Changes in epipedal development in soils of a gravelly hilly terrain

E .U.Onweremadu 1 Aand C.N.Mbah 2

1.Department of Soil Science and Technology, Federal University of Technology, PMB 1526 Owerri, Nigeria .E-mail: uzomaonweremadu@yahoo.com

2.Department of Soil and Environmental Management.Ebonyi State University,Abakaliki,Nigeria

Abstract

This study investigated variations in properties of surface soils of 4 physiographic positions on a hilly landscape in 2007. A transect was used to align sampling sites on the identified topographic land units of summit, midslope footslope and valley bottom. Ten soil samples (replicates) were collected from each physiographic position (treatment) and the experiment was arranged in a randomized complete block design. Soil data were subjected to analysis of variance using the PROC mix-model of SAS computer software. Results showed significant differences (P <0.05) in soil properties except bulk density. There were also variations in soil morphological properties. Based on these, topsoils from summit, midslope and valley bottom were classified as ochric epipedons while those of valley bottom were categorized as plaggen epipedons. There is need to study similar landscapes in the study area for the purpose of using data for delineating soil in terms of suitability for different land uses. [Report and Opinion. 2009;1(2):45-55]. (ISSN: 1553-9873).

Keywords: Edaphology, epipedon, pedogenesis, topography, tropical soils.

Introduction

Soil is a product of interactions between climate, parent material, relief and organisms over a period of time. Its formation involves complex pedogenic processes (Buol *et al*., 1997) such as additions, losses, translocations and transformations. While climate (Johnson. Maynard *et al*., 2004) and organisms (Quideau *et al*., 2001) actively influence soil formation, topography indirectly affects rate of pedogenesis and distribution of soil nutrients (Wang *et al.*, 2001).

Differences in soil formation along a hillslope result in differences in soil properties (Brubaker *et al.*, 1993) which affect pattem of plant production, litter production and decomposition (Wang *et al.*, 2001). Whereas organic matter varied with landscape position (Bhatti *et al*.,1991), C and N processes were found to be influenced by the same factor (Hobbie,1996). In addition to the above edaphic properties, landscape influences soil texture, penetration resistance (Bruand *et al.*, 2004) root development (Busscher *et al*., 2001) exchangeable basic and acidic cations (Stutten *et al.*, 2004), soil exchange chemistry (Clien *et al.*, 1997), and nutrient budget (Mallarino 1996) hence important in fertilizer management (Paz-gonzalez *et al*., 2000).

These changes in soil physicochemical properties affect greatly epipedal or surface horizons of soils being an interface between the earth's crest and atmosphere with direct influence of climo-and bio-sequence on it. It is in this regard that an index was developed to characterize and monitor changes in near surface soils in soil survey and land evaluation studies (Grossman *et al*., 2001; Seybold *et al.*, 2004). Field morphological evaluations of epipedons of near surface soils have not be actively applied in soil quality assessments (Grossman *et al.*, 2001). Absence of such near surface evaluations could be responsible for the spate of land degradation in the hilly landscape of the southeastern Nigeria. Most pedological studies in the study area dwell on profile pit studies including subsurface horizons (Akamigbo and Igwe, 1990; Igwe *et al.*, 2005; Onweremadu, 2008) and in lowland area of southeastern Nigeria. It becomes necessary to characterize epipedal horizons of soils of a hilly landscape for the purpose of sustained use of soil and for environmental friendliness. Based on the above, the major objective of this study was to investigate the selected physico chemical characteristics of gravelly topsoils overlying a hilly slope in southeastern Nigeria for the purpose of classification and use in soil management

Materials and Methods

Study Area

The study was carried out before the on-set of wet season in 2007 on a gravelly hilly uncultivated landscape at Okigwe, southeastern Nigeria. It is located on latitude $5^0$48'46. 970''N longitude $7^0$35'54.810"E and with an altitude of 300 m (Handheld Global Positioning System Receiver readings- Garmin Ltd Kansas, USA). Soils of the study are derived from falsebedded sandstones (Ajalli formation) of the maestrichtian geologic era and proximal to the upper coal measures (Nsukka formation) of the Danian geologic era. Okigwe has a humid tropical climate, having a mean annual rainfall of 2250 mm and a mean annual temperature range of 27-28 ^{0}C (FDALR, 1985). Orographic rainfall is common in the area occupying over 25 km^2 land area, and the windward side of hills receive more rainfall than the leeward landscape. it has a sparsely vegetated shrubby rainforest with windward portions of hills having taller and varied plant species occurring in distinct tiers. Hillside farming, stone mining, hunting, quarrying, gathering of fruits especially cashew (*Anarcadium occidentale*), nomadism and several agro-based cottage industrial ventures constitute major socio-economic activities.

