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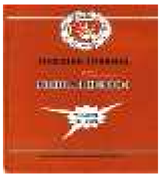

YIELD DECLINE OF MAJOR CROPS INDUCED BY EROSION ON THE ULTISOLS OF OWERRI, SOUTHEASTERN NIGERIA: MAIZE RESPONSE TO NATURAL EROSION

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ABSTRACT

Few studies have been made to quantify the yield decline trends of major stable crops induced by erosion (natural and artificial) on the ultisols of Southeastern Nigeria, it is known that erosion's impact on soil productivity is crop, environment and soil specific. This paper reports an aspect of a larger body of research work conducted between 1996 and 2002 to document erosion – induced productivity decline in ultisols of Southeastern Nigeria. The specific objective of the study was to quantify the impact of various levels of in situ erosion on maize yield and yield attributes. Field studies were conducted on non eroded (NE), slightly (S), moderately (M) and severaly (Sv) eroded phases of a fine, loamy, kaolinitic isohyperthermic Typic Tropohymult, which included two croppings of maize in 1998 and 1999. Statistical design was a Completely Randomized Design (CRD) with four replications. Maize yields and yield attributes declined significantly with increasing severity of erosion at both croppings. The blanket application of NPK fertilizer and improved management practices boosted yields of the second crop without masking the effects of erosion. The relative yields of maize grain in 1998 were 100:23:16:10 for NE:S:M:Sv eroded sites, and the corresponding yield values were 3.8, 0.86, 0.59 and 0.39 Mg ha-1 respectively. The best-fit regression equations, with six soil variables explained 47.3% of variability in maize grain yield and soil organic matter content (SOC) was the most important indicator. Mean linear yield decline Rates per centimeter of soil lost was 0.290 for Slight, 0.159 for moderate and 0.113 Mg ha-1 for severely eroded. The calculated half-life of the soils under current management systems is 18 to 25 year.

INTRODUCTION

Important soil biological, chemical and physical properties for plant production have degraded as a soil erodes causing a reduction in crop productivity (Lal, 1987; Oti et al, 2007, Oti 2002). Different researchers working in different environments, soil types and with different crops have associated yield declines induced by erosion to various altered soil properties. The loss of rooting depth, changes in soil texture and associated changes in water holding capacity, were identified as having the most profound impact by Swan et al., (1987), Andraski and Lowery, (1992) and Arriaga and Lowery (2003) in temperate environments. However, in tropical soils, diminished organic matter levels and nutrient pools, nutrient imbalance and aluminium toxicity were reported as key factors for erosion induced productivity decline. (Oti, 2002, and Mbagwu et al., 1984).

Tenge et al. (1998), reported increasing reductions of maize yield as the severity of erosion increased, Mokma et al., (1992) observed maize yield decline of 21% between slightly and severely eroded phases. In fact a comprehensive review of the global impact of soil erosion on productivity published by den Biggelaar et al., (2004) confirmed that erosion not only leads to yield declines of major crops, but its impact is magnified by four to five orders in soils of the tropics (Africa, Asia, Latin America). They also established that very little work has been done in these regions to quantify erosions' impact on the yield of major crops like maize. Without such data, economic loss estimates arising from erosion cannot be authenticated. This study was conducted with these specific objectives:

(1) To quantify maize yield decline trends associated with different levels of natural erosion on Owerri Ultisols.

(2) To establish the cause and effect –relationship between erosion severity and maize yield decline.

MATERIALS AND METHODS

Study Area

This study was carried out at the Otamiri watershed basin in Owerri zone, Imo state, (5! 100 - 6! 300 N, 6! 450, 7! 450 E), Southeastern, Nigeria. It is within the humid tropics ecological zone with mean daily temperature of about 27^{O}C, night and day, and monthly variations are minimal. The annual average rainfall is about 2,400mm. The rains come as intensive violent showers of short durations especially at the beginning (April) and the end of the raining season (October). Rainfall pattern is bimodal with a short interval in August known as "August break".

Soil type of the four eroded phases selected for study was fine, loamy, kaolinitic isohyperthermic Typic Tropohumult (Ultisols) Table 1.

Preliminary Field Survey/Sites Selection.

A detailed preliminary survey was conducted in 1996 and 1997 to select and delineate the four distinct eroded phases on toposequences within the Otamiri catchment area. Three levels of erosion were identified based on topsoil depth as the primary criterion as recommended by USDA's Soil Survey Manual (1993) and USDA's Soil Conservation Service (1975). The four erosion phases were as follows:

Non eroded (NE): wooded Plateau with average slope 0.71 – 1.30% (estimated age 30 – 35 years). Average A horizon depths 40 – 45cm. severed as the reference plots.

Slightly eroded (S): upper slopes of selected toposequneces. Average slopes 3 – 3.60%. Average A horizon depth 32 – 35cm (had lost about 22% of the A horizon to natural erosion)

Moderately eroded (M): middle slopes of selected toposequenses. Average slopes of 3 – 3.62%. Average A horizon depths 18 – 20 cm (about 54 – 56% of A horizon lost to natural erosion).

