SOIL CHARACTERISTICS AND FERTILITY CAPABILITY CLASSIFICATION OF SOILS OF LIMESTONE LITHOLOGY ALONG A TOPOSEQUENCE IN CROSS RIVER STATE, NIGERIA

Nsor, M. E.

ABSTRACT

Department of Soil Science and Meteorology, Michael Okpara University of Agriculture,. Umudike, Abia State, Nigeria.
E-mail:michaeledimnsor@gmail.com; phone: 07060767244

This study investigated the morphology, physical and chemical characteristics of soils on limestone lithology developed on a toposequence at Mfamosing in the forest zone of Cross River State, Nigeria. The topographic units studied include upper slope, middle slope, lower slope and flood plains. The texture of the soils in the study area was generally medium to coarse. Sand content was high (49-84%) and decreased down the profile while clay ranged from (8-41%). Sand and clay content related inversely with increasing profile depth. The pH of soils in the study area ranged from slightly acid to neutral (pH 5.08-7.20). Organic carbon was high (18.0gkg^{-1}) at the floodplains, medium (10.3gkg^{-1}) at the lower slope and low at the upper (6.5gkg^{-1}) and middle slope (7.6gkg^{-1}). Available phosphorus (P) was generally low (4.70-15.60 gkg^{-1}) in all the topographic positions investigated. Values of Cation Exchange Capacity (CEC) in the study area were generally low (5.4-12.3cmolkg^{-1}), except for soils at the flood plains and lower slope that had medium values (10.1-17.5cmolkg^{-1}). The fertility capability classification of soils in the study area indicated that soils at the upper and middle slopes had sandy top soils having less than 35% clay sub soils with fertility problems of low CEC and available P. The soils on lower slope and flood plains had loamy top soils having less than 35% clay sub soils with low available P and evidence of gleization at the floodplains. Soils derived from limestone lithology exhibited high natural fertility in terms of high pH, CEC and base saturation, but constraint by low to deficient levels of micronutrients. Consequently, these soils will require manuring, moderate level application of NPK 15:15:15 and micro nutrient fertilizers. The soils at the middle and upper slopes will in addition require good erosion control.

Keywords*: Toposequence, Limestone Lithology, Fertility Capability Classification*

INTRODUCTION

Toposequence plays an important role in managing our soil resources for enhanced productivity and preventing them from unpleasant environmental hazards of degradation. Nsor and Akamigbo (2014) posited that slope steepness is one of the most important factors that causes variation in soil characteristics. They further remark that soils of valley bottom were averagely better than those of middle slope and crest in important fertility indices. The type of soil formed in particular place is related to relief or toposequence of the area. Ufot (2012) noted that the sequence of soils in any given location is due to differences in landscape. This results in variation in drainage, soil depth, texture as well as in chemical and biological characteristics of the soil. Supporting this assertion, Nsor and Ibanga (2008) reported that soils derived from different parent materials are distinct in a number of morphological and chemical characteristics. Plaster (1992) stated that limestone is high in calcium and weathers easily to soils high in pH, calcium and magnesium. Ahn (1993) is of the view that soils overlying limestone lithology are texturally medium-coarse textured, well drained and usually of good structure. Soils of limestone lithology in the humid tropical climates which are usually depleted of calcium in the top horizons due to their surface medium-coarse texture (Ibanga *et al.*, 2005) under intense rainfall of the region, had not received the attention it deserves and hence had not been intensively studied. This study however seeks to investigate the relationship between toposequence and the soils morphological, physical and chemical properties; perform a fertility capability classification for these soils; and suggest appropriate management measures for sustainable crop production in the study area.

MATERIALS AND METHODS

This study was carried out at Mfamosing village, Akamkpa Local Government Area located in the humid tropics of Southern Nigeria. Mfamosing lies between latitudes 5° 05′ and 5° 20′ N and longitudes 7° 15′ and 8° 30′ E. The limestone deposits are located approximately 40km, North East of Calabar along the Calabar-Oban road. The study area was stratified into four (4) topographic strata including: upper, middle, lower slope and flood plains. A total of four (4) profile pits, one per topographic strata were morphologically described and horizons were designated in-situ according to the guidelines of FAO (2006). In the laboratory, the samples were air-dried at room temperature, ground with a wooden pestle and sieved with a 2mm mesh sized sieve. The materials collected on the sieve (> 2mm in diameter), regarded as gravels, were weighed and its percentage to the whole soil sample weight calculated. Particle size analysis was determined by the pipette method (Gee and Bauder, 1986). Bulk and particle densities were determined by the cylindrical core method (Grossman and Reinch, 2002). Porosity was determined by calculation.

