to litter falls which after decomposition increases soil organic matter and exchangeable bases thereby reducing the accumulation of H and Al ions on soil exchange complex (Onwudike, 2010).

Soil organic carbon ranged from 10.9-18.8 g kg^{-1} with mean of 13.0 g kg^{-1} indicating medium organic matter content according to Esu (1991). The highest soil organic carbon was recorded in the fallow land 18.8 g kg^{-1} at the surface and 13.6 g kg^{-1} at the sub-surface. The highest organic carbon in the fallow land could be due to litter fall and expected increase in soil biodiversity (Miller and Gardiner, 2001). Bewket and Stroosnijder (2003) have observed that conversion of forest vegetation to agricultural land results in a decline of soil organic carbon content. The above trend was observed in soil total nitrogen and available phosphorus as shown in Table 2. Highest value of total nitrogen (1.6 g kg^{-1}) was recorded in the fallow land at the surface with mean value of 1.3 g kg^{-1}. This value according to Enwenzor *et al*. (1989) is rated medium when compared with the range 2-5 g kg^{-1} for productive soils. Similarly, the highest value (16.2 mg kg^{-1}) of available phosphorus was recorded in fallow land with mean value of 14.0 mg kg^{-1}. The mean value indicates that the soil is rated medium according to Esu (1991) when compared with the values >20 mg kg^{-1} for high available P. Highest value of total nitrogen and available phosphorus recorded in fallow land could be due to litter fall and higher soil organisms that help in organic matter decomposition since there is a positive correlation between organic matter and total nitrogen (Onwudike, 2010).

The exchangeable cations were low in the three land use types with the highest values recorded in fallow lands. Exchangeable Ca, Mg, K and effective cation exchange capacity had the highest values of 3.1, 2.7, 0.8 and 7.8 cmol kg^{-1}, respectively in fallow land at the epipedon. According to FAO (2006), the soils are rated low in exchangeable Ca (mean 2.2 cmol kg^{-1}), moderate in exchangeable Mg (mean 2.0 cmol kg^{-1}), low in exchangeable K (mean 0.3 cmol kg^{-1}) and very low in effective cation exchange capacity (mean 1.42 cmol kg^{-1}). Base saturation is ranked medium since the mean falls within 50-80% (Esu, 1991). The low exchangeable bases in these locations could be due to high rainfall which accelerates runoff and leaching of nutrient elements down the subsoil. Higher exchangeable bases in the fallow land could be due to the macro and micro climate that hinders the impact of rain drops on soil (Brady and Weil, 2002). Similarly, high ECEC and percentage base saturation in fallow land could be attributed to increase in exchangeable bases and organic carbon obtained from mineralization of litter falls in fallow land.

Variability among soil physicochemical properties in the studied locations: Results of the relationship among soil physicochemical properties are shown in Table 3 and 4. Results showed that there was no variation among soil physical properties except in silt and silt/clay ratio that had low to moderate variation. Among soil chemical properties, there was variation in the three land use types. There was low to moderate variations in soil pH, high variation in soil organic carbon and total nitrogen as well as in exchangeable cations and ECEC. The parent material dominant in the locations could be responsible for no variations in the particle size fractions while different management practices existing in these three land use types such as tillage practices that alter the chemical equilibrium of the soil could attribute to variations among soil chemical properties.

Degradation rate and vulnerability potentials of soils in the studied locations: Soil properties that were used to assess the degradation rate and vulnerability potentials of the studied

Table 3: Variability among the physical properties of soil in the studied locations

Parameters	Sand	Silt	Clay	BD	TP	MC	Silt/clay
Fallow land							
CV (%)	4	7.7	25.6	8.7	7.4	9.2	29.3
Rank	Low	Low	Medium	Low	Low	Low	Medium
Cassava cultivated land							
CV (%)	5.9	25.4	19.1	5.1	4.1	7.9	13.5
Rank	Low	Medium	Medium	Low	Low	Low	Low
Maize and yam inter crop							
CV (%)	6.5	22.3	25.8	9.4	6.9	12	18.2
Rank	Low	Medium	Medium	Low	Low	Low	Medium

CV: Coefficient of variation, BD: Bulk density, TP: Total porosity, MC: Moisture content

Table 4: Variability among the chemical properties of soil in the studied locations

Parameters	pH (H_2O)	pH (KCl)	Organic C	Total N	Avail. P	Ca	Mg	K	Exch. Na	H	Al	ECEC	BS	Ca/Mg
Fallow land														
CV (%)	11	13.5	42	37.1	14.4	52.9	29.2	51.1	60.6	60.3	83.5	36	6.3	26.3
Rank	Low	Low	High	High	Low	High	Medium	High	High	High	High	High	Low	Medium
Cassava cultivated land														
CV (%)	16.2	15.1	20.2	18	10.7	45	8.9	28.6	42.8	13.7	70.3	22	4.6	38.4
Rank	Medium	Medium	High	Medium	Low	High	Low	Medium	High	Low	High	Medium	Low	High
Maize and yam inter crop														
CV (%)	11.6	14.5	14.1	13.1	20.5	30.8	19.3	78.6	55.3	49.2	49.1	23.3	6.2	19.5
Rank	Low	Low	Low	Low	Medium	Medium	Medium	High	High	High	High	Medium	Low	Medium