Severely eroded (Sv): lower slopes of selected toposequences. These sites were characterized by surface stoniness/sandiness, runoff tracks, sparse vegetation and exposure of subsoils at some portions, steep slopes of 4.12 – 8.82% terminated at the Otamiri River. Average A horizon depths 8-10 cm (about 78% of A horizon lost to past erosion).

Experimental Design and Agronomic Practices.

The total land areas delineated for study at each location were fields of 20 m length and 50 m width. Lengths of plots were kept narrow to minimize variations of soil depth within each erosion phase. Other crops beside maize were sown, result of which will be reported separately. All sites were under 4-6 years old fallows.

In early march 1998, all the experimental

Table 1. Selected Soil properties of each erosion class used for classification

Site	Horizon	Depth — cm —	Clay	Silt %	Sand	Textural Class	N	OC %	pH	Na	K	Ca	Mg	Ex.Al.	E.C.E.C	B.S %
												Mequiv./100g				
Non-eroded																
	AP	0-45	12.00	4	84	Loamy sand	0.11	1.55	4.8	0.27	0.31	4.40	2.00	1.40	6.4	53
	B1	45-70	16.00	4	80	Sandy loam	0.07	0.84	4.5	0.19	0.18	4.40	2.40	0.90	6.0	58
	B3	70-90	20.00	2	78	Sandy loam	0.04	0.42	4.9	0.22	0.15	3.60	0.80	1.80	6.6	42
	C	90-150	20.00	2	78	Sandy loam	0.01	0.28	4.8	0.20	0.16	3.20	1.60	1.50	6.6	48
Slightly eroded																
	Ap	0-35	12.00	4	84	Loamy sand	0.12	1.51	4.1	0.04	0.17	3.20	1.60	2.40	5.4	38
	B1	35-67	12.00	4	84	Loamy sand	0.06	0.77	4.4	0.17	0.18	4.00	1.60	1.60	5.2	48
	B3	67-90	18.00	4	84	Sandy loam	0.04	0.28	4.6	0.24	0.20	3.6	2.00	1.50	5.5	50
	C	90-150	20.00	4	84	Sandy loam	0.01	0.81	5.1	0.29	0.19	2.8	2.40	1.50	5.1	49
Moderately eroded																
	Ap	0-20	10.00	2	88	Loamy sand	0.08	1.21	4.6	0.10	0.18	3.20	2.00	1.70	5.2	46
	B1	20-64	12.00	2	86	Loamy sand	0.06	1.03	5.2	0.17	0.16	3.60	2.40	1.30	5.6	52
	B3	64-90	14.00	4	82	Sandy loam	0.02	0.18	4.8	0.19	0.15	2.40	1.60	1.70	4.0	40
	C	90-150	16.00	4	80	Sandy loam	0.01	0.18	4.7	0.13	0.25	2.80	1.20	1.30	3.6	40
Severely eroded																
	Ap	0-12	8.00	6	86	Loamy sand	0.08	0.08	4.4	0.10	0.20	2.40	1.20	1.50	3.4	42
	B1	12-50	12.00	2	86	Loamy sand	0.05	0.64	4.5	0.22	0.24	3.20	1.20	1.30	4.2	48
	B3	50-80	14.00	2	84	Loamy sand	0.02	0.20	4.3	0.17	0.18	2.40	1.20	1.70	3.6	38
	C	80-150	16.00	4	80	Loamy sand	0.10	0.18	4.8	0.20	0.22	2.40	0.80	1.20	2.8	35

sites were subjected to the same land clearing and preparation activities. The traditional slash and burn was employed. All operations were manual.

The statistical design was a Completely Randomized Design (CRD) with four replications. The CRD was chosen despite some of its shortcomings. It is the preferred experimental design employed by researchers who study erosion – crop production relations using the erosion phases approach (Ebeid et al, 1995; Fahnestock et al, 1995; Arriaga and Lowery, 2003). All plots were treated the same way with regards to all agronomic practices associated with maize cultivation like weeding, minimum tillage, etc.

First Maize Cropping (April – July 1998)

Maize variety, IITA farz 27, was used. Plant spacing was 25 cm x 75 cm giving plant population of 50, 000 plants per hectare.

Second Maize Cropping (April – July 1999)

After routine land clearing activities, delineation of plot boundaries, a blanket dose of NPK fertilizer (20:10:10) was applied on all plots to prevent total crop failure. All other activities were same as for the 1998 crop.

Harvesting and yield computation

At four, six and eight weeks after planting (WAP), percentage plant establishment, plant height and total dry matter accumulation (TDMY) was assessed. Sampling was based on 24 randomly selected inner rolls plants at each site. Each plant was uprooted, and all the roots within a depth of 0 – 20 cm and circumference of 0 – 10 cm from plant were extracted with a hand trowel. The plants were separated into leaves, stems and roots and dried at 600^{O}C to constant weight for biomass assessment. At 7 weeks, total leaf area per plant was computed using the method of Mckee (1964). Final harvest was done at 14 weeks when cobs were mature. Harvested cobs were separated into stover and grain. Grain yields are reported at 10% moisture content, expressed as g/plant, kg/ha or Mg/ha. Harvest index (HI) was computed as the ratio between grain and straw.

