Assessment of Two Toposequences in Forest-Savanna Transition Area for the Cultivation of Yam, Cassava and Maize in Eastern Nigeria

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Abstract: **The soils of two toposequences in the sub-humid tropical climate of Southeastern Nigeria were characterized and assessed for yam (*Dioscorea spp.*), cassava (*Manihot esculenta*) and maize (*Zea mays*) production in this study. Data were obtained following standard field and laboratory analytical procedures. Six profile pits were dug three on each toposequence described and samples from the pedogenic horizons were collected, processed and analyzed. The profiles located at Ekpe village toposequence were designated EUP, EMP, ETP for upper- , Mid- and Toe- slopes respectively. The corresponding profiles at Amadia village toposequence were designated AUP, AMP and ATP. The soils were generally deep, loose, slightly sticky and non-plastic. The dominant textural was sandy loam or loamy sand. The soils were generally acidic (pH < 5.6); The total nitrogen and available phosphorus contents exchangeable bases were generally low; soil organic matter contents were low to moderate but decreased down the profile depth. The soils met the morphological and physical requirements for the production of the three crops but chemical requirements were deficient with total N, available P and exchangeable K being the limiting nutrients. Thus, the soils were classified into S2f subclass due to these fertility constraints. Therefore for optimum production of the crops, application of compound mineral fertilizers such as NPK 20:10:10 or 15:15:15 at the rate of at least 300 kg ha^{-1} for yam, 250 kg ha^{-1} for cassava and 200 kg ha^{-1} for maize is recommended.**

Keywords: **Toposequence, forest-savannah, land evaluation, yam, cassava, maize.**

I.INTRODUCTION

The soil toposequence model is based on the catena concept, which comes from the Latin word ‘‘catena’’, meaning “chain”. This concept was developed in central Uganda to describe the close relationship between a sequence of soils in different positions in the landscape likened to ‘‘a chain of soils linked by topography’’ (Milne, 1935). The relationship between soils and physiographic features has been widely accepted by soil scientists and physiographers (Daniels, et al. 1970). Toposequence refers to a succession of soils from crest to a valley which contains a range of the soil profiles that are representative of the landscape and soils (Amhakhian and Achimugu, 2011). As the landscape is undulating, soil characteristics at different topographic positions also differ.

Soil is a natural body arranged in layers (horizons) consisting of mineral and organic constituents. Soils are amongst the most important natural resources of a nation and the wealth of a nation lies in quality and management of her soils (Isirimah, 2004). The concept of a soil as a component of landscape is of paramount importance in soil survey, since soil survey is similar to landscape survey (Akamigbo, 1984). Soil is a “synthograph” which is a natural device recording a synthesis of much that has happened to it in the landscape (Akamigbo, 2016).

Toposequence studies in any area show that such properties as clay and silt contents, soil colour, exchange capacity increased down the slope (Akamigbo and Asadu, 1986), Topography affects the deposition of material down a toposequence (Akamigbo et al, 1987). The lateral movement of materials down a slope often involves more of the finer than coarser materials (Asadu, 1990).

Soils developed on toposequences have been found useful in the production of tree crops such as Cacao (*Theobroma cacao*), Gmelina (*Gmelina aborea*); food crops such as yam (*Dioscorea rotundata*), cassava (*Manihot esculenta*) and maize (*Zea mays*) and vegetables (Tomatoes, Fluted pumpkin, Egg plants, etc) (Eshiet, 1987).

In farming, risk is minimized by matching the requirements of land use to land qualities, which is the role of land evaluation. stated that land evaluation. It is a prediction process of land potential for various alternative uses, and it is one important component in the process of land-use planning (FAO, 1976; Dent and Young, 1981).

A review of the future of soil science (Blum, 2006) showed that in countries with food deficiencies especially in Africa, Asia, South, and Central America, soil science would mainly target soil fertility in its largest sense as long as these deficits existed while in countries with sufficient food supply, soil science would increasingly target environmental and cultural issues, such as protection of the food chain against contamination, protection of groundwater resources, protection of the air and of human health as well as protection of soil as a cultural and natural heritage. Characterization and classification of soils in countries like Nigeria with insufficient food supplies should be accompanied by land suitability evaluation for making the research more relevant to local users of soil information especially farmers while satisfying the interest of soil researchers.

Land evaluation is a process that matches the characteristics of land resources for certain uses using a scientifically standardized technique. The results can be used as a guide by land users and planners to identify alternative land uses. This study characterised and assessed the soils of two toposequences in the Forest- Savannah transition area in eastern Nigeria for maize, yam and cassava production.