CV: Coefficient of variation, Avail. P: Available P, TN: Total nitrogen, ECEC: Effective cation exchange capacity, BS: Base saturation

soils included soil textural class, soil pH, soil organic carbon, total nitrogen, available phosphorus, effective cation exchange capacity and percentage base saturation. Results in Table 5 showed that the SDR for soil texture, soil pH, soil organic carbon, total nitrogen, available phosphorus, ECEC and base saturations was 4, 4, 3, 3, 4 and 3, respectively while their SVP was 2, 2, 3, 3, 2 and 3, respectively. The ratio of SDR and SVP for soil texture (4/2) showed that the studied soils have high susceptibility to degradation and vulnerability potential. This could be attributed to the parent material of the soil (coastal plain sand) that is characterized by high coursed sand fractions as well as high precipitation dominant in the region which enhances soil erosion. Similar observation was made by Akpan-Idiok and Ofem (2014) on Odudu cattle ranch soils of Southeastern Nigeria. The SDR/SVP for soil pH (4/2) showed severe acidity which could be attributed to high rainfall in the area, erosion and leaching of nutrient elements below the epipedon irrespective of the land use and crop management systems. The SDR/SVP for soil organic carbon, total nitrogen, available phosphorus, ECEC and base saturation indicate moderate degradation rate and vulnerability potential which showed that there are moderate availability of basic cations and organic matter in the studied soils which could support plant growth. Therefore, these results showed that soil organic carbon, total nitrogen, available P and base saturation are good soil quality indicators of soil in the studied location. These qualities together will soil pH and texture needs more improvement for maximum crop yield.

Relationship mong soil physicochemical properties: Relationships between selected physical properties with soil chemical properties are presented in Table 6. Results showed that sand significantly correlated negatively with available P, base saturation, exchangeable Ca, ECEC, organic carbon, total N and soil pH. Clay correlated positively with the chemical properties except soil pH. There was positive correlation between total porosity and base saturation and negative with exchangeable H. Moisture content correlated positively with the chemical properties while bulk density correlated negatively with base saturation and positively with exchangeable H. High sand fractions in the studied location could reduce the nutrient concentration through runoff and

Table 5: Rating scheme for soil degradation rates and soil vulnerability potential of selected soil quality indicators

Soil properties	Mean	SDR	SVP	SDR/SVP
Soil texture	SL	4	2	4/2 (High)
Soil pH (H_2O)	5.5	4	2	4/2 (Severe)
Soil organic carbon (g kg^{-1})	13.0	3	3	3/3 (Moderate)
Soil total nitrogen (g kg^{-1})	1.3	3	3	3/3 (Moderate)
Soil available phosphorus (mg kg^{-1})	14.0	3	3	3/3 (Moderate)
Effective cation exchange capacity (cmol kg^{-1})	6.0	4	2	4/2 (Low)
Percentage base saturation (%)	77.4	3	3	3/3 (Moderate)

SDR: Soil degradation rate, SVP: Soil vulnerability potential. For SVP, 1: None, 2: Slight, 3: Moderate, 4: Severe, 5: Extreme for SVP, 5: None, 4: Low, 3: Moderate, 2: High, 1: Very high, Ratings based on mean soil quality and criteria limits according to Akpan-Idiok and Ofem (2014) and Lal (1993)

Table 6: Relationship between soil physical properties with soil chemical properties

Properties	Sand	Silt	Clay	TP	MC	BD	Silt/clay
Available P	-0.783**	-0.515*	0.705**	0.292^{ns}	0.771**	-0.317^{ns}	0.124^{ns}
BS	-0.663*	-0.239^{ns}	0.755**	0.616*	0.663*	-0.634*	0.357^{ns}
Exch. Ca	-0.762**	-0.367^{ns}	0.794**	0.418^{ns}	0.724**	-0.432^{ns}	0.345^{ns}
ECEC	-0.615*	-0.303^{ns}	0.634*	0.343^{ns}	0.622*	-0.346^{ns}	0.252^{ns}
Exchangeable H	-0.286^{ns}	0.0330^{ns}	-0.383^{ns}	-0.509*	-0.409^{ns}	0.515*	-0.162^{ns}
Exchangeable K	-0.413^{ns}	-0.207^{ns}	0.424^{ns}	0.351^{ns}	0.473^{ns}	-0.349^{ns}	0.097^{ns}
Exchangeable Mg	-0.4078^{ns}	-0.197^{ns}	0.424^{ns}	0.263^{ns}	0.459ns	-0.253^{ns}	0.159^{ns}
Organic C	-0.746**	-0.317^{ns}	0.812**	0.366^{ns}	0.723**	-0.381^{ns}	0.397^{ns}
Total N	-0.699*	-0.295^{ns}	0.762**	0.410^{ns}	0.727**	-0.428^{ns}	0.351^{ns}
pH (H_2O)	-0.693*	-0.386^{ns}	-0.679*	0.414^{ns}	0.704**	-0.433^{ns}	0.138^{ns}

*and **:Significant at 0.05 and 0.05 probability levels, respectively, ns: Not significant

leaching. Increasing the bulk density of the soil could reduce water infiltration, soil aeration and even soil biodiversity which will negatively affect the nutrient available to plants.

CONCLUSION

Soils of the studied locations are dominated by sand fraction, strongly acidic with low to moderate plant nutrient concentration. Variations existed among soil chemical properties in the three land use types. From the results obtained in this investigation, soils of Owerri Southeastern Nigeria have strong to moderate degradation rate and vulnerability potential. Relationship existed among soil physicochemical properties which positively or negatively interfere with nutrient availability. To reduce high degradation rate and vulnerability potential of these soil as well as to improve the fertility status of the soils, farmers should be advised to plant acid tolerant plants. Organic fertilization and liming should be practiced. Cover cropping and conservational tillage should be practiced to minimize erosion and runoff.

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