

INFLUENCE OF PARENT MATERIALS ON THE PHYSICO-CHEMICAL PROPERTIES OF SOILS IN CENTRAL CROSS RIVER STATE, NIGERIA

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ABSTRACT

This study was designed to highlight the potentials of soils formed on diverse parent materials in Central Cross River State in order to enhance their management for increased productivity. Three profile pits were sited at the crest, middle slope and valley bottom topographic positions representing the different parent materials. Soil samples were collected, processed and analysed for physico-chemical properties according to standard procedures. The study indicated that sand content ranged from 62.3 to 81.3%, averaging 74.8% indicating that sandstone dominates shales and siltstone in the mixed parent materials. Sand fraction also dominated soils of basement complex origin averaging 69.3%. However clay was the dominant separate in soils developed on basalt parent materials. Bulk densities averaged 1.47, 1.40 and 1.17g/cm³ for surface soils and 1.56, 1.75 and 1.22g/cm³ for sub-soils derived from sandstone-shale-siltstone intercalations, basement complex and basalt parent materials respectively. The study basically highlighted that soils formed on sandstone-shale-siltstone intercalation are moderately acid in reaction, low in organic carbon, total nitrogen, available phosphorus, exchangeable potassium and CEC; medium in exchangeable calcium and sodium and high in exchangeable magnesium. Basement complex soils are moderately acid; low in organic carbon, total nitrogen, available phosphorus, exchangeable sodium; medium in exchangeable calcium; high in exchangeable magnesium, potassium and CEC whereas basaltic soils had low organic carbon, total nitrogen, available phosphorus and sodium; medium levels of calcium, CEC and base saturation; but high in magnesium and potassium. Based on these properties, soil conservation practices such as contour ploughing or ridging, organic mulching, proper fertilization and liming programme will make the highly erodible sandy loam and loamy soils developed on sandstone-shale-siltstone and basement complex soils more productive whereas proper fertilization liming and crop rotation are recommended in the basaltic soils for sustainable production.

KEY WORDS: parent materials, toposequence, soil conditioning and sustainability.

INTRODUCTION

Parent materials are considered an important soil – forming factor exerting a strong force that produces changes in soil properties. Esu (1999) identified parent materials as the most dominant soil – forming factor that contribute to differences in soil properties. Ezenwa (1987) showed that there exist significant differences in many physical and chemical properties between soil formed on basalt and basement complex rocks. Parent materials affect soil properties such as colour, texture, structure and nutrient status. A comparison of soils formed from the weathering of basalt and granite showed that most minerals present in basalt weathered into kaolinite, ferric hydroxides or hydrous oxides and some aluminium hydroxides. Such soil will be low in sand, high in clay and well structured. Granites on the other hand will weather much slowly and form soils high in fine sand, much of which is quartz and mixture of micaceous and kaolinitic clays, low in iron and less well structured (Russell, 1973). Aiboni (1985) noted that rocks differ greatly in their physical, chemical and mineralogical properties. Consequently, the weathered products derived from such rocks are themselves very different in their properties. The geology of Central Cross River State consists mainly of sandstone – siltstone intercalations, shale, and basalt (Amajor, 1989). Bulktrade and Investment Company Limited (1989) reported that the geomorphology of Central Cross River State consists of dissected basement complex plains and pediments; level to gently undulating sandy coastal plains; steep sided hills of undifferentiated igneous and metamorphic rocks; undulating sandstone plains and ridges and dissected basement complex hills and pediments. It is expected that the soils of Central Cross River State with diverse parent materials will exhibit great variability in many physico-chemical properties. Knowledge of the variability in soil properties is very essential as this can affect crop production. A study of these variability trends with respect to parent material is essential in order to highlight the soil potentials and enhance their management for increased

productivity. The objectives of the study were to evaluate the physico-chemical properties of soils formed on three parent materials in Central Cross River State and to recommend management practices that will enhance their productivity.

