Distribution of Primary Nutrients (NPK) in Profiles of Soils derived from Coastal Plain Sand in Ikot Ekpo, Calabar, Cross River State, Nigeria, to crop productions.

ABSTRACT

This study was conducted to evaluate the distribution of primary nutrients (NPK) in profiles of the coastal plain soils of Ikot Ekpo, Calabar, as well as evaluate other soil properties critical to agricultural productivity, in a bid to generate data that will serve as a guide to effective land use and management of the soils for arable crop production. Three (3) Profile pits were dug on the crest, middle slope and valley bottom, and soil samples were collected from their pedogenetic horizons for analysis. Analytical results showed the three profiles of coastal plain soils studied had predominantly sandy particle sizes (ranged from 77,000 - 91,000g/ kg^{-1} sand across the three profiles) and mostly loamy sand in texture; especially at the topsoil level. The soils were also acidic (pH 4.7 to 5.1) and low in organic matter (1.0 mg kg^{-1}**mg/kg** to 16.0 mg kg^{-1}**mg/kg**) as expected. Generally, the soils were found to be low in total nitrogen content (0.1 to 1.3mg/ kg^{-1}) and exchangeable potassium (0.08 to 0.10cmolc/ kg^{-1}); however, they were high in available phosphorus (17.20 to 29.75 mg kg^{-1}**mg/kg**). NPK distribution charts showed that N and P decreased consecutively with increasing depth for the crest profile. The middle-slope and valley bottom profile showed no definite pattern of distribution. However, the concentration of NPK was highest at topsoil level across most profiles. N had the shallowest intra-profile distribution with significantly higher levels of topsoil concentration indicated by the high percentages of intra-profile CV (94%, 85% & 97% for CUF, MUF & VUF respectively). P showed a shallow intra-profile distribution across the three profiles but did not vary significantly from the intra-profile mean (12.5%, 12.0% & 2.6% for CUF, MUF & VUF respectively). On the other hand K was more evenly distributed within all three profiles (CV of 9.4%, 5.3% & 8.6% for CUF, MUF & VUF respective) compared to N and P. Inter-profile distribution of NPK showed that N and P had higher concentrations at crest level, with P showing consecutive decrease in concentration down the slope. This study therefore recommends adoption of different NPK fertilizer recommendations for different soil depths and topographic locations for optimal productivity.

Keywords: Primary nutrients, coastal plain soils, inherent limitations, productivity.

INTRODUCTION

The challenge for agriculture over the coming decades is to meet the world's increasing demand for food and sustaining optimal production. Declining soil fertility and mismanagement of available soil nutrients have made this task more difficult. As long as agriculture remains a soil-based industry, major increases in productivity are unlikely to be attained without ensuring that plants have an adequate and balanced supply of **essential** nutrients required for optimum productivity. This calls for efficient analysis of agricultural

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soils to determine soil quality in terms of **essential** nutrient composition, and to maintain or enhance soil quality when necessary in order to effectively manage plant nutrient and soil fertility [14].

Coastal plain soils are mainly unconsolidated sediments defined by unique geological substrates which consist of wind worked quaternary sand [32]. They are characterized by acidic conditions, low cation exchange capacity, and multiple nutrient deficiencies due to factors such as intensive weathering, leaching and inappropriate agricultural activities [5; 18]. The clay fraction of the soil is rich in kaolinitic clay minerals [18; 37]. Coastal plain sands cover an area of 480 km^2 in Cross River State, 3,470.32 km^2 in Benue State, 42.20 km^2 in Lagos State, 213.16 km^2 in Akwa Ibom State, 12.18 km^2 in Ogun State, 40.62 km^2 in Ondo State; and 5.435.92 km^2 in River State. In Cross River State, coastal plain soils are found mostly in Akpabuyo, Bakassi, Calabar and Odukpani Local Government Areas [16].

Coastal plain soils have good agricultural potentials because they have moderate inherent fertility and availability of water during the dry season. In crop production and land use, the evaluation of soils' chemical properties is important because properties such as pH, organic matter, nitrogen, phosphorus exchangeable bases, cation exchange capacity and base saturation affect plant growth and development [9]. To increase crop performance, there is always the need to establish relationships between soil chemical properties and soil capacity to produce food crops, that **. The soils capacity and capability to produce crops** is indeed the basis of yield predictions and could be considered as the most useful expression of soil productivity [9].

Soil characterization in relation to evaluation of fertility status of the soils of an area or region is an important aspect in context of sustainable agricultural production. Because of imbalanced and inadequate fertilizer use coupled with low efficiency of other inputs, the production efficiency of chemical fertilizer nutrients has declined tremendously under intensive agriculture in recent years. Introduction of high yielding varieties to agriculture in the mid-sixties compelled the farmers to use high doses of NPK (Nitrogen, Phosphorus and Potassium) fertilizers along with micronutrient fertilizers. NPK are among the **essential** nutrients required by plants because they are primarily required for plants to complete their life cycle. They are the most critical plant nutrients in agriculture because they are mobile and easily leached from the soil. The deficiencies of these nutrients have become major constraints to productivity, stability and sustainability of soils. Soils with finer particles and with higher organic matter can generally provide a greater reserve of nutrients whereas, coarse textured soils such as sand have fewer reserves and tend to get depleted rather quickly.

Plants take up nitrogen from the soil solution mainly as nitrate (NO_3) and ammonium ions (NH_4^+). Nitrogen is responsible for rapid growth and its content in surface soils ranges from 0.02 to 0.5 %, which is below the critical level of plant nutrient of 2.0 % as reported by Espinoza *et al.* [10]. The mineral forms of nitrogen are soluble in water and are easily lost from soils through leaching and volatilization. Minimization of environmentally damaging impact from soil plant system and regulation of soluble forms of nitrogen through split application and slow release fertilizer is therefore imperative in order to maintain adequate supply in the soil as reported by Espinoza *et.al.* [10].

Phosphorus has been identified as one of the most limited nutrient elements in tropical soils. The total phosphorus level of soils is low and is mostly unavailable for plant uptake because they are highly insoluble. When soluble forms are added to the soil, they are also fixed and in time form unavailable forms, leaving a very small percentage for plant utilization. Low availability of phosphorus in tropical soils is attributed to the nature of chemical forms of the soils phosphorus and high content of oxides of iron and aluminum, which are associated with high phosphorus fixation [25]. Phosphorus promotes root

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formation, affects quality of seeds, fruit and flowers, and increases disease resistance on the plants [20].

Potassium is the third most important plant element after nitrogen and phosphorus. It is essential for plant growth, useful for helping plants overcome drought stress and increases diseases resistance. Potassium is generally high in most mineral soils but very large portion is unavailable to plants, it is also subject to leaching and removal by plants. Problem associated with potassium use by plants is rarely of its total supply but rather of adequate supply of available forms at depths below plough layer as reported by Espinoza *et. al.*[10].

It is well recognized that soils are the storehouse of most of the plant nutrients **essential** for plant growth and that the way in which soils are managed will have a major impact on soil fertility, plant growth and agricultural sustainability. Since soils are dynamic systems it is expedient to ascertain levels of primary nutrients in soils and to establish management practices for the soils. This is necessary to maintain and improve agricultural productivity and sustainability.

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MATERIALS AND METHODS

Location of Study Area

Ikot-Ekpo, Calabar is located between latitude 008^{0}20.030`E and longitude 05$^{0}$38.45`N in Cross River State. Cross River State is located in the South Eastern part of the Federal Republic of Nigeria. Geographically, it lies between latitude 5^{0}32` and 4$^{0}$27` North of the equator and 7^{0}50` and 0$^{0}$25` East of the Greenwich Meridian. It is bounded by Ebonyi and Abia State in the West, Benue State in the North, Akwa Ibom State in the South, and Atlantic Ocean in the South-East and in the East by the Cameroon Republic. The total land mass of Cross River State is about 23,074,245 square kilometer. Cross River State has a population of

4.6 million people living in the state. The state **is blessed with thick**has rainforest vegetation and very rich soils [5].

Climate

The climate of the study area is marked by a rainy season and a dry season. The rainy season lasts from March to July with heavy downpours, and strong wing storm, and the dry season last from November to early March which climaxes between December and January during harmattan. The area has rainfall range of 2000 mm to 2739 mm per annum and a temperature of 25^0C in the rainy season and 28^0C in the dry season. The area has a relative humidity range of 70 to 80 %.

