Chronosequential Pedon Development on a Mined Landscape

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Abstract: Variability in properties of different ages of minesoils was studied in 2006 at Okigwe Stone Mining Sites in Southeastern Nigeria. Assisted by land users 5-, 10-, 15-, and 30 – year-old minesoils and a native soil were identified. A profile pit was dug, described and sampled from each soil group. Soil data were subjected to coefficient of variation (CV). Results showed that O- and A – horizons were found in Native soil but O–horizon was absent in minesoils. Rock fragments decreased with age of minesoil, and soils were more grayish in colour compared with redder colours of native soils. Minesoils had higher values of silt-clay ratios and lower clay content. Higher values of bulk density and pH were also recorded in minesoils. Available water holding capacity, cation exchange capacity, electrical conductivity, organic fractions and Available phosphorus (Av.P) increased with age of minesoils. While little to moderate variations were found in some soil properties (CV < 50%), clay and Av.P (CV = 71.8%) varied highly. There may be need for pedometric approaches to the evaluation of minesoils as this will enhance modelling and sustained use of this group of soils. [The Journal of American Science. 2007;3(2):16-22]. (ISSN: 1545-1003).

Key words: Anthropogenic activity; chronosequence; pedogenesis temporal variability; tropical soils

Introduction

Mining has been disturbing land, forests and water ways (Rodrigue and Burger, 2004). Mining alters soil physical and structural properties (Shukla et al., 2004), implying that minesoils differ from original soil (Thomas et al., 2000). Mining disrupts partially or totally the original characteristics of soils. It alters soil structure and water storage and transmission characteristics (Barnhisel and Hower, 1997) such as water infiltration rate (Guebert and Gardner, 2001) Over burden at mine sites influence soil texture, soil colour and subsurface pH (Haering et al., 2004) Gorman and Sencindiver (1999) reported 58% water stable aggregation in the top 8 cm of a minesoil while Thomas et al. (2000) recorded more water-stable aggregates in native than mine soils. Minesoils are generally young although their ages vary. Consequently, stages in the pedogenesis differ, and this dictates properties and usefulness of soils for agriculture and non agricultural purposes.

In Nigeria and southeastern Nigeria in particular, mineral exploration activities form a major socio-economic aspect of the people's life. Mining regulations are not strictly adhered to, leading to serious environmental problems, such as soil pollution. As part of the mining activities subsoils and lithic material are excavated and dumped on near mine surfaces, and this overlies the native soils. The overlay of native soils by mine spoils reset the time for pedogenesis of such soils. Kosse (2000) observed that unconsolidated or organic soil materials resulting largely from landfills, mine spoils, urban rubble, garbage dumps and dredgings produced by human activities generate fresh anthropogeomorphic parent materials upon which soil forming factors start acting anew. The mine soil takes time to evolve into soils, thereby reducing the capacity of such earth materials to produce crops and pastures. To worsen the situation, exposed and overlying susbtereanean materials may be very toxic, thereby retarding plant establishment on them hence Aiyesanmi (2005) called for constant monitoring of mine environment. Again mine spoils reduce cultivable arable lands and rangelands and this becomes worrisome in a rapidly increasing population of southeastern Nigeria. Because most of the mined minerals are more economically rewarding than farming, land users are unrepentant in the quest for excavating and selling these resources. However, it becomes necessary to characterize and classify these soils. This is in order to avoid a splintering of soil classes (Dudal et al., 2002). Based on the foregoing, the major objective of this study was to characterize and classify some mine soils in Okigwe, Southeastern Nigeria as this will enhance sustained use of soils.

Materials and Methods

Study area: Okigwe is the study site in Imo State, Southeastern Nigeria. It lies on latitude $5^0 56^1 35^{11}$ 513 and longitude $7^0 44^1 06^{11}$. 500, and on an elevation of 318 m (Global Positioning Systems (GPS) Receiver (Garmin Ltd, Kansas, USA). Soils originated from falsebedded sandstones (Ajalli formation) and lie on a scarpy terrain of the area. Okigwe has a humid tropical climate, having a mean annual rainfall range of 2000 – 2250 mm. It has a mean annual temperature range of 27 – 28 ^{0}C and relative humidity varies with seasons as 80 – 90 % range occurs at 10 am in the rainy season while 60 – 80 % relative humidity is recorded at 10 am during the dry season. Tropical rainfoest vegetation predominates in the area. Agriculture, stone mining and quarrying are major socio-economic activities in the area. More economic benefits are derived from the excavation of stones, sands and gravels, causing the native population to engage on it. Yet, construction companies also depend on the rock fragment resources of the area as consolidation materials. The use of earth movers have resulted in the formation of mine spoils whose ages vary according to time of activity.

