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Characterization and Management of Some Inland Depression Soils For Sustainable Crop Production in Southeastern Nigeria

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Abstract:
This study was conducted to characterize some inland depression soils in Southeastern Nigeria and recommend management option for sustainable crop production. Eight profile pits were sited at Ekpene Ukpa (Ek_1), Nung Obong (NO_3 and NO_4), Ikot Obong (KS_2), Ibiaku Ikot Obong (TU_{16}), Ikot Eto (ND_{15}), Awa Ntong (AU_{17}) and Ikot Okobo (AU_{18}) depressions. Results showed that soil texture ranged from sand through sandy loam to sandy clay loam. Soil reaction varied from very strongly to moderately acid (3.0 - 6.0) with pH value averaged 5.0 ± 0.4. Organic matter content was high in the surface soils (23.22 - 51.43gkg^{-1}) while total N level was low (0.1 – 1.3gkg^{-1}). Available P (4.26 - 253$mgkg^{-1}$) ranged from low to very high. Cation exchange capacity (CEC) was low while percentage base saturation ranged from moderate to high (33 - 83%). The main constraints to sustainable crop production in these soils are low chemical fertility (moderate to high exchange acidity, low CEC, total N level, high percent Al saturation, 20 - 98%) and rapid weed growth. Slash and mulch system along with crop residues return and application of green leaf manures to the soil could affect several restorative processes in addition to suppressing weed growth. Mineral fertilizers, if available could have the desired effect on the soil by increasing biomass production for use as residue mulch and yield of crops.

Keywords: Inland wetlands, characteristics, soil management, crop production, Nigeria.

INTRODUCTION

Wetland soils varied widely and are extensive throughout Nigeria. In Nigeria large areas of wetland soils with potential for food production remain undeveloped. Various types of wetlands found include inland valleys, inland basins (depressions), river flood plains and coastal plains or coastal swamps (Andriesse, 1986). Inland depressions or inland basins belong to an area of wetland (water saturated) soils in Nigeria quantitatively undocumented as they have neither been mapped nor studied at all (Omoti, 2001). These are soils whose development and properties are strongly influenced by temporary or permanent saturation in the upper part of the pedon (Moormann and van de Wetering, 1985, Akinbola, 2001).

Inland depression soils comprise extensive depressions (Udo, 2001) and occupy a sizeable area of the wetland soils in the Niger Delta of Nigeria which could offer the greatest potentials as the nations food basket because the tropical climate and increasing demand for food make wetland soils especially attractive for agricultural development (Guthrie, 1984). Inland depression soils are poorly drained due to flooding from the surface, overland flow and poor underground drainage outlets.

Given that water is sometimes one of the most critical factors in agricultural production (Omoti, 2001), this wetland could serve as nature’s gift, and if properly harnessed could sustain long growing season (Juo and Hossner, 1992). However, wetlands in Akwa Ibom State are hardly utilized at the moment for any beneficial agricultural production. The lack of adequate scientific knowledge and arduous and teduous agronomic tasks on the soils than their upland counterparts (Eshett, 1990) contribute to their underutilization.

The desire to expand food production to wetland soils in the face of declining productivity from their upland counterparts, population pressure on existing agricultural lands and surging food prices in the country underscores the need for an in-depth study of the characteristics, assess the constraints and management options of some inland depressions soils for sustainable crop production in Akwa Ibom State, Southeastern Nigeria.

MATERIALS AND METHODS

Environment of study area

Akwa Ibom State is located at latitudes 4.5° and 5.5°N and longitudes 7.5° and 8.7°E. The climate is humid tropical, characterized by long wet season (April - October) with heavy annual rainfall (2000 - 4000mm) and short dry season (November - March). The wet season is interrupted by a stress period of relative dryness in August, known as 'August Break', which gives rise to bimodal pattern of rainfall and varies in duration from year to year. Equally, there is a short period of relative coldness and hazy weather from late December to January, known as the *Harmattan*. Temperatures are uniformly high throughout the year with slight variation between 23 - 30°C,

The above climatic factors favour luxuriant tropical rainforest with teaming populations of insect pest and fauna of extremely high terrestrial and aquatic biomass (SLUS-AK, 1989). The soils are formed on coastal plain sands and beach reach sands parent materials and are collectively called Acid sands (Obioro, 1961). The soils are subjected to severe weathering conditions and the most abundant clay mineral is kaolinite (Udo, 1977, Jungerius and Levelt, 1964).

Field Studies

Eight representative soil profile pits were sited in selected inland depressions soils (IDS) at Ekpene Ukpa (EK$_1$), Nung Obong I (NG$_3$) and Nung Obong 11 (NG$_4$), Ikot Obong (KS$_2$), Ibiaku Ikot Obong (TU$_{16}$), Ikot Eto (ND$_{15}$), Awa Ntong (AU$_{17}$) and Ikot Okobo (AU$_{18}$). Locations of the profile pits, parent materials, vegetation/land use and soil classification are presented in Table 1. Soil profile horizons were demarcated, described and sampled (FAO, 1990). As a result of high water table in four of the profiles (MG$_4$, ND$_{15}$, AU$_{17}$ and AU$_{18}$) a regular 20cm vertical interval was used in their descriptions. Soil colours were described (Munsell Colour Chart) and texture determined (Glossary of Soil Science Terms, 1987). Soil samples were taken from all horizons distinguished in the profile pit and bagged in properly labelled polyethylene bags for laboratory analysis.

