ASSESSMENT OF MINED SOILS IN EROSION-DEGRADED FARMLANDS IN SOUTH-EASTERN NIGERIA

Avaliação do solo em terras férteis degradadas por erosão no sudoeste da Nigéria

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Abstract

This study assessed degradation status of erosion devastated soils as well as ameliorative measures on such soils. Field sampling was aided by morphological landscape changes. Surface samples (0-20 cm) depth were randomly collected from two erosion units and used in conducting a greenhouse experiment using maize (*Zea mays L.*) as a test crop. The experiment was laid out in a completely randomized design (CRD) and rates of ground periwinkle shells (GPS) and sewage sludge (SS) used as treatment. Treatments were replicated 9 times. Statistical tests of difference in soil properties were performed using t-statistic at $p < 0.05$. Status of soil degradation was evaluated using Land Degradation Index (LDI). Results showed low organic carbon content, and high bulk density and aggregate instability in eroded soils. The LDI values were high in most of physical parameters. The GPS and SS treatments significantly ($p < 0.05$) improved yield and soil properties except soil pH and aluminium saturation.

Keywords: Degradation; Soil amendment; Soil erosion; Soil mining; Soil properties.

Resumo

Esse estudo avaliou a situação da degradação, por erosão, de solos esgotados, bem como medidas para sua recuperação. Parte dessas áreas erodidas foi recuperada por meio de mudanças no perfil morfológico do solo. Amostras da superfície (0-20 cm) foram coletadas randomicamente, de duas regiões erodidas, e usadas em um experimento, numa casa de vegetação, com milho (*Zea mays L.*). O experimento foi desenvolvido totalmente ao acaso. Para ajudar a recuperação, restos de conchas de moluscos terrestres (CMT) mais lodo de esgoto (LE) foram usados como complementos para o tratamento da amostra de solo erodido. Nos experimentos (repetidos 9 vezes), o teste-t ($p < 0,05$) foi utilizado para a avaliação estatística. Também foi utilizado o Índice de Degradação de Solo (IDS) para verificar o estado deste. Os resultados mostraram baixa quantidade de carbono, alta densidade e instabilidade da massa de agregados dos solos analisados. Os valores de IDS eram altos na maioria dos parâmetros físicos. Os tratamentos com CMT e LE melhoraram significativamente ($p < 0,05$) a produção e as propriedades do solo, exceto o pH e a saturação de alumínio.

Palavras-chave: Degradação; Correção de solos; Erosão do solo; Infiltração de solos; Propriedades do solo.

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Introduction

Agriculture is a soil-based industry that extracts nutrients from the soil. Because soils are the storehouse of most plant nutrients continual withdrawals from them by continuous cropping practices without equivalent soil regenerating inputs endanger resource sustainability. An alarming concept that African soils are steadily depleted of nutrients due to farming without fertilizers has gained wide credence in the scientific community (1). As these soils become non-productive and vulnerable to natural agents of degradation, farmers still continue to cultivate on them, even expand to available and poorer non-farmlands in order to meet their basic food needs. This situation become worse in African as her population increased from an average of 2.5% in the 1960s to more than 3% in the 1990s (2).

The story of soil degradation by water erosion is topical in southeastern Nigeria (3). In this region, harsh climate, especially high intensity and long duration rainfall, high population density, land tenure constraints, shortened fallow periods, overgrazing and inefficiency of the traditional soil management practices have reduced the productive potentials of soils. The increasing farming population of the area cultivate even on fragile slope soils without appropriate conservation technology. As soils are not yielding to satisfy their basic needs, they resort to cutting down trees for fuelwood for economic gains as well as for domestic use in cooking as petroleum products are unaffordable given their socio-economic status. All these practices do not match soil quality and land use.