MATERIALS AND METHODS

This study was carried out in selected soils derived from three different types of parent materials in Central part of Cross River state, Nigeria. Central Cross River State lies between longitudes 8° 00' and 9° 10' E., and latitudes 5° 20' and 6° 20' N. It covers Yakurr, Abi, Obubra, Ikrom, Etung and Boki Local Government Areas (Figure 1). The study sites were selected based on previous works of Ekwueme *et al.*, (1995) and Bulktrade and Investment Company limited (1989).

The climate of the study area is uniformly hot, wet and humid. The area experiences great uniformity of temperature, which is always around 27°C (Petters and Ekweozor, 1982). The annual rainfall ranges from 1,800 to 2,800 mm. The relative humidity varies from 60-70% in January to 70 -80% in July (Bulktrade and Investment Company Limited, 1989).

Three profile pits were sited at the crest, middle slope and valley bottom topographic positions at each of the different parent materials studied. The soils investigated were derived from the sandstone-shale-siltstone intercalations, basement complex, and basalt parent materials

Soil samples were collected for physical and chemical analysis. The bulk and particle densities of each undisturbed sample were determined by the cylindrical core method (Blake, 1965). The hydraulic conductivity was determined according to Klute's procedure (Klute, 1986). Particle size distribution was determined by the Bouyoucos hydrometer method (Klute, 1986). Soil erodibility index was estimated by evaluating the ratio of sand and silt contents to clay content (Hudson, 1995). Chemical properties were determined as follows: soil pH in a 1:2.5 soil: water suspension using glass electrode pH metre, organic carbon by the dichromate wet oxidation method of

Walkley and Black (Jackson, 1969); total Nitrogen according to the macro-Kjeldahl method (Jackson, 1969). Organic matter was calculated by multiplying values of organic carbon by a factor of 1.724; available phosphorus was extracted by the Bray NO. 1 procedure (Bray and Kurtz, 1945) and estimated by the molybdenum blue color technique (Murphy and Riley, 1962); exchangeable cations were extracted by leaching the soils with 1 N ammonium acetate solution (pH 7.0) and the exchangeable K and Na contents in the extracts were determined using a flame photometer while exchangeable Ca and Mg were determined using the versenate titration method (Jackson, 1969). Exchangeable H and Al (exchangeable

acidity) were determined by the titration method from an extract obtained using 1N KCl solution (McLean, 1965). The cation exchange capacity at pH 7.0 was determined using the NH₄OAc method (Jackson, 1969); while the effective cation exchange capacity (ECEC) was obtained by summing up the exchangeable bases and exchangeable Al and H. The base saturation was determined using the relationship:

$$BS (\%) = \frac{\sum (\text{Exch Bases})}{\sum \text{Exch. Bases} + \text{Exch. Acidity}} \times \frac{100}{1}$$

