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Physicochemical Properties, Degradation Rate and Vulnerability Potential of Soils Formed on Coastal Plain Sands in Southeast, Nigeria

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ABSTRACT

The aim of this research was to study the physicochemical properties, degradation rates and vulnerability potential of coastal plain soils and suggest appropriate management strategies. Twenty composite soil samples (0-15 and 15-30 cm) collected from agricultural lands at ten locations in Akpabuyo Local Government Area of Cross River State of Nigeria were studied. The soils were characterized as follows: texture of loamy sand surface overlying sandy loam subsurface; pH (4.9-5.2), organic carbon (4.2-26.5 g kg^{-1}), total nitrogen (0.4-2.2 g kg^{-1}), carbon-nitrogen ratio (11-18), available P (45-73 mg kg^{-1}), effective Cation Exchange Capacity (CEC) (2.63-5.52 cmol kg^{-1}), base saturation (39-92%), Ca:Mg ratio (1.50-3.00) and Mg:K ratio (2.94-20.00). The Soil Degradation Rate (SDR)/Vulnerability potential (Vp) weighted values of texture (4/2), soil $pH_{(H_2O)}$ (5/1), organic carbon (4/2), total nitrogen (1/5) and effective cation exchange capacity (2/4) showed susceptibility of the soils to degradation or vulnerability. The soils could be managed by liming, planting of acid tolerant species and adopting appropriate cultural practices.

Key words: Physicochemical properties, coastal plain sands, soil degradation, vulnerability potential

INTRODUCTION

The soils of Akpabuyo Local Government Area are derived from geologic materials of Tertiary coastal plain deposits otherwise referred to as Benin Formation and is made up of continental sands and sandstones (>90%) with a few shale intercalations (Nton and Esua, 2010). The physicochemical properties of interest include particle size distribution, soil pH, organic carbon, available P, exchangeable bases, exchangeable acidity among others. These properties of soils have been used as soil quality indicators to assess the Soil Degradation Rates (SDR) and Vulnerability potential (Vp) with the aim of understanding the productivity of the soils under agricultural management systems (Lal, 1994; Akpan-Idiok *et al.*, 2012).

Worldwide, coastal plain soils are variable and agricultural with inherent limitations. The coastal plain soils of Southeastern United States of America are characterized by low soil fertility, sandy texture, acidic pH values, low contents of basic cations, organic carbon and activity clays; the soils are strongly weathered and are classified as Ultisols under USDA Soil Taxonomy and are cropped to corn and cotton (Shiyam *et al.*, 2007; Novak *et al.*, 2009). The Swan coastal plain soils in West Australia are porous, thus favouring leaching of applied nutrients and pesticides from the soil surface (Salama *et al.*, 2001). The coastal plain soils in Somalia consist of alluvial and marine deposits and are poorly developed and shallow probably due to less amount of rainfall (50-200 mm) in the region (Sommerlatte and Umar, 2000).

In Nigeria, the soils occupy Akpabuyo Local Government Area and Calabar Metropolis in Cross River State as well as Abia, Akwa Ibom, Delta, Imo and Rivers States. They are strongly weathered and are characterized by coarse to fine sand texture in the surface to subsurface soils, low contents of organic carbon, total nitrogen, exchangeable bases, activity clays (kaolinite) and low/high content of available phosphorus. The soils are highly leached and are therefore, acidic in reaction probably due to high amounts of rainfall in the area (Udo, 1977; FPDD, 1990; Ogban *et al.*, 1998; Chikezie *et al.*, 2010).

The soils support a lot of agricultural crops such as tree crop plantations (oil palm, rubber, coffee, kola nut, etc.) and food crop production such as cassava, yam, cocoyam, vegetables, etc. The soils produce most of the food crops available in Calabar Metropolis (Shiyam *et al.*, 2007). With the increasing population in Calabar due to rapid urbanization and industrialization, most of the available lands in Akpabuyo would be used for agricultural purposes. The envisaged extensive cropping in the area may enhance degradation of the soils in the area. The objectives of this study were to determine the physicochemical properties, soil degradation rate and vulnerability potential of soils in Akpabuyo Local Government Area of Cross River State. The management strategies for improvement of the productivity of the soils would be suggested.