Soil pH was determined in a 1:2.5, soil: water suspension (Thomas, 1996). Organic carbon was determined by the dichromate wet oxidation method of Walkley and Black (Nelson and Sommers, 1996). Total nitrogen was analysed according to the macro kjeldahl digestion method (Bremmer, 1996). Available phosphorus was extracted by the Bray No. 1 procedure and estimated by the molybdenum blue colour technique (Kuo, 1996). Cation exchange capacity was determined by 1N Ammonium acetate method. The exchangeable cations were extracted by leaching the soil with 1N ammonium acetate solution. Exchangeable Na and K in the extract were determined by flame photometry while Ca and Mg were determined by the versenate titration method. Exchangeable acidity was determined by titration method. Available micro nutrients (Fe, Zn, Mn and Cu) were extracted with 1N KCl and determined by Atomic Absorption Spectrophotometry (AAS) at appropriate wave lengths as described by Schnug *et al.*, (1996).

The potential of these soils for farming were assessed using the fertility capability classification (FCC), Sanchez *et al.* (2003). The FCC system is a three categorical land evaluation method that lists the type, substrata type (texture) and modifiers (nutrient deficiencies, toxicities and physiologic disorders) of the soil specific to agricultural land use.

The legend for FCC is:

S = loamy sands and sands

L = < 35% clay but not loamy sand or sand (loamy soils)

C = > 35% clay (clayed soils)

g = gley, mottles ≤ 2 chroma, that is saturated with water for > 60 days in most years

d = dry, ustic environment

e = low CEC of plough layer

h = acidic, pH in 1:2.5 H_2O between 5 and 6

i = (Fe – P fixation) used only in clay types and hues of 7.5YR or redder and granular structure

k = deficiency, exch. k<0.20 cmol kg^{-1}

RESULTS AND DISCUSSIONS

Morphological characteristics

The results of the morphological characteristics of soils derived from limestone lithology on diverse geomorphic landforms indicate that the soils generally had very dark brown (7.5YR 6/4), brownish yellow (10YR 6/6) dark brown (7.5YR 3/2) and brown (7.5YR 4/4) surface soils over light brown (7.5YR 6/4), brownish yellow (10YR 6/6) to dark yellowish brown (10YR 4/6) sub-surface soils (Table 1). However the colours of the subsurface soils formed on the flood plains were dark grey (7.5YR 4/1) to grey (7.5YR 5/1), probably due to gleization. Similar grey colourations were reported by Okonkwo and Nsor (2015) in the sub-soils of the wetlands of Adani, Enugu State, Nigeria. Soils of the upper, middle and lower slopes were characterized with weak fine to medium granular and crumb top soils over moderate to strong, medium to coarse sub angular blocky sub soil structures. The soils in flood plain landforms had weak medium crumbs top soils over weak to moderate medium prismatic sub-soil structures (Table 1). The consistence of soils at the upper slope indicated a soft (dry), very friable (moist) and non-sticky-non-plastic (wet) top soil over slightly hard (dry), friable to firm (moist) and slightly sticky-slightly plastic to sticky-plastic (wet) sub-soil consistence. Soils at the middle slopes were characterized with soft to slightly hard (dry), friable (moist) and non-sticky-non plastic (wet) top soils over hard (dry), firm (moist) and slightly sticky-slightly plastic (wet) sub soils (Table 1). The soils of lower slope landforms had slightly hard (dry), very friable to friable (moist), non-sticky slightly plastic (wet) epipedons over hard to very hard (dry), firm to very firm (moist) and sticky-plastic, to sticky very plastic (wet) top soil consistence over hard to very hard (dry), firm to very firm (moist) and sticky-very plastic (wet) sub soil consistence (Table 1). Generally, the top soils horizon had clear horizon boundary width with smooth boundary topographic shapes over gradual wavy sub soil horizon boundaries.