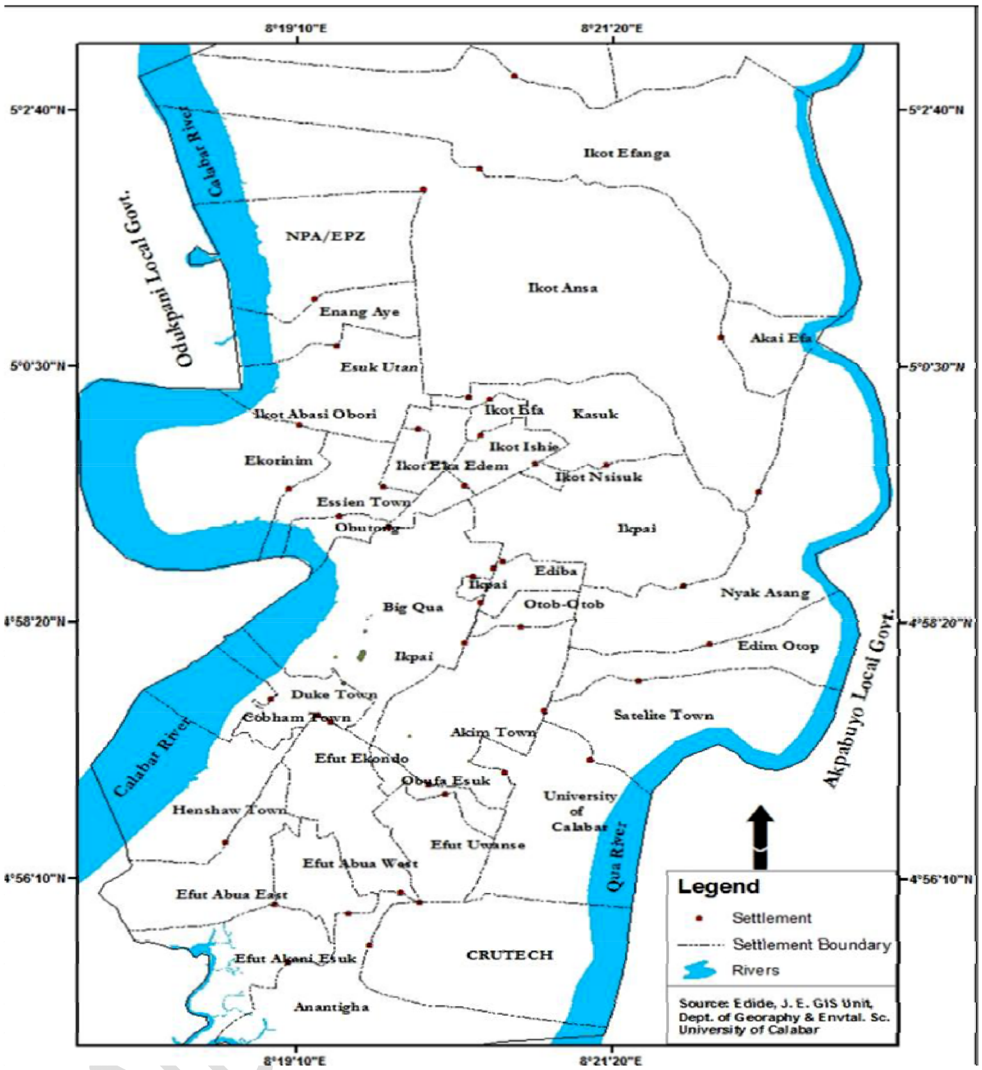

Fig.1 Map of Calabar metropolis showing location of Ikot Ekpo.

Geology

The area is dominated by coastal plain sands belonging to the tertiary deposit and alluvial deposit on low lying swampy areas.

Vegetation

The area is mainly used for arable cropping and rubber plantation. The plantation is more than 15 years and contains other vegetable crops like *Telferia occidentalis*, *Talinum triangulare and Manihot esculentus.*

Field Studies

Three (3) Profile pits were dug on the crest, middle slope and valley bottom. A full range of environmental conditions, selected soils morphological properties and soil physico-chemical properties were recorded on soil description sheets. Each profile pit measured 1.5 m x 2 m x 2 m. The profile pits were dug to impenetrable layer or water level depending on whichever is shallower. Each profile pit was described in the moist state for their full ranges of morphological characteristics. Description was done according to guidelines [15].

Laboratory Analysis

In the laboratory, the soil samples were air dried at room temperature for 48 hours and then gently crushed with pestle and mortar and sieved through 2 mm sieve to obtain fine earth fractions for the analysis. The physico-chemical properties of the soils were determined using standard procedures, as outlined by Udo *et al.* [46]. Bulk cores were taken using cylindrical cores, later oven dried to constant weight and then the bulk density was calculated [4]. The particle size distribution was determined by the Hydrometer method using sodium hexametaphosphate (calgon) as dispersant [19]. The soil texture was determined using the textural triangle. The soil pH was determined potentiometrically after equilibration with water and 0.01 M $CaCl_2$ in a 1:2.5 soils to solution ratio using glass electrode pH meter as outlined by Isirimah *et al.* [26]. Organic carbon was determined by the Walkley-Black wet oxidation method and the value multiplied by Van Bemmelan factor of 1.724 to obtain organic matter value [47]. The method involves the digestion of the soil organic matter with potassium dichromate ($K_2Cr_2O_7$) using concentrated sulphuric acid to increase the temperature and hasten the reaction. The total **nitrogen** N was determined by the salicyclic acid-thiosulphate digestion method followed by the distillation method using modified micro-kjeldhal method [30]. Available P**phosphorous** was extracted by the Bray No. 1 method and 2 ml of the extract was used to determine P in solution colorimetrically by the ascorbic acid method [38], after, **.** 2 mL**l** of the extract is made up to 50 ml with distilled water; it is then kept for some time for colour development before taking reading in a spectrophotometer. Exchangeable Cations (Ca^{2+}, Mg^{2+}, K^+, Na^+) were determined with ammonium acetate (pH 7.0) using 1:10 soil-liquid ratio. Calcium (Ca) and Magnesium (Mg) in the filtrate were then determined with atomic absorption spectrophotometer (AAS) while sodium (Na) and **potassium** Kwere determined by flame photometer analyzer [45]. Exchangeable acidity was determined by successive leaching of soils with neutral unbuffered **potassium** K chloride (KCl) using 1:10 soil to liquid ratio. Exchangeable hydrogen (H) and aluminum (Al) were determined by titration method [29], for this, **.** 1mL**l** of KCl was used as an extracting agent, after adding 5 drops of phenolphthalein indicator. It is titrated with 0.01 ml of NaOH until permanent pink coloration is reached. The solution is titrated against 0.01 ml HCl until a colourless solution is obtained. Cation Exchange capacity was determined by neutral ammonium acetate (pH 7.0) saturation method described by Udoh *et al.* [46]. Percentage base saturation was determined mathematically as follows:

$$\frac{\text{Sum of exchangeable cations}}{\text{Effective cation exch. capacity (ECEC)}} \times \frac{100}{1}$$

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Statistical Analysis

Variability in soil properties NPK within the soil profiles were subjected to analysis of variance (ANOVA). Linear regression was used to explore the relationship between NPK and depth. A table of the physical and chemical properties showing relationship of nutrient with depth was made. Also, a table showing variation of NPK with soil depth in the profiles was made.

RESULTS AND DISCUSSIONS

Morphological Properties

The morphological properties of soil derived from coastal plain sand in Ikot Ekpo, Calabar are presented in Table 1.

Soil colour

The hue values were mostly 10YR, with 2.5YR at AP horizon (0 – 30 cm depth) of the crest. The hue value 2.5YR for surface soil (0-30 cm) crest, and 10YR value, with colour range from dark grayish brown to dark yellowish brown conform to [23]. The dark grayish colour may indicate the presence of organic matter content in the soil. However, the yellowish colour may be an indication of the presence of iron (iii) oxide. This in line with [48], who stated that coastal plain soils merge into deep permeable red-earth or yellow earth strata derived from tertiary sediments, an indication of iron (iii) oxide.