MATERIALS AND METHODS

Description of the study area: Akpabuyo Local Government Area (4°45′N and 5°10′N; 8°20′E and 8°40′E) is located in Cross River State, Nigeria (Fig. 1). The climate of the area is typical of tropical humid region with a mean annual rainfall of 3500-4000 mm, a mean annual temperature of 26-27°C and a mean relative humidity of 80-90% (Bulktrade and Investment Company Limited, 1989).

The soils of the area are derived from the Tertiary Coastal Plain Sands. The area is gently to strongly undulating in most places. The original rain forest in the area has been deforested, so the vegetation is that of the secondary bush. The cropping system practised in the area include rotational bush fallow and mixed cropping.

Soil sampling: Twenty composite soil samples were collected at the depth of 0-15 and 15-30 cm from ten locations in the month of May, 2009 at Akpabuyo Local Government Area of Cross River State, Nigeria (Fig. 1). Each composite soil sample was stored in a well-labelled polythene bag and transported to the Soil Science laboratory, University of Calabar for analysis.

Laboratory analysis: Soil samples were air-dried and sieved through a 2 mm mesh. Particle size analysis was carried out by hydrometer method (Juo, 1979) using sodium hexametaphosphate (calgon) as the dispersant. Soil pH was determined in soil water ratio of 1:2.5 using a glass electrode pH meter. Organic carbon was determined by the Walkley and Black (1934) method while total nitrogen was by the Kjeldahl digestion method (Juo, 1979). Available phosphorus was determined by the Bray and Kurtz (1945) No. 1 method. Exchangeable bases (Ca, Mg, K and Na) were extracted in 1 N NH_4OAc at pH 7. Potassium and sodium were determined with a flame photometer while Ca and Mg were determined by the EDTA titration method (Black *et al.*, 1965). Exchangeable acidity was by titration method using 1 N KCl extract (McLean, 1965). Effective cation exchange capacity was a summation of exchangeable bases (Ca, Mg, K and Na) and exchangeable acidity. Percent base saturation was obtained by dividing the total exchangeable bases (Ca, Mg, K and Na) by the effective cation exchange capacity.