Physical characteristics

The textures of soils in the study area were generally medium to coarse textured. Sand content was high (49-84%) and decreased down the soil profile. Clay fractions of the soils which ranged from 8-41%, increased with increase in profile depth (Table 2). This is an indication of clay migration by lessivage in the process of illuviation, suggestive of an argillic (Bt) subsurface diagnostic horizon. The soils generally had loamy sand to sandy loam top soils over sandy clay loam to sandy clay sub soils. These coarse soil textures observed corroborate the findings of Ibanga *et al.* (2005) on some limestone soils of Southern Nigeria. The soils in the study area were generally gravelly, with the soils at the upper and Middle slopes having the highest gravel contents (23.2-66.5%). The gravel content was low at the lower slope and flood plain soils (9.1-16.2%). The decreasing surface gravel content from soils of high altitude down the low lying soils might be due to high intensity of erosion at the upper and middle slopes, which removes the fine earth fraction leaving behind the gravels. Bulk density in the study area was in the range (1.74–1.95gcm^{-3}) which is ideal for agronomic activities. The soils at the upper and middle slopes had relatively highest top soil porosity (28.4–29.7%) compared to the low porosity values at the lower slopes and flood plains (24.1-26.0%). The moderate porosities of soils derived from limestone lithology might be attributed to their coarse textured nature, and accounts for the moderate to high drainability of soils of limestone derived soils.

Table 1: Morphological characteristics of soils of limestone lithology on a toposequence at Mfamosing, Cross River State, Nigeria

Horizon Designation	Horizon depth (cm)	Major colour	Mottles	Structure	Consistence Dry	Moist	Wet	Roots	Pores	Horizon Boundary
Upper slope										
Ap	0-13	7.5YR3/2;Db		1M granular	s	vfr	ns-np	cf	cm	cs
Bt_1	13-37	7.5YR 4/4; B		2M sbk	sh	fr	ss-sp	fvf	cf	gw
Bt_2	37-77	10YR 4/6;Dyb		3M sbk	sh	fr	ss-sp	fc	ff	gw
Bt_3	77-97	10YR 5/4, Yb		3C sbk	h	f	s-p	fc	fvf	
Middle slope										
Ap	0-16	10YR 2/2; Vdb		1F crumb	s	fr	ns-np	cf	cm	cs
BC	16-41	7.5YR 3/2; Db		2M sbk	sh	fr	ss-sp	cf	fm	gw
B_t	41-78	7.5YR 4/4; B		3C sbk	h	fr	ss-sp	cm	cf	
Lower slope										
Ap	0-14	10YR 2/2; Vdb		1M granular	sh	vfr	ns-sp	cm	mm	cs
Bt_1	14-35	7.5YR 6/4; Lb		2M sbk	sh	fr	ss-sp	cm	cf	gw
Bt_2	35-86	10YR 6/6; By		3M sbk	h	f	s-p	fm	cvf	gw
Bt_3	86-122	10YR 4/6; Dyb		3C sbk	vh	vf	s-vp	fc	cvf	
Flood plains										
Ap	0-15	7.5YR 3/2;Db		1M crumb	sh	fr	ss-sp	ff	cm	cs
Bhg	15-47	7.5YR 4/1; Dg	7.5YR 4/6;cmd,Sb	1M prismatic	h	f	s-np	cf	fm	gw
Bg	47-77	7.5YR 5/1;G	7.5YR 4/6;mcp,Sb	1M prismatic	vh	vf	s-vp	fvf	mvf	

Colour: Db = Dark brown, B = Brown, Dyb = Dark yellowish brown, Yb = yellowish brown, Vdb – Very dark brown, Lb = Light brown, By = Brownish yellow, Dg = Dark grey, G = Grey, Sb = Strong brown. **Mottles**: cmd = common medium distinct, mcp = many coarse prominent **Structure**: 1 = weak, 2 = moderate, 3 = strong, F = fine, M = medium, C = Coarse, sbk = sub-angular blocky. **Consistence**: s = soft, sh = slightly hard, h = hard, vh = very hard, vfr = very friable, fr = friable, f = firm, vf = very firm, ns-np = non sticky-non plastic, ss-p = slightly sticky-plastic, ss-sp = slightly sticky-slightly plastic, s-p = sticky-plastic, s-vp = sticky-very plastic. **Roots**/**Pores**: cf = common fine, fvf = few very fine, fc = few coarse, cm = common medium, fm = few medium, ff = few fine, mvf = many very fine, cvf = common very fine, mm = many medium . **Boundary**: gw = gradual wavy, cs = clear smooth