Field work: Five different ages of minesoils, namely native, 5, 10 15 and 30 years were sampled in 2006. Topography of the mine site ranges from 2-3 %. A soil profile pit was sunk on each age group. Soil sampling was done according to the procedure of FAO (1990). Large soil samples (5 kg) from each horizon were sieved in the field to determine approximate weight percentage of rock fragments greater than 75 mm while contents of fragments less than 75 mm wee determined in the laboratory. Total rock fragments content was estimated according to the method of Soil Survey Division Staff (1993) and these estimates were converted to weight estimates (Method 3B1, USDA-NRCS, 1996). Soil colour was determine using Munsell Colour Chart while Abney level was used to estimate percent slope of sampling sites. Collected soil samples were air-dried and sieved using 2- mm sieve. Three core samples were collected per horizon and used for bulk density determinations.

Laboratory Methods: Bulk density was estimated by core method (Grossman and Reinsch, 2002). Particle size fractions were determined by hydrometer method (Gee and Or, 2002). Soil moisture retention characteristic was measured by soaking disturbed soil samples for 48 hours to allow the samples get saturated. The saturated soil samples were put in the pressure plate extractor and pressure applies at 0.03, 0.05, 0.1 and 1.5 Mpa suction until water ceased to drain out. The soil samples were weighted and oven-dried at 105 ^{0}C for 24 hours. Available water capacity (AWC) was calculated as the difference in water content between 0.03 and 1.5 MPa. Soil pH was estimated by a 1:2.5 soil to water suspension method using a standard pH probe on an Accumet 915 pH meter (Method 8CI, Soil Survey Staff, 1996). Cation exchange capacity (CEC) was analysed as sum of ammonium acetate extractable bases (Soil Survey Staff 1996). Total carbon (C) and nitrogen (N) were estimated on aliquots by dry combustion 1060 ^{0}C and detection of evolved CO_2 and NO_2, using a Carlo Erba element analyzer (Carlo Erba, Italy). Organic matter was obtained by multiphping C by a factor of 1.724. Available phosphorus (Av.P) was measured by Olsen method (Emeteryd, 1989). Electrical conductivity (EC) was determined by a 1: 5 soil/water extract (Rhoades, 1982).

Classification: Soils were classified using USDA soil Taxonomy (Soil Survey Staff, 2003).

Statistics: Variability among studies soil was estimated using coefficient of variation (CV) measured in percentage (SAS Institute, 1999) ranked according to the procedure of Aweto (1982).

Results and Discussion

Soil morphology: Table 1 shows morphological properties of minesoils. There were differences in horizonation among minesoils. Differences between horizons generally reflect the type and intensity of the processes that have caused changes in the soil. The variations reflect vertical partitioning in the type and intensity of the various processes that influence soil development. Solum was more developed in Native soils than in minesoils due to mechanical disturbance of the latter. However, more developed horizons were identified with age of minesoils. At 5, 10 and 15 years minesoils still had lithic contact, which affected colour of subsoils being more grayish than subsoils of Native soils. Cambic horizons were thick enough to be recognized as such in 30 year minesoil which allowed the classification of soils as Inceptisols, while other minesoils had no Bw (5 years) or weakly developed Bw (10 and 15 years). The Native soils were deeper and highly differentiated in pedogenic horizon characteristics. The A-horizon thickness increased with age of soil, and variability in A-horizon thickness could be attributed to land use history and status of mechanical disturbance in the study site. Unlike reports of Thurman and Sencindiver (1986) that A- horizon was 9-13 cm thick in 23 to 29 – year –old minesoils in West Virginia, A- horizons in the studied sites were not as thick as in minsesoils of Okigwe in Southeastern Nigeria. Variability in A – thickness in these locations could due to influences of climate and land use activities. In the study area the original rainforest vegetation has been highly depleted resulting, to direct impact of heavy rainfall and intense heat typical of the area.

Rock fragments decreased with age and with least disturbance, hence more rock fragments were recorded in 5-year–old minesoil. Rocks disintegrate with time and coupled with increased pedogenesis, rock fragments reduce in abundance and size. Crumb structures were found in Native soils compared to minesoils, having weakly developed structures. It is possibly due to absence of mechanisms that group soil particles into clusters in minesoils. There were fewer plants in minesoils while plants are the primary agents for moving soil particles into close contact with each other.