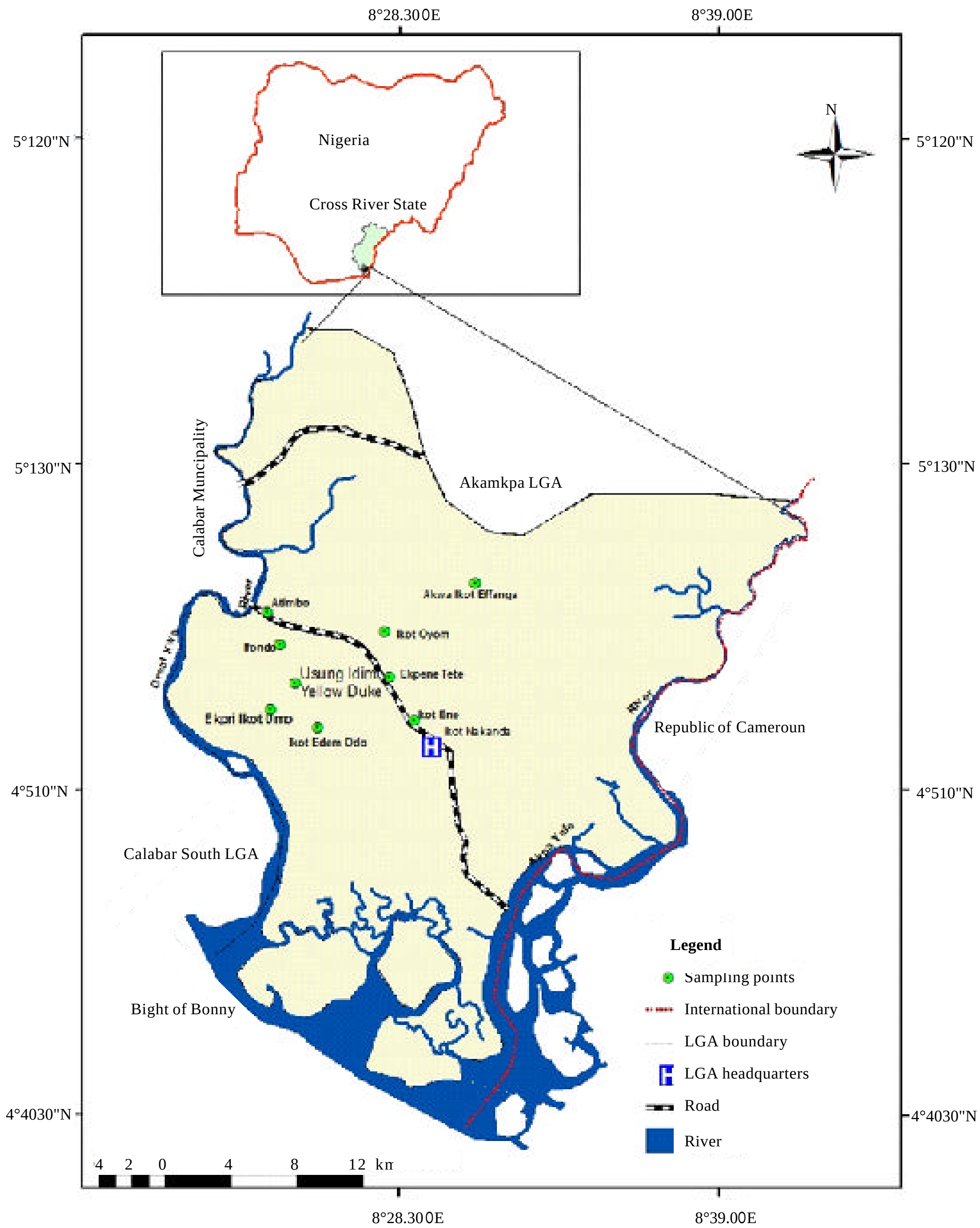

Fig. 1: Akpabuyo local government area showing sampling locations

Soil degradation rating (SDR)/vulnerability potential (Vp): The rating scheme for soil degradation developed by Lal (1994) and Akpan-Idiok *et al.* (2012) for soil physicochemical properties namely texture, soil $pH_{(H_2O)}$, organic carbon, total nitrogen, Effective Cation Exchange Capacity (ECEC), available P as well as base saturation were used in this study. Vulnerability potential (Vp) of the physical properties were also determined. For the SDR, the weighting sequence was as follows: 1 = none, 2 = slight, 3 = moderate, 4 = severe and 5 = extreme. In this way, good soils have the lowest SDR and poor soils the highest value. For the vulnerability potential, the weighting order was the reverse as follows: 5 = none, 4 = low, 3 = moderate, 2 = high and 1 = very high (Lal, 1994).

Statistical analysis: The data collected were analysed using descriptive statistics (the mean, range, standard deviation) with the help of SPSS software.

RESULTS AND DISCUSSION

Particle size distribution: Sand fraction ranged from 716.0-866.0 g kg^{-1} with a mean of 802.0 g kg^{-1} in the soils (Table 1). Silt fraction varied between 37.0 and 117.0 g kg^{-1} with a mean of 67.0 g kg^{-1} in the soils; clay fraction ranged from 10.7-197.0 g kg^{-1} with a mean of 120.0 g kg^{-1} in the soils. The soils are coarse-textured with a high content of sand exceeding 700.0 g kg^{-1}, giving dominant textural classes of loamy sand and sandy loam. Similar textural classes of loamy sand and sandy loam were obtained in coastal plain soils in Owerri, Southern Nigeria (Oguike and Mbagwu, 2009). Such soils lack adsorption capacity for basic plant nutrients and water.

Chemical characteristics: The soil $pH_{(H_2O)}$ values ranged from 4.9-5.2 with a mean value of 5.0 in the soils. The acidic conditions of the soils might be due to the high rainfall exceeding 3500 mm which could leach out basic cations from the soil solum in the area. Organic carbon content ranged from 4.20-26.50 g kg^{-1} with a mean value of 10.90 g kg^{-1}. This level of organic carbon is rated low as most values are lower than 15.00 g kg^{-1} (Enwezor *et al.*, 1989). Such levels of organic carbon cannot sustain the intensive cropping system in the area. However, comparable values of 12.8-22.1 g kg^{-1} organic carbon were reported for coastal plain soils of Owerri in Southeastern Nigeria (Oguike and Mbagwu, 2009). Total nitrogen varied between 0.49 and 2.20 g kg^{-1} with mean value of 0.9 g kg^{-1}; this range of value is rated low when compared with the medium range of 1.00-4.50 g kg^{-1} (Enwezor *et al.*, 1989) for soils of the ecological zone. Available P varied from 45-73 mg kg^{-1}, with a mean value of 57 mg kg^{-1} for surface and subsurface soils. This range of values is high exceeding 15 mg kg^{-1} (FPDD, 1990) regarded for productive soils in the ecological zone. Exchangeable bases were as follows: Ca (1.00-2.90 cmol kg^{-1}), Mg (0.09-1.50 cmol kg^{-1}), K (0.05-0.17 cmol kg^{-1}) and Na (0.04-0.11 cmol kg^{-1}). These values are low when compared with the threshold values of individual basic cations for crop production in the ecological zone (Enwezor *et al.*, 1989).

