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Pedogenesis of Soils of a Colliery

E.U. Onweremadu
Department of Soil Science and Technology, Federal University of Technology,
P.M.B. 1526, Owerri, Nigeria

Abstract: The morphological, physical and chemical changes taking place in fine earth materials proximal to *Onyema* coal mine in Enugu Southeastern Nigeria were studied in 2006 using routine techniques. Anisotropy among soil properties were determined using Coefficient of Variation (CV) measured in percentages. Results indicate formation of cambic (Bw) horizons, presence of carbolithic materials and prominence of rock fragments (25-60%). Soils were more grayish in horizons closest to consolidated basement rocks. There were little to moderate variations in soil properties except in silt-clay ratio (CV = 48-76%) and silt content (CV = 37.4-69.0%). Total sulphur content and soil pH increased with depth as underlying soil were poorly drained. Aluminium saturation (Alsat) was high in both mine soil sites (Alsat = 38-71%). Soils were classified as Typic Dystrudepts (Dystric Anthrosols) in Pedon I while Oxic Dystrudepts (Dystric Anthrosols) in Pedon 2. The use of geostatistical and pedometric techniques is suggested for modelling for sustained use of soils for agriculture and environment.

Key words: Anisotropy, mine soils, soil morphology, pedogenesis, weathering, young tropical soils

INTRODUCTION

Mining is a major socioeconomic activity in Nigeria. Mining activities impact on environmental quality (Gabler and Schneider, 2000; Marszalek and Wasik, 2000). Intensive mining activities have resulted in significant deterioration of the terrestrial ecosystems in the vicinity of mines (Malinovsky *et al*., 2002) and these occurrences in Russia may also pose problems in minesoils of southeastern Nigeria Such activities are also pedoturabative as soil inversions and overburden characterize minesoils. In most cases, mining activity disturbs and changes the topography of land and adversely affects the hydrogeologic conditions (Bell *et al*., 2000). However, the degree of impact depends on many factors, in particular, mining method and size of the operation (Nabi Bidhendi *et al*., 2007).

Coal mining activity started during the pre-independence era and has been associated with terrestrial changes around the colliery in Enugu, southeastern Nigeria. Original soils and plants were buried by mine spoils and this also affected the faunal composition of the site. In a similar area, Haering *et al*. (2004) reported that surface coal mining resulted in an exposed highwall directly above a level to gently rolling bench covered with varying depths of blasted and bulldozed rocky spoils and a steep outslope composed of soils that had been bulldozed over the edge of the bench. Mining activity may reset soil formation (Alemu and Abebe, 2007) and exposes toxic subsurface horizons. Brady and Weil (1999) reported high sulphur content of coal mines, which acidify minesoils. This could be why modern mining regulations require isolation of acid-producing pyrite (Skousen *et al*., 2000). Some researchers (Indorante *et al*., 1992) noted that soil texture, colour and subsurface pH are generally inherited from overburden type. Minesoils commonly have A-C or A-AC-C horizonation (Thomas *et al*., 2000). Sometimes, minesoils are associated with redder hue or higher clay in underlying or overlying horizon (Soil Survey Staff, 1999). Mine soils formed in oxidized material tended to be more acidic and in the presence of small amounts of acid-forming material resulted in low soil pH in some soils formed in gray unoxidized material (Haering *et al*., 2004). In the study, the soils of a coal mine in Enugu Southastern Nigeria are characterized and classified.

MATERIALS AND METHODS

Study Area

Onyema Mine is in Enugu, southeatern Nigeria and lies between latitudes 6°20^1 and 6°50^1 N and longitudes 6°50^1 and 7°25^1 E. Geomorphlogically study area is a highland hence Enugu meaning high elevation. Red and brown soils of the study area are derived from sandstones and shales. The study area is situated within the humid tropical climate, with two distinct season. Rainfall is bimodal and mean annual rainfall ranges from 1600 to 2000 mm while the temperature is uniformly high throughout the year (Asadu, 1990). However, temperature falls below 21°C during harmattan (Nnaji *et al*., 2002). The site has a rainforest which has been so depleted to resemble derived savanna. Government-controlled coal mining is a major socio-economic activity with low input agriculture taking place around mine site and on old mine spoils. It is cassava-based mixed cropping and fertility regeneration is by very shortened bush fallowing land clearing is by slash-and-burn method.