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Soils structure

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One group of structure was observed in the surface soil namely weak fine granular. The subsurface had two groups and were dominated by moderate to medium sub-angular blocky structure. According to [24], soils derived from coastal plain sands have medium sub-angular blocky subsurface. The structure of these soils is influenced basically by their particle size distribution.

Soil texture

The texture of the surface and subsurface soils varied from loamy sand surface **soils** to sandy clay loam subsurface soils and this agrees with Shaw *et al.* [42], who stated that soils derived from coastal plain sands have sand or loamy sand surface and sandy loam or sandy clay loam subsurface. Such textural classes could have serious implications on hydrological processes such as erosion, aeration and water holding capacity as reported by Schoenholtz *et al*. [41].

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Soil consistency

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The soil consistency was very friable at surface level. The subsurface level were both firm and friable but were largely dominated by firm consistency. [24] described the consistency of coastal plain soils as none or slightly stick or plastic when wet, and loose when dry.

Table 1: The morphological properties of soils derived from coastal plain sands under arable crop production in Ikot Ekpo, Calabar, Cross River State

Profile location	Horizon	Depth (cm)	Munsell colour (wet)	Texture	Structure	Consistence	Boundary	Other features
CUF	AP	0 - 30	2.5YR $^{4}/_{2}$	Loamy sand	1 fgr	Vfr	Cs	Many fine roots
E008^{0} 19.91’	B	30 – 70	10YR $^{4}/_{4}$	Sandy clay loam	2 msbk	Fi	Cs	Common fine roots
N05^{0} 03.65’	BC	70 – 120	10YR $^{4}/_{4}$	Sandy clay	2 msbk	Fi	Cs	Few fine roots
	C	120 – 150	10YR $^{3}/_{6}$	Sandy clay	2 msbk	Fi	Cs	Few fine roots
MUF	AP	0 – 26	10YR $^{4}/_{3}$	Loamy sand	1 fgr	Vfr	Cg	Few fine roots, many ants
E008^{0} 19.95’	AB	26 - 57	10YR $^{6}/_{6}$	Sandy loam	1 sbk	Fr	Cs	Few fine roots
N05^{0} 03.87’	B	57 – 110	10YR $^{5}/_{4}$	Sandy clay	2 msbk	Fi	Cs	Few fine roots
	C	110 – 150	10YR $^{6}/_{8}$	Sandy clay	2 msbk	Fi	Cs	Few fine roots
VUF	AP	0 – 20	10YR $^{3}/_{2}$	Loamy sand	1 fgr	Vfr	Cs	Many roots
E008^{0} 9.09’	B	20 - 60	10YR $^{4}/_{4}$	Sandy loam	1 sbk	Fr	Cs	Few medium roots
N05^{0} 03.65’	BC	60 - 115	10YR $^{4}/_{4}$	Sandy clay loam	2 msbk	Fi	Sg	Few fine roots
	C	115 – 150	10YR $^{5}/_{6}$	Sandy clay loam	2 msbk	Fi	Sg	Few fine roots

Structure: 1 = weak; 2 = moderate; 3 = strong; f = fine; m = medium; gr = granular; cr = crumb; sbk = sub-angular blocky.
Consistence : Vfr = very friable; Fi = firm; Fr = friable.
Boundary : C = clear; S = smooth; g = gradual; w = wavy.

CUF = Crest Unical Farm
MUF = Middle-slope Unical Farm
VUF = Valley-Bottom Unical Farm

Physical Properties

Table 2 shows the physical properties of soils derived from coastal plain sands under arable crop production in Ikot Ekpo, Calabar

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Particle size distribution

Particle size distribution of the soil showed that sand ranged from 77,000 g kg^{-1}**g/kg** to 91,000 g/ kg^{-1}, silt ranged from 6,000 g kg^{-1}**g/kg** to 12,000 g kg^{-1}**g/kg** while that of clay ranged from 3,000 g kg^{-1}**g/kg** to 11,000 g kg^{-1}**g/kg**. Surface soils had a mean of 89,300 g kg^{-1}**g/kg**, 7,700 g kg^{-1}**g/kg** and 3000 g kg^{-1} **g/kg** for sand silt and clay respectively while the subsurface soil had a mean of 80,300 g kg^{-1}**g/kg**, 10110 g kg^{-1}**g/kg** and 9,700 g kg^{-1}**g/kg** for sand silt and clay respectively. Sand was the dominant particles size fraction at both surface and subsurface soils, placing the textural classes of all the soils as loamy sand for top soils and sandy clay loam to sandy clay for sub soils. The sandy nature of the soils at both levels could be attributed largely to the parent material. The predominantly sandy nature of the soils was an indication of low fertility arising from physical causes. Sandy soils have loosed particles and so are unable to hold organic matter as well as nutrients [34].

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Bulk density

The bulk density of the soils ranged from 1.4 g cm^{-3}**g/cm^{3}** to 1.8 g cm^{-3}**g/cm3** at all depths. The surface soils had a range of 1.6 g /cm^{-3} to 1.8 g cm^{-3}**g/cm^{3}** with a mean value of 1.7 g cm^{-3}**g/cm^{3}**. The subsurface values ranged from 1.4 g cm^{-3}**g/cm^{3}** to 1.8 g cm^{-3}**g/cm^{3}** with a mean value of 1.5 g cm^{-3}**g/cm^{3}**. The mean value for surface bulk density is higher than that of the subsurface, this agrees with Donahue *et al.* [7] who stated that soils derived from coastal plain sands have higher bulk density in the surface than the subsurface. This higher surface bulk density is likely due to higher levels of organic matter in surface profile of the soils. It could also be attributed to soil compaction as a result of continuous and intensive

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cultivation of the soils. High levels of bulk density are capable of impeding root penetration and development thereby limiting crop yield.

Particle density

The particle density ranged between 2.30 g cm^{-3}**g/cm^{3}** and 2.81 g cm^{-3}**g/cm^{3}** at all depths. The surface soils for the three locations ranged 2.30 g cm^{-3}**g/cm^{3}** to 2.57 g cm^{-3}**g/cm^{3}** with a mean of 2.49 g cm^{-3}**g/cm^{3}**. The subsurface soils ranged from 2.45 g cm^{-3}**g/cm^{3}** to 2.81 g cm^{-3}**g/cm^{3}** with a mean of 2.67 g cm^{-3}**g/cm^{3}**. This result is closely ranged with that obtained by [13]. The particle density is higher than the bulk density as expected and is considered moderate to high compare with the generally accepted range of 2.6 to 2.7 mg /m^{-3} (Landon 1991). The relatively high values obtained is likely due to the low level of organic matter observe in the soils; because**as** high organic matter tend to lower particle density of associated soils.

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Total porosity

The total porosity varied between 7 % and 90 % at all depths. The surface soils porosity ranged from 61 % to 90 % with a mean value of 79.3 %. The subsurface had values ranging from 7 % to 90 % with a mean value of 46.6 %. This indicates that the soils have more porous surface than subsurface. According to [1], top soils **of soils** form from coastal plain sands had more bulk density porous than subsoil. The highly porous surface soil values reflect typical sandy soils; with porosity that ensures even circulation of air and growth of microorganisms.