Exchangeable acidity values were low (range, 0.08-2.52 cmol kg^{-1}) when compared with a medium range of 2.1 to 4 cmol kg^{-1} (Holland *et al.*, 1989) but impact of Al^{3+} in the soil solution could be significant in terms of influencing the biochemical behaviour in the soils. Effective Cation Exchange Capacity (ECEC) values were low (range, 3.03-5.52 cmol kg^{-1} (FPDD, 1990) established for productive soils. With mean percentage base saturation of 71, basic nutrients must have occurred in available forms in soil solution in spite of the low cation reserves in the soils.

Mineralization/nutrient availability ratios

Carbon-nitrogen ratio: Values of carbon-nitrogen ratio were low (range, 11-18) as all the values were less than the separating index of 25 (Paul and Clark, 1989) (Table 1) for mineralization and

Table 1: Physicochemical properties of soils formed from coastal plain sands in Akpabuyo local government area

Samples location	Depth (cm)	pH (H_2O)	Org. C (g kg^{-1})	Total N (g kg^{-1})	C:N ratio	Bray P (m kg^{-1})	Exchangeable bases (cmol kg^{-1}) Ca	Mg	K	Na
Ikot Edem Odo	0-15	5.2	10.9	0.9	12	63	1.5	0.5	0.12	0.06
	15-30	5.0	6.2	0.5	12	62	1.5	0.5	0.08	0.10
Ikot Nakanda	0-15	5.0	8.4	0.7	12	63	1.5	0.5	0.17	0.09
	15-30	4.9	9.0	0.8	11	64	1.5	0.5	0.13	0.06
Ikot Effanga	0-15	5.3	11.9	1.0	12	45	2.5	0.09	0.12	0.04
	15-30	5.1	6.8	0.6	11	48	1.5	1.0	0.10	0.06
Ikot Ene	0-15	5.2	11.1	0.9	12	47	2.5	1.0	0.07	0.06
	15-30	5.0	10.5	0.9	12	50	1.5	1.0	0.05	0.06
Itono	0-15	5.0	10.9	1.0	11	51	1.0	1.5	0.08	0.10
	15-30	4.9	7.4	0.6	12	53	1.0	1.5	0.06	0.08
Ikot Oyom	0-15	5.2	26.5	2.2	12	56	1.5	1.0	0.12	0.11
	15-30	4.9	16.5	1.2	14	55	1.5	0.8	0.06	0.09
Usung Idim Yellow Duke	0-15	5.0	7.2	0.6	12	51	2.0	1.5	0.08	0.09
	15-30	4.9	5.1	0.4	13	52	1.0	1.0	0.07	0.09
Ekpri Iko Umo	0-15	5.1	14.2	1.3	11	50	2.9	1.5	0.16	0.06
	15-30	4.9	12.4	1.1	11	50	1.5	1.0	0.10	0.11
Esuk Ekpo	0-15	5.2	17.6	1.0	18	70	1.5	1.0	0.45	0.11
	15-30	5.0	7.6	0.7	11	71	1.5	0.5	0.07	0.08
Ekpene Tete	0-15	5.0	14.5	1.2	12	72	1.6	1.0	0.17	0.06
	15-30	4.9	4.2	0.4	11	73	1.5	0.5	0.09	0.09
Range		4.9-5.2	4.20-26.50	0.4-2.20	11-18	45-73	1.0-2.90	0.09-1.50	0.05-0.17	0.04-0.11
Mean		5.0	10.9	0.9	12	57	1.63	0.89	0.12	0.08