Field Sampling

A windward side of the hilly landscape was used for the study. The method of Brubaker *et al*. (1993) guided field sampling of soils. In this method, categories of landscape positions were identified as upper interfluves, lower interfluves, shoulder, upper linear, lower linear and footslope. However, the study was divided into 4 landscape positions namely summit, midslope, footslope and valley bottom and these physiographic positions were connected by a transect. Soil sampling (topsoil) was done along the transect. Abney level was used in measuring slope percent while Munsell colour chart was used to determine colour of peds. Ten soil samples were collected from each sampling point giving a total of 40 soil samples from the 4 landscape positions .The 4 landscape positions constituted treatments while 10 samples were replicates and the experiment was laid out in a Randomized Complete Block Design (RCBD) in order to accommodate other sources of variation being a field study. Soil samples were air-dried, sieved using a 2-mm sieve and stored in polyethylene bags in readiness for laboratory analyses. Gravel content was estimated by weight of the total soil (50 g for each soil sample).

Laboratory Analyses

Particle size distribution dispersed in sodium hexametaphosphate, was determined by hydrometer method according to the procedure of Gee and Or (2002). Bulk density was measured by core procedure (Grossman and Reinsch, 2002). Water holding capacity was determined on undisturbed samples as the difference of water contents at – 0.03 MPa, determined by pressure plate and –1.5 MPa, determined by pressure membrane (Dane and Hopmans, 2002). Total soil carbon was estimated by combustion at 1140 ^{o}C using Leco (R-12 analyzer (Leco Corp, St. Joseph, M1). Soil pH was measured potentiometrically on a 1:2 soil/water solution (Henderson *et al.*, 1993). Cation exchange capacity was estimated by ammonium acetate at pH 7 (Soil Survey Staff, 2003). Calcium carbonate equivalent (CCE) was measured by treating soil sample (<2 mm) with HCl and evolved $C0_2$ estimated manometrically (Soil Survey Staff, 2003).

Data Analyses

Soil data were subjected to analysis of variance (ANOVA) using PROC Mix –model of SAS (Little *et al.*, 1996) and means were separated using a standard error of the difference (SED) at 5% level of probability.

Results and Discussion

Soil morphology: Morphological features of studied soils are shown in Table I, indicating thin epipedons (0 –8 cm) for soil of the summit, midslope and footslope while epipedons of the valley bottom were thick (0 – 58 cm) with few artifacts. Except in valley bottom, soils of other physiographic positions were well drained and redder. Soils of the summit and footslope were weak fine granular–structured with soils of the midslope exhibiting massive structure. Soil rupture-résistance was dominated by very friable status at all the epipedons except in those originating from valley bottom. Soils were predominantly A- (Summit and Midslope) and Ap-horizons (Footslope and Valley bottom). Variability in depth of soils could be as a result of colluviation, although in a similar landscape in Sweden, Allen (2002) attributed it to vertical schistosity. Colour changes in the study site could be due to drainage differences since soils might have originated from similar parent material (Ajalli and Nsukka formations). Mechanization difficulties may constrain the use of soil of the summit and midslope due to slope (>16%) coupled with high gravel content. Indeed, intensive cultivation of soils of the higher physiographic positions may lead to land degradation. However, adoption of conservation measures such as terraces and vegetative strips may sustain arable agriculture (11RR and ACT, 2005) .

Soil physical properties: Soil physical properties are presented in Table 2, with soils exhibiting significant ($P< 0.0001$) variations in particle size distribution and moisture content while bulk density showed non-significant differences among physiographic land units. Sandiness decreased downslope while the other particle sizes increased in the same direction. This could be due to larger size of sand and its decreased transportability while silt and clay sizes are smaller and lighter hence easily moved in suspension towards the valley bottom. Silt – clay ratio, which is an index of age of soil, decreased downlope, indicating that soils of the summit are younger due to instability caused by erosion and colluviation unlike epipedons of lower physiographic positions. Despite non-significant variability in bulk density, the attrribule was found to be higher in valley bottom possibly due to seasonal flooding of soils. Continued wetting and drying of soils decreases aggregate stability (Caron *et al.*, 1992) , leading to collapse of soil pores and production of finer particles and macro-aggregates (Levy and Miller, 1997), implying increased bulk density and decreased macro-porosity .In a similar study on a fragipan, Scalenghe *et al.(*2004) reported higher density on wetted soil when compared with dry soil.