II. MATERIALS AND METHOD

Site Description

Location: The study area is located in Umuoka (Udi Local Government Area in Enugu State) and along lat 06^0 63' N and long 007^0 39' E of the equator, However, the two toposequences are located in two different villages in Umuoka¸ the first toposequence is located in Ekpe village while the second toposequence is located in Amadia village (Figs 1-3).

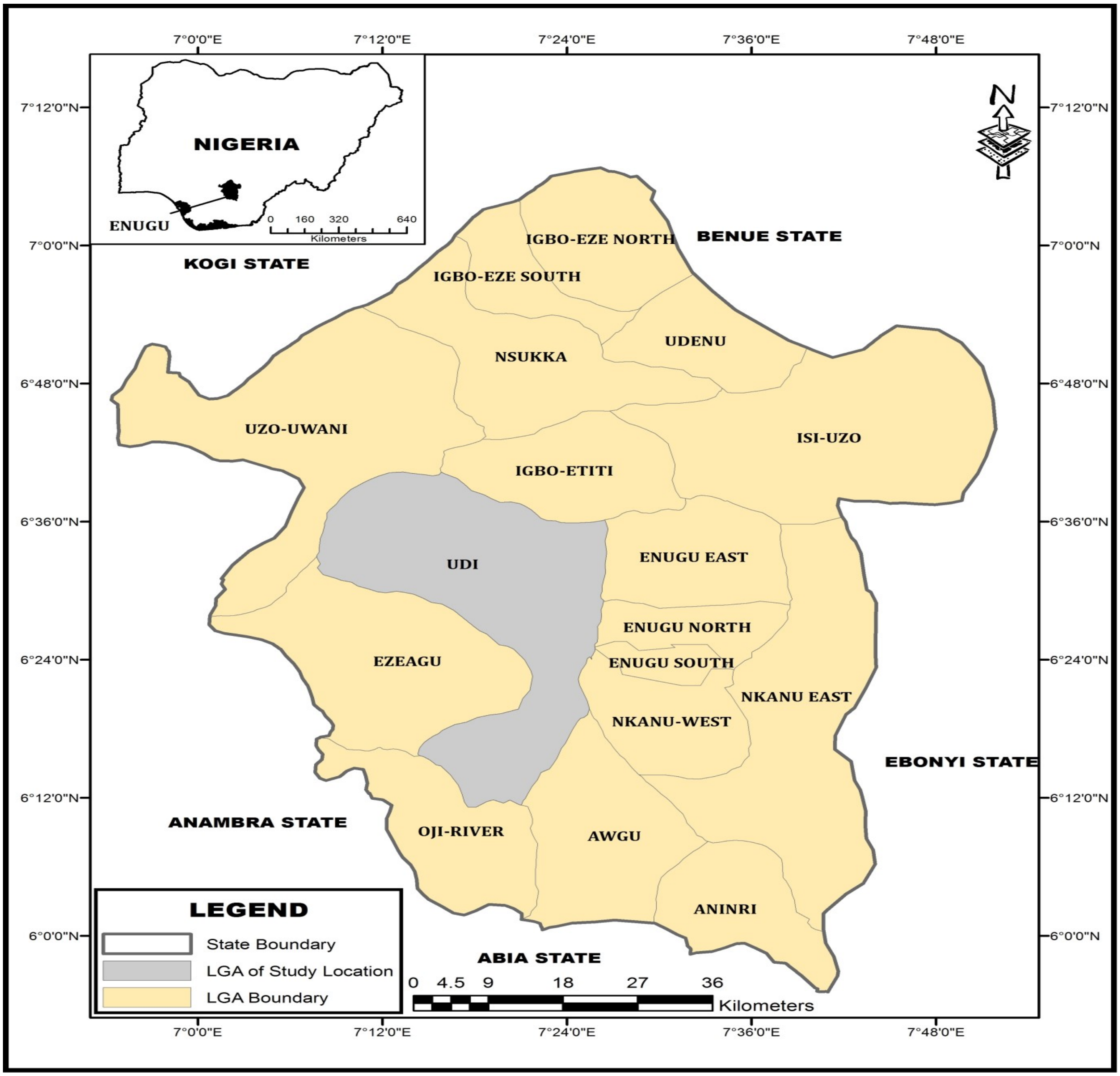

Fig 1: Administrative map of Udi Local Government Area Enugu State

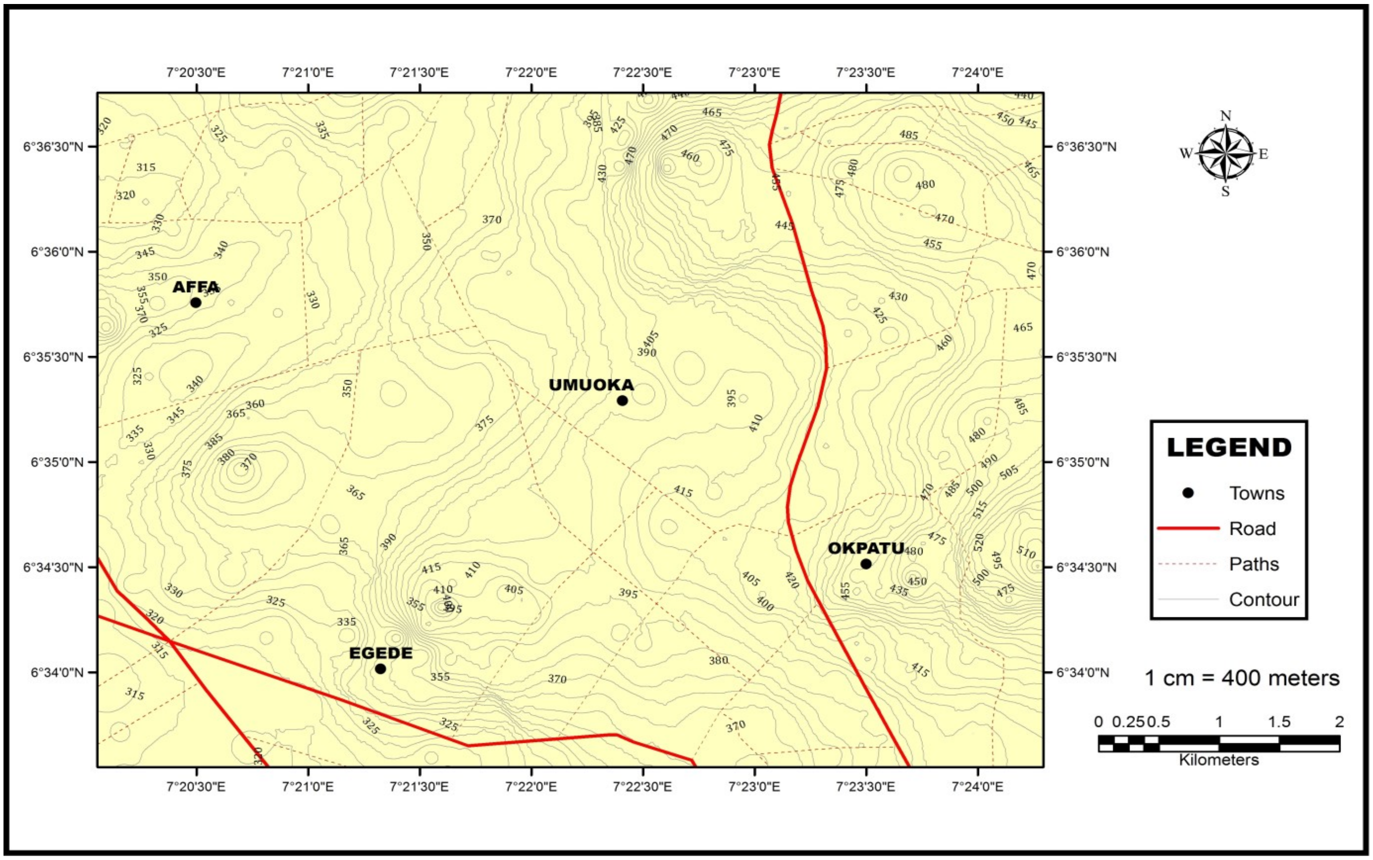

Fig 2: Topomap of Umuoka Udi Local Government Area Enugu State

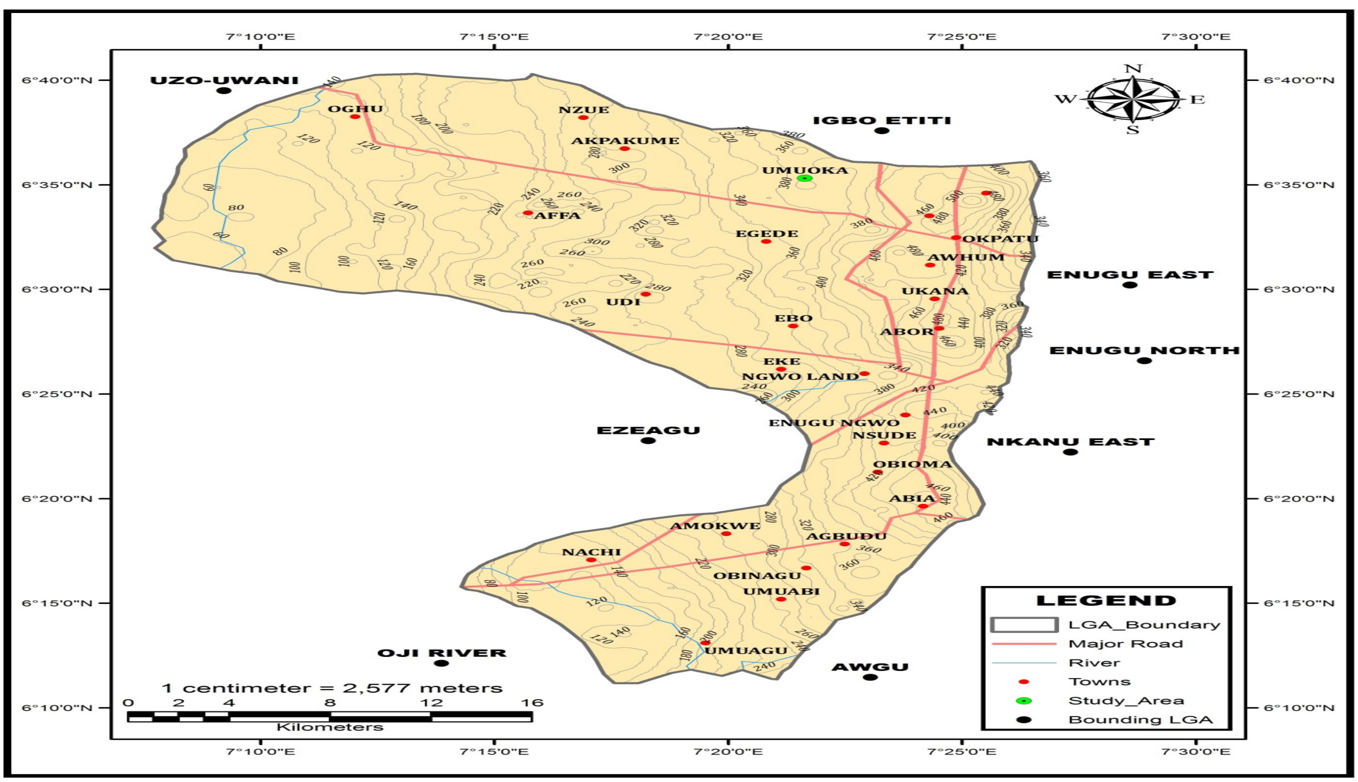

Fig 3: Map of Udi Local Government Area Enugu State showing Umuoka location

The area is covered with grasses and scattered shrubs. The topography of this land is strongly undulating. Common crops grown by the farmers are yam (*Dioscorea rotundata*), cassava (*Manihot esculenta*) and maize (*Zea mays*)