Table 1: Summary of Profile Location, Parent Material, Vegetation/Land Use and Soil Classification

Profile No/Location	Parent Material	Vegetation & Landuse	Soil Classification (USDA/FAO)*
EK$_1$ 4°48'30"N, 7°50'40"E	CPS	Farmland	Oxic Dystropept; Dystric Cambisol
NG$_3$ 04°42'10"N, 07°59'08"E	CPS	Farmland	Typic Tropaquept; Gleyic Cambisol
NG$_4$ 04°42'10"N, 07°59'09"E	CAD	Farmland	Typic Tropaquept; Gleyic Cambisol
KS$_2$ 04°46'18"N, 07°43'37"E	BRS	Farmland	Typic Paleudult; Eutric Nitosol
TU$_{16}$ 05°10'50"N, 07°51'57"E	CPS	Farmland	Typic Tropudult; Orthic Acrisol
ND$_{15}$ 04°57'28"N, 07°59'16"E	CPS	Farmland	Oxic Dystropept; Dystic Cambisol
AU$_{17}$ nd	CPS	Farmland	Oxic Dystropept; Dystic Cambisol
AU$_{18}$ nd	CPS	Farmland	Typic Paleudult; Dystric Nitosol

*Soil Survey Staff (1990), FAO/UNESCO (1988), nd – not determined, CPS - Coastal plain sands, BR – Beach ridge sands, CAD – Colluvio – alluvial deposit.

Laboratory Method

Soil samples were processed for mechanical and chemical analyses. Particle size distribution was determined by Bouyoucos hydrometer method (Klute, 1986) while chemical analysis followed standard methods (Sparks, 1996) for pH, organic C, total N, available P, electrical conductivity (EC), exchangeable bases (Ca, Mg, K, Na) and exchange acidity (EA). Cation exchange capacity (CEC), percent base saturation (BS) and C/N ratio were obtained by calculations. Correlation coefficients were calculated among various soil variables to assess their relationships.

RESULTS AND DISCUSSION

Some Physical and Morphological Properties of Inland Depression Soils

Particle size distribution, texture and colour values of inland depressions soils are presented in Table 2. Four profiles (NG_4, ND_{15}, AU_{17} and AU_{18}) were characterized by aquic soil moisture regime as defined by soil taxonomy, or hydromorphic properties according to the terminology in the soil Map of the World. Other profiles (EK_1, NG_3, KS_2, TU_{16}) were saturated only in the lower horizons and thus belong to aquic subgroup (Wilding and Rchage, 1985).

Textural distribution did not follow any regular pattern in the profiles. Most of the soils were coarsed textured with KS_2 and NG_3 profiles having the most sandy texture. In others, the textures were much finer covering the sandy loam in the surface (TU_{16}, EK_1 and AU_{17}) and sandy clay loam (TU_{16}, AU_{17}) in the subsoil and mixed sandy loam and loamy sand textures in the NO_4, ND_{15} and AU_{18} profiles.

The sand fraction was the dominant particle size and ranged from 502.2 in the EK_1 to 936.2gkg^{-1} in the KS_2 with a mean of 719gkg^{-1}; silt fraction ranged from 20 in the KS_2 to 160 in the NG_4 with a mean of 80gkg and clay fraction ranged from 18 in the ND_{15} to 398 in the TU_{16} with a mean of 209gkg^{-1}, respectively. The clay fraction was observed to increase while sand decrease with profile depth. The silt to clay ratios of the soils showed values dominantly less than unity except in the surface and subsurface of the NG_4 and ND_{15} profiles, signifying low ratios and this type of results indicate soils with pedogenitically feralitic in nature (Ashaye, 1965). The low silt + clay contents indicates that the soils have no weatherable minerals or are highly weathered, as reflected in the low silt/clay ratios.

Chemical Properties of Inland Depression Soils

The chemical characteristics of the soil are presented in Tables 3 and 4. The pH in water suspension ranged from very strongly acid (3.9) in the NG_4 to moderately acid (6.0) in the TU_{16} profiles with a mean of 5.0 ± 0.4. In KCI solution, the pH ranged from 3.2 in the NG_4 to 5.3 in the same TU_{16} with a mean of 4.5 ± 0.3. In all the cases, the pH values in water suspension were higher by about 0.5 units than corresponding values, in a molar KCI solution (Table 3), indicating a net negative charge on exchange complex. The pH values were observed to increase with depth in the NG_3, KS_2 and TU_{16} profiles while in others (EK_1, ND_{15}, AU_{17} and AU_{18}), there was no regular pattern of distribution within their profiles. In general, soil pH ranged from very strongly to moderately acid. Effiong and Ibia (2009) and Effiong and Ayolagha (2010) have obtained similar results in some wetland soils in Akwa Ibom State.

Exchange acidity values ranged from low to high (0.24 - 6.12 cmolg^{-1}) with a mean of 2.46 ± 1.7 cmolkg^{-1}. Higher values of exchange acidity were found in the EK_1 (3.12 - 6.00 cmolkg^{-1}), TU16 (2.56 - 5.12 cmolkg^{-1}) and AU_{17} (3.48 - 4.70 cmolkg^{-1}) with means of 5.13 ± 1.39, 3.82 ± 1.38 and 4.13 ± 0.44 cmolkg^{-1}, respectively. Lower values of exchange acidity were observed for the NG_3 (0.60 - 1.80), NG_4 (1.44 - 2.28), KS_2 (0.36 - 1.92), ND_{15} (1.20 - 3.04) and AU_{18} (0.72 - 1.92) with mean values of 0.98 ± 0.48, 1.78 ± 0.32, 0.82 ± 0.63, 1.94 ± 0.78 and 1.08 ± 0.56 cmolkg^{-1} for NG_3, NG_4, KS_2, ND_{15} and AU_{18}, respectively. Meanwhile exchange acidity value tended to decrease with profile depth in the NG_3, NG_4, ND_{15} and AU_{18} profiles.

