Chemical Factors in Erosion-Induced Soil Degradation in Owner-Managed Farms in Central Southeastern Nigeria

E.U. Onweremadu[1], F.O.R. Akamigbo[2] and C.A. Igwe[2]
1. Department of soil science and Technology, Federal University of Technology
PMB 1526 Owerri, Nigeria.
2. Department of Soil Science, University of Nigeria, Nsukka Nigeria
E-mail: uzomaonweremadu@yahoo.com

Abstract: Guided mainly by a reconnaissance survey and geological map of the study area 18 owner-managed farms were identified and used for a study in 2004 which investigated the principal chemical factors in erosion-induced soil degradation. Field sampling along a transect resulted in the collection of 3 soil samples per farm. These samples were prepared for analyses and results showed varying rates of degradation using land degradation index (LDI) among soil parameters and locations. Least LDI values were found in total sulphur. Soil pH (PRIN I), organic carbon (PRIN 2) and total nitrogen (PRIN 3) explained a greater proportion of the total variance in erosion-induced degradation among soils. Some farms clustered, indicating similarity in management. Further research should include physical, biological, and other soil related factors associated with erosion-induced degradation. [Nature and Science. 2007;5(2):22-29].

Keywords: Chemistry, degradation, erosion, farms, principal component analysis, low input farming, tropical soil.

Introduction

As populations grow, farmers are forced to cultivate smaller plots where the soil eventually becomes depleted, or expand into fragile hillsides (Scherr and Yadav, 1996). This scenario is common in the sub-Saharan humid tropics and this could be one of the reasons for low productivity (Eswaran *et al,*. 1997). The situation worsens as farmers may not adopt modern technologies (Reich *et al.,* 2001) amidst inappropriate management practices such as continuous cropping, burning, deforestation (Mbagwu and Obi, 2003). They noted that 85% of the cause of land degradation world wide is due to soil erosion, which according to Brady and Weil (1999) starts from slight to medium to severe to extreme severe soil and vegetative degradation. This is brought about by a prolonged interface between human –induced and natural factors (Di Falco *et al.,* 2006).

In central Eastern Nigeria, the major causes of soil degradation are soil erosion due to high rainfall deforestation, fragile nature of the soil and farming activities (Igwe 2003). As a consequence of soil erosion by the agency of water, soil nutrients are depleted leading to decline in crop production (Henao and Baanante, 2001). Changes in soil properties due to erosion may be accountable for the vulncability and reduction in the cherished qualities of soils. Oti (2002) reported a decline in water stable aggregates and this makes soils unstable to raindrop impact thereby enhancing disintegration and slaking. Increased soil erosion promotes soil compaction (Mainville et al., 2006) and loss of weakened top layers of soil (Farella *et al.,* 2001) especially in agroecosystems characterized by high rate of deforestation (Sierra, 2002). About 300 tons of soil loss per year were recorded in Honduras due to soil crosion (Thurow et al., 2002)

Chemistry of soil is also altered as a result of soil erosion on farmlands. It results in net decrease in soil carbon and nitrogen (Mainville *et al.,* 2006) due to leaching, burning and volatilization (Roulet et al., 1999). Loss of organic matter results in soil structural instability since it is a major binding agent (Mikha and Rice, 2004). Mbagwu and Auerswald (1999) reported low exchangeable sodium percentage due to soil erosion. Increase in aluminium saturation and reduced calcium magnesium ratios were also reported with heightened severity of soil erosion (Oti, 2002). In addition to the above, removal of epipedal layers may lead to subsoil exposure, and consequently heavy metals pollution (Mainville *et al.,* 2006). There show that eroded soils are sick (IIRR, 2005), hence a major limitation in most farmlands in Africa (Lal, 1995) due to declining agricultural productivity and farmers income (Hans *et al.,* 2006). The main aim of this investigation was to identify specific soil chemical properties altered by soil erosion that would serve as reliable predictors of status of soil degradation.