Samples location	EA (cmol kg^{-1})	ECEC (cmol kg^{-1})	BS (%)	Cation ratio	Sand (g kg^{-1})	Silt (g kg^{-1})	Clay (g kg^{-1}) Ca:Mg	Mg:K	Texture
Ikot Edem Odo	1.36	3.54	62	3.00	4.17	806	77	117	LS
	1.40	3.58	61	3.00	6.25	766	57	177	SL
Ikot Nakanda	1.20	3.46	65	3.00	2.94	806	57	137	LS
	1.52	3.71	59	3.00	3.85	756	57	187	SL
Ikot Effanga	0.29	3.45	92	2.78	7.50	836	57	10.7	LS
	0.29	3.58	74	1.50	10.00	776	57	167	SL
Ikot Ene	1.02	4.65	78	2.50	14.29	826	57	117	LS
	1.14	3.75	70	1.50	20.00	816	67	117	SL
Itono	1.40	3.08	55	2.00	6.25	796	47	157	LS
	2.52	4.16.	39	2.00	8.33	776	67	157	SL
Ikot Oyom	0.48	3.21	85	1.50	8.33	786	87	127	LS
	1.04	3.49	70	2.00	13.33	766	97	137	SL
Usung Idim Yellow Duke	0.48	4.15	87	1.67	12.50	856	47	97	LS
	0.84	2.60	68	1.93	8.57	846	37	117	SL
Ekpri Iko Umo	0.80	5.52	85	1.50	9.38	836	107	57	LS
	1.36	4.07	66	1.50	10.00	716	87	197	SL
Esuk Ekpo	0.32	3.38	90	1.50	6.70	866	57	77	LS
	0.88	3.03	71	3.00	7.14	806	74	117	SL
Ekpene Tete	0.08	3.63	78	1.60	5.88	796	37	167	LS
	1.52	3.42	59	3.00	5.55	796	117	117	SL
Range	0.08-2.52	3.03-5.52	39-92	1.50-3.00	2.94-20.0	716.0-866.0	37.0-117.0	10.7-197.0	LS-SL
Mean	0.10	3.67	71	2.17	8.55	802	70	128	LS

LS: Loamy sand, SL: Sandy loam

immobilization of nitrogen in soils. The implications of the narrow C:N ratios in the soils reflect high levels of microbial activity and rapid decomposition of organic matter with a concomitant release of nutrient elements into soil solution for crop plant uptake.

Magnesium-Potassium (Mg:K) ratio: The ratios of Mg:K were high when compared with a critical level of 1:2 for productive soils (Landon, 1991). This is an indication that Mg is available to crop plants in the soils relative to that of K. Magnesium is absorbed by crop plants as Mg^{2+}. It is a vital element in the formation of chlorophyll, aids in the translocation of starch within plant and is essential for the formation of oils and fats. Potassium is absorbed by crop plants as K^{+}. It improves plant's ability to resist disease and cold, aids in the production of carbohydrates and proteins and an active plant of enzyme systems (Epstein, 1972).

Calcium-Magnesium (Ca:Mg) ratio: The Ca:Mg rates were low (range, 1.50-3.00) when compared with a normal range of 3:1-5:1 for productive soils (Landon, 1991). This indicates that the soils have low amounts of Ca with considerable amount of Mg in the soil solution. Calcium is absorbed by plants as Ca^{2+}. It is essential for root growth and as a constituent of cell wall materials (Epstein, 1972). Replenishing Ca contents in the soils requires liming which in turn reduces acidity of the soils.

Soil degradation rating (SDR)/vulnerability potential (Vp): Seven physicochemical parameters (soil qualities) namely, texture, soil pH, organic carbon, total nitrogen, effective cation exchange capacity, available phosphorous and base saturation were used to assess Soil Degradation Rate (SDR) and vulnerability potential (Vp) of the soils. The soil qualities have varied potential for degradation. Based on the selected physicochemical properties, the results (Table 2) indicated that texture (SDR = 4, Vp = 2) showed high susceptibility to degradation or vulnerability caused by erosion due to the sandy nature of the soils. The SDR/Vp of soil $pH_{(H_2O)}$ (5/1) indicated severe degradation or vulnerability as such level of pH does not allow plant nutrients to exist in available forms for plant absorption. The SDR/Vp weighted value for organic carbon (4/2) and nitrogen (1/5) showed low and very low degradation or vulnerability, an indication that the soils require application of organic manure for any intensive crop production. With the SDR/Vp of effective cation exchange capacity (2/4), the soils showed high degradation or vulnerability, implying that the soils require applied fertilizers for effective crop production. The SDR/Vp of 5/1 for available phosphorus showed considerable high concentrations of available P in the soils. Based on the principle that "good soil quality has least SDR and poor soil quality has the high SDR and vice versa for Vp", the better soil quality indicator was available phosphorus in the soils.