Several techniques and approaches are suggested in the evaluation of soil quality particularly as it affects soil degradation. Some authors evaluate decline in agricultural productivity in terms of fertilizer input, water management and tillage methods (4). Others use the soil quality morphological index (SQMI) to assess soil quality of near-surface soil physical properties (5). Again, criteria such as land use, management, prevalent weather, relative or comparative degradation, reversible and irreversible degradation indices have been suggested for the assessment of effects of degradation in terms of agricultural productivity (6). The degradative effects of soil mining due to continuous cultivation was evaluated using Land Degradation Index (7). In this technique, status of soil properties in less degraded soils are compared with values of the same properties in adjacent highly degraded sites. Levels of soil degradation are ascertained by observation of morphological variabilities of farmlands. Such morphological attributes include soil colour, soil drainage soil texture, soil structure, rupture resistance and other properties. The major objective of this study was to investigate the status of soil degradation in nutrient-mined soils of Southeastern Nigeria using Land Degradation Index (LDI). Specifically, the study evaluated the effect of different rates of ground periwinkle shells and sewage sludge in restoring degraded soils of the study area.

Materials and methods

Site description

Southeastern Nigeria lies between latitudes 4°15' and 7°00'N and longitudes 5°51' and 9°30'E. Soils are derived from 6 major parent materials, namely alluvium, coastal plain sands, shale, lower coal measures, upper coal measures and falsebedded sandstones. Soils are highly weathered and over 70% belong to the order ultisols. It has a humid tropical climate with the southernmost part of the agroecology having udic moisture regime when compared with the ustic nature of the northern fringes of the area. Annual rainfall ranges from 1750 to over 2500 mm. Mean annual temperature ranges from 26°C (78° F) to 28°C (82° F) or hotter. Cuesta and scarped landscapes and gentle to undulating lowland area are characteristic of the site. Soils in the study area have multiple uses ranging from agriculture, forestry, mining, waste disposal and constructions. Land use is not planned. Climate population density and poverty interact to cause land degradation.

Field studies

Four maps, namely geological, geomorphological, hydrological and land use maps were superimposed to create homogenous study units. The study area covers about 13032 km^2 and soils were delineated from the same parent material (Coastal Plain Sands). Four sampling units were identified as Mbaise, Umuahia, Akwette and Oguta and their geographical coordinates are given on Table 1. Geographical coordinates were obtained using Handheld Global Positioning System (GPS) Receiver (Garmin Ltd, Kansas, USA). Macromorphological features are shown on Table 1. In each sampling unit, an eroded farmland and its adjacent uneroded farmland were chosen for the study. These two farmlands were considered similar in many edaphological features but intensity of water erosion. These sampling units were identified assisted by village informants and were randomly chosen as there existed several other similar units in the area.

Fifty topsoil samples were collected from each subsampling unit (eroded or uneroded) and from the four sampling units, giving a total of 200 soil samples for eroded and 200 soil samples for uneroded units. Undisturbed cores (diameter, 15 cm; length, 15-20 cm were excavated from the surface horizon (Ap). The column of soil encased in the polyvinyl chloride pipe (diameter, 15 cm) was trimmed at the base, packed, and transported to the laboratory for relevant determinations. Soil samples were collected at 0-20 cm depth (Ap horizon). These soil samples were air-dried, crushed and sieved using 2 mm sieve. Soils of the sampling units were classified as Ultisols (Acrisols) (8).

Greenhouse studies

Differences in productivity potentials of different rates of amendments on soil samples collected from uneroded and eroded portions of owner-managed farmlands were assessed by comparing yields obtained using maize (*Zea mays* L.) as indicator crop. Maize variety used was 8329-22.

In the greenhouse study, bulked soil samples collected from Ap horizon (0-20 cm depth) in each sampling unit of the study site were maintained at field capacity (20% gravimetric moisture content) and planted with maize in a Completely Randomized Design (CRD) with each treatment replicated 9 times. The maize grain yield was harvested and recorded at maturity.