Table 2: The physical properties of soils derived from coastal plain sands under arable crop production in Ikot Ekpo, Calabar, Cross River State

Profile location	Horizon	Depth (cm)	Particle Size Distribution Sand (g/kg)	Silt (g/kg)	Clay (g/kg)	Particle Density (g/cm^3)	Bulk Density (g/cm^3)	Total Porosity (%)
CUF	AP	0 - 30	86,000	11,000	3,000	2.30	1.5	61
E008^0 19.91’	B	30 - 70	84,000	8,000	8,000	2.80	1.5	29
N05^0 03.65’	BC	70 - 120	79,000	10,000	11,000	2.81	1.7	67
	C	120 - 150	79,000	12,000	9,000	2.63	1.7	68
MUF	AP	0 - 26	91,000	6,000	3,000	2.61	1.4	87
E008^0 19.95’	AB	26 - 57	81,000	11,000	8,000	2.53	1.4	27
N05^0 03.87’	B	57 - 110	80,000	12,000	8,000	2.54	1.7	49
	C	110 - 150	77,000	12,000	11,000	2.64	1.8	70
VUF	AP	0 - 20	91,000	6,000	3,000	2.56	1.6	90
E008^0 9.09’	B	20 - 60	84,000	7,000	10,000	2.45	1.6	70
N05^0 03.65	BC	60 - 115	79,000	10,000	11,000	2.62	1.7	90
	C	115 - 150	80,000	9,000	11,000	2.71	1.8	10
Surface Range			86,000 – 91,000	6,000 – 11,000	3,000 – 3,000	2.30 – 2.57	1.6 – 1.8	61 – 90
Surface Mean			89,300	7,700	3,000	2.49	1.7	79.30
Subsurface Range			77,000 – 84,000	7,000 – 11,000	8,000 – 11,000	2.45 – 8.10	1.4 – 1.8	7 – 90
Subsurface Mean			80,300	10,110	9,700	2.67	1.5	46.60

CUF = Crest Unical Farm
MUF = Middle-slope Unical Farm
VUF = Valley-Bottom Unical Farm

Chemical Properties

Table 3 shows the chemical properties of soils derived from coastal plain sands under arable crop production in Ikot Ekpo, Calabar

Soil pH

The pH values ranged from 4.7 to 5.1 at all depths. The surface soils pH ranged from 4.7 to 5.1 with a mean value of 4.9. The subsurface had values ranging from 4.9 to 5.1 with a mean value of 5.0. From the result, the soils at both surface and subsurface depths are strongly acidic. This pH range does not fall within the optimal pH range of 6.0 - 7.5 for the growth of higher plants and microorganisms as reported by Havlin *et al.* [21]. This may be due to the high level of rainfall in the region. High level of rainfall causes the basic cations in the soils to leach away from the profile [23]. According to [11], the soil pH of soils in Calabar had values ranging from 4.8 to 5.5, indicating moderate to strong acidity and this agrees with the findings of this research.

Organic Carbon (O/C)

The organic carbon content of the soils ranged from 1.0 mg kg^{-1} **mg/kg** to 16.0 mg kg^{-1} **mg/kg**. The top soil values ranged from 7.0 to 16.0 mg /kg^{-1} with a mean value of 10.80 mg kg^{-1} **mg/kg**. The subsurface organic carbon values ranged from 1.0 to 5.0 mg kg^{-1} **mg/kg** with a mean value of 2.0 mg kg^{-1} **mg/kg**. This result shows that the **organic carbon**OC level was significantly higher in the soil surface than in the subsurface depth. This is due to accumulation of organic matter at the top soil. However, the organic matter content at both depths was generally low, as all the values were below the critical level of 40 mg kg^{-1} **mg/kg** [36]. This may be due to intensive use of the land for agricultural activities without return of plant residue to the soils as reported by Bunemann *et al.* [6].

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Total Nitrogen (N_T)

The total nitrogen content of the soils is shown in Table 4. It ranged from 0.1 to 1.3 mg /kg^{-1} at both surface and subsurface soils. The surface soils ranged from 0.5 to 1.3 mg kg^{-1} **mg/kg** with a mean value of 0.8 mg kg^{-1} **mg/kg** while the subsurface soil ranged from 0.1 to 0.4 mg kg^{-1} **mg/kg** with a mean value of 0.2 mg kg^{-1} **mg/kg**. This result compared with the critical value of 0.35 mg kg^{-1} **mg/kg** [36] show that the total nitrogen content of the soil is low as observed by [17] for acid sands of Eastern Nigeria. Such levels of **total nitrogen** N_T in soils might have serious negative implications on soil and crop productivity. These low values may be as a result of low organic matter content as well as leaching of nitrates from the soil; as is common in coastal plain soils.

Available Phosphorus (P_A)

The available phosphorus content of the soils as shown in Table 4 ranged from 17.20 to 29.75 mg kg^{-1} **mg/kg** at both depths. The values for surface soils ranged from 21.12 to 29.75 mg kg^{-1} **mg/kg** with a mean value of 25.33 mg kg^{-1} **mg/kg** while the subsurface soil ranged from 17.20 to 23.50 mg kg^{-1} **mg/kg** with a mean value of 20.15 mg kg^{-1} **mg/kg**. This result shows that the soils are generally high in available **phosphorus** P; as it exceeds the critical value of 15 mg kg^{-1} **mg/kg** [17]. None of the profiles was observed to fall below the critical value. Furthermore, [9] estimated an average value of 20 mg kg^{-1} **mg/kg** of available **phosphorus** P for the soils of coastal plain sands and this conforms to these findings.

Exchangeable Bases

Exchangeable K^+

The exchangeable K^+ content of the soils ranged from 0.08 cmol$_c$ kg^{-1} **cmol/kg** to 0.10 cmol$_c$ kg^{-1} **cmol/kg** at both depths. The top soil values ranged from 0.08 to 0.10 cmol$_c$ kg^{-1}

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cmol/kg with a mean value of 0.09 cmol$_c$/ kg^{-1} while the subsurface values ranged from 0.08 to 0.10 cmol$_c$ kg^{-1} **cmol/kg** with a mean value of 0.09 cmol$_c$ kg^{-1}**cmol/kg**. This result indicates that level of exchangeable K^+ is generally very low as observed by Holland *et al.* [22]. This contrasts with the mean value of 0.16 obtained by Ewulo *et al*. [12] for the coastal plain soils of Uyo. The low value of K^+ which is below critical level of 0.2 cmol$_c$ kg^{-1}**cmol/kg** as reported by Kyuma *et. a1*. [33] might be attributed to the high rainfall and leaching intensity normally often encountered in coastal plain soil.

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Exchangeable Ca^{2+}

The exchangeable Ca^{2+} content of the soils varied from 2.2 cmol$_c$ kg^{-1}**cmol/kg** to 4.4 cmol$_c$ kg^{-1}**cmol/kg** at both depths. The top soil values ranged from 2.2 to 3.0 cmol$_c$ kg^{-1}**cmol/kg** with a mean value of 2.7 cmol$_c$ kg^{-1}**cmol/kg** while the subsurface values ranged from 2.2 to 4.4 cmol$_c$ kg^{-1}**cmol/kg** with a mean value of 3.2 cmol$_c$ kg^{-1}**cmol/kg**. This result shows that level of exchangeable Ca^{2+} is generally low to moderate (Holland *et al.* [22].

Exchangeable Mg^{2+}

The exchangeable Mg^{2+} content of the soils varied from 0.8 cmol$_c$ kg^{-1}**cmol/kg** to 2.8 cmol$_c$ kg^{-1}**cmol/kg** at both depths. The top soil values ranged from 1.2 to 2.4 cmol$_c$ kg^{-1}**cmol/kg** with a mean value of 1.7 cmol$_c$ kg^{-1}**cmol/kg** while the subsurface values ranged from 0.8 to 2.8 cmol$_c$ kg^{-1}**cmol/kg** with a mean value of 1.9 cmol$_c$ kg^{-1}**cmol/kg**. This result shows that level of exchangeable Mg^{2+} is generally moderate [2] to high as reported by Holland *et al*. [22]

Exchangeable Na^+

The exchangeable Na^+ content of the soils varied from 0.05 cmol$_c$ kg^{-1}**cmol/kg** to 0.08 cmol$_c$ kg^{-1}**cmol/kg** at both depths. The top soil values ranged from 0.05 to 0.08 cmol$_c$ kg^{-1}**cmol/kg** with a mean value of 0.06 cmol$_c$ kg^{-1}**cmol/kg** while the subsurface values ranged from 0.06 to 0.08 cmol$_c$ kg^{-1}**cmol/kg** with a mean value of 0.06 cmol$_c$ kg^{-1}**cmol/kg**. This result shows that level of exchangeable Na is rated very low compared to similar soils in the region as reported by Ewulo *et al.* [12].