Table 2: Physical properties of soils in the study area

Horizon Designation	Horizon Depth (cm)	Sand (%)	Silt (%)	Clay (%)	TC	BD (g cm^{-3})	PD (g cm^{-3})	Porosity (%)	Gravels (%)
Upper slope									
Ap	0-13	82	10	8	LS	1.90	2.70	29.7	36.7
Bt_1	13-37	73	9	18	SL				58.4
Bt_2	37-77	70	5	25	SL	1.85	2.51	26.3	71.6
Bt_3	77-97	61	6	33	SCL				66.5
Middle slope									
Ap	0-16	84	6	10	LS	1.89	2.58	28.4	23.2
BC	16-41	75	13	12	SL				27.1
B_t	41-78	63	10	27	SCL	1.82	2.55	25.2	38.5
Lower slope									
Ap	0-14	70	14	16	SCL	1.95	2.57	24.1	9.2
Bt_1	14-35	69	7	24	SCL				11.3
Bt_2	35-86	60	4	36	SCL	1.74	2.34	25.6	16.2
Bt_3	86-122	49	10	41	SC				
Flood plains									
Ap	0-15	77	12	11	SL	1.85	2.50	26.0	10.5
Bhg	15-47	72	8	20	SL				9.1
Bg	47-77	51	9	40	SC	1.79	2.60	24.8	15.4

TC = Textural class, LS = Loamy sand, SL = Sandy loam, SCL = Sandy clay loam, SC = Sandy clay, BD = Bulk density, PD = Particle densit

Chemical characteristics

The soils in the study area were slightly acid to neutral (pH 5.08-7.20) in reaction. The pH was highest in flood plains and lower slopes than the upper and middle slopes (Table 3). This might probably be due to movement and deposition of organic materials and weathered products of limestone outcrops by water erosion, down slope through solution, surface wash and lateral flow. The organic carbon content in the study area was high (18.0 g kg^{-1}) at the flood plains, medium (10.3 g kg^{-1}) on lower slopes and low on upper (6.5 g kg^{-1}) and middle slopes (7.6 gkg^{-1}). The increase organic carbon at the flood plains and lower slopes might have resulted from organic debris accumulation and biomass recycling. The values of total nitrogen in the study area were medium at the flood plains and lower slopes (1.0-2.7 g kg^{-1}) and low at the upper and middle slopes (0.1-1.6 g kg^{-1}).

Available phosphorus was generally low (4.70-15.60 mg kg^{-1}) in all the topographic positions investigated. The low available phosphorus encountered in the study area might probably be due to the abundance of calcium which might had fixed appreciable amounts of phosphorus (Ca-P) in these soils. This finding corroborates that of Enwezor (1977) who observed that low available phosphorus in most tropical soils are due to their high fixation capabilities. Amongst the exchangeable cations, calcium (2.0-6.2cmolkg^{-1}) and magnesium (0.8-2.2 cmol kg^{-1}) were medium to high. This might be due to their high contents in the limestone parent material. This is in agreement with Plaster (1992) who reported that limestone is high in Ca and Mg, and weathers easily into soils high in Ca and Mg with high pH. Potassium is low to medium in content (0.15-0.51 cmol kg^{-1}) while sodium was low to medium (0.05-0.32 cmol kg^{-1}) Table 3. The soils in the study area were saline due of their high Ca^{2+} and Mg^{2+} contents, but low sodium adsorption ratio (0.04-0.24) which is less than 13 (Table 3). In terms of topographic position, the contents of exchangeable cations were highest at the flood plains, followed by the lower slopes and middle slopes but least at the upper slope. The increasing cations contents down the slope may be due to down slope movement in solution from higher topographic positions. The low to medium levels of K and Na might be due to the limestone parent material which according to Best (1982) contains low Na_2O (0.05%) and K_2O (0.33%), and the intensity of leaching caused by heavy rainfall as well as their high solubilities. The exchangeable acidity in the study area was low (1.14-3.81cmolkg^{-1}) in all the pedons studied. This may be attributed to the limestone parent materials which weather into soils of high pH (Plaster, 1992). Enwezor (1977) also noted that soils with low pH will have high exchangeable acidities and vice versa. Values of cation exchange capacity (CEC) in the study area were generally low (5.4-12.3 cmol kg^{-1}), except for soils at the flood plains and lower slopes that had medium values (10.1-17.5 cmol kg^{-1}) Table 3. The low to medium CEC values encountered in the study area might be due to the medium to coarse textured nature of these soils. This observation corroborates Ahn (1993).