Laboratory analysis

Bulk density was measured by core method of Grossman and Reinsch (2002) (9). In the laboratory, the polyvinyl chloride casing was carefully removed from each column. Therefore, each column was coated with 5- to 8 – mm layer of liquid paraffin to seal the column walls against side flow and creation of crevices between the wall of the casing and the soil. This approach would equally circumvent possible overestimation of saturated hydraulic conductivity (Ksat) in each column. The soil column were slowly welted from the bottom. After the wetting process, two 10-cm stainless steel probes were inserted horizontally to monitor volumetric water content by using time domain reflectometry (10). Saturation hydraulic conductivity (Ksat) was determined using the constant-head method (11) and 0.025 mol L^{-1} of KNO3 solution was used to minimize clay dispersion. Soil water-holding capacity was measured on undisturbed samples as the difference of water contents at – 0.03 MPa, determined by pressure plate, and at -1.5 MPa, determined by pressure membrane (12). Total porosity was estimated from bulk density using an assumed bulk density of 2.65 Mgm^{-3} while macro-porosity (MP) was calculated as the ratio of volume of water drained at 60 cm tension to the volume of the bulk soil used (13). Aggregate instability was estimated as the number of water droplets required to break a ped.

After equilibrating for 30 minutes, soil pH was determined in 0.1 N KCl solution, with a soil-liquid ratio of 1:2.5 using a Beckman Zeromatic pH meter (9). Soil organic carbon, total nitrogen, and available phosphorus were measured by wet oxidation (14,15), micro-kjeldahl (16) and bicarbonate techniques (17). Exchangeable basic cations were determined by the method of the Association of Official Analytical Chemists (18) while exchangeable acidity was measured titrimentically.

Calculation

$$\mathbf{LDI} = \left[\frac{\mathbf{D}}{\mathbf{ND}} \ \mathbf{X} \ \ \mathbf{100} \right] - \mathbf{100}$$

Land degradation index (LDI) was computed as follows:

Where
D = degraded value of selected parameter
ND = non-degraded value of selected parameter
100% = percentage grade
100 = constant representing ideal soil state.

Negative values indicate degradation while otherwise show movement in parameter values.

Statistical analyses

Statistical tests of difference of selected soil properties were performed using t – statistic at 5% level of probability.

Results and discussion

Macromorphological

Table 1 shows results of macromorphological studies of the site. Soils were sandy and well-drained. Uneroded soils were very dark to dark brown while eroded soils were dark gray to yellowish red while sandiness is attributable to nature of parent materials, soil colour variability was in response to differential removal of organic materials by runoff water from the Ap horizon. Although soil colour is scarcely used as an indicator of soil fertility reliable extrapolations from colour of these soils can be used to predict soil quality. Grade of soil structure indicates moderate to strong structure (uneroded soils) while structureless to weak soil structures predominated in eroded soils. Similar findings were made in earlier studies in the region (19). They attributed poor soil structure at topsoils to low organic carbon content leading to macro-aggregate instability.

TABLE 1 - Macromorphological features of study site (Ap horizon)

Location	Depth(cm)	Colour (moist)	Texture (feel)	Structure	Grade	Consistence (moist)	Drainage	Geographical coordimates
Mbaise								
Uneroded	0-20	OB 10 YR 3/3	SL	2	2%	mfr	WD	5^{o} 48^{1} 33^{11}. 010^{o}N
Eroded	0-10	YB 10 YR 5/6	LS	0		ml	WD	7^{o} 37^{1} 10^{11}. 040^{o}E 60 m (Z)
Umuahia								
Uneroded	0-20	VDB 10 YR 2/2	SL	2	2%	mfi	WD	5^{o} 47^{1} 58^{11}. 047N
Eroded	0-13	YB 10 YR 5/4	SL	0		ml	WD	7^{o} 37^{1} 26^{11}. 120E 95 m (Z)
Akwette								
Uneroded	0-22	DB 7.5YR 3/2	SL	3	2%	mfi	WD	$5^{o}3^{1}$ 13^{11}.450N
Eroded	0-14	DG 10YR 4/1	SL	1		mfr	PD	7^{o} 39^{1} 45^{11}. 310E 48m (Z)
Oguta								
Uneroded	0-24	VSB 7.5 YR 2/2	SL	3	2%	mfi	WD	5^{o} 53^{1} 16^{11}. 148N
Eroded	0-14	YB 10YR 5/8	SL	1		mfr	PD	7^{o} 20^{1} 32^{11}. 40^{o} E 50 m (Z)

Colour: VDB = very dark brown, DG = dark gray, YB = Yellowish brown, YR = Yellowish red
Texture: LS = loamy sand, SL = sandy loam
Structure: O = structureless, 1 = weak, 2 = moderate, 3 = strong
Consistence: ml = loose, mfr = friable, mfi = firm
Drainage: wd = well-drained, PD = poorly drained
Geographical coordinates: Z = altitude.