Exchangeable Al ranged from low to relatively high (0.12 - 3.48cmolkg^{-1}) with mean Al saturation being between 13-98%. Landon (1990) stated that percent Al saturation > 30% affect sensitive crops while Kyuma, (1985) observed that values > 60% could lead to Al toxicity. A concentration of exchangeable Al of more than l cmolkg^{-1} in the soil solution could lead to Al toxicity (Amberger, 2006), implying that such large concentration obtained for the TU$_{16}$, EK$_1$ and AU$_{17}$ with mean percent Al saturation of 98.9, 80.5 and 81.3% can restrict root development and affect water absorption by plants resulting in Al toxicity and yield reduction.

Table 2: Some Physical and Morphological Properties of Wetland Soil

	Depth (cm)	**Sand**	**Silt**	**Clay**	**Texture**	**Colour values (Munsell)**
		(gkg^{-1})				
	0 – 14	756.2	106.8	137.0	SL	7.5 YR 3/1
	14 – 46	776.2	86.8	137.0	SL	10 YR 3/2
EK$_1$	46 – 68	792.2	86.8	117.0	SL	7.5 YR 4/3
	68 – 90	656.2	71.8	277.0	SCL	7.5 YR 6/2
	x ± SD	746.2 ± 62.2	88.05 ± 14.4	167.0 ± 73.9	SL	
	0 – 17	856.2	69.2	77.0	S	10 YR 4/1
	17 – 51	896.2	46.8	57.0	S	10 YR 6/4
NG$_3$	51 – 98	836.2	46.8	117.0	SL	7.5 YR 4/3
	98 – 123	856.2	46.8	97.0	S	7.5 YR 4/2
	123 – 143	856.2	46.8	97.0	S	10 YR 5/2
	x ± SD	860.2 ± 21.9	51.3 ± 10.0	89.0 ± 22.8	S	
	0 – 20	816.2	120.0	63.8*	S	7.5 YR 7/1
	20 – 40	716.2	160.0	123.8*	SL	7.5 YR 5/2
NG$_4$	40 – 60	856.2	40.0	103.8	SL	7.5 YR 5/1
	60 – 80	776.2	100.0	123.8	SL	7.5 YR 6/1
	80 – 100	756.2	100.0	143.8	SL	7.5 YR 6/1
	x ± SD	784.2 ± 54.0	104.0 ± 43.4	111.8 ± 30.3	SL	
	0 – 17	936.2	nd^1	63.8	S	7.5 YR 5/2
	17 – 38	936.2	nd	63.8	S	10 YR 6/2
KS$_2$	38 – 50	936.2	nd	63.8	S	2.5 YR 4/1
	50 – 75	916.2	20.0	63.8	S	2.5 YR 4/1
	75 – 90	916.2	20.0	63.8	S	7.5 YR 5/1
	x ± SD	928.2 ± 10.6	20.0 ± 0.0	63.8 ± 0.0	S	
	0 – 11	700.4	102.4	197.2	SL	10 YR 4/3
	11 – 20	620.4	102.4	257.2	SCL	10 YR 4/4
TU$_{16}$	20 – 51	560.4	62.4	357.2	SCL	10 YR 4/6
	51 – 83	502.0	80.0	398.0	SCL	10 YR 5/4
	x ± SD	595.8 ± 84.8	86.8 ± 19.4	302.4 ± 91.7	SCL	
	0 – 20	902.0	80.0	18.0*	SL	7.5 YR 5/2
	20 – 40	842.0	40.0	118.0	LS	7.5 YR 4/2
ND$_{15}$	40 – 60	882.0	40.0	78.0	S	7.5 YR 4/4
	60 – 80	782.0	100.0	178.0	SL	7.5 YR 4/4
	x ± SD	852.0 ± 52.9	65.0 ± 30	98.0 ± 67.3	SL	
	0 – 20	776.2	66.8	157.0	SL	10 YR 4/3
	20 – 40	696.2	106.8	197.0	SL	10 YR 4/4
AU$_{17}$	40 – 60	682.2	86.8	257.0	SCL	10 YR 4/6
	60 – 80	636.2	46.8	317.0	SCL	10 YR 5/4
	80 – 100	616.2	46.8	337.0	SCL	10 YR 5/4
	x ± SD	681.4 ± 62.3	70.8 ± 26.1	253.0 ± 76.7	SCL	
	0 – 20	836.2	60.0	101.8	LS	
	20 – 40	836.2	40.0	123.8	SL	
AU$_{17}$	40 – 60	816.2	40.0	143.8	SL	nd^2
	60 – 80	856.2	40.0	103.8	LS	
	x ± SD	836.2 ± 16.3	45.0 ± 10	118.3 ± 19.7	SL	

S – Sand, SL –Sandy loam, LS – Loamy sand, SCL – Sandy clay loam; nd^1 – not described, nd^2 – not detected

Electrical conductivity (EC$_{25}$) of the saturation extract was low (0.014 - 0.280 dSm^{-1}), being less than 1.0dSm^{-1} in all the profiles examined, indicating non saline nature of the soils and absence of salinity problem to any crops that would be grown. Crops are sensitive to salinity values > 2dSm1 (FAO, 1988).