Field Sampling

Target sampling of minespoils was done in April 2006 at Onyema Mines. The mine soils were about 26 years without mining disturbance. Two minespoils out of several spoils located in the site were chosen for the investigation. The soil profile pit was dug in each mine spoil described according to FAO guidelines (FAO, 1990; Sencindiver and Ammons, 2000). Soil colour was determined using Munsell Colour Chart. Soil sampling was done based on degree of horizon differentiation. Large soil samples (3-4 kg) of each horizon were taken for laboratory analysis. Soil samples were air-dried, gently crushed and sieved through a 2 mm (10 mesh) sieve. Large samples (5 kg) of each horizon were sieved in the field to determine the approximate weight percentage of rock fragments ≥ 75 mm. Content of fragments <75 mm was determined in the laboratory. The total rock fragments content and relative percentages of gravels, cobbles and stones were estimated in the field using the procedure of Soil Survey Division Staff (1993). Field rock fragment volume estimates were converted to weight estimates (Method 3 B1, USDA-NRCS, 1996). Percentage of small gravel (<20 mm) content was also quantified in the laboratory by sieving and weighing the 5 kg samples. This is unlike very large samples (60 kg) samples required to accurately measure the percentage of rock fragments between 25 and 75 mm and visual estimates recommended for determining percentage of rock fragments >75 mm (Soil Survey Division Staff, 1993; USDA-NRCS, 1996). Five core samples were also collected from each pedogenic horizon for bulk density determination.

Laboratory Analysis

Particle size distribution was determined by hydrometer method (Gee and Or, 2002) as bulk density was estimated according to the procedure of Grossman and Reinsch (2002). Water Holding Capacity (WHC) was measured using undisturbed samples and as a difference of water contents at -0.03 and -1.5 MPa determined by pressure plate membrane (Dane and Hopman, 2002). Soil pH was determined by the glass-electrode method on a 1:1 soil/water volume (Watson and Brown, 1998). Soil organic carbon was estimated in the fine-earth fraction of each horizon according to the method of Eynard (2001). Soil organic carbon content was multiphed by a factor of 1.724 to obtain Organic Matter (OM). Total sulphur was measured by potassium-nitrate/nitric acid digestion method (Thomas, 1982). Base saturation (Bsat) was calculated as the sum of the basic cations (Ca, Mg, K and Na) divided by CEC, multiplied by 100% while aluminium saturation (Alsat) was computed as the exchangeable aluminium divided by CEC multiplied by 100%.

Data Analysis

Inter-horizon variability was estimated using coefficient of variation measured in percentages. Ranking of variability was done according to the procedure of Aweto (1982).

RESULTS AND DISCUSSION

Field Morphology and Physical Properties

Morphology of mine soils are presented on Table 1, indicating variability in measured properties. Soils were generally shallow (<100 cm) with Pedon 2 exhibiting lithic contact at 80 cm depth. There was variation in horizon depths between Pedons 1 and 2. It is possible that the strata removed during mining were transported laterally as well as downward, resulting in very heterogenous mine soils of widely varying depth. Both pedons had A and Bw horizons, indicating the beginning of horizonation in soil development. The A horizons of the minesoil had weak granular structure with Bw horizons underlying them and thick enough to be classified as cambic, thus soils were classified as Inceptisols (Soil Survey Staff, 2003).

Rock fragments content of minesoils fell within 25 to 60%, which is somehow within the range reported by Reberts *et al*. (1988). But epipedal horizons had lower values of rock fragments and this can be attributed to physical weathering. Generally, accelerated physical weathering of rocks in the study site may have been caused by blasting and vehicular movement during mining. This implied that previous blasting activities which may have resulted to rapid rate of soil development in the area and with time these rock fragments will decrease (Roberts *et al*., 1988) in abundance and size. The upper horizons differed in sand content from the underlying particle-size control section, with deeper particle-size control section being high in silt content, suggesting the existence of some translocatory pedogenic processes. It is also possible that the fine earth fraction of the epipedons of mine soils evolved from pre weathered and oxidized earth materials. Influence of external agents like climate in addition to anthropogenic activities affected oxidized surficial horizons more than the unoxidized earth materials.