Water erosion-induced discernable changes in soil properties, especially in physical attributes. Changes in soil physical properties resulting from water erosion are presented in Table 2. With the exception of bulk density and aggregate instability, values of all physical parameter measured were higher in uneroded units of farmland. Increases bulk in density with consequent reduction in total porosity, macroporosity and saturated hydraulic conductivity has been reported (20). These lead to reduction in infiltration capacity and total available water capacity of soils. Aggregate instability values were higher in eroded soils possibly due to loss of binding agents to the erosive runoff.

TABLE 2 - Changes in some physical properties of an ultisol (Acrisol) induced by water erosion (AP horizon)

		Mbaise		Umuahia		Akwette		Oguta	
Property	Unit	Uneroded	Eroded	Uneroded	Eroded	Uneroded	Eroded	Uneroded	Eroded
Bulk density (BD)	Mg m^{-1}	1.19	1.68	1.21	1.65	1.16	1.61	1.25	1.56
Total porosity (TP)	%	55.09	36.60	54.33	37.73	56.23	39.25	52.83	41.13
Macroporosity (Ma.P)	%	32.26	18.13	31.06	17.92	30.24	17.66	29.18	15.77
Water retained @									
-0.3	MPa	56.12	41.23	57.18	42.16	62.35	50.38	55.52	39.63
-15	MPa	25.03	28.01	24.26	25.81	28.21	33.06	27.82	29.11
Total Available water (TAW)	%	31.09	13.22	32.92	16.35	34.14	17.32	27.70	10.52
Saturation hydraulic									
Conductivity (Ksat)	Cmsec^{-1}	0.084	0.037	0.88	0.036	0.087	0.040	0.92	0.42
Aggregate instability	N^{-1*}	0.116	0.215	0.119	0.218	0.119	0.228	0.121	0.231

* = Number of water drops required to break a ped.

Adverse changes in soil chemical properties were observed (Table 3) following water erosion of farmlands. Reduced pH and increased aluminium saturation of studies eroded soils suggest unfavourable chemical changes which impair the over all fertility status of farmlands. With substantial proportion of its occupation of cation exchange site, high Al (Aluminium saturation = 54 – 68%) in eroded soils at low soil pH it suggests unavailability of plant essential nutrients at optimal levels. The pH range (pH = 3.7 – 4.9) is limiting to plant performance and may cause aluminium toxicity although this depends on the species of aluminium (21). Aluminium in solution forms hydroxyl – Al polymers, ion pairs with anions, and complexes with organic substances and such complexation renders aluminium ions non-toxic. However, low organic matter content of eroded soils (OM = 1.1 – 1.4%) may be suggesting poor influence of organic matter in detoxifying aluminium in these highly weathered soils of the tropics. These low pH and organic matter values could be responsible for the lower available phosphorus in eroded soils (Available P = 8.3 – 10.1 mg kg^{-1}). Again, soil P is lost through surface runoff, erosion of sediment, leaching and plant uptake (22). These losses endanger the environment to non-point-source pollution, such as eutrophication.

TABLE 3 - Changes in chemical properties in an ultisol Acrisol in southeastern Nigeria induced by water erosion (Ap horizon) (mean values)

		Mbaise		Umuahia		Akwette		Oguta	
Property	Unit	Uneroded	Eroded	Uneroded	Eroded	Uneroded	Eroded	Uneroded	Eroded
pH (KCl)	-	4.3	3.7	5.0	4.1	4.9	3.9	5.2	4.6
ECEC	cmol kg^{-1}	10.8	5.6	12.1	6.3	11.2	6.6	13.2	7.0
Base saturation	%	56.6	38.9	58.0	4.0	57.8	42.0	60.0	32
Aluminium saturation	%	43.4	61.1	42.0	54.0	42.2	57.0	40.0	6.8
Organic matter	%	3.2	1.1	3.3	1.5	3.6	1.4	3.5	1.3
Total nitrogen	%	0.28	0.09	0.29	0.11	0.3	0.1	0.3	1.1
Available phosphorus	mg kg^{-1}	18.6	8.3	18.3	9.8	26.1	9.6	20.1	10.1

ECEC: Effective cation exchange capacity.