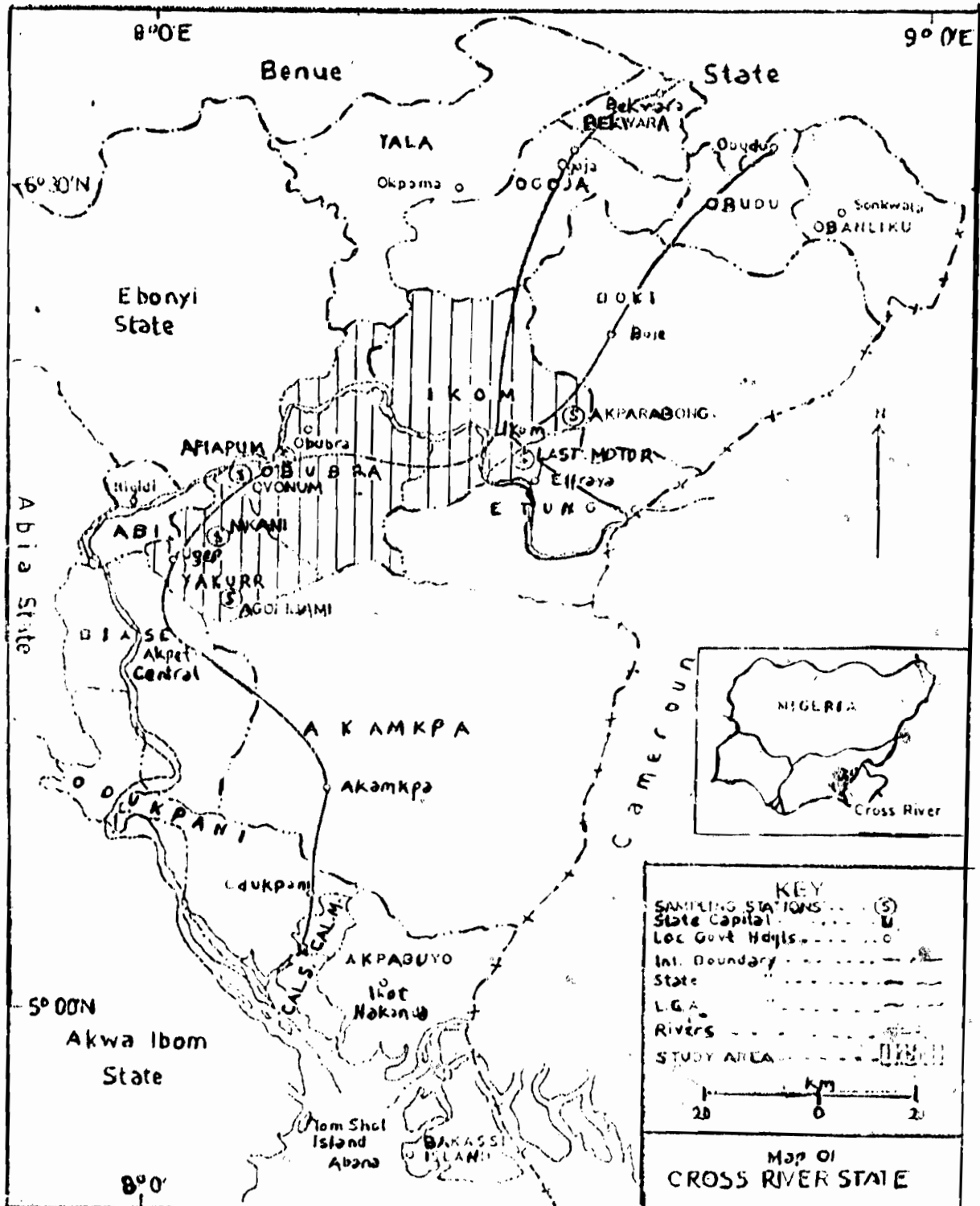


Fig. 1. Map of Cross River State, Nigeria showing Sampling Stations and Study Area.

RESULTS AND DISCUSSION

Physical Properties

Particle size distribution

Sand is the dominant fine earth fraction in the soils studied. The sand content ranged from 62.3 to 81.3% and averaged 74.8%, indicating that sandstone dominates shale and siltstone in the mixed parent material (Table 1). Similarly, the sand fraction dominated in the soils formed on basement complex parent materials and range from 40.3 to 82.3% (averaging 69.3%). This agrees with the findings of Ritter (2006) who remarked that soils developed on coarse grained parent materials with minerals resistant to weathering are likely to exhibit coarse grained textures whereas fine grain soil develop where the parent material contain minerals that readily weather. Furthermore, the soils developed from basement complex and sandstone-shale-siltstone parent materials had almost the same content of silt fraction, both averaging 17.4% (Table 1).

Clay separate dominated all the soils developed on basalt parent materials and were in the range 19.7 to 67.4% averaging 53.8% (Table 1). The dominance of clay in these soils is attributable to the weathering of basalt into secondary clay minerals which are low in sand and are well structured (Russell, 1973). The dominant texture in these soils was loamy sand overlying sandy loam subsoil. Basement complex soils had a higher content of clay particle especially in the sub-soil than soils formed on sandstone-shale-siltstone parent materials.