Yield decline rate (YDR) was computed as the difference in maize grain yields between the non eroded (NE) and the next level of erosion (x) divided by the depth of the soil lost d(cm)

$$YDY = \frac{NE - x}{d(cm)}$$

Soil sampling/Analysis

Composite samples from 10 subsamples from each soil horizon were used. Standard laboratory procedures and techniques were used for analysis of chemical and physical properties. Sampling of the top 0 – 20 cm soil layer for the analysis of select soil chemical properties were done before planting in March 1998 and 1999. Results are reported in Table 2.

Data analysis

Analysis of variance (ANOVA) was used to evaluate erosion effect on maize performance and mean separation of significant effects was based on Least Significant – Difference (LSD) at 5% probability level (Steel and Torrie, 1980)

RESULTS AND DISCUSSION

Soil properties and study sites.

The classification of study sites as fine, loamy, kaolinitic, isohyperthermic, Typic Tropohumult is based on Table 1 and detailed profile study and description. All the sites were well-drained, with no water logging at any time of the year.

Table 2. Mean soil properties of the eroded plots.

Erosion Phase	BD (Mg Kg^{-1})	pH (1: 1 $H_2$0)	pH (Kcl) (0.1N)	Exchangeable Acidity Cmol kg	Sum of Basic Cation	CEC	Al^{+++} Saturation	SOC (%)	TN	BS	AP (Mg Kg^{-1})	AWC (v/v %)
A. 1998												
NE	1.39	4.8	3.9	2.9	3.81	6.3	33	1.01	0.092	56	8.25	14.65
S	1.50	4.9	4.0	2.9	2.26	4.5	50	0.75	0.071	50	6.43	18.66
M	1.48	4.9	4.0	2.9	2.31	4.3	49	0.64	0.061	52	6.95	13.90
Sv	1.47	4.7	4.0	3.3	1.55	3.6	60	0.60	0.077	43	10.25	18.77
LSD (0.05)	0.04	NS	NS	0.29	0.13	0.6	-	0.02	0.006	06	0.20	1.40
B. 1999												
NE	1.44	4.9	-	3.4	1.96	4.3	56	1.34	0.114	44	27.05	-
S	1.66	5.1	-	3.1	1.62	3.0	73	1.08	0.077	52	11.85	-
M	1.69	5.3	-	3.7	1.39	3.0	90	1.08	0.069	43	17.80	-
Sv	1.69	4.8	-	2.6	1.63	3.0	63	0.91	0.088	53	14.55	-
LSD (0.05)	0.04	0.1	-	0.14	0.28	0.49	-	0.19	0.015	NS	0.49	-

BD = Bulk Density; SOC = Soil Organic Carbon; TN = Total Nitrogen; BS = Base Saturation
CEC = Cation Exchange Capacity; AP = Available Phosphorus; AWC = Available Water Capacity.

All the soils had very low silt content (2 – 4%) sandy, low soil organic matter (highest level 1.55%), acidic pH, low CEC, low base saturation and nutrient pool. Table 2 shows selected soil properties of the soil before planting in 1998 and 1999. Bulk density (BD) falls within the medium range, and so was available water capacity (AWC). Aluminium Saturation (Al+++) increased in 1999, after just one cropping cycle of maize, Relatively the Non eroded (NE) sites were more fertile than the eroded plots and details of these differences in soil chemical and physical properties have been published in other papers (Oti, 2002 and Oti, 2007).

Natural Erosion Impact on maize yield and yield variables.

1998 Cropping

Percentage Plant Establishment (PE %), Harvest Index (HI), Total Dry Matter Yield (TDMY), Dry Grain Yield (DGY) and Fresh Cob Yield (FCY) and there relative values are shown in Table 3.