Soil degradation

Table 4 shows land degradation index values of these mined and eroded soils as they affect soil physical properties. Water retained at 1.5 MPa and aggregate instability increased in value which implies loss of available water in the rhizosphere and soil structural breakdown respectively. There were outstanding degradation in bulk density (LDI mean = - 60), total porosity (LDI mean = - 71), macroporosity (LDI mean = - 56) and water retained at 0.1 MPa (LDI mean = - 75) and these reduced saturated hydraulic conductivity (LDI mean = - 25) and total available water (LDI mean = - 45).

TABLE 4 - Land degradation index values of mined and eroded sites (physical properties)

Property Location	BD	TP	MaP	Water retained 0.1 MPa	Water retained 1.5 MPa	TAW	Ksat	Agg. Inst.
Mbaise	- 41	- 66	- 56	- 73	+ 11	- 42	- 44	+ 15
Umuahia	- 63	- 69	- 57	- 74	+ 55	- 49	- 4	+ 17
Akwette	- 61	- 70	- 58	- 80	+ 17	- 51	- 46	+ 9
Oguta	- 75	- 78	- 54	- 71	+ 5	- 38	- 5	+ 10
Mean	**- 60**	**- 71**	**- 56**	**- 75**	**+ 40**	**- 45**	**- 25**	**+ 13**

Agg. Inst. = aggregate instability.

Soil chemical properties were also degraded (Table 5) with base saturation and soil pH having highest LDI mean values of – 68 and – 63 respectively.

TABLE 5 - Land degradation index values of mined and eroded sites (chemical properties)

Location	pH	ECEC	Bsat	Alsat	OM	TN	Avail. P
Mbaise	- 77	- 52	- 68	+ 59	- 34	- 32	- 45
Umuahia	- 82	- 52	- 79	+ 71	- 45	- 38	- 53
Akwette	- 79	- 59	- 74	+ 65	- 39	- 33	- 36
Oguta	- 88	- 55	- 53	+ 30	- 37	- 33	- 50
Mean	**- 63**	**- 55**	**- 68**	**+ 54**	**- 36**	**- 34**	**- 46**

ECEC = effective cation exchange capacity, Bsat = base saturation, Alsat = aluminium saturation, OM = organic matter, T.N = total nitrogen, Avail. P = available phosphorus.

These degradations in both physical and chemical properties of soils influence overall productivity of soils and responses of even inorganic fertilizers when applied on eroded lands. This is worst under soil physical infertility thus the call for integration of organic and inorganic fertilization as a low-cost technology for restoring and sustaining mined and eroded soils of southeastern Nigeria (23). It is also implied that these degradations eventually affect micro- and macro-organisms as their activities reduced following soil loss (24), suggesting negative effects on the elemental transformations within the soil system.

Effects of amendments on maize yield

Table 6 indicates yield responses of maize (*Zea mays* L.) following application of different rates of ground periwinkle shells (GPS) and sewage sludge (SS). A mixture of GPS and SS significantly ($p < 0.05$) improved yield probably due to liming effect and nutrient increase in treated soils. Ground periwinkle shells released high amount of calcium which de-acidified soils, and consequent release of fixed nutrients while transformation of sewage sludge resulted in additions of nutrients.

TABLE 6 - Effectiveness of ground periwinkle shell/sewage sludgle mixture in restoring productivity of mined and eroded soils in southeastern Nigeria using maize test as crop (t ha^{-1})