Physical Properties: Selected physical properties of soil 'studied are shown in Table 2. Minesoils were sandier than Native soil and had high proportion of silt than clay in 15-to 30-year–old mine soil. Silt clay ratio decreased with age of minsesoil suggesting that older soils had lower silt-clay ratios. Lower clay content in minesoils could be responsible for low available water capacity (AWC) when compared with native soil (AWC = 236 g kg^{-1}) in surface samples. Bulk density (BD) of minesoils was somewhat higher than that of Native soil. Overburden and human activities are possibly causing higher BD in minesoils. The weight of unweathered fragments decreased with age (Table 1) and this increased soil BD. Available Water Capacity, and BD content increased with depth but varied at epipedal and subsurface horizons. Generally, silt clay content was high at subsurface horizons, suggesting great influences on soil moisture and soil temperature. Bulk density and sandiness showed little variation (CV < 20 %), and silt content and AWC varied moderately (CV =20-50 %) while clay differed greatly (CV > 50 %) with age.

Available water holding capacity is one of the most important growth-promoting factors but values were lower in minesoils. These results are consistent with the findings of Rodrigue and Burger (2004). Low AWC is attributable to high fragments content of minesoils while increased silt and clay increased its values – as observed in Native soil.

Chemical properties: Electrical conductivity (EC) increased with depth and varied moderately (CV = 34.3-39.9 %) with age. However, values of EC fall well below critical limits (>1000-3000 μs cm^{-1}) defined for agronomic purposes (McFee et al., 1981). Soil pH increased with depth and exhibited little variation (CV = 11.1-11.3 %) with age of minesoils. But soil pH decreased with age of minesoils and this agrees with the report of Thomas et al. (2000) that minesoil pH tended to decrease with age, and that native soils had lower pH values than minesoils. Lower values of pH with age, indicates that advanced weathering, leaching and other translocatory pedogenic processes of loss had influenced older soils allowing loss of basic cations from epipedal horizons to deeper portions of the pedosphere. Generally, soils were acidic, and this is attributable to acidic parent materials (Falsebedded Sandstones) coupled with high rainfall amount of the area.

Organic matter (OM) was generally low in minesoils but increased with age. However, OM showed little variation among soils at epipedal horizons but varied moderately in subsurface horizons. Total nitrogen (TN) exhibited high variation (CV = 61.0 -77.4 %) as Available Phosphorus (Av.P) did at surface horizon (CV = 71.8 %). These organic fractions have been identified as limiting factors in the productivity of 10-year-old minesoils (Andrews et al., 1998). Low TN in minesoils could be due to deficiency of N-fixing organisms since young minesoils are associated with primary succession. Organic matter and TN are good indicators of N- availability in minesoil (Bendfedt et al., 2001). These indicators increased with age of minesoils, implying that they could be used in modelling N- availability in precision farming.

Soil classification: Based on morphological, physical and chemical characteristics, soils were classified as shown in Table 4. Native soil was classified as Rhodudults based on colour value, presence of agrillic horizon and low silt-clay ratio (SCR = 0.10) while 30-year-old minesoil had a well developed cambic horizon (Bw and C) thick enough to be classified as Ruptic-Ultic Dystrudepts. Younger minesoils were classified as Udorthents, having A and weakly developed Bw (10-15 years) and a very high SCR (SCR = 1.22 – 2.00).

Table 1. Soil morphology of minesoils

Property	Native	5	10	15	30
O	Present	Nil	Nil	Nil	Nil
A	Present	Present	Present	Present	Present
B	Present	Nil	Bw	Bw	Bw
C	Present	Nil	Present	Present	C
R	NE	Present	Present	Present	NE
O- thickness (cm)	0-2	NA	NA	NA	NA
A – thickness (cm)	13	2	4	5	8
Depth to Lithic contact (cm)	NA	44	48	66	80^+
Colour of Epipedon (Moist)	Dark brown 10 YR 3/3	Dark gray (10 YR 4/1)	Dark grayish brown (10 YR 4/2)	Brown (10 YR 4/2)	Dark Grayish brown (10 YR 3/1
Colour of C/R horizons (moist)	Red (10 YR 4/1)	Gray (2.5 YR 3/1)	Light Gray (2.5 YR 7/2)	Yellowish brown (10 YR 5/8)	Dark Grayish brown (10 YR 4/2)
Fragments at epipedon (%)	Nil	65	45	38	32
Fragments at horizon next to coherent mass (%)	Nil	78	55	50	26
Plant	Abundant	Too scanty	Very scanty	Scanty	Substantial
Slope (%)	3	2	3	2	2
Structure at epipedon	crumb	Weak fine subangular blocky	Weak fine subangular blocky	Medium fine subangular blocky	Medium fine subangular blocky
Consistence at epipedon	Firm	Friable	Friable	Friable	Firm