Table 2: Rating scheme for soil degradation rates (SDR) and vulnerability potential (Vp) of selected soil qualities

Parameters	Mean values	SDR/Vp*
Texture	LS	4/2
Soil $pH_{(H_2O)}$	5.0	5/1
Organic carbon (%)	1.09	4/2
Total nitrogen (%)	0.09	1/5
Effective CEC (cmol kg^{-1})	3.67	2/4
Available P (mg kg^{-1})	57	5/1

NB: 1: None, 2: Slight, 3: Moderate, 4: Severe, 5: Extreme for SDR, *Vulnerability potential as none = 5, moderate = 3, high = 2, very high = 1, Ratings based on mean soil quality and criteria limits (Metson, 1961; Lal, 1994; Ikemefuna, 2010)

Management strategies of the soils: The soils formed from coastal plain sands are very strongly acidic in reaction and are also characterized by low to moderate contents of organic carbon, total nitrogen, effective cation exchange capacity and high available phosphorus. The soils are mostly loamy sand in the surface and are rated low in fertility status. Some management strategies proposed for cultivation of the soils for increased crop production include the following:

- **Liming of the soils:** Acidity of the soils can be controlled by liming. Liming supplies Ca and Mg and eliminates Al^{3+} in soil solution. Tropical crops such as cassava, yam, maize, etc thrive well at pH range of 5.5-6.5 at which most soil nutrients exist in ionic forms in soil solution for crop absorption. Application of about 0.5 to 1.0 t ha^{-1} of lime to the plough layer of 15 cm depth can ameliorate the acidic condition of the soils and would promote crop yields (FPDD, 1989)
- **Planting of acid tolerant crops:** Most of the native crops grown in the area are acid tolerant species. For increased yield, acid tolerant crop species should be planted. The new improved varieties of cassava produced by International Institute for Tropical Agriculture (IITA) have been found to yield between 32 and 38 tonnes per hectare. Among the cassava varieties are 98/0505, TME 419, 30572, 98/0510, 98/0581, 4(2) 142 (Shiyam *et al.*, 2007)
- **Maintenance of soil fertility:** The climatic and edaphic conditions of the area favour the growth of both permanent crops (oil palm, rubber, coffee, kola, mango, etc.) and food crops such as cassava, yam, cocoyam, etc. The fertility status of the soils is rated low to medium depending on the land use and period of fallow in different communities in the area. For intensive crop production, the proper soil fertility maintenance should include spreading of crop residues on the soils after harvesting, inclusion of legumes during fallow, timely and appropriate application of soil nutrient additives such as fertilizers. For crop mixtures (yam, maize/cassava) about 174 kg or 3.5 bags of urea, 333 kg or 6.7 bags of P_2O_5 and 100 kg or 2 bags of K_2O fertilizer materials per hectare are recommended (FPDD, 1989)
- **Soil conservation measures:** Soil erosion causes serious land degradation in the area. Erosion by water involves the detachment and transport of soil constituents. Human activities such as destruction of vegetation cover, fuel wood collection, bush burning accelerate soil erosion in the area. The soils are coarse-textured, so the surface is light and should be protected against erosion by cultural techniques such as cultivation of legumes, rotational cropping, bush fallow and incorporation of organic matter into the soils. Legume such as *Pueraria phaseoloides*, *Calopogonium mucunoides* and *Centrosema pubescens* are recommended for the soils

CONCLUSIONS

The study highlights the physicochemical properties of soils formed on coastal plain sands in Akpabuyo Local Government Area of Cross River State, Nigeria. The soils are characterized by having textural variation of loamy sand and sandy loam, strongly acid in reaction, low to moderate contents of organic carbon, total nitrogen, effective cation exchange capacity and high available P. With the high soil degradation rate or low vulnerability potential values for the above stated parameters, the soils are generally poor in quality except for available P. The management strategies of the soils for crop production therefore include the following: planting of acid tolerant crops, liming and adoption of cultural conservation practices to check erosion and maintain soil fertility.

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