Some Laboratory determined physical properties are shown in Table 2, with soil showing more sandiness in the upper horizons while silt increased with depth in the minesoils. Silt clay ratio

Table 1: Morphology of mine soils

Horizon	Depth (cm)	Description
Pedon 1		
Ap	0-9	Dark grayish brown (10 Yr 4/2) moist, sandy loam, weak granular structure, friable non sticky, non plastic 25% rock fragments (sandstone), common fine roots 10% carboliths, extremely acidic (pH 3.9), clear wavy boundary.
Bw	9-50	Dark grayish brown (10 YR 4/7) moist, sandy loam, with 5% strong brown (7.5 YR 5/8) iron masses and 3% yellowish brown (10 YR 4/6) iron concentrations, yellow brown (10 YR 4/1) and olive yellow 2.5 Y 5/6) lithochromic colour variegations, massive with
pockets		of weak medium sub-angular blocky structures firm 45% rock fragments (50% gray sandstones, 30% brown sandstone, 10% gray siltstones, 10% carboliths), many very fine roots, Strongly acidic (pH 4.8), clear smooth boundary.
C	50-77	Yellowish brown (10 YR 3/6) moist gravely sandy loam, structureless firm, no roots 40% rock fragments (sandstone) 3% carbolith, extremely acidic (pH 4.9).
Pedon 2		
A	0-7	Dark grayish brown (10 YR 4/2) moist, loamy sand weak granular structure, friable, coarse and common fine roots, 80% rock fragments (sandstones and siltstones) few line roots 2% carboliths, strongly acidic (pH 3.7), abrupt smooth boundary.
Bw	7-65	Yellowish brown (10 YR 5/6) moist, sandy loam, with common coarse gray lithochromic colour variegations massive firm, few fine roots, 55% rock fragments (siltstones and sandstone), 3% carboliths, slightly acidic (pH 5.5), abrupt smooth boundary.
Cg	65-20	Dark gray (10 YR 4/1) moist, sandy clay loam, massive, firm no roots, 60% rock fragments (Sandstone), 2% carbolith, slightly acidic (pH 6.2).
R	80+	Gray (10 YR 5/1) moist, lithic contact.

Table 2: Physical properties of studied minesoils

Horizon	Depth (cm)	Sand (g kg^{-1})	Silt (g kg^{-1})	Clay (g kg^{-1})	SCR	BD (mg m^{-3})	WHC (g kg^{-1})	Drainage
Pedon 1 (Typic Dystrudepts/Dystric Anthrosols)								
Ap	0-9	650.0	120.0	230.0	0.500	1.53	325.0	WD
Bw	9-50	550.0	250.0	200.0	1.130	1.56	338.0	WD
C	50-77	600.0	280.0	120.0	2.330	1.62	342.0	PD
	Mean	600.0	127.0	183.0	1.320	1.57	325.0	-
	CV (%)	40.8	69.0	46.0	76.000	3.70	2.2	-
Pedon 2 (Oxic Dystrudepts/Dystric Anthrosols)								
A	0-7	660.0	130.0	210.0	0.620	1.49	383.0	WD
Bw	7-65	570.0	70.0	160.0	1.870	1.57	476.0	PD
Cg	65-80	500.0	360.0	140.0	2.257	1.63	484.0	PD
R	80+	-	-	-	-	-	-	-
	Mean	557.0	253.0	170.0	1.680	1.56	447.0	-
	CV (%)	11.3	37.4	17.3	48.000	3.60	10.2	-

SCR = Silt Clay Ratio, BD = Bulk Density, WHC = Water Holding Capacity, CV = Coefficient of Variation, WD = Well Drained, PD = Poorly Drained