Exchangeable bases of the soils were low with Na and K values being lower than those of Ca and Mg (Table 3). The exchangeable K (0.05 - 0.l2cmolkg^{-1} was very low in all the profiles with values being below 0.2cmolkg^{-1} regarded as the critical value of K availability in the soil (Kyuma, 1985; NSPFS, 2005). In the FAO (1976) fertility evaluation, the soils would be placed in the S$_3$ category (marginally suitable) for crop production with respect of K availability.

The level of exchangeable Ca ranged from l cmolkg^{-1} in the KS$_2$ to 2.88cmolkg^{-1}' in the EK$_1$ profiles, with values higher than 2cmolkg^{-1} in the surface horizon of the EK$_1$, NG$_3$, NG$_4$, NS$_{15}$, AU$_{17}$ and AU$_{18}$ profiles (Table 3). The values are far below 4cmolkg^{-1} regarded as the lower limit for fertile soils. Exchangeable Mg values (0.4 - 1.30cmolkg^{-1}) were high with the surface profiles having values >0.5cmolkg^{-1}, regarded as the critical value (Landon, 1990). Exchangeable Na was generally low with values remaining below 0.lcmolkg^{-1}, therefore the problem associated with excess Na would not be encountered in these soils. The cation exchange capacity (CEC) values were rated very low since all the soils contained less than 5cmolkg' soil. This agrees with Amberger (2006) that in acid soils of the humid tropics, the base cations (K, Ca, Mg) tend to be deficient.

The low level of CEC may probably be due to absolute low value in the soil minerals which are dominantly kaolinitic or/that exchangeable bases (Ca, Ma, K) are removed by leaching/sedimentation. Exchangeable cation ratio, especially Ca/Mg ratio is known to affect the growth of plants with approximate optimum range of Ca/Mg ratio of 3:1 - 4:1 (Landon, 1990). The values recorded for these soils (mean for surface layers) were below 3:1. These low values indicate low availability of Ca and preponderance of Mg ions over those of Ca. This may lead to weakening of the soil structure because of deflocculation of the clay by the preponderant Mg ions. However, the low contents of K and Na indicates that soil dispersion is unlikely.

The soils have a wide range of percent base saturation, with values ranging from 23.92 in the TU$_{16}$ to 83.43% in the NG$_4$ profiles (Tables 3). Five profiles, NG$_3$ (76.96 ± 5.8%), NG$_4$ (63.28 ± 3.7%), KS$_2$ (70.8 ± 14.1%), ND$_5$ (67.52 ± 7.9%) and AU$_{18}$ (76.55 ± 6.6%) have mean values above 50% (critical limit) and are described as eutric, indicating high potential fertility, while the EK$_1$ (41.46 ± 6.8%), TU$_{16}$ (34.50 ± 10.5%) and AU$_{17}$ (44.20 ± 4.7%) profiles have mean values much less than 50%. Those profiles are described as being dystric and potentially less fertile (Landon, 1990), with respect to percent base saturation.

Although the soils were generally acidic, the degree of base saturation was high, confirming observation by Clark (1966) that some soils are base saturated at pH 5, which explains why acid sensitive crops can be grown on some tropical soils with pH values about 5.5, and why liming does not increase their yield (Russell, 1973).

The organic C content varied widely among the soils and within the profiles studied (Table 4). The values ranged from 0.8 in the ND$_{15}$ to 29.9gkg^{-1} in the TU$_{16}$ profiles. Mean organic C content in each profile was in the order: AU$_{17}$ > NG$_3$ NG$_4$> TU$_{16}$> EK$_1$ > AU$_{18}$ > ND$_{15}$ > KS$_2$. All the profiles had substantial amount of organic C content in the surface soils (23.22 - 51.43gkg^{-1}), an indication of high organic matter level, implying the presence of nutrients like N and P in sufficient amount for plant growth. A combination of biomass production by plants and reduced microbial decomposition in waterlogged soil resulted in the accumulation of soil organic matter, producing the surficial organic - rich horizon common to many hydric soils. (Patrick, 1990; Effiong and Ibia, 2009).

Table 3: Some Chemical Properties of Wetland Soils Studied

Depth (cm)		pH		EC$_{25}$°	EA	EAl	Ca	Mg	K	Na	CEC	BS	PAS
		H_2O	Kcl	(dSm^{-1})	cmolkg^{-1}				cmolkg^{-1}			1-(%)-1	(mean)
EK$_1$	0 – 14	4.7	4.0	0.087	5.28	3.12	2.40	1.20	0.12	0.07	3.79	41.79	