Materials and Methods

Study area: The study site (Abia and Imo State in central southeastern Nigeria lies between latitudes $4^0 40^1$ and $8^0 15^1$N and $6^0 40^1$ and $8^0 15^1$ E. Predominant parent materials underlying soils of the site include Alluvium Coastal Plain Sands, Shale, Lower Coal measures, Upper Coal Measures, Falsebedded Sandstones. This guided field sampling as follows: Akwette, Oguta and Oweninta (Alluvium), Okeikpe, Owerri and Umuahia (Coastal Plain Sands) Arondizuogu, Bende and Nkporo (Shale) Arochukwu, Ohafia and Uturu (Lower Coal Measures), Abiriba, Item and Ihube (Upper Coal Measures and Ezere, Okigwe and Umulolo (Falsebedded Sandstones). The study site is generally a lowland area, with few scarpy landscapes in the northeast orientation. It has a humid tropical climate, with marked wet and dry seasons of nine and three months, respectively. Mean annual rainfall ranges from 2000-2500 mm while annual temperatures range from 26-29^{o}C. It has a typical rainforest vegetation which has been drastically altered by anthropogenic activities. Farming is a major socio-economic activity in the area and is mainly practiced at subsistence level. Soil fertility regeneration is by use of bush fallow, whose length has been drastically reduced due to demographic pressure on land (Onweremadu, 1994). Mixed cropping is popular in the area.

Field studies: After a reconnaissance survey of the area and guided by the geology map of the region, field sampling using the transect technique was conducted in 18 owner-managed farms in the study area in 2004. In each geological zone, 3 owner-managed farms were selected and this activity was done on 6 geological zones, giving a total of 18 farms. On each farm, surface soil samples were collected representing a bulked sample, sample from eroded portion and sample from non-eroded portion of the farm. This gives a total of 54 soil samples used for the study. These soil samples were collected based on differences in erosion-related morphological properties, such as thickness of A-horizon, incidence of rills, topography, sandiness and soil colour. The farms were under similar management practices and of 2-year fallow length. Soil samples were air-dried, crushed and sieved using 2-mm sieve in readiness for various laboratory analyses on selected chemical prosperities. The 18 bulked soil samples were used for characterizing surface soil of the studies farmlands while samples from eroded and non-eroded portions were used in investigating status of soil degradation.

Laboratory analyses: Particle size distribution was determined by hydrometer method according to the procedure of Gee and Or (2002). Soil pH water was estimated electrometrically in soil liquid ratio of 1:2.5 as described by Hendershot *et al*. (1993). Soil organic carbon was estimated by wet digestion (Nelson and Sommers, 1996). Total nitrogen (TN) was determined by microkjeldahl method (Bremner, 1996). Total sulphur content of soils was estimated by potassium nitrate/nitric acid digestion method (Blauchar, 1986) while available phosphorus was obtained by Bray 2 method (Olsen and Sommers, 1982). Exchangeable cations were estimated by inductively coupled plasma atomic emission spectrometer (ICP-AES) (Integra XMP, GBC, Arlington Heights, IL).

Soil degradation determinations: Status of soil degradation was computed from results of laboratory analyses of samples from eroded (E) and non eroded (NE) portions of the farmland, using the land degradation index as described by Barrow (1992). The LDI is given as follows:

$$LDI = \left(\frac{D}{ND} \times 100\ \% \right) - 100$$

Where LDI = Land degradation index
D = Value of soil parameter in the degraded tract
ND = Value of soil parameter in the non –degraded tract
100% = Percentage grade
100 = Constant representing ideal soil state

Statistical analyses: Principal component analysis was performed on the values of soil chemical properties measured in the on – farm studies with the aid of SAS computer package after values have been subjected to linear correlation analysis to produce correlation matrix. Cluster analysis was used to group the 18 farmers fields according to similarity in certain response patterns.