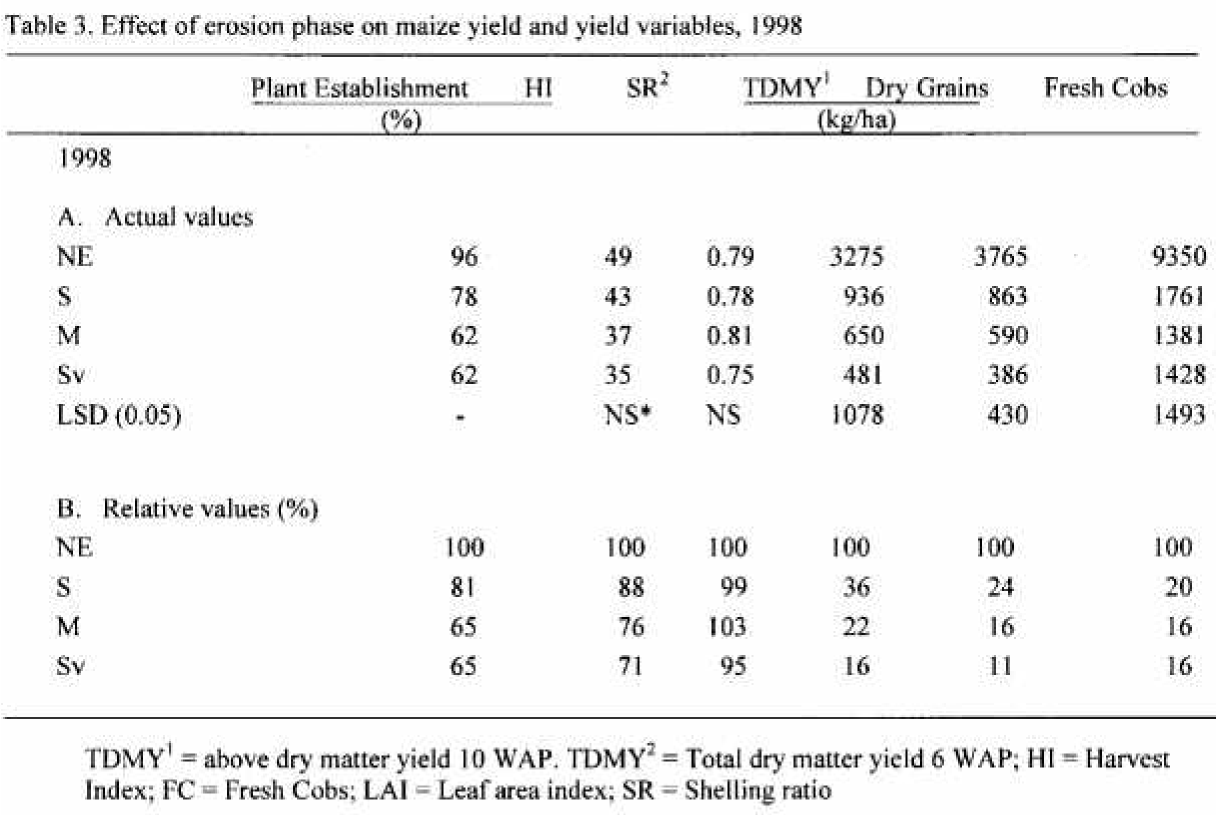

Table 3. Effect of erosion phase on maize yield and yield variables, 1998

	Plant Establishment (%)	HI	SR^{2}	TDMY^{1} (kg/ha)	Dry Grains (kg/ha)	Fresh Cobs
1998						
A. Actual values						
NE	96	49	0.79	3275	3765	9350
S	78	43	0.78	936	863	1761
M	62	37	0.81	650	590	1381
Sv	62	35	0.75	481	386	1428
LSD (0.05)	-	NS*	NS	1078	430	1493
B. Relative values (%)						
NE	100	100	100	100	100	100
S	81	88	99	36	24	20
M	65	76	103	22	16	16
Sv	65	71	95	16	11	16

TDMY^{1} = above dry matter yield 10 WAP. TDMY^{2} = Total dry matter yield 6 WAP; HI = Harvest Index; FC = Fresh Cobs; LAI = Leaf area index; SR = Shelling ratio

The general trend for most of these attributes was in the order NE>S M Sv. For instance the TDMY was 3765 kg/ha for non eroded, 936 kg/ha for slightly eroded, 650 kg/ha for moderately eroded and 481 kg/ha for the severely eroded sites. However, these values were only significantly different between the non eroded phases and all the other three phases. Among the slight, moderate and severely eroded phases there were no statistical differences. Because the maize variety used was an improved high yielding, variety, the grain yield values obtained in the non-eroded sites (3, 765 kg/ha) was much higher than the average grain yield of Owerri zone during the same period (1950 kg/ha; source Imo State Agricultural Development Corporation, yield records, 1998). However, average yield value for all the sites combined (1401 kg/ha) was lower. The implication of these trends is that the soil – plant system is greatly traumatized by the initiation of erosion. For instance, the initial loss of 10 cm of the A horizon between the non and slightly eroded sites led to a 50% loss in leaf dry matter yield, whereas the loss of about 30cm of the same A horizon in the severely eroded soil site led to 72% loss in leaf dry matter production, an additional impact of only 22%.

The leaf/stem ratio, an indicator of dry matter partitioning in plants was a rather stable parameter, not influenced by soil degradation. It was more a function of plant age.

The relative grain yield was in the other 100:32:25:26 for non eroded: slightly eroded: moderately eroded: severely eroded plots respectively. The superior performance of grain fresh cob yields in the non eroded sites was a function of both higher percentage plant establishment (96%) in NE, and higher grain yields per plant relative to the eroded sites.

Yield per se, was more adversely affected by erosion than yield indicators. Harvest Index (HI), and shelling ratio (SR), showed only minimal variations, across the different erosion phases. These attributes, strongly controlled by genetic constitution of the plant, are not good indicators in understanding or characterizing the impact of erosion on crop production.

Erosion led to severe yield decline in all the eroded phases and the values depending on the yield parameter was as high as 89% (grain yield reduction of severe erosion sites, kg/ha), in some cases. Even the loss of less than 25% of the A horizon as found in the slightly eroded plots led to over 60% loss in fresh cob and dry grain yields.