	14 – 46	4.7	4.1	0.059	6.12	3.36	2.88	1.30	0.11	0.06	4.35	41.55	
	46 – 68	4.6	4.0	0.058	3.12	1.44	1.92	1.00	0.10	0.06	3.08	49.68	
	68 - 90	4.5	4.0	0.073	6.00	3.48	1.90	0.90	0.08	0.05	2.93	32.81	
	x ± SD	4.6±0.1	4.0±0.05	0.069±0.01	5.13±1.39	2.85±0.95	2.28±0.46	1.1±0.18	0.10±0.02	0.06±0.008	3.54±0.65	41.46±6.89	80.5
NG$_3$	0 – 17	4.7	4.3	0.055	1.80	1.20	2.40	1.20	0.09	0.07	3.76	67.63	
	17 – 51	5.1	4.7	0.045	0.98	0.36	2.16	1.00	0.09	0.06	3.31	77.76	
	51 – 98	5.2	4.1	0.050	0.84	0.24	2.00	1.00	0.08	0.06	3.14	78.89	
	98 - 123	5.4	4.5	0.066	0.60	0.24	1.90	1.00	0.07	0.05	3.02	83.43	
	123-143	5.2	4.8	0.033	0.72	0.36	1.60	0.80	0.07	0.04	2.51	77.71	
	x ± SD	5.1±0.3	4.5±0.3	0.050±0.012	0.99±0.48	0.48±0.41	2.01±0.29	1.00±0.14	0.08±0.01	0.06±0.01	3.15±0.45	76.96±5.77	15.2
NG$_4$	0 – 20	5.3	4.8	0.087	2.28	1.32	2.08	1.00	0.10	0.06	3.24	58.69	
	20 – 40	5.1	4.8	0.059	1.80	1.26	2.00	1.00	0.09	0.05	3.14	63.56	
	40 – 60	3.9	3.2	0.058	1.44	0.72	2.00	0.90	0.08	0.05	3.03	67.78	
	60 – 80	5.3	5.0	0.073	1.56	0.84	2.00	0.90	0.07	0.04	3.01	65.86	
	80 – 100	5.2	4.8	0.066	1.80	1.20	1.96	0.70	0.07	0.03	2.76	60.53	
	x ± SD	4.96±0.6	4.5±0.7	0.069±0.012	1.78±0.32	1.07±0.28	2.01±0.04	0.90±0.12	0.08±0.01	0.05±0.01	3.04±0.18	63.28±3.73	35.2
KS$_2$	0 –	5.1	4.6	0.100	0.60	0.24	1.48	0.60	0.07	0.05	2.20	76.57	

	17												
	17 – 38	5.1	4.6	0.125	0.60	0.24	1.30	0.50	0.06	0.05	1.91	76.09	
	38 – 50	5.6	5.2	0.046	0.36	0.12	1.20	0.50	0.05	0.04	1.79	83.26	
	50 – 75	5.6	5.1	0.045	0.60	0.24	1.00	0.40	0.05	0.03	1.48	71.15	
	75 – 90	5.6	5.2	0.041	1.92	0.96	1.20	0.40	0.05	0.03	1.68	46.67	
	x ± SD	5.4±0.3	4.9±0.3	0.071±0.04	0.82±0.63	0.36±0.34	1.24±0.17	0.48±0.08	0.06±0.008	0.04±0.01	1.81±0.27	70.75±14.13	19.9
TU$_{16}$	0 – 11	5.2	4.7	0.250	2.56	1.48	1.20	0.60	0.07	0.05	1.92	42.86	
	11 – 20	5.3	4.3	0.123	2.72	1.30	1.44	0.60	0.06	0.05	2.15	44.15	
	20 – 51	6.0	5.3	0.193	5.12	2.26	1.00	0.50	0.07	0.04	1.61	23.92	
	51 – 83	5.6	4.9	0.115	4.80	2.37	1.30	0.40	0.05	0.03	1.78	27.05	
	x ± SD	5.5±0.4	4.8±0.4	0.017±0.06	3.82±1.38	1.85±0.54	1.19±0.51	0.53±0.10	0.06±0.09	0.04±0.009	1.87±0.23	34.50±10.50	98.9
ND$_{15}$	0 – 20	4.0	4.0	0.169	1.76	1.07	2.80	1.40	0.12	0.07	4.39	71.38	
	20 – 40	5.0	4.4	0.091	3.04	1.92	2.56	1.20	0.11	0.06	3.93	56.38	
	40 – 60	5.0	4.8	0.078	1.76	1.00	2.40	1.10	0.10	0.06	3.66	67.38	
	60 – 80	4.9	4.2	0.086	1.20	0.76	2.40	1.00	0.10	0.06	3.56	74.79	
	x ± SD	4.7±0.5	4.4±0.3	0.106±0.04	1.94±0.78	1.19±0.51	2.54±0.19	1.18±0.17	0.11±0.009	0.06±0.005	3.89±0.37	67.52±7.99	49.1
AU$_{17}$	0 – 20	4.2	3.9	0.014	4.20	2.88	2.40	1.10	0.09	0.06	3.65	46.49	
	20 – 40	4.4	3.9	0.083	4.20	3.12	2.16	1.00	0.08	0.06	3.30	44.00	
	40	4.6	4.0	0.067	3.48	2.04	2.40	1.00	0.08	0.05	3.52	50.29	