The analysis of micro nutrients in the study area indicated marginal to adequate levels of copper (0.09-0.35 g kg^{-1}), deficient level of iron (1.09-1.13 g kg^{-1}) and zinc (0.04-0.20 g kg^{-1}) for soils on middle and upper slopes. However, adequate levels of Cu (0.11-0.65 g kg^{-1}), manganese (0.6-1.4 g kg^{-1}), iron (2.50-4.60 g kg^{-1}) and zinc (0.50-1.62 g kg^{-1}) were encountered for soils at the flood plains and lower slopes (Table 3). Generally, the micro-nutrient levels in the soils at the flood plains and lower slopes in the study area are ideal for agronomic activities and did not indicate any toxic level (McKenzie, 1992). However, the deficient to marginal levels of micro-nutrients at the upper and middle slopes might require some supplementations for optimal crop production.

Fertility Capability Classification (FCC) of soils in the study area

The Fertility Capability Classification (FCC) of Soils developed on limestone lithology along a toposequence at Mfamosing was done to evaluate the soils and give additional attributes of the soil as modified by terrain variation directly relevant to crop production. The FCC of soils in the study area consequently evaluated the potentials of soils developed on limestone parent material as influenced by terrain variation for crop production. The summary of the FCC is presented in Table 4 and 5.The soils of upper and middle slopes belonged to sandy (S) type and loamy (L) substrata type. These soils were associated with modifiers k, e and i, indicating fertility challenges of low cation exchange capacity, low exchangeable potassium and low available phosphorus. The soils of upper and middle slopes had similar potentials, constraints and management requirements. The soils on lower slopes belonged to the loamy (L) type and clay (C) substrata type and having fertility challenge of low available phosphorus as its modifier (Table 4). The flood plain soils also belonged to the loamy (L) type and clay (C) substrata type. These soils had prolonged water logging (aquic moisture regime) and low available phosphorus as modifiers.

CONCLUSION

Relief and parent material are two most important factors of soil formation influencing soil properties. The influence of limestone on properties of soils is more in lower geomorphic altitudinal locations than on higher altitudes. Generally soils derived from limestone parent materials exhibited high natural fertility in terms of pH, cation exchange capacity, base saturation etc. but constrained by low to deficient levels of micro nutrients. The pH (5.08-7.20) is within the range (pH 5.5-6.5) considered ideal for the availability of most plant materials. The fertility Capability Classification (FCC) of soils in the study area indicate that the soils at the upper and middle slopes belonged to sand (S) type and loamy (L) sub strata types with limitation of low cation exchange capacity, exchangeable potassium and available phosphorus. The lower slope and floodplain soils belonged to the loamy (L) type and clay (C) substrata types with limitations of low available phosphorus and aquic moisture regime specifically at the floodplains.