Exchangeable Acidity

Exchangeable H^+

The exchangeable H^+ content of the soils varied from 0.2 cmol$_c$ kg^{-1}**cmol/kg** to 0.88 cmol$_c$ kg^{-1}**cmol/kg** at both depths. The top soil values ranged from 0.2 to 0.40 cmol$_c$ kg^{-1}**cmol/kg** with a mean value of 0.28 cmol$_c$ kg^{-1}**cmol/kg** while the subsurface values ranged from 0.12 to 0.88 cmol$_c$ kg^{-1}**cmol/kg** with a mean value of 0.39 cmol$_c$ kg^{-1}**cmol/kg**. This result shows that the subsurface soil had higher exchangeable H^+ values than the surface soil. The soil is generally low in exchangeable H^+ as reported by Holland *et al*. [22]

Exchangeable Al^{3+}

The exchangeable Al^{3+} content of the soils varied from 0.24 cmol$_c$ kg^{-1}**cmol/kg** to 1.04 cmol$_c$ kg^{-1}**cmol/kg** at both depths. The top soil values ranged from 0.32 to 0.96 cmol$_c$ kg^{-1}**cmol/kg** with a mean value of 0.53 cmol$_c$ kg^{-1}**cmol/kg** while the subsurface values ranged from 0.24 to 1.04 cmol$_c$ kg^{-1}**cmol/kg** with a mean value of 0.57 cmol$_c$ kg^{-1}**cmol/kg**. This result shows that exchangeable H^+ values of the soils is generally low as reported by Holland *et al.* [22]. The low levels of exchangeable acidity is solely attributed to leaching away of the basic cations (Ca^{2+}, Mg^{2+}, K^+, Na^+) from the surface soil, which leaves the surface soil acidic.

Effective Cation Exchange Capacity (ECEC)

The ECEC content of the soils raged between 4.85 cmol$_c$ kg^{-1}**cmol/kg** to 7.06 cmol$_c$ kg^{-1}**cmol/kg** at both depths. The top soil values ranged from 4.85 to 6.30 cmol$_c$ kg^{-1}**cmol/kg** with a mean value of 5.44 cmol$_c$ kg^{-1}**cmol/kg** while the subsurface values ranged from 5.24 to

7.06 cmol$_c$ kg^{-1}**cmol/kg** with a mean value of 6.32 cmol$_c$ kg^{-1}**cmol/kg**. This result shows that level of ECEC is rated very low and regarded as unsuitable for crop production [16].

Comment [H18]: This is not logical.
How does the loss of basic cations, which leaves the soil more acidic, cause the acidity to decrease?

Percent Base Saturation (BS)

The base saturation of the soils ranged from 76 % to 115 % at both depths. The top soil values ranged from 76 to 115 % with a mean value of 93 % while the subsurface values ranged from 80 to 9 % with a mean value of 83 %. These values indicate the availability of the basic cations and it shows a higher value than that obtained by [11] for the utisols of Cross River State and so could be regarded as being moderate to high.

Comment [H19]: With low Ca, Mg and K contents, was base saturation high?
How could a base saturation of 115% occur?

Comment [H20]: ????

Table 3: The chemical properties of soils of coastal plain sands under arable crop production in Ikot Ekpo, Calabar, Cross River State

Profile location	Horizon	Depth (cm)	pH	O/C (mg/kg)	N_T (mg/kg)	P_A (mg/kg)	Exchangeable Bases (cmolc/kg) Ca^{2+}	Mg^{2+}	K^+	Na^+	Exchangeable Acidity (cmol/kg) H^+	Al^{3+}	ECEC (cmol/kg)	BS (%)
CUF E008^0 19.91' N05^0 03.65'	AP	0 - 30	5.1	16.0	1.3	29.80	3.0	1.2	0.08	0.05	0.20	0.32	4.85	115
	B	30 – 70	5.1	5.0	0.4	23.50	4.4	0.8	0.10	0.07	0.90	0.24	6.49	82
	BC	70 – 120	5.2	3.0	0.2	19.25	3.2	2.4	0.09	0.06	0.40	0.83	6.99	82
	C	120 –150	5.2	1.0	0.1	17.20	3.8	2.0	0.08	0.06	0.12	0.56	6.62	89
MUF E008^0 19.95' N05^0 03.87'	AP	0 – 26	4.9	7.0	0.5	25.10	3.0	2.4	0.10	0.08	0.40	0.32	6.30	88
	AB	26 - 57	5.0	2.0	0.1	19.40	3.5	2.8	0.10	0.08	0.24	0.24	7.06	93
	B	57 – 110	4.9	2.0	0.1	21.50	3.4	2.2	0.09	0.06	0.48	0.40	6.63	86
	C	110 –150	4.9	2.0	0.1	18.50	2.2	2.6	0.09	0.06	0.85	0.32	6.15	80
VUF E008^0 9.09' N05^0 03.65	AP	0 – 20	4.7	9.40	0.8	21.10	2.2	1.5	0.10	0.07	0.24	0.96	5.17	76
	B	20 - 60	4.9	0.40	0.1	21.50	2.6	1.2	0.09	0.07	0.24	1.04	5.24	75
	BC	60 - 115	4.9	1.0	0.1	20.10	2.8	1.8	0.08	0.06	0.24	0.72	5.70	83
	C	115 –150	4.9	3.0	0.2	20.50	3.0	2.0	0.10	0.07	0.80	0.80	6.05	85
Topsoil Range			4.7- 5.1	7.0 - 16	0.5 - 1.3	21.12- 29.75	2.2 -3.0	1.2-2.4	0.08 -0.1	0.05-0.08	0.2-0.40	0.32-0.96	4.85-6.30	76 -115
Subsoil Range			4.9- 5.2	1.0 -5.0	0.1 - 0.4	17.20 -23.50	2.2 -4.4	0.8- 2.8	0.08 -0.1	0.06-0.08	0.12-0.90	0.24-1.04	5.24-7.06	80 - 93
Topsoil Mean			4.9	10.60	0.8	25.33	2.7	1.7	0.09	0.06	0.28	0.53	5.44	93
Subsoil Mean			4.8	2.1	0.2	20.15	3.2	1.9	0.09	0.06	0.39	0.57	6.32	83

Distribution of NPK in the soils

The intra-profile and inter-profile distribution of total **nitrogen**N, available P**phosphorus** and exchangeable K**potassium** were discussed intensively with respect to Table 4 and 5.

Total nitrogen

Intra-profile distribution of total **nitrogen** N as shown in Table 4 indicates a value of 1.3 mg kg^{-1} **mg/kg** for top soil of crest profile (CUF). The values ranged from 0.1 to 1.3 mg kg^{-1} **mg/kg** throughout CUF profile depth with a mean of 0.5 mg kg^{-1}**mg/kg**, SD of 0.47 mg/ kg^{-1} and CV of 94 %. The middle slope profile (MUF) had a topsoil value of 0.5 mg kg^{-1} **mg/kg** and ranged from 0.1 to 0.5 mg kg^{-1} **mg/kg** with a mean value of 0.2 mg kg^{-1}**mg/kg**, SD of 0.17 and CV of 85 %. While the valley bottom profile (VUF) had a topsoil value of 0.8 mg kg^{-1} **mg/kg** and ranged from 0.1 to 0.8 mg kg^{-1} **mg/kg** with a mean of 0.3 mg kg^{-1} **mg/kg**, SD of 0.29 mg kg^{-1} **mg/kg** and CV of 97 %.

The inter-profile distribution of total **nitrogen** N as shown in Table 4 ranged from 0.2 to 0.5 mg kg^{-1} **mg/kg** across the three profiles (using intra-profile means), with a mean value of 0.33 mg kg^{-1} **mg/kg**, SD of 0.125 mg kg^{-1} **mg/kg** and CV of 38.0 %.

These values indicate higher concentration of N in top soil and lower concentration; below critical value in the sub soils [17]. Total **nitrogen** N in CUF decreased consistently with increase in profile depth (Fig.2a) while MUF and VUF showed inconsistent patterns (Fig.3a&4a). However, the topsoil had a significantly higher **nitrogen** N concentration for all three profiles (Fig.2a, 3a &4a) and this accounts for the high CV observed within the profiles; 94 %, 85 % and 97 % for CUF, MUF and VUF respectively (Table 5). This agrees with the findings of [28], who stated that N concentration was significantly higher in topsoil. The high levels of total N in the topsoil could be attributed to the high natural organic matter returns and mineralization of plant residue as well as N fertilizer application. According to [44],

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biological cycling generally moves nutrients upwards because some proportion of the nutrients absorbed by plants are transported aboveground and then recycled to the soil surface.