1999 Cropping.

Table 4 shows the performance of maize in 1999. In general dry matter yields were in the order of non eroded>slight>moderate>severe erosion for all plant components. Trends were similar to the 1998 maize crop. Significant differences were observed only between the non eroded sites and all the other three erosion phases. Among the eroded plots, differences in maize performance were only marginal. Despite the application of a blanket dose of 120 kg/ha of NPK fertilizer to all plots, plants in the eroded phases had stunted growth. However, as compared to the 1998 maize crop when no fertilizer was used, yield levels in 1999 were much better. This increased yield was a result of higher grain yields per plant. The relative grain yield values were 100:49:46:14 for non eroded: slight: moderate: severe erosion phases, while mean grain yields per plant was 140.00g for NE; 66.70g for S, 60.90g for M and 18.85g for Sv.

Leaf Area Index (LAI) determined at 7 WAP was assessed as an indicator of canopy cover. Erosion led to significant decreases in LAI between the non-eroded and the eroded sites.

In the two cropping seasons of maize, erosion led to consistent decline in maize establishment, stunted growth, poor biomass accumulation, and grain yields. Reductions of maize yields were a function of reduced plant performance, confounded by diminished plant populations. Several researchers here reported similar effects of erosion on maize yield and yield parameters (Tegene, 1992, Nill, 1993, Shumacher et al., 1994) the application of fertilizer and management inputs did not make the negative impacts of erosion as also reported by several scholars (Olson and Carmer, 1990, Frye et al., 1982) in the USA.

The percentage reductions of 60% - 80% in maize yield is much higher than values reported for temperate soils 8-18% (Fahnestock, 1995b; Weesies et al., 1994). This dramatic decline in maize yields is caused by the concentration of most of the plant available nutrients in the top few centiments of the soil intricately bond to organic matter. Once this top nutrient-rich layer is lost to erosion, the productive capacities of these soils decline rapidly.

Erosion – maize yield relationships

a. Linear functions of maize grain yield.

Linear functions of grain yield reductions are contained in Table 5. Mean yield decline per centimeter of soil lost was 290kg for the slight, 159kg for moderate and 113 kg.ha for the severely eroded sites. As erosion intensified, the rate of yield per unit of soil lost reduced. The ad-