The high sand content in the soils of basement complex and sandstone-shale-siltstone parent materials suggest that these soils will be low in nutrient reserves water holding capacity and poorly structured. Consequently, the basaltic soils will be high in nutrient reserves, water holding capacity and of good structure due to it high clay content (Brandy, 1974). This textural characteristics will require specific management techniques to enhance their productivity.

Bulk density

Bulk density was generally high in soils formed from sandstone-shale-siltstone intercalations and basement complex parent materials averaging 1.47g/cm^3 and 1.40g/cm^3 for surface soil and 1.56g/cm^3 and 1.75g/cm^3 for sub-soils respectively (Table 2). However, lower values were obtained for soils formed from basalt parent materials, which averaged 1.17g/cm^3 and 1.22g/cm^3 for surface and sub-soils respectively. These low density values obtained in soils developed from basalt was due to their low sand content whereas the higher value of bulk densities in soils formed from sandstone-shale-siltstone intercalations and basement complex parent materials were due to the high sand contents which usually exert greater weight per soil volume. Generally, sub-soil had higher values of bulk density than surface soil due to compaction arising from trampling and overlying weight of surface soil (Russell, 1973).

Particle density

Particle density showed similar trends like bulk density. Particle densities for soils developed from sandstone-shale-siltstone and basement complex averaged 2.93g/cm^3 and 2.79g/cm^3 for surface soils and 3.11g/cm^3 and 3.49g/cm^3 for sub respectively (Table 2).

Hydraulic conductivity

Hydraulic conductivity was high in the surface soil and sub-soils formed on sandstone-shale-siltstone and Basement complex parent materials averaging 116.45cm/hr and 65.79cm/hr , and 100.93cm/hr and 57.30cm/hr respectively but low in basaltic soils averaging 87.67cm/hr and 55.13cm/hr for surface and sub-soils respectively. The high proportion of macro-pores in soils of sandstone-shale-siltstone and basement complex origin arising from their high sand content was responsible for the high hydraulic conductivity values in these soils.

Soil Erodibility

Soil developed on Basement complex and sandstone-shale-siltstone intercalations were generally highly erodible with a erodibility indexes averaging 23.8 and 5.2; and 23.1 and 7.1 for surface soils and sub-soils respectively. Soils formed on basalts have erodibility index averaging 1.5 and 0.7 for surface and sub-soils respectively. The low erodibility index in basaltic soils is due to their high clay contents, thus making them very stable and less susceptible to erosion (Hudson, 1995).

CHEMICAL PROPERTIES

The results of chemical properties are presented in Table 3. The soils are very strongly to moderately acid in reaction (pH. 4.74-5.96). The low pH values of these soils is due to extensive leaching of exchangeable cations leaving behind hydrogen ions and subsequent hydrolysis of aluminum ions into hydroxyls and hydrogen ions (Amalu, 1998).

Organic carbon contents ranged from 1.4 to 9.1g/kg ; 1.4 to 14.1g/kg , and 3.6 to 19.9g/kg averaging 4.41, 6.40 and 9.60g/kg in soils formed from sandstone-shale-siltstone intercalations. Basement complex and Basalt parent material respectively. This indicated that organic carbon content is low in the study area.

Total nitrogen contents ranged from 0.1 to 0.7g/kg ; 0.1 to 1.2g/kg and 0.4 to 1.5g/kg averaging 0.4, 0.5 and 0.8g/kg for soils formed on sandstone-shale-siltstone, Basement complex and Basalt parent materials respectively. Total nitrogen content in all the soils studied was also rated low. The low organic carbon and total nitrogen contents observed are attributable to the extensive leaching induced by the high rainfall experienced in the study area (Jones, 1973).

Available phosphorus was low in all the soils studied (Table 3). Averages of 3.30, 3.52 and 2.96mg/kg were obtained for sandstone-shale-siltstone, Basement complex and Basaltic soils respectively. The low content of available phosphorus is due to phosphate fixation or adsorption by ligand exchange, enhanced under strong acid soil condition arising from high rainfall experienced in the study area (Russell, 1973; Amalu 1998).