Water holding capacity increased towards the valley bottom physiographic position, and this could be attributed to higher values of clay downslope .Similar findings were reported by Ezeaku and Anikwe (2006)in soils of southeastern Nigeria. In addition to clay content, organic matter distribution contributed significantly ($P\leq 0.05$) to differences in soil moisture content (Table 3.) in line with the findings of Dekker *et al.* (1999) in topsoils in Netherlands, France, Sweden and Germany. However, soil organic matter interacts with other soil properties to influence water behaviour in soils (Ellerbrock *et al.*, 2005; Eynard *et al.*, 2006).

Other soil chemical properties of epipedons in the study site are shown in Table 3 and they varied significantly ($P\leq 0.05$) along physiographic positions. Soil pH decreased towards the summit, suggesting possible loss of basic cations which finally accumulate at the valley bottom. Differences in soil pH were very significant among physiographic positions, and this could be used in delineating the hilly landscape into different arable land use types since soil pH governs the distribution crop nutrients in soil. Although soils were generally acidic, topography may have contributed to local differences in its distribution in the studied soils. Results of soil pH were higher (pH water = 5.27-7.6) and contrasted with findings of Onweremadu (2007) in a similar study (pH water =4.0-4.7 in the same agroecology. This variation could be due to land use and topography. Calcium carbonate equivalent (CCE) values were low in all physiographic units particularly in epipedons from the summit. This could be as a result of combined effect of leaching and runoff losses. The study site is within the northernmost part of the rainforest agroecology of southeastern Nigeria while higher values of CCE are expected in drier ecological zones of Nigeria. Presley *et al*. (2004) reported higher values of CCE in semi-arid soils of Kansas in USA, and these values increased with depth of soils. However, this study did not investigate sub-horizons of studied soils.

Classification of epipedons

The soils of summit, midslope and footslope were thin (0-3,0-5, and 0-8 cm respectively) with Munsll colour values greater than 4 (moist) and chroma of 4. In addition to these, soils of summit, midslope and footshop had CCE of 10, 12 and 14 g kg, respectively (Table 3), suggesting the classification of these topsoils as ochric epipedones. Soils of the valley bottom contained artifacts with Ap horizon of 0- 58 cm thick possibly due to cultivation and prominent marks of farm tools unlike the other soils , hence classified as plaggen epipedons.

Table 1. Selected Soil Morphological Properties

Physiography	Horizon	% slope	Depth (cm)	Colour (moist)	Structure	Artifacts	Consistency (moist)	Gravel (32-2 mm)	Drainage
Summit	A	21	0-3	LRB 5YRS 6/4	1fgr	Nil	Vfr	46	WD
Midslope	A	16	0-5	LRB 5YR 6/4	0 ma	Nil	Vfr	43	WD
Footslope	Ap	8	0-8	RB 5YR5/4	2 fgr	Nil	Vfr	32	WD
Valley bottom	Ap	0-2	0-58	DG 5YR 4/1	2 m abk	Few	fi	26	PD

LRB = light reddish brown, RB = Reddish brown, DG = Dark gray

O = Structure less, 1 = weak, 2 = moderate, f = fine m = medium Ma = massive base = angular blocky, Vfr = very friable, WD= well drained, PD = poorly drained, fi = friable

Table 2. Soil Physical Properties

Physiographic horizon Depth	Sand g kg^{-1}	Silt g kg^{-1}	Clay g kg^{-1}	SCR	BD M gm^{-3}	WHC g kg^{-1}
Summit	850	90	60	1.5	1.41	24
Midslope	845	70	85	0.7	1.37	28
Footslope	800	90	110	0.8	1.32	36
Valley bottom	780	95	126	0.7	1.43	44
SEDp=0.05	1.38	1.95	5.06	0.05	0.02	1.22
P = values	<0.0001	<0.0001	<0.0001	0.0001	NS	<0.0001

SCR = silt – clay ratio, TC = textural class WHC = water holding capacity.