Results and Discussion

Soil properties: With the exception of shale-derived soils, other soils were very sandy (Table 1) and this is attributable to the nature of parent materials. Climate promotes physical weathering, which according to Esser *et al*.(1992) exerts a great influence on the distribution of silt and clay fractions. Soils were strongly to moderately acidic, possibly due to differences in parent materials and land use since all the sampled points are within similar agroecology. Exchangeable basic cations were low, suggesting that they have been leached away and/or excessively used for crop production without replenishment as it is a low-input low- output agriculture. Organic fractions were low, and this is consistent with the findings of Igwe and Stahr (2004) in their study of soil of southeastern Nigeria. The low organic fractions content could be attributed to young age of fallow coupled with influences of high temperature and associated rapid mineralization (Esu *et al.,* 1991). Low values of available phosphorus (Av. P) were found in all soils studied irrespective of lithological origin. Although not investigated, P- availability is governed by one or a combination of chemical and mineralogical properties, such as clay type, clay content, sesquioxides, organic carbon, pH and calcium carbonate content (Burt *et al.,* 2002). Again, there are many mechanisms through which it can leave the soil through uptake, runoff and leaching (Giesler et al., 2005). Sulphur content is relatively high and Isirimah *et al.* (2003) attributed this to strong to moderate acidity of soils. Results of soil chemical properties in eroded (E) and non eroded tracts of farmands are shown in Table 2, indicating lower values of studies parameters in E parts of the farm in all the locations. These results reflect on the negative values of land Degradation Index (LDI) as presented on Table 3. The negative values indicate losses and this differed with location and chemical parameters assessed. Highest percentage degradation in pH in the study (- 14.5%) was recorded on very sandy soils of Owerri (Coastal Plain Sands), Oguta (lacustrine Alluvium) and Abiriba (Upper Coal Measures). The study area is of rainforest agroecology with extreme sandiness which suggests excessive leaching of basic cations. But soils derived from Shale also showed spectacular degradation, implying that some other factors contribute to soil acidity

Soil degradation: High LDI values on OC were recorded mainly on soils Lower Coal Measures Abiriba and Item), Falsebedded sandstones (Umulolo and Ezere) and fluvial Alluvium (Owerrinta). With the exception of Owerrinta other locations are within the drier part of the region, characterized by sparsely vegetated rainforest. The vegetal form, climate and land use may have interactively reduced OC content of epipedal layers studies. These factors also affected basic cations content and availability of phosphorus and total nitrogen. Least LDI were recorded in total sulphur content of soil, suggesting greater sufficiency of this macronutrient in soils of central southeastern Nigeria. Higher sulphur sufficiency status is possible if organic matter is sustained the latter being a reservoir if the former (Isirimah *et al.,* 2003). Nonetheless, elemental sulphur is stable and predominates in highly oxidized to slightly reducing acidic conditions.

The main chemical factors in E and NE portions soils of the farms studied are shown in Tables 4 and 5, respectively. In eroded portions of farmlands, soil (pH PRIN 1) explained 51.8 of the total variance, followed by OC (PRIN 2), explaining 20.4% and total nitrogen (PRIN 3) , contributing 13.6% of the total variance. Similar trend was observed in NE where pH, OC and TN explained 38.7, 24.8 and 14.5% of the total variance. respectively. These results show that soil reaction controlled greatly to the distribution, abundance and activity of other chemical soil properties. Lower pH does not favour basic cations which significantly influenced soil –water relations (Dontsova *et al.,* 2004). The results suggest the relevance of pH and organic fractions in the sustainable management of soils of southeastern Nigeria. Erosion of epipedal layers which account for high soil organic storage in the study area (Onweremadu, 2007).

Cluster analysis resulted to an ordination plot of 18 farmers' fields based on similarity of LDI values (Fig. 1), indicating that all farms in the same quadrant can be managed alike. It implies that similar farm-input model can be made for farms on each quadrant and this is a hallmark in precision farming. However, there is need for inclusion of other non-chemical parameters since soil productivity is a result of interactions among soil and soil-related factors. This reduce bias and errors thus increasing predictiveness of models generated from the soil data.