Exchangeable calcium content was medium in all the soils studied averaging 2.9, 4.2 and 3.2cmol/kg for soils formed from sandstone-shale-siltstone, Basement complex and Basalt parent materials. Magnesium was high in all the soils average of 1.4, 1.2 and 2.6cmol/kg for soils of sandstone-shale-siltstone, Basement complex and Basalt origin respectively. Potassium was low in soils developed from sandstone-shale-siltstone intercalations and Basement complex soils averaging 0.13 and 0.15cmol/kg respectively but high in Basaltic soils averaging 0.70cmol/kg (Table 3). Sodium was rated medium in soils of sandstone-shale-siltstone and Basement complex origin but low in Basaltic soils. Variations in exchangeable bases in the soils from these three parent materials is the direct consequence of the differences in clay contents furnishing negative charges for the adsorption of these cations (Ahn, 1970). Cation exchange capacity (CEC) was rated medium in Basement complex and Basaltic soils averaging 6.36 and 6.35cmol/kg respectively but low in soils developed on sandstone-shale-siltstone intercalated parent materials, averaging 4.5cmol/kg . The medium CEC in Basement complex and Basaltic soils is due to their high contents of clay, resulting in enhanced colloidal activity unlike the sandstone-shale-siltstone parent materials with low clay contents. Clay content increases ion retention in soils (Russell, 1973).

Values of percent base saturation were generally medium in soils of Basalts and sandstone-shale-siltstone intercalated origin but low to medium in soils formed on Basement complex parent materials.

Table 2: Physical Prosperities of Soils derived from diverse parent materials in Central Cross River State

Sarr's Designation	Bulk Density g/cm ³	Particle Density g/cm ³	Hydraulic conductivity cm/hr	Soil Erodibility index	Bulk Density g/cm ³	Particle Density g/cm ³	Hydraulic Conductivity cm/hr	Soil Erodibility index
AP/A	1.57	3.14	102.01	20.0	1.52	3.04	70.48	10.5
AP/B	1.38	2.76	168.91	23.2	1.59	3.18	86.21	3.0
AP/C	1.45	2.90	78.44	26.0	1.56	3.12	40.69	10.2
Mean	1.47	2.93	116.45	23.1	1.56	3.11	65.79	7.9
SE ±	0.05	0.09	22.12	1.42	0.02	0.03	10.90	2.00
Soil of Basement complex Origin								
AG/A	1.44	2.88	97.09	14.3	1.69	3.38	62.09	2.3
AG/B	1.31	2.72	133.14	24.0	1.83	3.66	69.34	4.9
AG/C	1.39	2.78	72.56	33.1	1.72	3.44	4.48	8.3
Mean	1.40	2.79	100.93	23.8	1.75	3.49	57.30	5.2
SE ±	0.02	0.04	14.37	4.43	0.03	0.07	7.08	1.42
Soil of Basalt Origin								
LM/A	1.05	2.10	70.24	2.5	1.07	2.14	50.20	0.6
LM/B	1.16	2.32	128.32	1.0	1.26	2.52	81.36	0.7
LM/C	1.31	2.62	64.71	1.0	1.33	2.26	33.84	0.7
Mean	1.17	2.35	87.76	1.3	1.22	2.31	35.13	0.7
SE ±	0.06		16.61	0.41	0.06	0.09	11.38	0.03

Table 3: Chemical properties of representative profiles of soil formed on diverse parent materials