Climate

The area is characterized by two seasons, rainy and dry seasons which last from April to October and November to March respectively. The average annual temperature is 27^0C with a range from 22 to 35 ^{o} C. The mean annual rainfall is 1260mm with a range from 1200 to 1550 mm. Relative humidity is highest during the rainy season and lowest during the dry harmattan period within the dry season. The mean annual is above 65% (Asadu, 2000).

Vegetation

The vegetation of the area is typical of the derived savannah dominated by grass cover with few trees and shrubs. The dominant grasses include Guinea grass (*Panicum maximum*) and Spear grass (*Imperata cylindrical*) while some dominant economic trees are cashew (*Anacadium occidentale*), oil bean trees (*Pentacletra macrophylla*) and oil palm (*Elias guinensis*).

Soil sampling

A total of 12 soil samples were collected from the 6 profiles pit at depth intervals of 0 -20cm, 20– 45cm (for profile 1 at the crest), 0-25cm, 25-50cm (for profile 2 at the mid slope), 0-30cm, 30-60cm (for profile 3 at the foot slope) for the first toposequence in Ekpe village and 0-25cm, 25-50cm (for profile 1 at the crest), 0-30cm, 30-60cm (for profile 2 at the mid slope), 0-30cm, 30-65cm (for profile 3 at the foot slope) for the second toposequence in Amadia village.

Two horizons were described at the top and mid slopes due to depth to impenetrable layer while the toe slope is mainly made up of Entisols (young soils formed as a result of deposition which have not developed many horizons. The morphological characteristics such as soil colour, texture, structure, consistence, pores, drainage, depth and deposition were studied in each of the profile. Soil samples collected from each of the horizon were air dried, pulverized, sieved through 2mm, appropriately labelled and were taken to the laboratory for physical and chemical analysis.