	– 60											
	60 – 80	4.5	4.1	0.068	4.08	2.40	2.00	0.90	0.07	0.05	3.02	42.54	
	80 - 100	4.5	4.2	0.072	4.70	2.88	1.92	0.80	0.08	0.04	2.84	37.77	
	x ± SD	4.4± 0.15	4.0± 0.13	0.061± 0.03	4.13± 0.44	2.66± 0.44	2.18± 0.22	0.96± 0.11	0.08± 0.007	0.05± 0.008	3.27± 0.34	44.20± 4.67	81.3
AU$_{18}$	0 – 20	4.8	4.3	0.041	1.92	0.96	2.56	1.20	0.10	0.07	3.93	67.18	
	20 – 40	5.2	4.7	0.071	0.84	0.24	2.40	1.10	0.08	0.06	3.64	81.25	
	40 – 60	5.0	4.6	0.041	0.84	0.36	2.16	1.10	0.07	0.05	3.38	76.47	
	60 – 80	5.0	4.7	0.048	0.72	0.24	2.00	1.00	0.07	0.06	3.13	81.30	
	x ± SD	5.0± 0.16	4.6± 0.19	0.050± 0.19	1.08± 0.56	0.45± 0.34	2.28± 0.25	1.1±0 .08	0.08± 0.01	0.06± 0.008	3.52± 0.34	76.55± 6.64	12.8

EC – electrical conductivity, EA – exchange acidity, EAl – exchangeable Al, PAS – percent Al saturation.

Total N levels were low, ranging from 0.1 - 1.3 with a mean of 0.63gkg^{-1}, and values decreased significantly with profile depth. The moderate to high C/N ratio of 14 – 36 (mean 24) is indication of materials with poor N concentrations in the soil. The C/N ratio was slightly higher in the samples from the EK$_1$, KS$_2$, TU$_{16}$, AU$_{17}$ and AU$_{18}$ compared to the remaining sites, suggesting that organic matter in the former sites would be in a lower degree of decomposition than in the later, due to reduced microbial activity in the anaerobic and water saturated environment. As C/N ratio increased total N decreased confirming observation by Stevenson and Cole (1999) that increased C/N ratio (> 30) provided good conditions for net loss of N resulting in lower N reserve in such soils. The soils have low (TU$_{16}$) to high (KS$_2$, AU$_{18}$, NG$_3$) levels of P, and in most cases P values were very high (EK$_1$, NG$_4$, ND$_{15}$, AU$_{17}$), much higher than the critical available values (15 - 25mgkg^{-1}, Bray P methods) for well drained upland soils (Ibia and Udo, 1993). The observed P value could be attributed to organic matter mineralization, the main source as well as materials brought into the depression by runoff.

Table 4: Organic Carbon, Total Nitrogen and Available Phosphorus

	Depth	**Organic C**	**Total N**	**C/N**	**Available P**
	(cm)	(gkg^{-1}) $\longleftarrow$	$\longrightarrow$|		(mgkg^{-1})
EK$_1$	0 – 14	20.8	0.9	23	103.56
	14 – 46	19.7	0.8	25	106.64
	46 – 68	11.8	0.5	24	253.08
	68 – 90	5.7	0.2	27	159.60
	x ± SD	14.5 ± 7.1	0.6 ± 0.3	25 ± 1.7	156.47 ± 69.08
NG$_3$	0 - 17	26.0	1.1	24	22.38
	17 – 51	17.1	0.7	24	19.71

	51 – 98	16.0	0.7	23	14.39
	98 – 123	14.0	0.6	23	34.63
	123 – 143	13.3	0.6	22	37.29
	x ± SD	17.3 ± 5.1	0.74 ± 0.2	23 ± 0.8	25.68 ± 9.86
NG$_4$	0 – 20	28.1	1.2	23	199.80
	20 – 40	20.8	0.9	23	79.82
	40 – 60	17.8	0.8	22	14.92
	60 – 80	10.1	0.4	25	66.65
	80 – 100	9.0	0.4	23	103.89
	x ± SD	17.2 ± 7.9	0.74 ± 0.3	23 ± 2.	93.04 ± 67.98
KS$_2$	0 – 17	13.5	0.6	23	27.71
	17 – 38	5.0	0.2	25	20.62
	38 – 50	4.8	0.2	24	22.60
	50 – 75	3.0	0.1	30	17.70
	75 – 90	2.7	0.1	27	4.26
	x ± SD	5.8 ± 4.4	0.24 ± 0.2	26 ± 2.8	18.58 ± 8.80
TU$_{16}$	0 – 11	29.9	1.3	23	7.33
	11 – 20	16.8	0.7	24	7.99
	20 – 51	10.9	0.3	36	10.66
	51 – 83	6.9	0.3	23	7.33
	x ± SD	16.1 ± 10.0	0.65 ± 0.5	27 ± 6	8.33 ± 1.59
ND$_{15}$	0 – 20	20.5	0.9	23	129.87
	20 – 40	12.5	0.5	25	199.80
	40 – 60	8.3	0.8	14	89.90
	60 – 80	0.8	0.3	26	91.91
	x ± SD	10.5 ± 8.2	0.63 ± 0.3	22 ± 5	127.87 ± 51.36
AU$_{17}$	0 – 20	26.6	1.1	24	53.28
	20 – 40	25.0	1.1	23	78.65
	40 – 60	20.9	0.9	23	39.96
	60 – 80	19.6	0.8	25	50.62
	80 – 100	18.4	0.8	23	33.57
	x ± SD	22.1 ± 3.5	0.94 ± 0.2	24 ± 0.9	51.22 ± 17.29
AU$_{18}$	0 – 20	15.0	0.6	25	4.26
	20 – 40	11.0	0.5	22	18.11
	40 – 60	10.0	0.4	25	26.64
	60 – 80	9.1	0.4	28	13.64
	x ± SD	11.3 ± 2.6	0.48 ± 0.1	25 ± 2	15.66 ± 9.32