Table 3: Chemical characteristics of soils derived from limestone lithology on a toposequence at Mfamosing, Cross River State, Nigeria

Horizon Designation	Horizon Thickness (cm)	pH (H_2O)	Org. C g kg^{-1}	TN g kg^{-1}	Av.P mg kg^{-1}	Ca	Mg	K cmol kg^{-1}	Na	EA	BS %	Cu	Mn g kg^{-1}	Fe	Zn	CEC cmol kg^{-1}	SAR
Soils of Upper Slope																	
Ap	0-13	5.60	17.0	1.6	8.15	3.4	1.2	0.24	0.25	1.14	48.4	0.22	0.1	1.20	0.20	10.5	0.16
Bt_1	13-37	5.21	3.1	1.1	7.20	2.6	1.0	0.26	0.30	1.90	38.5	0.20	0.1	1.10	0.10	10.8	0.22
Bt_2	37-77	5.08	2.8	0.6	6.50	3.6	0.8	0.21	0.28	1.60	40.1	0.35	0.4	1.09	0.09	12.2	0.19
Bt_3	77-97	5.11	3.2	0.1	5.20	6.2	1.6	0.27	0.31	1.80	68.1	0.30	0.2	1.04	0.04	12.3	0.16
Soils of Middle Slope																	
Ap	0-16	5.66	13.8	1.3	7.25	1.6	0.4	0.20	0.09	1.40	42.4	0.15	0.2	1.10	0.10	5.4	0.09
BC	16-41	5.33	4.9	0.3	7.13	2.2	0.6	0.15	0.05	1.26	48.4	0.09	0.3	1.20	0.20	6.2	0.04
B_t	41-78	5.25	4.1	0.2	6.45	3.6	0.6	0.26	0.06	1.20	54.5	0.11	0.5	1.10	0.10	8.3	0.04
Soils of Lower Slope																	
Ap	0-14	5.84	15.7	1.4	10.10	2.8	6.8	0.34	0.32	1.36	41.8	0.16	0.9	2.60	0.60	10.2	0.24
Bt_1	14-35	5.40	14.2	1.4	10.40	2.0	1.0	0.20	0.29	1.76	31.7	0.16	1.0	3.70	0.70	11.0	0.24
Bt_2	35-86	5.81	8.2	1.0	5.50	3.2	1.2	0.18	0.20	3.70	41.6	0.11	0.8	2.50	0.50	11.5	0.14
Bt_3	86-122	5.60	3.2	1.1	4.70	3.0	2.2	0.29	0.20	3.81	56.3	0.15	0.6	3.80	0.80	10.1	0.12
Soils of Flood plains																	
Ap	0-15	7.20	30.6	2.7	12.50	3.1	1.1	0.33	0.20	1.60	37.5	0.44	1.2	4.40	1.45	12.6	0.14
Bhg	15-47	6.64	17.2	1.6	15.60	5.4	1.0	0.51	0.20	1.80	42.8	0.50	1.0	4.20	1.24	16.6	0.11
Bg	47-77	6.50	6.3	1.0	9.90	5.0	1.0	0.30	0.10	1.90	36.6	0.65	1.4	4.60	1.64	17.5	0.06

Table 4: Checklist showing type, substrata type and modifiers

Topographic position	Type	Substrata Type	Modifiers g	k	e	i	Aggregate
Upper slope	S	L	-	+	+	+	SLkei
Middle slope	S	L	-	+	+	+	SLkei
Lower slope	L	C	-	-	-	+	LCi
Floodplain	L	C	+	-	-	+	LCig

S = Loamy sands and sands, L = < 35% clay but not loamy sand or sands, C = > 35% clay, g = gley, mottles, saturated with water for > 60 days in most years, e = low CEC of plough layer, i = low available P, k = K-deficiency, exch. K < 0.2 cmol kg^{-1}

Table 5: Fertility Capability Classification (FCC) of different topographic positions in the study area

FCC	Geomorphic Unit	Description
SLkei	Upper slope	Sandy (loamy sand) top soils having < 35% clay sub soils. They have fertility problems of low CEC, exch. potassium and available phosphorus
SLkei	Middle slope	Sandy (loamy sand) top soils having < 35% clay sub soils. They have fertility problems of low CEC, exch. potassium and available phosphorus
LCi	Lower slope	Loamy (sandy clay loam) top soils having > 35% clay sub soils. They have fertility problem of low available phosphorus
LCig	Flood plains	Loamy (sandy loam) top soils having > 35% clay sub soils, prolonged water logging with mottle sub soils (aquic moisture regime) and having fertility problem of low available phosphorus