Generally, inter-profile distribution chart shows that the upper slope (CUF) had the highest **nitrogen** N concentration and the lowest concentration was observed in the middle slope (CUF > VUF > MUF) (Fig.5a). The level of significance of its inter-profile variation is visible in the percentage of its coefficient of variation (38 %). According to [8], soils on lower slope are more prone to **nitrogen** N runoff because they become saturated with excess precipitation.

Table 4

Intra-Profile distribution of NPK in soils of coastal plain sands under arable crop production in Ikot Ekpo, Calabar, Cross River State

Profile location	Horizon	Depth (cm)	N_T (mg/kg)	Mean	SD	CV (%)	P_A (mg/kg)	Mean	SD	CV (%)	K^+ (cmolc/kg)	Mean	SD	CV (%)
CUF E008^0 19.91' N05^0 03.65'	AP	0 - 30	1.3				29.80				0.08			
	B	30 – 70	0.4				23.50				0.10			
	BC	70 – 120	0.2	0.5	0.47	94	19.25	22.44	4.82	21.5	0.09	0.088	0.008	9.4
	C	120 – 150	0.1				17.20				0.08			
MUF E008^0 19.95' N05^0 03.87'	AP	0 – 26	0.5				25.10				0.10			
	AB	26 - 57	0.1				19.40				0.10			
	B	57 – 110	0.1	0.2	0.17	85	21.50	21.13	2.54	12.0	0.09	0.095	0.005	5.3
	C	110 – 150	0.1				18.50				0.09			
VUF E008^0 9.09'	AP	0 – 20	0.8				21.10				0.10			
	B	20 - 60	0.1	0.3	0.29	97	21.50	20.80	0.54	2.6	0.09	0.093	0.008	8.6

N05^{0} 03.65	BC	60 - 115	0.1	20.10	0.08
	C	115 – 150	0.2	20.50	0.10

SD = Standard deviation
CV = Coefficient of variation
CUF = Crest Unical Farm
MUF = Middle-slope Unical Farm
VUF = Valley-Bottom Unical Farm

Table 5

Inter-Profile distribution of NPK in soils of coastal plain sands under arable crop production in Ikot Ekpo, Calabar, Cross River State

Profile location	N_T (mg/kg)	Mean	SD	CV (%)	P_A (mg/kg)	Mean	SD	CV (%)	K^+ (cmolc/kg)	Mean	SD	CV (%)
CUF E008^0 19.91' N05^0 03.65'	0.5				22.44				0.088			
MUF E008^0 19.95' N05^0 03.87'	0.2	0.33	0.125	38.0	21.13	21.46	0.71	3.3	0.095	0.092	0.0029	3.2
VUF E008^0 9.09' N05^0 03.65	0.3				20.80				0.093			

SD = Standard deviation
CV = Coefficient of variation
CUF = Crest Unical Farm
MUF = Middle-slope Unical Farm
VUF = Valley-Bottom Unical Farm

Available phosphorus

Intra-profile distribution of available **phosphorus** P as shown in Table 4 shows a topsoil value of 29.80 mg/ kg^{-1} for crest profile (CUF) and the values ranged from 17.20 to 29.80 mg kg^{-1} **mg/kg** throughout the profile depth with a mean of 22.44 mg kg^{-1}**mg/kg**, SD of 4.82 mg kg^{-1}**mg/kg** and CV 21.5 %. The middle slope profile (MUF) had a topsoil value of 25.10 mg kg^{-1}**mg/kg** and ranged from 18.50 to 25.10 mg kg^{-1}**mg/kg** with a mean value of 21.13 mg kg^{-1}**mg/kg**, SD of 2.54 and CV of 12 %. While the valley bottom profile (VUF) had a topsoil value of 21.10 mg kg^{-1}**mg/kg** and ranged from 20.10 to 21.50 mg kg^{-1}**mg/kg** with a mean of 20.80 mg kg^{-1}**mg/kg**, SD of 0.54 mg kg^{-1}**mg/kg** and CV of 2.6 %.

The inter-profile distribution of available P**phosphorus** as shown in Table 4 ranged from 20.80 to 22.44 mg kg^{-1}**mg/kg** across the three slopes (using intra-profile means) with a mean value of 21.46 mg kg^{-1}**mg/kg**, SD of 0.71 mg kg^{-1}**mg/kg** and CV of 3.3 %.

These values show that available **phosphorus** P is generally high across all the profiles. This is indicated by the low inter-profile coefficient of variation (Table 5). However, in CUF profile it has a significantly higher concentration at surface level and decreased consistently with increased profile depth (Fig.2b), with a relatively high intra-profile coefficient of variation (Table 5). This is suggested to be due to vertical and lateral movement of P in the subsurface soil which could be a characteristic of soils of sand stone parent materials as reported by Salminen *et. al.* [40]. MUF and VUF (Fig.3b&4b) showed no definite pattern of distribution which could be due to variation in clay content and organic matter of these soils as reported by Yadav *et. al.* [49]. However, the top soil (0-26 cm) had the highest P concentration in the MUF profile as observed in the CUF profile. This may be a result of biological cycling as stated by [44].

Inter-profile distribution chart showed consistent decrease in P concentration down the slope; CUF had the highest concentration and VUF had the lowest concentration (CUF >

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MUF > VUF) (Fig.5b). This may be due to higher rate of runoff associated with down slope as stated by [8].

Exchangeable potassium

The intra-profile distribution of exchangeable potassium as shown in Table 4 ranged from 0.08 to 0.10 cmolc/ kg^{-1} for crest profile (CUF) with a mean of 0.088 cmolc kg^{-1} **cmol/kg**, SD of 0.008 cmol/kg and CV 9.4 %. The middle slope profile (MUF) ranged from 0.09 to 0.10 cmolc kg^{-1} **cmol/kg** with a mean value of 0.095 cmolc kg^{-1} **cmol/kg**, SD of 0.005 cmolc kg^{-1} **cmol/kg** and CV 5.3 %. While the valley bottom profile (VUF) ranged from 0.08 to 0.10 cmolc kg^{-1} **cmol/kg** with a mean of 0.093 cmolc kg^{-1} **cmol/kg**, SD of 0.008 cmolc kg^{-1} **cmol/kg** and CV of 8.6 %.

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Inter-profile distribution of exchangeable **potassium** K as shown in Table 5 ranged from 0.088 to 0.095 cmolc kg^{-1} **cmol/kg** across the three slopes (using intra-profile means) with a mean value of 0.092 cmolc kg^{-1} **cmol/kg**, SD of 0.0029 cmolc kg^{-1} **cmol/kg** and CV of 3.2 %.