Laboratory Determinations and Theoretical Crop Requirements

All the analyses were carried out at the Department of Soil Science laboratory, University of Nigeria, Nsukka following standard laboratory procedures: Pore size distribution was determined using the water retention data as follows: After air-drying the loose samples and gentle crushing they were sieved with 2mm sieve. Soil particle size distribution was determined by the Bouyoucos hydrometric method (Van Reeuwijk, 1992) using sodium hydroxides (NaOH) as a dispersing agent

The pH of the soil was measured in water and potassium chloride (1N KCl) suspension in a 1:2.5 (soil: liquid ratio) potentiometrically using a Beckman's zeromatic glass electrode pH meter (Mclean, 1982). Available P was extracted with Bray (II) solution (Bray and Kurtz; 1945) and measured using a colorimeter following the principles of light (Murphy and Riley method). Soil organic carbon content was determined using Walkley-Black's titration method (Jackson, 1973). Total N was determined using Kjeldahl digestion, distillation, and titration method as described by Bremner (1965) by oxidizing the organic matter in concentrated sulphuric acid (0.1N H_2SO4). Cation Exchange Capacity (CEC) and exchangeable bases (Ca, Mg, K and Na) were determined after extracting from the soil samples using ammonium acetate (1N NH4OAc) at pH 7.0. Exchangeable Na and K in the extracts were determined by Flame photometery (Rhoades, 1982) while Exchangeable Ca and Mg in the extracts were determined by the titration method using 0.1N EDTA (Chapman, 1965). Apparent Cation Exchange Capacity (ACEC) was thereafter estimated titrimetrically using 0.1N NaOH (Chapman, 1965). Exchangeable Acidity (EA) was determined by saturating samples with potassium chloride solution (1N KCl) and titrating with sodium hydroxide as described by Mclean (1965). Percentage Base Saturation was calculated as follows:

%BS = TEB/ACEC × 100

Where; %BS = percentage base saturation;

TEB = total exchangeable bases and

AECEC = Apparent cation exchange capacity.

Land Evaluation Procedure

The assessment of soils for production of yam, cassava and maize was done following matching procedure (FAO, 1976). In this procedure the information obtained from the climate of the area and soil data are matched with the crop requirements for optimum production. The classification considers the limiting factors and groups the soils into suitability orders “Suitable” (S) or “Not Suitable” (N). Further classification into classes is based on the major limitations and the classes are Highly suitable (S1), Suitable (S2) and Moderately suitable (S3). Classes of N are Currently not suitable (N1) and Permanently not suitable (N2). Units of classes are obtained based on the intensity of the limitations for example where soil fertility is of high intensity limiting production the soil can be classified as S2f. The requirements for the optimum production of yam, cassava and maize are shown in Tables1, 2 and 3 respectively with definitions of the suitability classes (Sys, 1985).

Table 1: Land and soil requirement for yam

Land Qualities	100 – 85 S1	85 – 60 S2	60 – 40 S3	40 – 25 N1	<25 N2
Climate (c):					
Mean annual rainfall (mm)	1000 – 750/ 1200 – 1600	750 – 600	600 – 550	550 – 500	<500
Mean annual temperature (ºC)	25 – 35	20 – 25	15 – 20	<15	<15
Soil texture	SL, SCL, CS, SiCL, CL, L,	Cs, LFs, LS, LCs	Cs, S	SC, Cm,	Cm, S
Fertility f:					
CEC (Cmol/kg)	>16	>10	<10	<5	<5
Base Saturation (%)	>35	>15	15 – 10	<10	<10
Organic Matter (g/kg OC) (0-15cm)	>15	>8	<5	<3	<3

Source: Sys (1985): S1: Highly suitable; S2: Suitable; S3: Moderately suitable; N: currently not suitable; N2; Permanently not suitable. Symbols used for soil texture and structures are defined as follows: Cs: structural clay; Cm: massive clay; SiCs: silty clay; SiCL: silty clay loam; CL: clay loam; Si: silt; L: loam; SCL: sandy clay loam; SL: sandy loam; LFs: loam fine sand; LCs: loam coarse sand; Fs: fine sand; S: sand

Table 2: Land and Soil Requirement for Cassava

Land Qualities	100 – 85 S1	85 – 60 S2	60 – 40 S3	40 – 25 N1	<25 N2
Climate (c)					
Mean annual rainfall (mm)	1000 – 1800/ 1800 – 2400	750 – 600/ >2400	600 – 550	550 – 500	<500
Mean annual temperature (˚C)	20 – 30/20-18	>30/18 – 16	16 – 14	14 – 12	<12
Soil texture	L, SCL, CL, SL, SiCL, SiC	Cs, LFs, LS, LCS,Fs	CS, S, Cs	SC, Cm	Cm, S
Fertility (f)					
CEC (Cmol/kg)	>16	>10	<10	<5	<5
Base saturation (%)	>35	35 – 15	15 – 10	<10	<10
Organic matter (g/kg OC), (0-15cm)	>15	>8	>5	<3	<3