RECOMMENDATIONS

The following recommendations will enhance the productivity of soils derived from limestone lithology on diverse topographic positions at Mfamosing, Akamkpa Local Government Area located in the humid tropics of southern Nigeria. Soils in the study area especially on the flood plains and lower slopes of loamy top soil type and clay sub-strata types (LCi and LCig) will require manuring, moderate application of NPK 15:15:15 and micro nutrient fertilizers such as Ferrous, Copper, Zinc and Manganese sulphates. Good water control and drainage will further enhance the productivity of these soils. Crops tolerant to high pH should be selected and cultivated for better performance. High pH tolerant humid tropical crops include: plantain, banana, pineapple, tomato, alfalfa, cassava, cowpea, soyabean, maize, etc. The soils on middle and upper slopes belonging to SLkei fertility capability class will in addition require good erosion control methods.

REFERENCES

Ahn, P. M. 1993. *Tropical soils and fertilizer use.* United Kingdom. Longman Scientific Technical Press, 391pp.

Bremner, M. M. 1996. *Total nitrogen*. *In: Methods of Soil Analysis*. *Part 3*. *Chemical Methods* No. 5. Edited by Sparks, D. L. American Society of Agronomy and Soil Science Society of America, Madison, Wisconsin. Pp 1085-1121.

FAO 2006. *Guidelines for soil description 4th edition*. Food and Agricultural Organization of the United Nations, Rome, 97pp.

Gee, G. W. and Bauder, J. W. 1986. *Particle size analysis*. *In*: *Methods of Soil Analysis: Physical and Mineralogical Methods*, *Part 1*. Edited by Klute, A. Soil Science Society of America, Madison, Wisconsin, USA, 1188 pp.

Grossman, R. B. and Reinch, T. G. 2002. *Bulk density*. *In: Methods of Soil Analysis*, *Part 4*, *Physical Methods*. Edited by Dame, J. H and Topp, G. C. Soil Science Society of American Book Series 5, American Society of Agronomy and Soil Science Society of America, Madison, Wisconsin. Pp. 225-293.

Kuo, S. 1996. *Determination of forms of phosphorus*. *In: Methods of Soil Analysis: Chemical Methods Part 3*. Edited by Sparks, D. L. Soil Science Society of America, Madison, Wisconsin, 1390pp.

McKenzie, R. 1992. Micronutrients requirement of crops. Agdex 531-1. Alberta Agriculture, Food and Rural Development.

Nelson, D. W. and Sommers, L. E. 1996. *Determination of organic carbon*. *In: Methods of soil analysis: chemical methods*, *Part 3*. Edited by Sparks, D. L. Soil Science Society of America, Madison, Wisconsin, USA, 1390pp.

Nsor, M. E. and Akamigbo, F. O. R. 2014. Pedological characterization of soils of two toposequences in the Kanyang and Ubang Areas of Cross River State, Nigeria. *Journal of Sustainable Agriculture and the Environment,* 15(2):217-231.

Nsor, M. E. and Ibanga, I. J. 2008. Morphological characteristics and classification of soils derived from diverse parent materials in central Cross River State, Nigeria. *Global Journal of Pure and Applied Sciences.* 14 (3):271-277.

Plaster, E. J. 1992. *Soil science and management*. *2nd edition.* Delmer Publishers Incorporated, Albany, New York. 514pp.

Sanchez, P. A., Palm, C. A. and Buol, S. W. 2003. Fertility capability classification. A tool to help assess soil quality in the tropics. *Geoderma*, 114:157-185.

Schnug, E., Fleckenstein, J. and Haneklaus, S. 1996. The ubiquitous extractants for micronutrients in soils. *Soil Science and Plant Analysis*, 27(5-8):1721-1730

Thomas, G. W. 1996. *Soil pH and soil acidity*. *In: Methods of Soil Analysis, Part 3, Chemical Methods*. Edited by Sparks, D. L. Soil Science Society of America, Book Series 5, Madison, Wisconsin, USA. Pp. 475-490.

Ufot, U. O. 2012. *Soils and the environment*. Shadows Publishers Limited, Owerri-Nigeria, 1635pp.

Webster, C. C. and Wilson, P. N. 1980. *Agriculture in the tropics*. English Language Book Society and Longman Group Limited, United Kingdom, England, 640pp