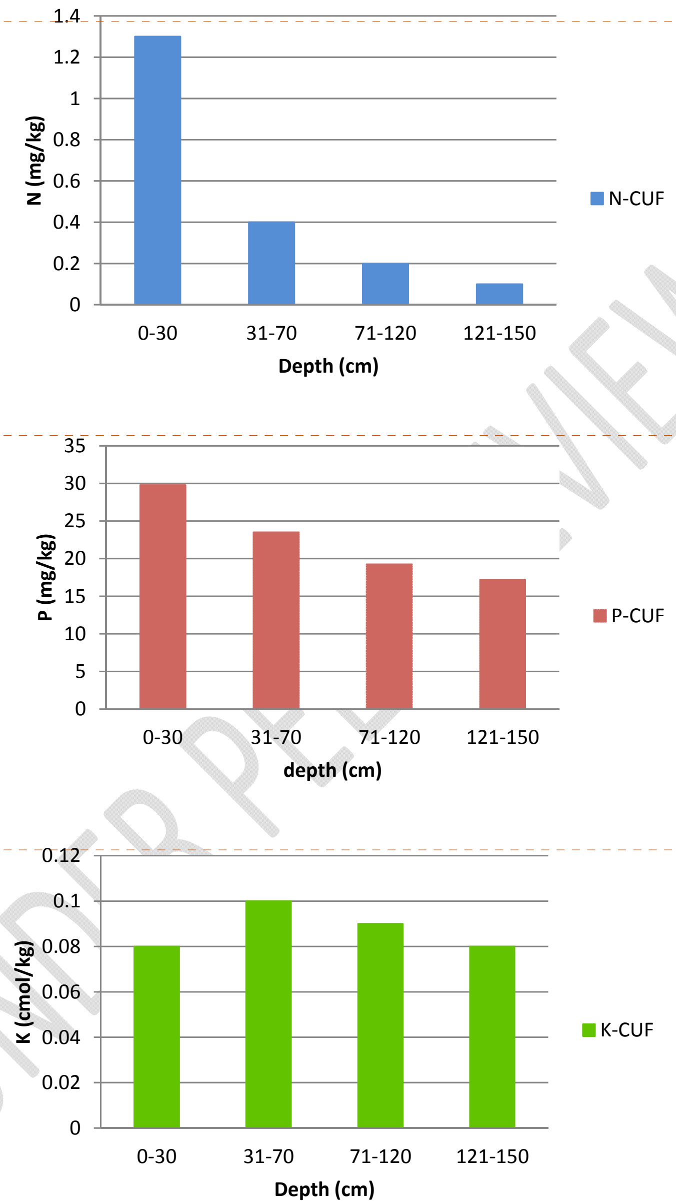
These values show **very** low exchangeable **potassium** K at all depths and profiles; as indicated by the low intra and inter profile CV (Table 4&5). Furthermore, exchangeable K showed no definite distribution pattern down the profile depth of CUF and VUF (Fig.2c&4c). However, MUF showed a slightly higher level of K in shallower part of profile depth (Fig.3c). The VUF profile showed that K was higher in the surface though it did not decrease regularly with soil depths; as its concentration increased at lower profile depth of 116-150 cm (Fig.4c). This could be due to the effect of **potassium** K cycling by the crops from bottom to surface horizons as reported by Singh *et al.* [43] and leaching respectively. According to [31], leaching moves nutrients downward and may increase nutrient concentrations with depth due to the effect of annual water table fluctuations causing leaching of nutrients down the profile, a characteristic of coastal sands. The distribution of K was shallowest in MUF (Fig.3c) where its abundance was highest (fig.5c) this contrasts with the predictions of [28] who stated that a high ratio of plant uptake to soil supply should result in higher rates of upward transport by plants and, hence, shallower vertical distributions.

Inter-profile distribution reveals that K was higher in valley bottom than crest and highest in the middle-slope (MUF > VUF > CUF) (Fig.5c), this may be due to deposition of K at valley bottom from upper slope [31].

a)

b)

c)



N-CUF = Nitrogen in the crest unicial farm
P-CUF = Phosphorus in crest uncial farm
K-CUF = Potassium in crest uncial farm

Fig. 2: Intra-profile distribution of primary nutrients (NPK) in crest uncial farm (CUF) soil profile.

Comment [H22]: mg kg^{-1}

Comment [H23]: Standardize the graphics.

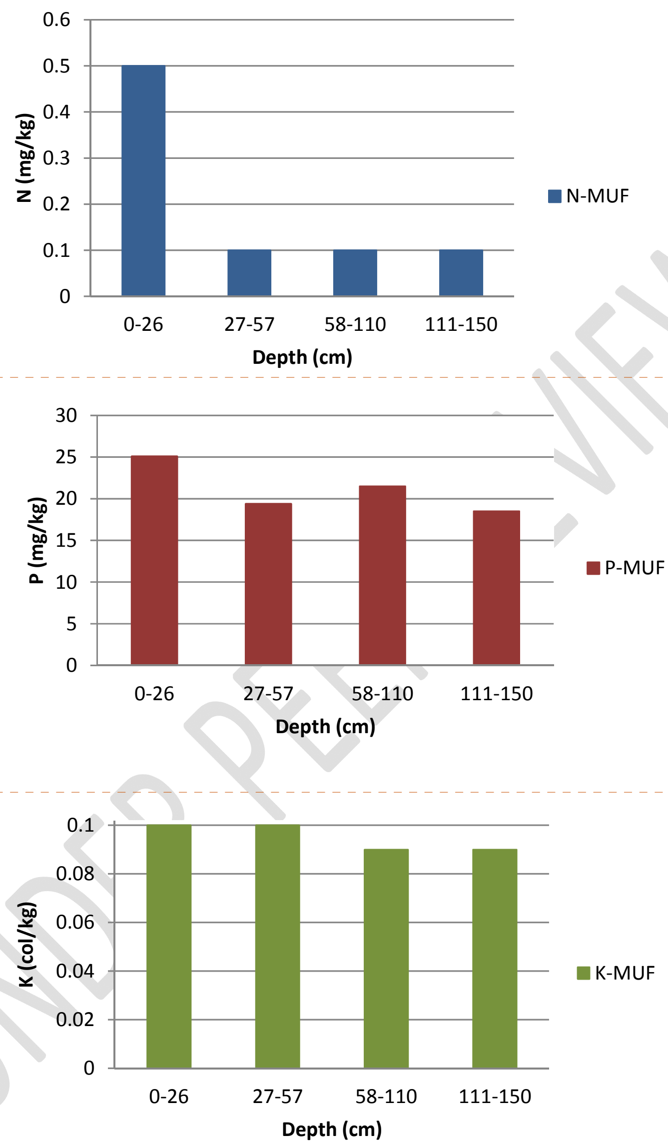
Comment [H24]: Idem.

Comment [H25]: cmol$_c$ kg^{-1}

a)

b)

c)



N-MUF = Nitrogen in middle-slope uncial farm
P-MUF = Phosphorus in middle-slope uncial farm
K-MUF = Potassium in middle-slope uncial farm

Fig. 3: Intra-profile distribution of primary nutrients (NPK) in middle-slope uncial farm (MUF) soil profile.

Comment [H26]: Idem.

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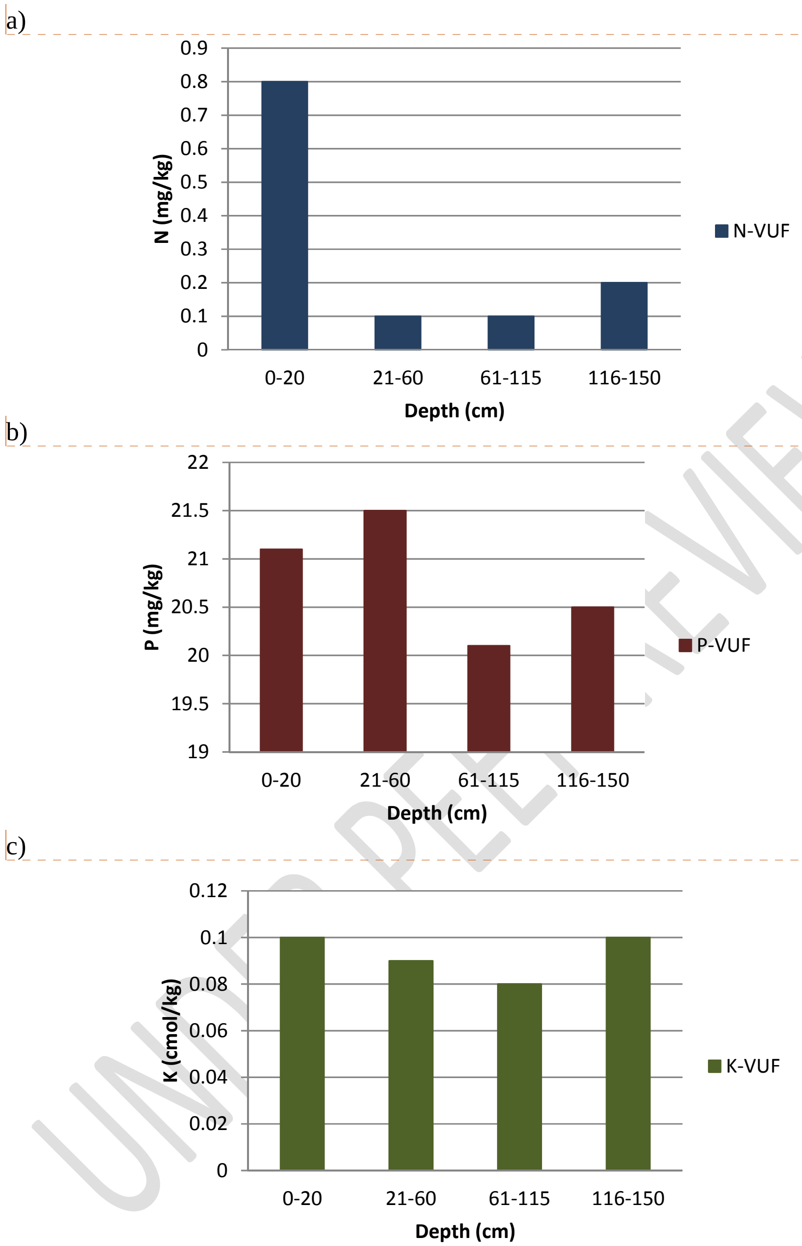

Comment [H29]: Idem.