increased with depth, showing that epipedal soils have undergone more weathering and pedogenesis than sub-surface horizons of the mine pedospher. However, the preferential translocation of silt-sized fractions among other particle sizes could be explained by large sizes of sand on one hand and very high binding effect of clay-sized fractions on the other hand. Sand and clay contents exhibited little to moderate variation in both soils while a silt had moderate to high variation. Such vertical and lateral anisotropy that yield spatial variability of a random nature over short range or intermediate distances could be due to intensity of pedogenic weathering processes, hydrology biological activity, erosion, land use, deposition and pedoturbation (Wilding *et al*., 1994). Bulk Density (BD) increased with depth and was relatively high, possibly due to overburden. Thomas *et al*. (2000) reported that BD of minesoils are usually higher than native soils. In the study sites, BD showed little variation intrapedally. However, greater variability is expected at surficial layers due to varying land use types, histories and intensities in the locality. Moisture status of soils increased with depth in both pedons and varied minimally (CV = 2.2-10.2%). Increase in moisture content with depth is attributable to reduced sand content with depth as well as increased BD. Heuscher *et al*. (2005), established a good relationship between soil water content, soil texture and bulk density.

Soil Chemical Properties

Soils were extremely to strongly acidic (mean = 3.9-4.9) in Pedon 1 while pH in Pedon 2 ranged from 3.7 to 6.2 (Table 3). Both pedons showed little variation in pH. Soil pH changes rapidly in minesoils as rock fragments weather and oxidize. Pyritic minerals oxidize to sulphuric acid and this lowers soil pH. Soil Cation Exchange Capacity (CEC) values were low, which is attributable to the age soil pH status of mine solids. Aluminium saturation (Alsat) was higher than base saturation (Bsat) implying some possibility of Al-toxicity though this depends on Al-species. Low pH and high Alsat can be explained by high content of total sulphur (250-465 mg kg^{-1}) in studied soils. High total sulphur content suggests that coal earth materials compose of FeS_2 and other sulphur forms, which in oxidation yields H_2SO_4. Under acidified status (low pH,) solubilization of Al. Mn Fe and heavy metals is rapid leading to varying degrees of toxicity and bioavailability of crops growing on minesoils. Organic matter is low which is typical of minesoils (Bendfeldt *et al*., 2001). This could also be part of the reasons for the scantiness of plants in the site. Improving of the site may include the use of limiting materials, less-acid-forming fertilizers and organic farming as low OM and total nitrogen are limiting factors in minesoils. The acidity of minesoils is usually attributed to the parent material overburden but Sobek *et al*. (2000) observed that oxidized and pre weathered overburden strata generally contain little oxidizable pyrite. However, the studied soils had carbolithic materials (fragments and high carbon, black Shales) which may have contributed to high S-content, especially at lower horizons.

Table 3: Chemical properties of studied minesoil

Horizon	Depth (cm)	pH (water)	CEC (cmol kg^{-1})	Bsat (%)	Alsat (%)	OM (%)	Total S
Pedon 1 (Typic Dystrudepts /Dystric Anthrosols)							
Ap	0-9	3.9	12.0	35.0	66.0	5.6	289.0
Bw	9-50	4.8	10.0	40.0	56.0	4.4	250.0
C	50-77	4.9	5.0	42.0	54.0	3.5	351.0
	Mean	4.5	9.0	39.0	58.6		296.6
	CV (%)	9.4	34.5	7.5	8.9	19.1	14.0
Pedon 2 (Oxic Dystrudepts/Dystric Anthrosols)							
A	0-7	3.7	15.0	32.0	71.0	5.8	305.0
Bw	7-65	5.5	9.0	48.0	42.0	4.5	321.0
Cg	65-80	6.2	6.0	51.0	38.0	3.1	465.0
R	80+	-	-	-	-	-	-
	Mean	51.0	10.0	43.6	50.3	4.4	363.6
	CV (%)	20.6	37.4	19.1	29.2	25.4	19.7

CEC = Cation Exchange Capacity, Bsat = Base saturation, Alsat = Aluminium saturation, OM = Organic Matter, S = Sulphur

In terms of variability, all soil chemical properties showed little to moderate variation, indicating the youthfulness of soil chemical transformations. Nonetheless, soil pH in Pedon 2 was higher in lower horizons due to high WHC which kept that part of the pedosphere under reduced state. Variability in organic matter could be due to land use as Pedon I was cropped while Pedon 2 was under fallow. Organic matter was relatively high possibly due to weathering of carbonaceous materials and decomposition of litter buried by mining activities.

Finally, there may be need for more detailed sampling using geostatistical and pedometric techniques. The results of such studies will be subjected to stepwise regression analyses, which will eventually enhance landscape modelling of the study area.

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