Table 3. Selected soil chemical properties

Physiography	Horizon	Depth cm	pH water	CEC $cmo1kg^{-1}$	CCE $g\ kg^{-1}$	OC $g\ kg^{-1}$
Summit	A	0-3	5.2	5.6	10	11.6
Midslope	A	0-5	5.4	7.8	12	14.2
Footslope	Ap	0-8	5.5	7.9	14	34.4
Valley Bottom	Ap	0-58	6.1	9.8	24	39.8
SEDp= 0.05			0.09	1.56	0.08	0.07
P-values			<0.001	<0.001	<0.001	<0.0001

CEC = cation exchange capacity, CCE = calcium carbonate equivalent, OC=organic carbon.

Table 4. Classification of studies epipedons

Physiography	Horizon	Depth (cm)	Epipedon
Summit	A	0-3	Ochric
Midslope	Ap	0-5	Ochric
Footslope	Ap	0-8	Ochric
Valley Bottom	Ap	0-58	Plaggen

References

Akamigbo F.O.R and C.A Igwe. 1990 Morphology, geography, genesis and taxonomy of three soils series in eastern Nigeria, *Samaru J. Agric Res*., 7:33-48.

Allen, C.E. 2002. The influence of schistocity on soil weathering on large boulder tops, Karkevageje, Sweden.*Catena*, 49:157-169.

Bhatti, A.U., D.J. Mulla and B.E. Frasier .1991. Estimation of soil properties and wheat yields in a complex eroded hills using geostatistics and thematic mapper images. *Remote Sens Environ.*, 37:181-191.

Bruand, A., C. Hartmann, S. Ratana-Anupap, P. Sindtusen, R, Poss and M hardy, 2004 .Composition, fabric and porosity of an Arenic Haplustalf of Northeast Thailand: Relation to penetration resistance. *Soil Sci. Soc. Am. J.*, 185-193.

Brubaker. S.C., A. J Jones, D.T. Lewis and K Frank 1993. Soil properties associated with landscape position. *Soil Sci Soc. Am. J*. 57:235-239.

Buol S.W., F.D. Hole, R.J. McCracken and R.J. Southard. 1997. *Soil genesis and classification*. 4th edition lowa State University Press, Ames.

Busscher, W.J. J.R. Federick and P.J. Bauer. 2001. Effect of penetration resistance and timing of rain on grain yield of a narrow–row corn on a coastal plain loamy sand. *Soil Till. Res*., 63:15-24.

Caron, J. B.O. Kay and J.A. Stone. 1992. Improvement of structural stability of a clay loam with drying .*Soil Sci. Soc Am. J*., 56:1583-1590.

Chien, Y.J., D.Y. Lee H.Y. Guo and K.H. Honng. 1997. Geoststisical analysis of soil properties of mid –west Taiwan soils. *Soil Sci.*, 162:291-298.

Dane, J.H. and J.W. Hopmans 2002. Water retention and storage: Laboratory methods. In: J.H. Dane and G.C. Topp (eds.) .*Methods of soil analysis.* Part 4 Physical methods. Soil Sci. Soc. Am. Book series No 5, ASA and SSSA, Madison WI. Pp. 675-720.

Dekker, L. W., C.J. Ritsema, O. Wendroth, N. Jarvis, K. Ostindie W. Pohi, M. Larsson and J.P. Gaudet 1999. Mositure distributions and wetting rates of soils os experimental fields in Netherlands, France, Sweden and Germany. *J. Hydrol.*, 215:4-22

Ellerbrock, R.H., H.H. Gerke, J. Bachimann and M.O. Goebel. 2005. Compsition of organic matter fractions for explaining wettability of three forest soil. Soil Sci: Soc Am. J., 64: 57-66.

Eynard, A., T.E. Schumacher, R.A. Kohl and D.D. Malo 2006, Soil wettability relationships with soil organic C and aggregate stability. 12th World congress of soil Science, Philadephia, Pennyslavia, USA 9-15 July 2006.

Gee, G.W, and D. Or. 2002. Particle size analysis. In: J.H. Dane and G.C. Topp (eds.) *Methods of soil analysis* Part 4, Physical methods. Soil Sci. Soc. Am. Book Series No. 5, ASA and SSSA, Madison WI pp. 255-293.