C/N – carbon to nitrogen ratio

Relationship among Soil Properties

The calculated coefficients used for assessing the relationships among soil variables are presented in Table 5. Soil pH in water suspension correlated strongly positively and significantly with pH (Kcl) (r = 0.893**) and negatively with Ca (r = -0.655**), Mg (r = -626**), K(r = -0.563**), Na(r = -0.545**) and CEC (r = -651**), indicating that pH as a master variable regulates the availability of basic cations in the soil. Soil pH (H_2O) was also negatively related to organic C (r = -0.453**), TN (r = - 0.497**) and positively but weakly with C/N ratio (r = -0.336*). Soil pH in a molar Kcl solution correlated negatively but strongly, significantly with Ca (r = 0.569**), Mg (r = -0.522**), K (r = 0.507**), Na (r = - 0.545**), CEC (r = -0.571**), organic C (r = -0.437**) and TN (r = -0.461**).

Organic matter content being a sink and a source for many plant nutrients negatively exhibits significant relationship both positively and negatively with pH (H_20) and pH (Kcl), EAl (r = 0.378*), Ca (r = 0.365*), Mg (r = 0.440**), Na(r = 0.479**), CEC (r = 0.400*) and Silt (r = 0.484**). Similarly, total N correlated negatively significantly with pH in water and Kcl solution but positively with Ca (r = 0.445**), Mg (r 0.499**), K(r = 0.501**), Na (r = 0.541**), CEC (r = 0.470**), Silt (r = 0.495**), organic C (r = 0.957**) and C/N ratio (r = -0.465**). The close to unity, that is, perfect relationship exhibited by total N with organic C content implies that almost 96% of total N in the soil are derived from microbial decomposition and mineralization of organic residues.

As a dominant cation in the absorption complex, Ca positively and highly significantly related to Mg (r = 0.954**), K (r = 0.832**), Na (r = 0.746**), CEC (r = 0.993**), total N (r = 0.445**) and weakly correlated with C/N ratio (r = -0.391*) and available P (r = 0.405*). The second most important and abundant cation in the soil exchange complex, Mg like Ca, highly significantly and positively related to K(r = 0.858**), Na (r = 0.830**), CEC (r = 0.982**), organic C (r = 0.440**), total N (r = 0.449**), and available P (r = 0.426**) and negatively related to C/N ratio (r = -0.336*).

Potassium highly significantly and positively correlated with Na (r = 0.808**), CEC (r = 0.859**), total N and available P but weakly related to silt (r = 0.413*). Sodium which had the least value in the exchange complex positively correlated with only organic C (r = 0.429**) and total N (r = 0.54**). The sand being the dominant fraction correlated with only clay (r = 0.948**) while silt correlated with both organic C and total N.

Constraints to Sustainable Crop Cultivation in Inland Depression Soils

Soils in the inland depressions are derived from coastal plain sands and beach ridge sands parent materials. This study has shown that the soils are acidic, low in exchangeable bases (K, Ca, Mg), CEC, but high in base saturation, and Al saturation, moderate to high in organic carbon and very high in P in some cases. The soils are relatively sandy and are therefore prone to leaching losses of K, Ca and Mg contents despite supply from run-off from nearby upland soils. Leaching losses of NPK have been put at more than 60kg ha^{-1} per year in wetlands (Henao and Baanante, 1999).

Table 5: Correlation Matrix for Some Soil Properties of Inland Depression Soils

	pH (H_2O)	pH (Kcl)	EA	EAl	Ca	Mg	K	Na	CEC	BS	Sand	Silt	Clay	OM	TN	CN	Av. P
pH(H_2O)	1.000																
pH(Kcl)	0.893**	1.000															
EA	-0.280	0.331*	1.000														
EAl	-0.390	0.399*	0.974**	1.000													

Ca	-0.653**	-0.569**	0.164	0.248	1.000											
Mg	-0.626**	-0.552**	0.115	0.188	0.954**	1.000										
K	-0.563**	-0.507**	0.279	0.327	0.832**	0.858**	1.000									
Na	-0.545**	-0.545**	0.048	0.099	0.746**	0.830**	0.808**	1.000								
CEC	-0.651**	-0.571**	0.151	0.231	0.993**	0.982**	0.859**	0.198	1.000							
BS	0.084	0.145	-0.917**	0.872**	0.131	0.184	0.034	0.191	0.148	1.000						
Sand	-0.003	0.115	-0.736**	-0.687**	0.115	0.158	0.095	0.230	0.133	0.808**	1.000					
Silt	0.166	-0.194	0.405*	0.449**	0.311	0.316	0.413*	0.207	0.319	0.405*	0.534	1.000				
Clay	0.031	-0.095	0.689**	0.626**	-0.208	-0.272	0.234	0.032	0.236	-0.760**	0.948**	0.260	1.000			
OM	-0.453**	-0.437**	-0.208	0.378*	0.365*	0.440**	0.426	0.479**	0.400*	0.240	-0.211	0.484**	-0.042	1.000		
TN	-0.497**	-0.461**	0.225	0.327	0.445**	0.499**	0.501**	0.541**	0.470**	0.160	-0.150	0.495**	-0.016	0.957**	1.000	
CN	0.336*	0.269	0.184	-0.091	-0.391*	-0.336*	-0.277	0.268	0.374*	0.257	-0.199	-0.093	0.260	-0.266	-0.465**	1.000	
Av. P	-0.303	-0.255	0.311	-0.345*	0.405*	0.426**	0.617**	0.313	0.423*	0.192	-0.005	0.395*	-0.123	0.094	0.127	0.135	1.000

EA – exchange acidity, EAl – exchangeable AL, BS – base saturation, OM – organic matter, CN – carbon to nitrogen ratio, TN – total nitrogen, CEC – cation exchange capacity.