Table 1. Properties of soils of the study site

Location	Clay (g kg^{-1})	Silt (g kg^{-1})	Sand (g kg^{-1})	pH (Water)	Ca	Mg	K	Na	OC	TN	Avp	S
			890		Cmo/kg^{-1}				(g kg^{-1})		(mg kg^{-1})	
Akwette	90	20	870	5.5	0.9	1.0	0.3	1.0	2.14	0.196	38.0	140
Oguta	11.0	20	880	5.2	0.7	0.8	0.2	0.8	1.89	0.192	6.0	135
Owerrinta	100	20	880	5.1	0.8	0.9	0.2	0.6	1.55	0.98	7.0	131
Okeikpe	110	10	850	4.9	1.0	0.4	0.4	0.2	2.13	0.101	38.0	127
Owerri	130	20	860	4.9	0.9	0.4	0.3	0.2	2.32	0.212	38.	132
Umuahia	120	20	700	5.0	0.6	0.5	9.2	0.2	1.92	0.112	34.0	127
Arondkwgu	280	80	550	5.1	2.1	0.6	0.5	0.2	2.10	0.146	5.0	125
Ende	350	100	600	5.3	2.5	1.1	0.3	0.3	2.25	0.223	9.0	129
Nkporo	300	100	750	5.3	2.6	0.9	0.4	0.2	2.28	0.250	8.0	123
Arochukwu	200	150	770	4.8	1.7	0.4	0.5	0.2	2.06	0.129	9.0	125
Ohafia	180	50	750	4.9	1.2	1.1	0.6	0.1	2.86	0.106	6.0	122
Uturu	170	80	920	4.9	0.8	0.9	0.5	0.1	1.51	0.11	4.0	123
Aburiba	60	20	890	4.4	0.6	0.5	0.2	0.2	1.22	0.098	5.0	120
Item	80	30	900	4.3	0.4	0.3	0.3	0.1	1.36	0.073	3.0	118
Ihube	70	30	900	4.1	0.8	0.2	0.2	0.1	1.13	0.92	5.0	117
Ezere	80	20	900	4.4	0.5	0.5	0.3	0.3	1.28	0.068	3.0	116
Okigwe	90	20	890	4.5	1.4	0.4	0.3	0.2	1.33	0.104	6.0	121
Umulolo	95	20	905	4.3	1.2	0.5	0.4	0.1	1.16	0.112	6.0	119

Table 2. Soil Chemical Properties of Eroded (E) And Non-Eroded portons of surveyed farms

S/ No	Location	**pH Water Eroded**	OC	**TN**	**Avail P.**	Ca	**Mg**	**K**	Na	**S**	pH Water	**OC**	**T N**	**Avail P.**	**Ca**	**Mg**	**K**	Na	S
							Non-eroded												
1	Akwette	5.3	2.03	0.192	36	0.70	0.82	0.18	0.88	138	5.9	2.41	0.256	44	1.01	0.98	0.28	0.92	148
2	Oguta	4.7	1.88	0.188	4	0.62	0.66	0.06	0.69	135	5.5	2.12	0.243	12	0.76	0.82	0.10	0.77	152
3	Owerrinta	4.7	0.86	0.083	4	0.68	0.69	0.14	0.51	128	5.3	1.55	0.116	14	0.98	0.86	0.20	0.63	144
4	Okeikpe	4.6	1.98	0.099	34	0.82	0.20	0.28	0.10	125	5.2	2.50	0.212	48	1.21	0.50	0.44	0.16	140
5	Owerri	4.7	2.02	0.196	35	0.71	0.25	0.16	0.05	128	5.5	2.46	0.251	50	0.90	0.40	0.24	0.06	136
6	Umuahia	4.2	1.61	0.099	32	0.40	0.15	0.06	0.03	124	5.4	1.96	0.242	70	0.70	0.40	0.14	0.06	156
7	Arondizuogu	4.8	1.80	0.141	3	1.88	0.90	0.28	0.09	122	5.6	2.55	0.218	12	3.00	1.40	0.36	0.15	135
8	Bende	5.1	1.96	0.193	7	2.06	0.70	0.18	0.04	125	5.9	2.40	0.222	15	3.86	1.10	0.24	0.05	136
9	Nkporo	5.2	1.98	0.197	6	3.20	0.20	0.26	0.08	120	6.0	2.46	0.231	13	3.70.2.	0.50	0.30	0.10	125
10	Arochukwu	4.4	1.66	0.118	3	1.28	0.82	0.26	0.10	122	4.8	2.21	0.196	9	20	1.44	0.34	0.16	127
11	Ohafia	4.4	1.40	0.099	2	0.86	0.66	0.40	0.05	120	5.0	1.84	0.124	7	1.46	0.90	0.56	0.09	127
12	Uturu	4.5	1.01	0.069	4	0.50	0.42	0.09	0.06	122	4.8	2.16	0.198	10	1.22	1.40	0.18	0.15	128
13	Abiriba	4.1	1.03	0.072	2	0.42	0.20	0.06	0.02	116	4.8	2.12	0.194	8	0.90	0.90	0.14	0.06	124
14	Item	4.0	0.92	0.066	1	0.10	0.10	0.08	0.03	114	4.6	1.85	0.133	7	0.40	1.60	0.22	0.08	123
15	Ihube	3.9	1.12	0.081	2	0.50.0.	0.18	0.08	0.03	112	4.4	1.94	0.125	8	0.90	0.99	0.18	0.05	127
16	Ezere	3.9	0.86	0.056	1	20	0.20	0.06	0.06	114	4.4	1.67	0.111	4	0.60	0.90	0.14	0.10	124
17	Isikwoato	4.0	1.10	0.099	4	0.90	0.30	0.16	0.03	118	4.5	1.93	0.127	9	1.96	0.80	0.28	0.05	130
18	Okigwe	4.0	0.98	0.094	5	0.88	0.25	0.18	0.07	114	4.6	2.18	0.129	11	1.98	0.96	0.26	0.09	131
	Umulolo																		