Sample Number	Horizon designatio n	Horizon thickness Cm	pH (H ₂ O)	Organic Carbon g/kg	Total Nitrogen g/kg	Available Phosphorus mg/ kg	Exchangeable bases			Cmol /Kg	Exchangeable Acidity	CEC	ECEC	Base saturation %
							Ca	Mg	K Na					
Soils of Sandstone - Shale-soil stone intercalation														
AP /A/1	Ap	0-10	5.86	6.0	0.5	2.81	2.8	1.4	0.11	0.06	2.36	4.37	6.73	64.93
AP /A/2	B	10-32	5.50	4.0	0.3	2.63	2.4	1.4	0.10	0.07	2.04	3.97	6.01	66.06
AP/A/ 3	BC	32-60	5.75	9.1	0.7	1.19	3.4	1.0	0.18	0.13	1.76	3.31	5.07	65.29
AP/ B/1	Ap	0-23	5.92	3.0	0.2	2.06	2.0	1.0	0.18	0.13	1.79	3.31	5.07	65.29
AP/ B/2	B	23-48	5.90	1.4	0.1	2.25	1.6	1.2	0.17	0.12	2.28	3.09	5.37	57.54
AP/B/3	Bct	48-87	5.03	2.8	0.2	1.50	3.6	1.8	0.15	0.09	3.56	5.64	9.20	61.30
AP /C/1	Ap	0-15	5.10	7.2	0.4	3.13	3.0	1.2	0.14	0.12	1.76	4.46	6.22	71.70
AP/C/2	AB	15-60	5.05	4.2	0.6	2.13	3.0	1.2	0.15	0.11	1.80	4.46	6.22	71.25
AP /C/3	B	60-99	5.13	3.4	0.3	3.50	3.2	1.8	0.10	1.09	1.60	5.19	6.76	76.44
AP/C/4	BC	99-116	5.96	3.0	0.2	1.63	3.8	2.6	0.10	0.08	1.78	5.98	7.76	77.06
Mean			5.52	4.41	0.4	3.30	2.9	1.4	0.13	0.19	1.78	4.50	7.76	81.13
SE ±			0.12	0.70	0.06	0.39	0.21	0.11	0.01	0.09	0.17	0.25	0.36	4.55
Soil of Basement Complex Origin														
AG/A/1	A	0-32	5.32	11.9	0.6	4.69	4.0	2.4	0.15	0.12	6.61	6.67	8.83	75.54
AG /A/2	B ₁	32-71	4.74	3.0	0.1	2.06	1.8	2.8	0.09	0.06	6.98	4.75	11.71	40.56
AG/A/3	B ₂	71-110	4.85	2.6	0.2	1.38	2.0	1.8	0.10	0.07	6.12	3.37	10.09	39.35
AG/B/1	A	0-21	5.83	14.1	1.1	2.81	7.8	3.0	0.18	2.09	2.09	11.14	13.23	34.20
AG/B/2	AB	21-48	5.38	5.2	0.4	2.44	3.6	1.8	0.17	2.08	2.08	6.49	8.57	75.73
AG/B/3	B	48-82	5.46	2.2	0.2	1.91	3.0	1.0	0.18	2.04	2.04	6.91	8.95	77.21
AG/B/4	BC	82-97	4.90	1.4	0.1	1.81	3.0	1.6	0.12	2.05	2.05	6.32	6.27	67.30
AG/C/1	A	0-24	5.89	14.7	1.2	8.31	3.2	2.6	0.21	2.40	2.40	9.16	11.56	79.24
AG/C/2	Bt	24-75	5.30	2.6	0.2	6.25	3.8	1.3	0.15	2.20	2.20	3.66	6.06	63.20
Mean			5.30	6.4	0.5	3.52	2.6	1.2	0.15	3.12	3.12	6.35	9.47	66.96
SE ±			0.13	1.73	0.13	0.75	0.2	0.10	0.01	6.61	0.16	0.79	0.76	5.18
Soil of Basalt Origin														
LM/A/1	A	0-17	5.28	19.9	1.0	4.44	4.8	4.0	0.33	0.10	3.60	9.23	12.83	71.74
LM/A/2	B ₁	17-49	4.93	10.9	0.9	3.31	3.2	3.6	0.22	0.11	0.00	7.13	13.13	54.30
LM/A/3	B ₂	49-101	4.98	5.4	0.5	3.00	3.4	2.8	0.13	0.10	5.90	7.43	13.33	55.74
LM/A/4	B ₃	101-161	4.90	5.0	0.4	2.96	3.4	2.0	0.09	0.07	5.92	6.56	12.48	52.56
LM/B/1	A	0-14	5.40	10.3	1.0	4.38	4.6	2.2	0.20	0.07	2.22	8.07	10.29	78.43
LM/B/2	B ₁	14-65	5.10	9.9	0.8	2.94	2.4	1.6	0.08	0.06	2.18	5.14	7.32	70.22
LM/B/3	B ₂	65-114	5.44	3.6	0.3	2.76	2.2	1.6	0.09	0.05	2.30	3.94	6.24	63.14
LM/C/1	A	0-24	5.08	18.1	1.5	2.31	4.4	2.2	1.22	0.07	2.50	7.89	10.39	75.94
LM/C/2	B ₁	24-40	5.30	10.5	0.9	4.45	2.0	1.4	1.21	0.09	2.10	4.70	6.80	69.12
LM/C/3	B ₂	40-86	5.28	6.9	0.6	2.03	2.2	2.0	0.08	0.07	2.15	4.35	6.50	66.92
LM/C/4	B ₃	86-129	5.19	5.0	0.4	4.96	2.8	2.6	0.07	0.05	2.10	5.52	7.62	72.44
Mean			5.17	9.6	0.8	2.96	3.2	2.6	0.70	0.08	3.36	6.36	9.72	66.43
SE ±			0.05	1.53	0.10	0.24	0.29	0.25	0.15	0.01	0.58	0.50	0.83	2.55