	Mbaise			Umuahia			Akwette			Oguta		
Rate of amendment	Uneroded	Eroded	t-cal	Uneroded1.92	Eroded	t-cal	Uneroded	Eroded	t-cal	Uneroded	Eroded	t-cal
GPS_0 SS_0	0.32	0.26	0.8 NS	1.92	1.16	NS	3.22	2.82	NS	3.01	2.24	0.1NS
GPS_{60} SS_{150}	2.98	0.62	0.2*	3.08	1.11	0.5*	3.76	1.98	0.5*	4.16	2.46	0.7*
GPS_{120} SS_{300}	3.16	0.89	0.5*	3.67	2.36	0.6*	4.92	2.13	0.6*	4.96	2.66	0.7**
GPS_{180} SS_{450}	3.64	1.82	0.4**	3.96	2.65	0.8**	2.97	2.78	0.4*	4.82	2.86	0.6**
GPS_{240} SS_{600}	3.72	2.06	0.6**	3.06	2.68	0.7*	4.02	2.81	0.7*	4.93	2.76	0.7*

t-cal ** significant at P<0.01, * significant at P<0.05, NS not significant.
numerical subscripts under rate of amendment refer to rates of ground periwinkle shell (GPS) and sewage sludge (SS) measured in kg ha^{-1}.

Post-harvest changes in soil roperties

Results of post-harvest soil tests are shown in Table 7 (physical properties) and Table 8 (chemical properties). There were significant changes ($p < 0.05$) in most soil properties with the exception of pH and aluminium saturation (Table 9). Insignificant changes in soil pH could be attributed to dissociation of weakly bonded hydrogen ions of amino and phenolic groups present in sewage-sourced organic matter and their consequent release into the soil system.

TABLE 7 - Post-harvest changes in soil physical properties in ultisols (Acrisols) Nigeria induced by soil amendment

Rate of application	BD (Mgm^{-1})	TP (%)	MaP (%)	Water retained at 0.1 (MPa)	Water retained at 1.5 (MPa)	TAW (%)	Ksat (cmsec^{-1})	Agg. Int. (N^{-1})
GPS_0SS_0	1.71	35.0	28.34	40.6	29.5	11.1	0.35	0.315
$GPS_{60}SS_{150}$	1.58	40.0	34.23	52.0	25.0	27.0	0.52	0.208
$GPS_{120}SS_{300}$	1.46	44.0	37.41	54.5	24.1	30.4	0.66	0.113
$Gps_{180}SS_{450}$	1.41	46.0	37.88	56.1	28.1	33.0	0.86	0.104
$GPS_{240}SS_{600}$	1.40	47.2	38.14	56.8	23.7	33.1	0.96	0.093

TABLE 8 - Post-harvest changes in soil chemical properties in ultisols (Acrisols) in southeastern Nigeria induced by soil amendment

Rate of application	pH (KCl)	ECEC (cmol kg^{-1})	Bsat (%)	Alsat (%)	OM (%)	TN (%)	Avail. P (mg kg^{-1})
GPS_0 SS_0	3.5	5.3	33	67	1.2	0.09	6.8
GPS_{60} SS_{150}	3.9	8.7	39	61	1.8	0.16	8.8
$GPS_{120}SS_{300}$	4.6	10.8	45	55	2.1	0.18	11.6
GPS_{180} SS_{450}	4.9	13.4	48	52	2.7	0.22	15.6
GPS_{240} SS_{600}	5.4	14.5	52	48	2.9	0.25	14.8

TABLE 9 - Statiscal tests of difference of some soil properties in amended and non-amended soils

Soil properties	Calculated t-values
Bulk density (mgm^{-3})	2.51*
Total available water (%)	2.76*
Aggregate instability (N^{-1})	2.26*
Saturated hydraulic conductivity	2.43*
pH	1.67^{NS}
ECEC ($cmolkg^{-1}$)	2.78*
Organic matter (%)	2.88*
Al saturation (%)	1.48^{NS}
Total nitrogen (%)	2.82*
Available phosphorus ($mgkg^{-1}$)	2.18*

* significant at $p < 0.05$, NS = not significant.

Organic matter (OM) content increased in sewage-treated soils in line with earlier findings (25) that sewage application increased soil OM. The OM increases at different rates may be responsible for improvements in other soil properties, such as total available water bulk density, aggregation, hydraulic conductivity (saturation), total nitrogen, available phosphorus and effective cation exchange capacity (ECEC). Macroporosity increased with reducing aggregate instability in the amended soils leading to increase in saturated hydraulic conductivity. As long-term intensive cultivation without replenishment deteriorates organic matter and loss of productivity (26), addition of sewage sludge which is a major waste products in the study site will be beneficial in arable farming.

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