Table 2. Selected physical properties of mine soil

Property	Native	5	10	15	30		
	←		Years	→		Mean	CV (%)
	Surface (Epipedon)						
Sand (g kg^{-1})	750	910	860	830	800	830	6.6
Silt (g kg^{-1})	20	60	80	100	110	74	41.3
Clay (g kg^{-1})	230	30	60	70	90	96	72.6
SCR	0.10	2.00	1.33	1.43	1.22	1.21	51.2
Texture	SCL	S	LS	LS	LS	-	-
BD (m gm^{-3})	1.38	1.72	1.67	1.61	1.52	1.58	7.6
AWC (g kg^{-1})	236	96	121	128	144	145	33
			Subsurface (Bw, C, R)*				
Sand (g kg^{-1})	720	890	860	840	800	822	7.1
Silt (g kg^{-1})	20	80	85	90	90	73	37.2
Clay (g kg^{-1})	260	30	55	70	110	105	77.8
SCR	0.10	2.66	1.54	1.28	0.82	1.28	66.0
Texture	SCL	S	LS	LS	SL	-	-
BD (m gm^{-3})	1.51	1.78	1.72	1.65	1.59	1.65	5.7
AWC (g kg^{-1})	286	97	1.26	135	216	172	40.3

BD = bulk density, AWC = Available water-holding Capacity, SCL = sand clay loam, S = sand , LS = loamy sand SL = sandy loam. SCR = silt – clay ratio
*average of subsurface horizons.

Table 3. Selected chemical properties of minesoil

Property	Native	5	10	15	30		
		←	Years	→		Mean	CV (%)
	Surface (Epipedon)						
pH Water	4.4	6.2	5.7	5.4	5.2	5.3	11.3
CEC (cmoI kg^{-1})	12.6	4.6	4.8	4.9	7.6	6.9	44.2
EC (Ms cm^{-1})	9.84	41.8	48.3	51.2	54.4	58.8	34.3
OM (g kg^{-1})	35.3	36.8	32.6	33.4	34.8	33.3	5.8
Total N (g kg^{-1})	3.2	0.6	0.9	1.2	1.7	1.5	61.0
Av P (Mg kg^{-1})	30.6	6.6	7.1	7.5	11.8	12.7	71.8
	Subsurface (Averages of subsurface horizons)*						
pH Water	4.8	6.7	6.1	5.7	5.5	5.7	11.1
CEC (cmol kg^{-1})	8.9	4.3	4.9	5.0	8.8	6.3	32.2
EC (Ms cm^{-1})	106.3	43.4	43.9	48.2	56.3	59.6	39.9
OM (g kg^{-1})	23.2	9.2	9.8	11.3	13.6	13.4	38.2
Total N (g kg^{-1})	1.3	0.2	0.4	0.4	0.5	0.5	77.4
Av P (Mg kg^{-1})	10.6	5.8	6.7	7.6	8.9	7.9	21.3

CEC = cation exchange capacity, EC = Electrical conductivity, OM = organic matter, N = nitrogen , P = phosphorus.
*average of subsurface horizons.

Table 4. Classification of studies minesoils

Age (years)	Classification (USDA Soil Taxonomy, 2003)
Native	Typic Rhodudults
5	Lithic Udorthents
10	Lithic Udorthents
15	Typic Udorthents
30	Ruptic–Ultic Dystrudepts

Conclusion

This study revealed that minesoils varied in morphological characteristics with time. Outstanding morphological properties in this differentiation include A- horizon thickness, depth to lithic materials, colour, fragments content and soil structure. Soils physical and chemical properties varied among minesoils and Native soil at both surface and subsurface horizons. Minesoils were younger than Native soil as shown by variability in SCR. In studied soils, clay content, SCR, AWC, and TN varied widely, suggesting the use of these attributes in modelling minesoils for sustained soil usage.

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Received: 5/23/2007

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