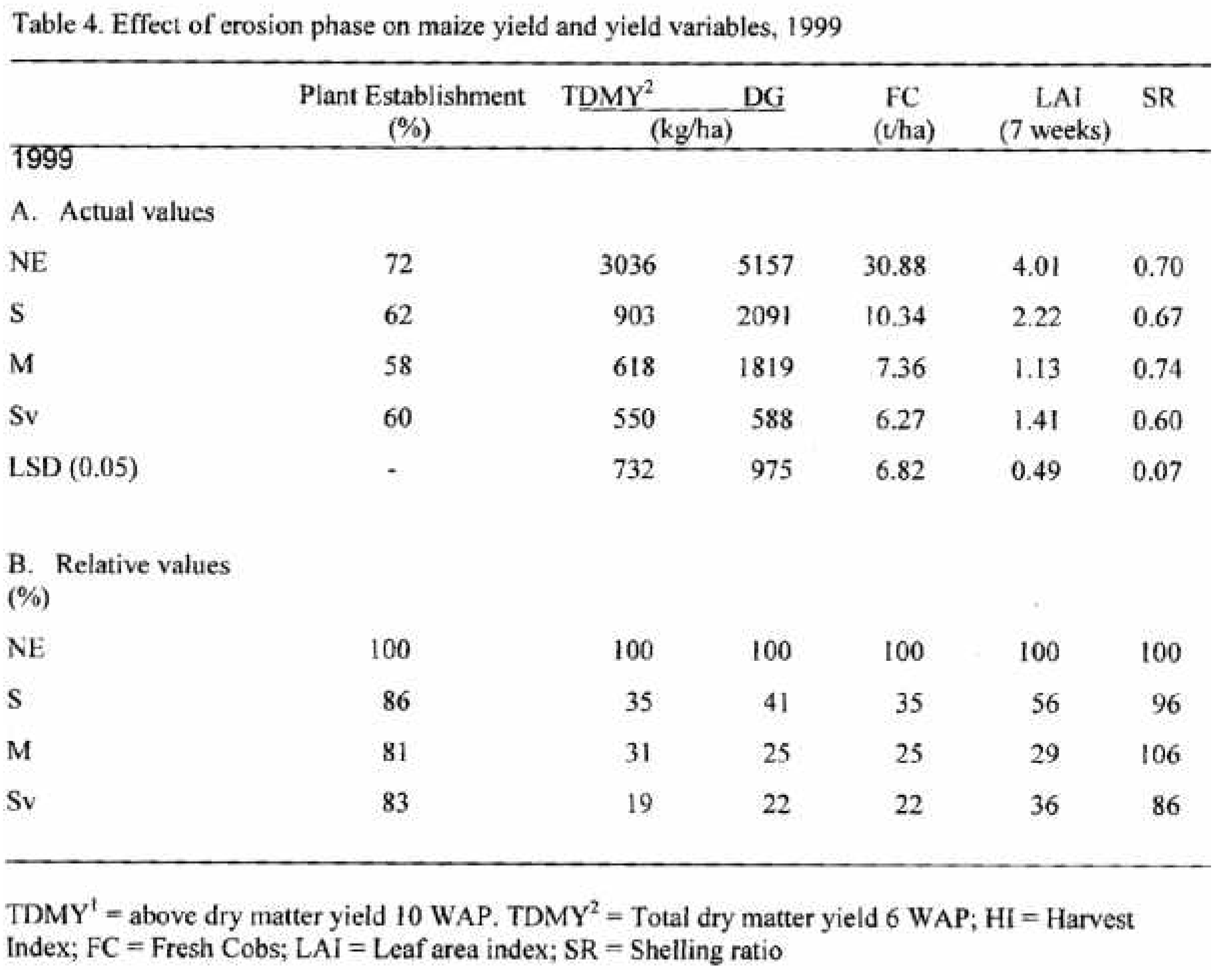

Table 4. Effect of erosion phase on maize yield and yield variables, 1999

	Plant Establishment (%)	$TDMY^2$ (kg/ha)	DG (kg/ha)	FC (t/ha)	LAI (7 weeks)	SR
1999						
A. Actual values						
NE	72	3036	5157	30.88	4.01	0.70
S	62	903	2091	10.34	2.22	0.67
M	58	618	1819	7.36	1.13	0.74
Sv	60	550	588	6.27	1.41	0.60
LSD (0.05)	-	732	975	6.82	0.49	0.07
B. Relative values (%)						
NE	100	100	100	100	100	100
S	86	35	41	35	56	96
M	81	31	25	25	29	106
Sv	83	19	22	22	36	86

$TDMY^1$ = above dry matter yield 10 WAP. $TDMY^2$ = Total dry matter yield 6 WAP; HI = Harvest Index; FC = Fresh Cobs; LAI = Leaf area index; SR = Shelling ratio

dition of fertilizer in the 1999 cropping season increased the rate of productivity loss per unit of soil eroded to 308 kg, 190 kg and 153 kg/ha for slight, moderate and severe erosion classes, respectively. That eroded lands tend to have diminished buffering capacity, soil resilience and fertilizer use efficiency has been reported by Chegere and Lal (1995) and Tegere (1992).

If we assume that the yield of the non-eroded phase (3765 kg/ha) is the maximum possible in these soils after 5 years of restorative fallow, under low input farming system, then the "half-life" of these soils is attained, and in fact exceeded by, the slight erosion phase level. The half-life in this context is defined "as the time taken for yields to decrease to 50% of their original level on non eroded soil."

Using the soil loss rate, 250t/ha/yr of Boers et al., (1988) derived from bare runoff plots on 9% slope loamy sand in an Owerri Ultisol as the maximum annual rate of soil loss, we predict the half-life of study sites, based on the following assumptions:

1. Average bulk density = 1.50 Mgm-3
2. Linear rate of soil loss
3. No conservation measures in place
4. High soil loss values, results from a combination of very erosive rainfalls and highly erodible sandy soils and
5. The soil loss of 250t/ha/yr is equivalent to a loss of 1.67cm of topsoil annually.

Therefore, it will require a minimum of 6 years i.e. $\frac{\text{(10 cm depth of soil lost)}}{\text{1.67 cm}}$ for the non eroded site to shift to the slightly eroded phase which leads to a yield decline of 50%.

However, in practice using a linear model to predict erosion rates gives highly exaggerated values which are not representative as erosion rates even within a cropping or fallow period is highly variable.

Soil loss (y) is only linearly related to time (x) for non-vegetated plots (bare soil) in the form:

$Y = Ax – B$ (Tengberg et al., 1998) where, A represents the relative rate of erosion and B the time lag for the onset of erosion.

In traditional farming systems, fallows (soil protection and reconstitution phase with minimal soil loss rates approaching zero) are punctuated by land clearing/cultivation activities (periods of maximum perturbation and very intense soil loss rates equivalent to the maximum values from bare plots). On fallow plots, the best fit relationship is one that takes a logarithm form.

A wholistic approach to assessing erosion decline rates should take into account the cyclic oscillations of erosion rates around a steady – state mean moderated by soil resilience and environmental factors. If, we therefore modify our earlier calculations of “half-life” based on a linear model, by assuming that each disturbance year (cultivation) is followed by 3 years of fallow (restoration phase), we get a new “half-life” which falls within 18 to 25 years for these soils.

We therefore, predict that without conservation efforts, the bare soils of study environment have a “half-life” of 6 years that is time taken for yields to decrease to 50% of their values on non eroded lands. The average “half-life” of the cultivated lands, under the current traditional farming systems 18 to 25 years.

b. Correlation relationships between maize yield and soil properties.