Comment [H30]: Idem.

Comment [H31]: Idem.

N-VUF = Nitrogen in valley bottom uncial farm
P-VUF = Phosphorus in valley bottom uncial farm
K-VUF = Potassium in valley bottom uncial farm

Fig. 4: Intra-profile distribution of primary nutrients (NPK) in valley bottom uncial farm (VUF) soil profile

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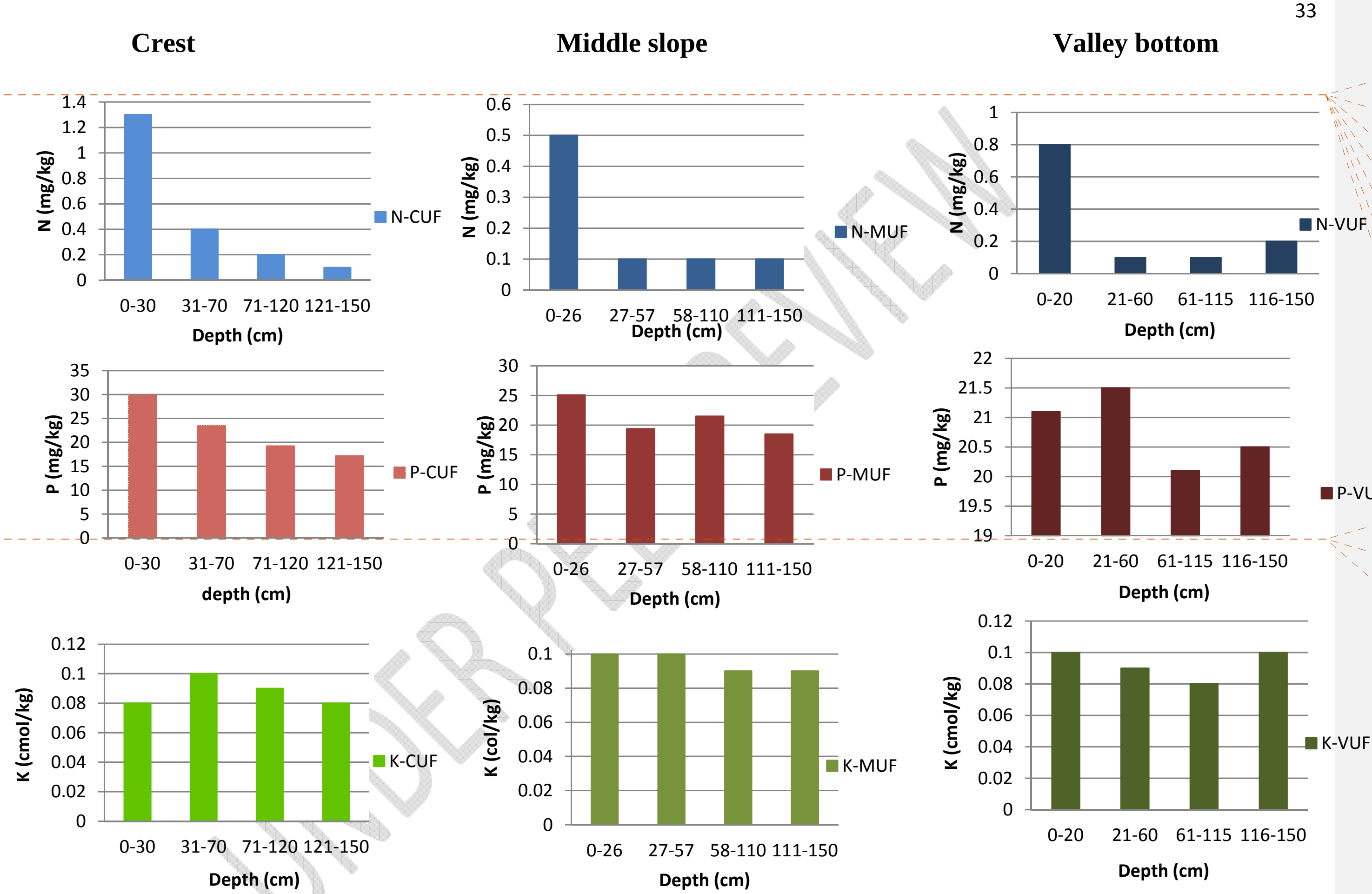

Fig. 5: Inter-profile distribution of primary nutrients (NPK) along the toposequence: *a, b & c for N, P & K respectively*

Comment [H32]: Idem.
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Comment [H42]: Figure 5, legend in italic?

CONCLUSION

This study assessed that coastal plain soils are formed from mainly unconsolidated tertiary deposit. The physical nature of coastal plain soil greatly influences their chemical properties and this physical nature is a result of their parent materials. Coastal plain soils are called acid soils due to low values of pH commonly associated with these soils. Low pH level influences soil reactions and generally limits crops growth. The three profiles studied had predominantly sandy particle size distributions and mostly loamy sand in texture; especially at the topsoil level. The study also determined that the soils had very friable consistency at topsoil levels but were less friable at subsurface depths. They had weak fine granular structure at topsoil level but had mostly moderate sub-angular blocky structure at subsurface depths. The chemical properties analyzed showed that the soils were of low fertility status; because **as** their total **nitrogen**N, exchangeable **potassium** K and organic matter contents were below established critical levels. However, **nitrogen** N was high at topsoil level but decreased consistently with increased depth especially at the crest profile. These, among other noticeable limitations including low contents of organic matter and high acidity were determined.

Comment [H43]: This did not need a study to know.
Improve your conclusion.

Furthermore, the NPK distribution charts showed that N and P decreased consecutively with increased depth for the crest profile. The middle-slope and valley bottom profile showed no definite pattern of distribution. However, the concentration of NPK was highest at topsoil level across almost all profiles. N had the shallowest intra-profile distribution with significantly higher level of topsoil concentration indicated by the high percentage of intra-profile coefficient of variation. P which had the highest concentration across all profiles also showed a shallow intra-profile distribution across the three profiles but did not vary significantly from the intra-profile mean as much as N. On the other hand K was more evenly distributed within all three profiles

Comment [H44]: Were the charts that showed this?

compared to N and P. Inter-profile distribution of NPK showed that N and P had higher concentrations at crest level, with P showing consecutive decrease in concentration down the slope. Furthermore, N had its lowest concentration in middle-slope profile while K was highest in the middle slope profile.

RECOMMENDATIONS

Based on the findings of the research, the following recommendations are made.

i. Conventional NPK fertilizer should be used to replenish inadequate contents of primary nutrients **essential for optimum** on the soil, for crop production.

ii. Slow release fertilizers **should** can be used or split applications should be practiced.

iii. Adoption of different NPK fertilizer recommendation with due considerations for different soil depths and topographic locations should be practiced to effectively tackle poor nutrient distribution.

iv. The soils should be managed by liming to replenish lost cations, which will increase the soil pH above the acid range for better crop production.

v. Planting of acid tolerant crops is recommended for easier soil acidity management.

vi. Artificial and live mulching in the form of cover crops are also recommended to reduce erosion, runoffs and leaching, and provide organic matter content for better supply of macro nutrients in the soil.

vii. Application of organic manure can will improve the soil structure and bring about the formation of soil aggregates that will withstand the high rainfall associated with the region and minimize water erosion.

Comment [H45]: Liming should not be used in agricultural areas for this purpose.
It should be used to reduce acidity.
Take it to a lighter level.

viii. Crop rotation is also recommended to enable natural replacement of nutrients removed from the soil by plants.

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