Source: Sys (1985): S1: Highly suitable; S2: Suitable; S3: Moderately suitable; N: currently not suitable; N2; Permanently not suitable. Symbols used for soil texture and structures are defined as follows: Cs: structural clay; Cm: massive clay; SiC: silty clay; SiCL: silty clay loam; CL: clay loam; Si: silt; L: loam; SCL: sandy clay loam; SL: sandy loam; LFs: loam fine sand; LCS: loam coarse sand; Fs: fine sand; S: sand

Table 3: Land and Soil Requirement for Maize

Land Qualities	100 – 85 S1	85 – 60 S2	60 - 40 S3	40 – 25 N1	<25 N2
Climate (c):					
Mean annual rainfall (mm)	750 -1250/ 1250-1600	750 – 600/ 1600 -1800	600 – 500/ >800	550 – 500	<500
Mean annual temperature (˚C)	26 –18/ 26 – 32	18 - 16/ >32	36 – 32	32 - 30	<30
Soil texture	Cs, SiC, CL, SC, L, SCL	SL, LFs, LS	LCS, Fs	Cm, CL	Cm, Cs
Fertility f:					
CEC (Cmol/kg)	>24	>16	<16	<10	<10
Base saturation (%)	>50	35 – 50	15 – 35	<15	<15
Organic matter (g/kg OC) (0-15cm)	>15	8 - 15	5 - 8	<5	<5

Source: Sys (1985): S1: Highly suitable; S2: Suitable; S3: Moderately suitable; N: currently not suitable; N2; Permanently not suitable

Symbols used for soil texture and structures are defined as follows: Cs: structural clay; Cm: massive clay; SiC: silty clay; SiCL: silty clay loam; CL: clay loam; Si: silt; L: loam; SCL: sandy clay loam; SL: sandy loam; LFs: loam fine sand; LCS: loam coarse sand; Fs: fine sand; S: sand.

III. RESULTS

Summary of Morphological Characteristics

Profile 1 (EUP), Lat. 06^0 60'N Long. 007^0 39'E, located at Ekpe village, on the upper slope position with a gradient of 12% ; elevation 480m above sea level; shallow (< 50 cm deep); dark reddish brown(5YR3/4) A-horizon; granular structure; firm' slightly sticky, non- plastic sandy loam:. reddish brown (5YR4/8) B-horizon; granular structure; firm, slightly sticky, non- plastic sandy loam; clear smooth boundary

Profile 2 (EMP) : Lat. 06^0 60'N Long. 007^0 39'E, located at Ekpe village, on the mid- slope position with a gradient of 9%; elevation 478m above sea level; deep (50 cm deep*); dark* reddish brown (5YR3/4) A-horizon; granular structure firm, slightly sticky, non- plastic sandy loam: reddish brown(5YR4/8) B-horizon: granular structure; firm, slightly sticky, non- plastic sandy loam; clear smooth boundary.

Profile 3 (ETP) : Lat. 06^0 61'N, Long. 007^0 39'E. located at Ekpe village, on the toe- slope position with a gradient of 7% ; elevation 466m above sea level; deep (> 50 cm deep); darkish brown(10YR5/3) A-horizon; granular structure firm, slightly sticky, non- plastic sandy loam; red () B-horizon: granular structure; firm, slightly sticky, non- plastic sandy loam; clear smooth boundary.

Profile 1 (AUP): Lat. $06^0$63'N, Long. 007^0 39'E, located at Amadia village, on the upper- slope position with a gradient of 12% ; elevation 491m above sea level; deep (50 cm deep); reddish brown(5YR4/8) A-horizon; granular structure firm, non- sticky, non- plastic loamy sand; red () B-horizon: granular structure; firm, slightly sticky, non- plastic sandy loam; clear smooth boundary

Profile 2 (AMP) : Lat. $06^0$63'N, Long. 007^0 39'E, located at Amadia village, on the mid-slope position with a gradient of 8% ; elevation 475m above sea level; deep (50 cm deep); reddish brown(5YR4/8) A-horizon; granular structure firm, non- sticky, non- plastic loamy sand:. reddish brown (5YR4/8) B-horizon: granular structure; firm, slightly sticky, non- plastic sandy loam; clear smooth boundary.