ID: OC (organic carbon) and T.N. (Total nitrogen) are in g kg^{-1}.
Ca, Mg, k and Na are in Cmol/Kg
Available phosphorus (Bray II method: 1:25) and Total sulphur are in mg kg^{-1}.

Table 3. Land Degradation Index (Ldi) on Farm Research (After Barrow, 1992) Parameters S

S/No	Location	pH Water	OC.	T.N	Avail P.	Ca	Mg	K	Na	S
1	Akwette	-10.1	-15.8	-25.0	-18.1	-30.6	-16.4	-35.8	-4.3	-6.7
2	Oguta	-14.5	-11.3	-22.6	-66.6	-18.4	-19.5	-40.0	-10.3	-11.1
3	Owerrinta	-11.3	-44.5	-28.4	-71.4	-30.6	-19.7	-30.0	-19.0	-11.1
4	Okeikpe	-11.5	-20.8	-53.3	-29.1	-32.2	-60.0	-36.3	-37.5	-10.7
5	Owerri	-14.5	-17.8	-21.9	-30.0	-21.1	-50.0	-33.3	-16.6	-5.8
6	Umuahia	-22.2	-17.8	-59.0	-54.2	-42.8	-62.5	-57.1	-50.0	-20.5
7	Arondizuogu	-14.2	-29.4	-35.3	-75.0	-37.3	-35.7	-22.2	-40.0	-9.6
8	Bende	-13.5	-18.3	-13.0	-53.3	-46.6	-36.3	-25.0	-20.0	-8.0
9	Nkporo	-13.3	-19.5	-14.7	-46.1	-13.5	-60.0	-13.3	-20.0	-4.0
10	Arochukwu	-8.3	-24.8	-39.7	-66.6	-41.8	-43.0	-23.5	-37.5	-3.9
11	Ohafia	-12.0	-23.9	-20.1	-71.4	-41.0	-26.6	-28.5	-44.4	-5.5
12	Uturu	-6.2	-53.2	-65.1	-60.0	-59.0	-70.0	-50.0	-60.0	-4.6
13	Abiriba	-14.5	-51.4	-62.8	-75.0	-53.3	-77.7	-57.1	-66.6	-6.4
14	Item	-13.0	-50.2	-50.3	-85.7	-75.0	-83.3	-63.6	-62.5	-7.3
15	Ihube	-11.3	-42.2	-35.2	-75.0	-44.4	-81.8	-55.5	-40.0	-11.8
16	Ezere Isikwuato	-11.3	-48.5	-49.5	-75.0	-66.6	-77.7	-57.1	-40.0.	-8.0
17	Okigwe	-11.1	-43.0	-22.0	-55.5	-54.0	-62.5	-42.8	-40.0	-9.2
18	Umulolo	-13.0	-55.0	-27.1	-54.5	-55.5	-73.9	-30.76	-22.2	-12.9

Table 4. Principal component analysis of soil properties in eroded portion of the farmers' fields.

	Prin 1	Prin 2	Prin 3
pHH_2O	0.433	0.069	0.031
OC	0.408	0.078	-0.330
TN	0.413	0.058	-0.144
P	0.226	-0.334	-0.588
Ca	0.250	0.556	-0.059
Mg	0.292	0.064	0.623
K	0.203	0.482	0.044
Na	0.283	-0.454	0.347
S	0.394	-0.350	0.099
Eigenvalue	4.66	1.84	1.22
% Var.	51.8	20.4	13.6
Cum. Var.%	51.8	72.3	

Table 5. Principal Component Analysis of soil properties in the Non-Eroded portion of the farmers' fields