Weeds are a major factor limiting crop yield in the depression soils because weeds grow vigorously when the soils are worked. Mortimer (1990) maintains that weeds are natural hazards and that they damage the yielding potential of the land surface managed by man. Some of the depressions are most often contained water and this supports rapid weed growth while others are seasonally wet but also support weeds that are adapted to seasonal changes. This condition imposes some strains on the farmer who could spend more than 50% of total time (and energy) on the field for weeding alone (Ogban and Babalola, 2003). Consequently, this makes cultivation of wetland soils less attractive for cultivation than their upland counterpart (Eshett, 1990).

Management of Inland Depression Soils for Sustainable Crop Production

The cultivation of inland depression soils is accompanied by nutrients decline, leaching and losses from harvests. If the nutrients removed by harvest are not replenished, soil fertility will continue to decline as well as yield of crops. The main crops grown are cassava (*Manihot esculenta*), taro (*Colocasia esculenta*.), maize (*Zea mays*), yam (*Dioscorea* spp.), cowpeas (*Vigna unguiculata*), Okra (*Abelmoschus esculenta*), fluted pumpkin (*Telfairia occidentalis*) and other not widely cultivated crops such as African yam bean (*Sphenostylis stenocarpa*) and sweet potatoes (*Ipomea batatas*). Despite the concern about low fertility, farmers use very little mineral fertilizers to improve crop yields. Fertilizers are very expensive and hard to come by. Francis et al. (1986) had emphasized the use of resources found on the farm in the development of a sustainable or regenerative agricultural production system. Peasant or small scale farmers continue to practice slash and burn type of farming to manage excessive weeds in the depressions but Thomich et al. (1998) recommended the slash and mulch system as suitable alternative to slash and burn.

The mulch materials and crop residues if returned to the soil have noticeable effects on soil properties and processes (Lal, 1995). However, large part of crop residues produced in these depression soils is used as fodder for feeding domestic animals, fuel, and sometimes as construction materials for poultry house used for keeping local fowl. Residues-induced changes in soil properties affect several restorative processes. In general, crop residues and other mulch materials increase nutrient cycling, decrease nutrient losses, improve nutrient use efficiency, increase soil organic matter content, enhance soil structure, influence soil moisture and temperature regimes. Some farmers who cultivate the depression soils select some useful weeds (cover crops) that seem to improve soil fertility and increase crop yield in upland soils, for use as mulch in the depressions. This is green leaf manures which are cheap and readily available in the nearby upland bush that can improve soil structure, serves as good food for earth worms, has no risk for soil health, and increases soil biodiversity of beneficial microbes. These weeds include *Pueraria phaseoloides*, *Mucuna pruriens var. utilis*, and shrubs such as *Chromolaena odorata and Penninsetium purpureum*. Depending on crop species and the type of management systems, crop residues contain a large quantity of plant nutrients. *Chromolaena* has been found to contain 2.3gkg^{-1} N, 8.9mgkg^{-1} P and 222gkg^{-1} organic carbon (Effiong et al., 1997). On a dry mass basis Miller (1958) and Allison (1973) gave the following concentrations of nutrients in Zea mays: 325gkg^{-1} C, 10.24gkg^{-1} N, 0.9gkg^{-1} P, 9.2gkg^{-1} K, 4.9gkg^{-1}, Ca and 3.1gkg^{-1} Mg; Cowpea: 12.48gkg^{-1} N, 2.8gkg^{-1} P, 15.5gkg^{-1} K, I l.6gkg^{-1} Ca and 3.8gkg^{-1} Mg.

Mulching is not a traditional practice in this part of the world. Fertilizer is costly and farmers now favour mulching because they know that it suppresses weed growth, maintains soil fertility and conserves soil moisture. The impact of crop residues on soil fertility depends on the way they are managed-burning, mulching, incorporation and their quality (C/N and C/P ratios), content of lignin and polyphenols. Nguu (1987) found, on an Acrisol in Cameroon, that burning of crop residues (4t ha^{-1}) and weeds out-yielded treatments in which crop residues were used as a mulch (2.7 vs 2.3t ha^{-1}). Kang et al. (1990), however reported that the practice of burning can lead to invasion of weed (*Imperata cylindrica*) which is hard to eradicate. Other field trials have shown that crop residues applied as a surface mulch protect the soil and improve crop yields (Kamara, 1988).

CONCLUSION

The declining soil fertility of upland soils necessitated the assessment of inland depression soils for crop production. The soils are generally moderately to strongly acid, have moderate base status, available P, low in total N and low to moderate in chemical fertility. The major constraints to sustainable crop production in these soils are acidity, low base status (Ca, K), total N and excessive weed growth. Management of these soils will include the use of crop residues and other mulching materials obtained from the farm and some shrubs to improve soil fertility and increase crop yield. Farmers need to add a little quantity of mineral fertilizer, and N-fertilizer will be the most effective to increase biomass production for use as crop residue mulch. Mulch will also suppress weed growth and reduce competition with cultivated crops.

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