Simple and multiple correlation and regression equations derived from step-wise regression analysis, between maize grain and dry matter yields and selected soil properties are shown in Tables 6 and 7. Dry grain yield and TDMY were significantly correlated with soil organic

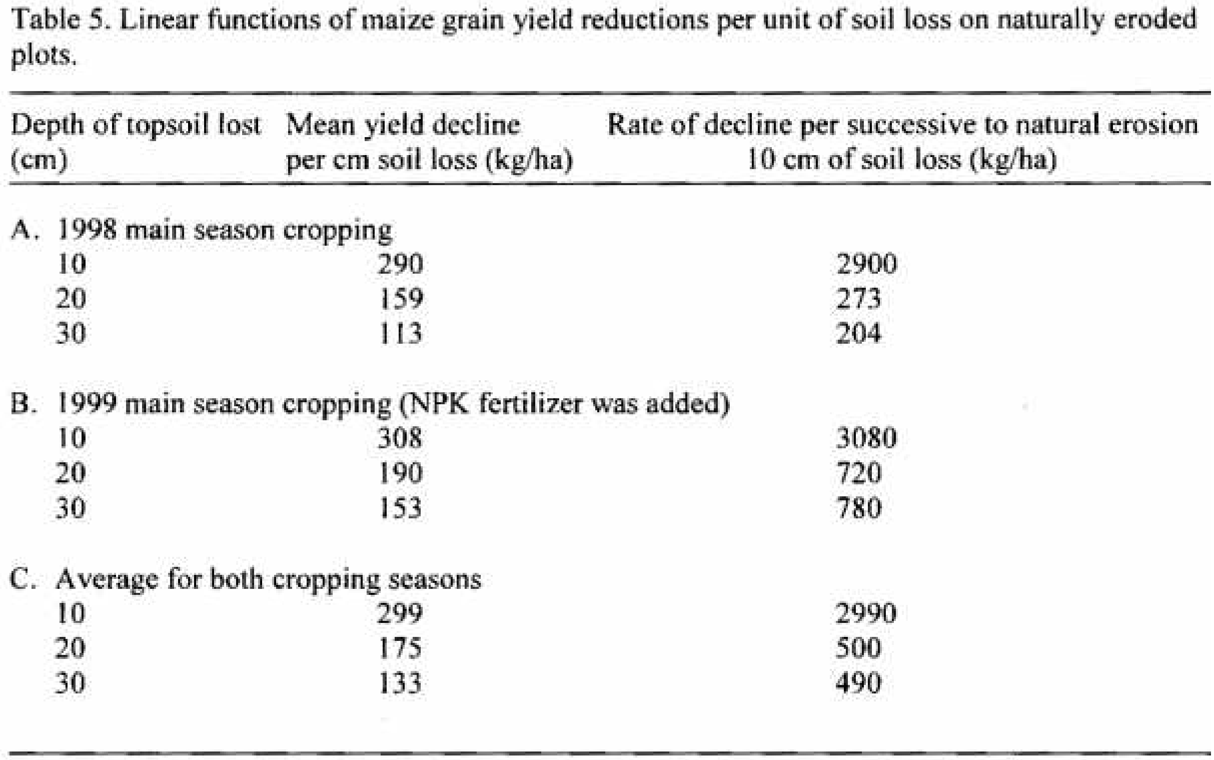

Table 5. Linear functions of maize grain yield reductions per unit of soil loss on naturally eroded plots.

Depth of topsoil lost (cm)	Mean yield decline per cm soil loss (kg/ha)	Rate of decline per successive to natural erosion 10 cm of soil loss (kg/ha)
A. 1998 main season cropping		
10	290	2900
20	159	273
30	113	204
B. 1999 main season cropping (NPK fertilizer was added)		
10	308	3080
20	190	720
30	153	780
C. Average for both cropping seasons		
10	299	2990
20	175	500
30	133	490

carbon (SOC), total nitrogen (TN) and depth of A horizon only. Multiple correlations, indicated that maize grain yield was significantly correlated to SOC, TN, CEC, BS, Al Sat, and sum of bases. Additional factors included depth A horizon, AWC, BD and (Ca + Mg)/(Al+H) ratio.

The best-fit regression equation for maize dry grain yield is the one based on SOC, TN, BN, Al Sat, and the sum of basic cations, with R value of 0.99; and these factors account for 47.3% of the grain yield variability. Soil organic carbon content alone explained 17.6% of grain yield variability.

The best-fit model for maize dry matter yield at 6WAP is regression equation based on soil organic carbon, aluminium saturation, (Ca + Mg)/(Al + H) ratio (an indication for nutrient imbalance), AWC, BD and A horizon depth as predictor variables with R value of 0.99. These six factors explained 57.5% of the variability in TDMY amongst the eroded phases. A ranking of the factors in decreasing order is as follows: SOC (32%), A horizon (10.4%), AWC (6.7%), Al sat (5.5%), BD (2%) and lastly (Ca + Mg)/(Al + H) ratio (0.9%).

CONCLUSION

The emphasis of this study was to qualify the effects of accelerated erosion on maize yield declines of the major agricultural soils found in Owerri, on maize yield and to establish empirical relationships between altered soil factors and yield loss. Erosion led to significant reductions in maize biomass and grain yields, due primarily on its negative impacts soil organic matter and nitrogen levels, aluminium toxicity, nutrient imbalance and diminished rooting depth. The mare addition of fertilizers did not compensate for this loss. Yield reductions per centimeter of soil lost is highest for the topsoil layer and estimated “half-life” of these soils is 18 – 25 years. Management strategies should target the prevention of erosion on these fragile soil systems.