CONCLUSION AND RECOMMENDATIONS

Soils formed from sandstone-shale-siltstone intercalations and Basement complex parent materials are moderately deep to deep whereas those developed from Basalt are deep to very deep. Clay particles dominate soils developed from Basalts in Central Cross River State. On the other hand, sand and sandstone-shale-siltstone intercalations. The soils fraction dominated soils developed on Basement complex studied were generally high in bulk and particles densities except those developed from Basalts. Hydraulic conductivity was also high in soils formed from sandstone-shale-siltstone and basements complex soils but low in those formed from Basalt. Basement complex and sandstone-shale-siltstone soils were rated highly erodible, whereas the Basaltic soils had low erodibility.

Among the soils studied, those formed on sandstone-shale-siltstone intercalations are moderately acid in reaction; low in organic carbon, organic matter total nitrogen, available phosphorus, exchangeable potassium and cation exchange capacity; medium in exchangeable calcium and sodium; high in exchangeable magnesium. Basement complex soils are moderately acid; low in organic carbon, total nitrogen, available phosphorus, exchangeable sodium and calcium; high in exchangeable magnesium, potassium, and cation exchange capacity.

Based on these properties, the following management practices are recommended for profitable crop production in soils developed on the different types of parent materials in Central Cross River State.

- * Soil conservation practices such as contour ploughing or ridging and organic mulching will make the highly erodible sandy loam and loamy sandy soils developed on sandstone-shale-siltstone and Basement complex soils more productive by reducing erosion risk and improving its water holding capacity.
- * Split fertilization/ liming programmes will make the sandstone-shale- siltstone and Basement complex soils, prone to leaching, respond positively to applied soil amendments.
- * The establishment of vetiver grass hedges or strips in between cultivated crops will improve soil structure and reduced erosion hazard in the highly erodible soils developed on sandstone-shale –siltstone and Basement complex parent materials.
- * The incorporation of organic manure into the soils of sandstone-shale-siltstone and Basement complex origin will improve their nutrient reserves and available moisture for enhanced crop production.
- * Basal fertilization programme especially of primary nutrients (Nitrogen, phosphorus and potassium) and proper liming to reduce soil acidity will make Basaltic soils highly suitable and productive.
- * A four course crop rotation in the sequence: cowpea/ maize, melon/ cocoyam, groundnut/ cassava, fallow is considered most suitable and appropriate for Basaltic soils.
- * The deep to very deep soils developed on Basalts will support plantation crops like cocoa, avocado, mango, African pears with banana and plantains serving as nurse crops.