Grossman, R.B. and T.G. Reinsch. 2002 Bulk density and linear extensibility. In: J.H. Dane and G.C. Topp (eds) *Methods of soil analysis*. Part 4, Physical methods. Soil Sci. Soc Am. Book series No5, ASA and SSSA Madison WI. Pp. 201-228

Grossman, R.B., D.S. Harms, C.A. Seybold and J.E. Herrick. 2001. Coupling use-dependent and use-invariant data for soil quality evaluation in the United States. *J. Soil Water Conserve.*, 56:63-68.

Hendershot, W.H., H. Lalande and M. Duquette. 1993. Soils reaction and exchangeable acidity. In: M.R. (carter (ed). *Soil sampling and methods of analysis* Can Soc. Soil Sci, Lewis Publishers, London. pp 141-145

Hobbie, S.E. 1996 Temperature and plant species control over litter decomposition in Alaskan tundra. *Eco. Monogr*., 66:503-522.

Igwe, C.A., M. Zare, and K. Stahr, 2005. Mineral and elemental distribution in soils formed on the River Nigeria floodplain, eastern Nigeria*. Austr. J. Soil Res*., 43:147-158.

IIRR and AC (International Institute of Rural Reconstruction) and (African Conservation Tillage). 2005. *Conservation agriculture: A manual for farmer and extension workers in Africa.* Majestic printing Work Ltd, Narrobi Kenya pp 251.

Johnson-Maynard J.L., P.J. Shouse, R.C Graham, P. Castiloglione and S.A. Quideau. 2004. Microchimate and pedogenic implications in a 50-year old chaparral and Pine biosequence. *Soil Sci. Soc. Am. J.* 68: 876-884.

Lamotte, M., A Bruand, F.X. Humbel, A.J. Herbillon and M. Revi. 1997. A hard sandy-loam soil from Northern Cameroon. I. Fabric of the groundmass. Eur J. Soil Sci., 48:2130225.

Levy, G.I. and W.P. Miller. 1997. Aggregate stability of some southern Us soils. *Soil Sci Soc Am. J.*, 61: 1176-1182.

Mallarino, A.P. 1996. Sparial patterns of phosphorus and potassium in non-tilled soils for two sampling scales. Soil Sci Soc. Am. J., 60:473-1481.

Onweremadu, E.U. 2007. Soil carbon distribution in a hilly landscape. *Int J. Agric. Res,* 2 (4): 377-384.

Onweremadu, E.U. 2008. Physico-chemical characterization of a farmland affected by wastewater in relation to heavy metals. *J. Zhejiang University Sci.*, 9:366-372..

Paz-Gonzalez, A. S.R. Vierira and M.T Taboada-Castro. 2000. The effect of cultivation on the spatial variability of selected properties of an umbric horizon. *Geoderma,* 97:273-292.

Presley, D.R., M.D. Ransom, G.J. Kluitenberg and P. R. Finnell 2004. Effects of thirty years of irrigation on the genies and morphology of two semi-and soils of Kansas. *Soil Sci Soc. Am J*., 68:1916-1926.

Quideau, S.A., O.A. Chadwick, R.C. Graham, S.E. Trumbore, J.L. Johnson-Maynard R.C. Graham and M.A. Anderson. 2001 Vegetation control on soil organic matter dynamics.*Org, Geochem*., 32:247-252.

Scalenge, R. G. Certini, G. Corti, E. Zanini and F.C. Ugolini, 2004 Segregated ice and liquefaction effects on compaction of fragipans. *Soil Sci. Soc Am. J.,* 68:204-214.

Seybold C.A., R.B. Grossman, H. Hoper, G. Muckel and D.L. Karlen 2004 Soil quality morphological index measured in the 1996 NRi pilot study. *Soil Surv. Hor.,* 45(3):86-95.

Soil Survey Staff 2003. *Keys to soil taxonomy,* Ninth Edition USDA/NRCS, Was hington D.C. pp. 332

Stutter, M.I. L.K. Deeks and M.F. Billett, 2004. Spatial variability in soil ion exchange chemistry in agranitic upland catchment. *Soil Sci Soc. Am J.,* 68:1304-1314.

Wang, J. B.Fu, Qi and L. Chen. 2001. Soil nutrients in relation to land use and landscape position in the semi-and small catchment on a loess plateau China.

12/18/2008