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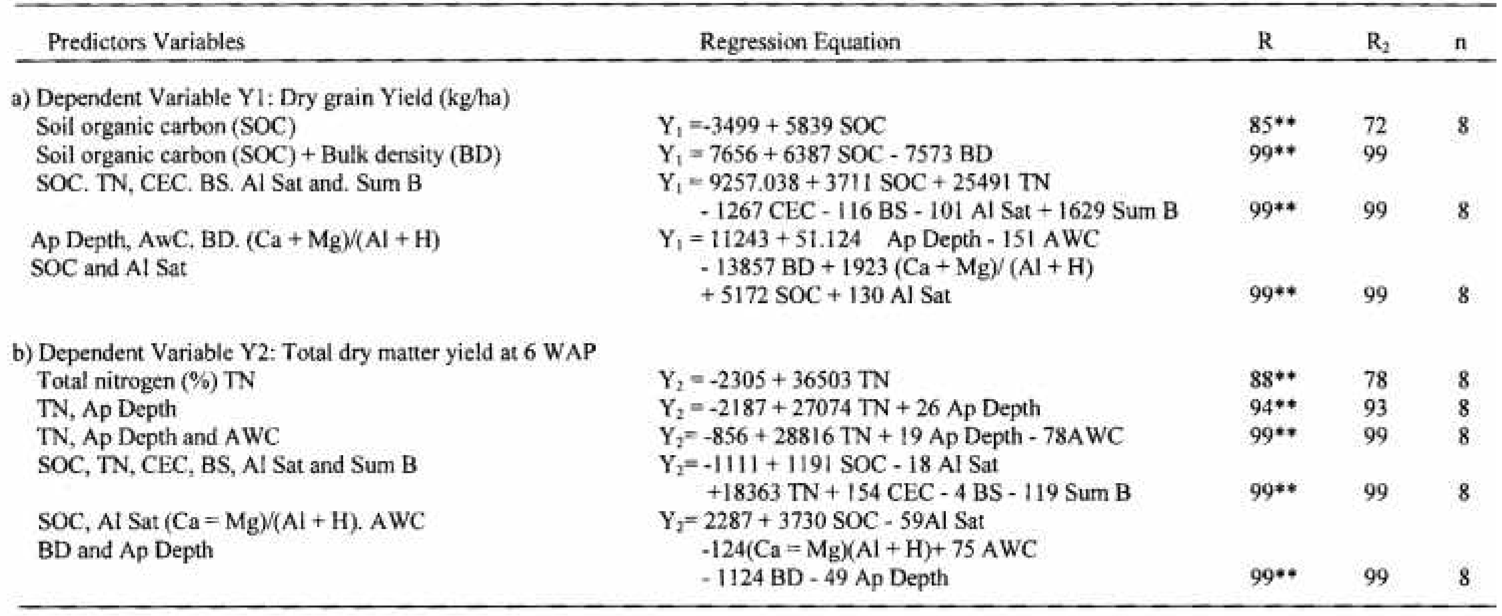
Table 7. Multiple Correlations and regressions equations relating maize yield to soil properties (0 - 10 cm depth) on eroded sites.



Predictors Variables	Regression Equation	R	R_2	n
a) Dependent Variable Y1: Dry grain Yield (kg/ha)				
Soil organic carbon (SOC)	Y_1 =-3499 + 5839 SOC	85**	72	8
Soil organic carbon (SOC) + Bulk density (BD)	Y_1 = 7656 + 6387 SOC - 7573 BD	99**	99	
SOC. TN, CEC. BS. Al Sat and. Sum B	Y_1 = 9257.038 + 3711 SOC + 25491 TN - 1267 CEC - 116 BS - 101 Al Sat + 1629 Sum B	99**	99	8
Ap Depth, AwC. BD. (Ca + Mg)/(Al + H) SOC and Al Sat	Y_1 = 11243 + 51.124 Ap Depth - 151 AWC - 13857 BD + 1923 (Ca + Mg)/ (Al + H) + 5172 SOC + 130 Al Sat	99**	99	8
b) Dependent Variable Y2: Total dry matter yield at 6 WAP				
Total nitrogen (%) TN	Y_2 = -2305 + 36503 TN	88**	78	8
TN, Ap Depth	Y_2 = -2187 + 27074 TN + 26 Ap Depth	94**	93	8
TN, Ap Depth and AWC	Y_2= -856 + 28816 TN + 19 Ap Depth - 78AWC	99**	99	8
SOC, TN, CEC, BS, Al Sat and Sum B	Y_2= -1111 + 1191 SOC - 18 Al Sat +18363 TN + 154 CEC - 4 BS - 119 Sum B	99**	99	8
SOC, Al Sat (Ca = Mg)/(Al + H). AWC BD and Ap Depth	Y_2= 2287 + 3730 SOC - 59Al Sat -124(Ca = Mg)(Al + H)+ 75 AWC - 1124 BD - 49 Ap Depth	99**	99	8

** Significant at P = 0.01

TN = Total Nitrogen (%): BS = Base Saturation (%): Al Sat = Aluminum Saturation (%): Ap Depth = Depth of Ap horizon (cm), CEC = Cation Exchange Capacity, AWC = Available Water Capacity (cm/cu), and Sum B = Sum of all Basic Cations (mequiv. 100^{-1})

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