- * The installation of irrigation facilities (drip irrigation) in Basaltic soils area will enhance their capacity to sustain arable cropping especially of high value crops (Cucumber, water-melon, egg plant, vegetable etc) all year round.

REFERENCES

- Ahn, P. M., 1970. *West African Agriculture* (3rd ed.). Oxford University press, Oxford.
- Aiboni, V. U., 1985. *Land Evaluation under different environmental and geological conditions in South – West Nigeria*, Ph. D thesis, University of Ife, Nigeria.
- Amajor, L. C., 1989. The Eze-Aku Sandstone Ridges (Turonian) of South Eastern Nigeria: A Re-interpretation of their depositional origin, *Nigeria Journal of Mineral Geology*, 23: 17-26.
- Amalu, U. C. 1998. Evaluation of properties of selected soils of Cross River Area and their management for increase cassava yields, *Global Journal of Pure and Applied Sciences*, 4(3): 243-249.
- Brady, N. C., 1974. *The Nature and Properties of Soils* (8th ed.) Macmillan Company Incorporated, United States of America.
- Bray, R. H. and Kurtz, L. T., 1945. Determination of Total, Organic and Available forms of phosphorus. *Soil Science*, 59: 45-49.
- Blake, G. R., 1965. Bulk density. In *methods of soil Analysis*, C. A. Black (Ed), American society of Agronomy 9: 374-390 Madison, Wisconsin.
- Bulktrade and Investment Company Limited (1989). *Soil and Land use Survey of Cross River State, Main Report*, Ministry of Agriculture and Natural Resources, Cross River State, Nigeria.
- Ekwueme, B., Nyong, E. E. and S. W. Petters., 1995. *Geological Excursion Guide Book to Oban massif, Calabar Flank and Manfe Embayment, South Eastern Nigeria*. Decford limited, Calabar, pp 36.
- Esu, I. E., 1999. *Fundamentals of Pedology* Stirling-Holden Publisher Limited, Ibadan.
- Ezenwa, M. I. S., 1987. Some physico-chemical characteristics of soils of Basement complex and Adjoining Basaltic rocks of Northern part of Nigeria; *Proceedings of the 15th Annual conference of the Soil Science Society of Nigeria*, Kaduna, October, 20-24, pp205-213.
- FAO., 1999. *Guidelines for soil profile description*, Revised Edition, Rome. Italy.
- Hudson, N., 1995. *Soil Conservation*. BT. Balford Limited, London
- Jackson, M. I., 1969. *Soil Chemical Analysis: Advanced course* (2nd ed.), United States Department of Agriculture, America, (217-224).
- Jones, M. J., 1973. The organic matter content of the savanna soils of West Africa, *Journal of Soil Science*, 24: 42-53.

- Klute, A., 1986. *Methods of soil Analysis, part 1, NO. 9 (2nd ed.) physical and mineralogical properties*, American Society of Agronomy, Madison, Wisconsin, USA.
- Nsor, M. E., 2004. *Evaluation of physico-chemical properties of soils Derived from diverse parent materials in Central Cross River State of Nigeria*, M.Sc. Thesis, University of Calabar
- Petters, S. W. and Ekweozor, L. M., 1982. *Petroleum Geology of Benue Trough and South Eastern Chad Basin, Nigeria*; Bulletin of American Association of Petroleum Geology. (1140-1148).
- Russell, E. W., 1973. *Soil Conditions and Plant Growth*, English Language Book society and Longman Group Limited London.
- Webster, C.C. and Wilson, P. N., 1980. *Agriculture in the Tropics*, English Language Book Society and Longman Group Limited, United Kingdom, England.
- Mclean, E. O., 1965. *Aluminum In: C. A. Black (Ed.) Methods of Soil Analysis* Madison, Wisconsin, American Society of Agronomy.
- Murphy, J. and Riley, J. P., 1962. *A modified single solution method for the determination of phosphorus in natural waters* Analytical chemist, 27: 31-36.