Profile 3 (ATP): Lat. $06^0$63'N, Long. 007^0 39'E. located at Amadia village, on the toe- slope position with a gradient of 5% ; elevation 460m above sea level; deep (> 50 cm deep); reddish brown(5YR4/8) A-horizon; granular structure firm, slightly sticky, non- plastic sandy loam; red (5Y4/6) B-horizon: granular structure; firm, slightly sticky, non- plastic sandy loam; clear smooth boundary.

Physical Properties

Table 4 shows that the dominant fine-earth fraction in all the soils is sand followed by clay especially in soils of the toposequence located at Ekpe Village (EUP, EMP and ETP). In the case of soils of the toposequence at Amadia village (AUP, AMP and ATP), the clay and silt fractions were almost similar, all ≤110 g kg^{-1} except in the subsurface horizon of ATU with silt content of 130 g kg^{-1}. In all the soils the clay content was always higher in the subsurface layers but remained almost the same down the toposequence indicating that vertical transfer dominated over lateral transfer of clay fractions in the soils. The clay values were either 130 g kg^{-1} or 150 g kg^{-1} in the topsoils of all the profile at Ekpe (EUP, EMP and ETP) but remained 150 g kg^{-1} in the subsoil layers. The clay values ranged from 70 g kg^{-1} to 110 g kg^{-1} in the topsoils of profile at Amadia profiles AUP, AMP and ATP) and 90 g kg^{-1} to 110 g kg^{-1} in the subsoil layers. The silt content ranged from 120 g kg^{-1} to 150 g kg^{-1} in all the soils. Fine sand ranged from 82 g kg^{-1} to 240 g kg^{-1} in Ekpe profiles and 200 to 290 g kg^{-1} in Amadia profiles while coarse sand ≥529 g kg^{-1} in the soils. The textures (Table 4) were generally sandy loam except in the Amadia upper and midslope profiles (AUP and AMP).

Table1: Result of Soil Particle Size Analysis

Horizons Depth (cm)	Clay	Silt	Fine sand	Coarse sand	Textural Class
	____________________g kg^{-1} ____________________				
		Profile 1 (EUP)			
0-20	130	120	190	560	Sandy Loam
20-45	150	150	171	529	Sandy Loam
		Profile 2 (EMP)			
0-25	130	130	150	590	Sandy Loam
25-50	150	150	82	618	Sandy Loam
		Profile 3 (ETP)			
0-30	130	120	139	611	Sandy Loam
30-60	150	130	164	556	Sandy Loam
		Profile 1 (AUP)			
0-25	70	90	240	600	Loamy Sand
20-50	90	110	249	551	Loamy Sand
		Profile 2 (AMP)			
0-30	90	90	290	530	Loamy Sand
30-60	90	110	240	560	Loamy Sand
		Profile 3 (ATP)			
0-30	110	110	200	560	Sandy Loam
30-65	110	130	205	555	Sandy Loam

Note: EUP= Ekpe Upper slope Profile; EMP= Ekpe mid- Slope Profile; ETP= Ekpe Toe Slope Profile; AUP= Amadia Upper Slope Profile; AMP= Amadia Mid-Slope Profile; ATP= Amadia Toe Slope Profile

Chemical Properties

Table 5 shows that all the soils were generally acidic in reaction with all the pH values in the acid range (< 6.0). The SOM contents in all the soils were low to very low (< 2.0 g kg^{-1}) except in AUP profile and topsoil of AMU profile where the values were moderate (> 2.0 g kg^{-1}). The exchangeable cations were generally low to medium and in decreasing order of Mg > Ca> K>Na. The total exchangeable bases was also low and occupies small proportion of the ammonium acetate CEC, thus resulting in all the base saturation values less than 50% (Table 5). These corroborate the values of pH and exchangeable acidity (EA) showing that the soils were acidic in reaction. The available phosphorus (AvP) values were generally low. The highest values obtained ≈7 mg kg^{-1} and 9 mg kg^{-1} were from the subsoil layer and topsoil of profiles ETP and AUP respectively. Other values obtained were less than 5 mg kg^{-1} (Table 5).