	Prin 1	Prin 2	Prin 3
pH_{H2O}	0.470	0.164	0.119
OC	0.356	0.406	-0.082
TN	0.485	0.098	0.022
P	0.404	-0.231	-0.381
Ca	0.099	0.583	0.064
Mg	-0.161	0.304	0.614
K	0.015	0.378	-0.235
Na	0.234	-0.259	0.607
S	0.404	-0.320	0.172
Eigenvalue	3.48	2.24	1.31
Var. %	38.7	24.8	14.5
Cum. Var.%	38.7	63.5	78.1

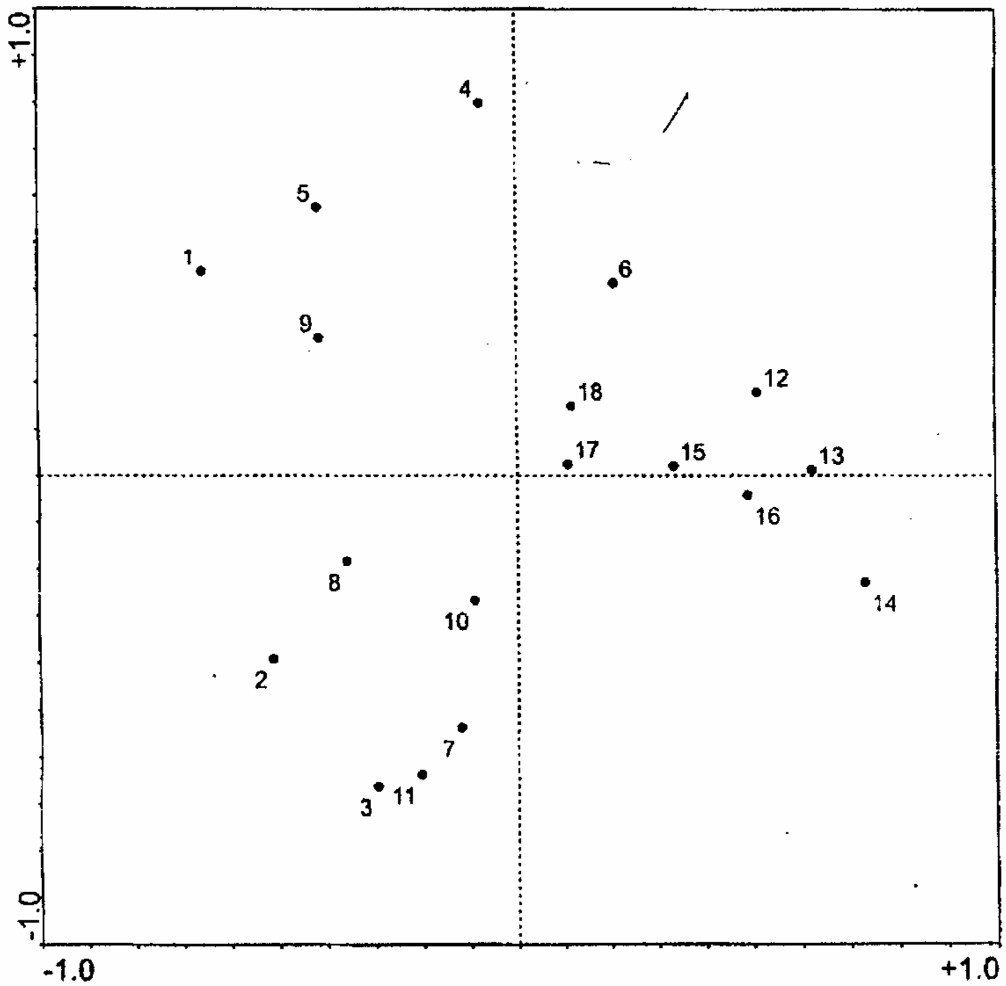

Figure 1. Ordination plot of 18 farmers fields based on similarity in land degradation index values.

ID:

1 = Akwette	7 = Arondizuogu	13 = Abiriba
2 = Oguta	8 = Bende	14 = Item
3 = Owerrinta	9 = Nkporo	15 = Ihube
4 = Okeikpe	10 = Arochukwu	16 = Isikwuato
5 = Owerri	11 = Ohafia	17 = Okigwe
6 = Umuahia	12= Uturu	18 = Umulolo

Correspondence to:
Dr. E. U. Onweremadu
Department of Soil Science and Technology
Federal University of Technology
PMB 1526 Owerri Nigeria
E-mail: uzomaonweremadu@yahoo.com

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