Table 5: Results of Chemical Analysis

Horizon	pH		SOM	TN	Ca	Mg	K	Na	EA	CEC	BS	AvP
(cm)	H_2O	KCl	_ g kg^{-1} __		_________Cmol kg^{-1} _________						%	mg kg^{-1}
Profile 1 (EUP)												
0-20	5.6	4,3	1.169	0.014	0.080	1.00	0.04	0.02	1.0	12.0	10	4.7
20-45	5.3	4.2	1.857	0.042	1.000	1.20	0.06	0.04	1.4	12.0	18	3.7
Profile 2 (EMP)												
0-25	5.3	4.3	0.751	0.070	1.000	1.20	0.03	0.10	1.8	14.0	17	2.8
25-50	5.2	4.3	1.376	0.028	1.200	1.40	0.06	0.03	2.0	12.0	21	3.7
Profile 3 (ETP)												
0-30	5.3	4.2	1.032	0.028	1.400	1.60	0.04	0.02	2.0	11.6	26	4.7
30-60	5.1	4.2	0.688	0.028	2.000	1.60	0.02	1.26	2.4	8.0	46	6.7
Profile 1 (AUP)												
0-25	5.6	4.4	2.614	0.042	0.400	1.20	0.09	0.05	0.8	10.4	17	9.3
20-50	5.3	4.3	2.476	1.363	0.600	1.60	0.19	0.11	1.4	8.4	30	3.7
Profile 2 (AMP)												
0-30	5.4	4.3	2.132	0.070	0.80	1.60	0.07	0.04	1.6	11.0	23	3.7
30-60	5.2	4.2	1.788	0.028	1.20	1.60	0.06	0.03	2.0	8.8	33	1.9
Profile 3 (ATP)												
0-30	5.2	4.2	1.926	0.126	1.20	2.0	0.06	0.04	2.0	10.0	33	2.8
30-65	5.3	4.2	0.894	0.210	1.80	2.4	0.08	0.02	2.0	9.2	47	1.9

Note; SOM= Soil Organic Matter; EA= Exchangeable Acidity; TN= Total Nitrogen; CEC= Cation Exchange Capacity; BS= Base Saturation; AvP= Available Phosphorus; EUP= Ekpe Upper slope Profile; EMP= Ekpe mid- Slope Profile; ETP= Ekpe Toe Slope Profile; AUP= Amadia Upper Slope Profile; AMP= Amadia Mid-Slope Profile; ATP= Amadia Toe Slope Profile

Suitability Assessment For The Yam, Cassava And Maize Production

Based on the morphological and physical properties of the soils obtained as well as the average climatic variables in the area (Asadu, 2002), all the three crops are highly suitable (S1) for production in the area. The major constraints are the chemical properties. However, soil pH, exchangeable Mg (Howler, 2002) and Na (no sodicity) would place the soils also in S1 class. By the same principle of matching TN and K values obtained would place the soils in N1 class (currently not suitable) supported by FPDD (1989) even though Chukwu *et al*. (2007) reported that major yam soils of southeastern Nigeria are deficient in total N corroborating earlier report (Asadu et.al., 1990). Again AvP, CEC, BS, Ca obtained placed the soils into S2 class (Moderately suitable). A combination of all the data suggest that all the soils are moderately suitable (S2) for the production of the yam, cassava and maize due some soil fertility constraints relating to TN and excK. Thus they were classified into S2f subclass as fertility constraints are their limiting factors. Therefore for optimum production of the crops application of compound mineral fertilizers such as NPK 20:10:10 or 15:15:15 at the rate of at least 300 kg ha^{-1} for yam, 250 kg ha^{-1} for cassava and 200 kg ha^{-1} for maize is recommended.

IV. DISCUSSION

The soils which are generally deep suggest that they would not offer resistance to crop roots and the development yam tubers and tuberous roots of cassava. The reddish brown colours indicate that the soils are well drained also favouring the growth of the crops which prefer such soils to waterlogged soils. The particle size distributions and soil textures (sandy loam and loamy sand) reflect the influence of parent materials on the soils as earlier reported by Akamigbo and Asadu (1983). The dominance of coarse particle (sand) over fine ones (clay and silt) has also been reported, particularly for silt which is well known to low in soils of eastern Nigeria (Akamigbo, 1984) The textures are also good for the production of the three crops (Sys 1985).

The generally poor fertility status of the soils is a reflection of the influence of parent material and climate of the area. The soils developed from false bedded sand stone material (Asadu 1986) and high rainfall amount and intensity lead to nutrient leaching generally characteristic of the area (Asadu and Akamigbo, 1986; Asadu et al., 1990}. This poor chemical fertility status of the soils led to the classification of the soils into suitability sub class S2f. The implication is that chemical nutrients especially NPK need to be applied in the soils to support optimum production of yam, cassava and maize in the area.

V. CONCLUSION AND RECOMENDATION

Generally the soils have suitable morphological and physical properties that can support the production of yam, cassava and maize but poor chemical fertility especially with respect to major nutrients NPK. Thus chemical fertility is the major limiting factor for the optimum production of these crops. It is recommended that NPK compound fertilizers should be applied to ensure optimum production of the crops. However, to ensure sustainability of production and maintain the good physical properties of the soil this should be done in combination with organic matter application.

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