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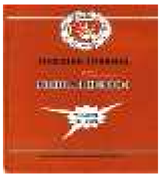


YIELD DECLINE TRENDS OF ERODED ULTISOLS IN OWERRI, SOUTHEASTERN NIGERIA: MAIZE RESPONSE TO ARTIFICIAL EROSION

Nnenna Nnannaya Oti *Department of Soil Science and Technology, Federal University of Technology, Owerri.*
Ogeriibeenwo@Yahoo.Com

ABSTRACT.

The artificial incremental removal of surface soil to varying depths to simulate erosion followed by subsequent evaluation of crop growth and performance under uniform management is a common agronomic technique to study erosion/soil productivity relationships. However, because its results tend to exaggerate yield decline rates it is being replaced by the more complex erosion phase approach. This paper is part of a series of elaborate studies conducted between 1996 and 2002 to document erosion induced productivity decline in Ultisols of Southeastern Nigeria. Specifically it evaluated the impact of mechanical topsoil removal, in 1998 and 1999 cropping seasons on maize yield performance and compares the two methods of assessment. Three levels of topsoil removals (2.5, 5.0, 7.5 cm) were imposed on the non-eroded reference plateau of the erosion phase experiment reported in paper I. Topsoil removal led to significant increases in bulk density, 1.64 Mgm-3 where 7.5 cm of topsoil was removed, 1.5 and 1.47 Mgm where 2.5 and 5.0 cm were removed respectively, 1.44 Mgm-3 in undisturbed plots. Declines in exchangeable acidity (from 3.4 Cmol/kg in control plots to 2.8 Cmol/kg in plots where 2.5 cm of topsoil was excavated) were observed in 1999. Significant reductions in soil organic carbon, by as much as 47% in all desurphased plots, and available P (27.05 Mg/kg in 0 cm and 11.90 Mg/kg in the other treatments) were recorded. In both cropping seasons, artificial soil loss effects on maize yield parameters were significantly affected. Most yield variables were similar among the 2.5, 5.0 and 7.5 cm depths of desurphased plots. However, significantly higher values were obtained in the undisturbed sites in the order 0>2.5≥5.0≥7.5 cm depths of topsoil removal. Relative grain yields in 1999 were in the other 100:41:9:6 for 0:2.5:5.0:7.5 cm depths of soil lost. The corresponding values were 5.18 t, 2.03 t, 0.48 t and 0.29 t/ha respectively. There was total crop failure in 1998 in plots from which more than 2.5cm of topsoil was excavated. Leaf Area Index (LAI) an indicator of canopy cover and photosynthetic efficiency was also negatively impacted by incremental soil loss. Shelling ratio (SR) was not affected by simulated erosion. Desurphasing technique exaggerated the magnitude of maize yield decline by a factor of 4. The erosion phase approach is recommended.

INTRODUCTION

Erosion-induced loss of crop production is the hidden face of erosion, and is severe in Nigeria, Ghana and other parts of Africa (Lal, 1994). Lal (1995) estimated the mean productivity loss due to past erosion in Africa to be 9%, and 2-40% for Sub-saharan Africa. Dregne (1990) estimated that soil productivity in some parts of Africa has declined by as much as 50% due to the combined effects of erosion and desertification, and if erosion continues unabated, mean productivity decline in Sub-saharan Africa may reach 14.5% by the year 2020.

The degree to which a unit quantity of erosion reduces productivity is dependent on a range of soil, crop and environmental factors. In tropical Altisols and Ultisols with concentrated nutrients on the topsoil tied to organic matter, topsoil loss leads to rapid yield declines (Stocking 1984; Mbagwu 1984a, b, Lal, 1985; 1979,). In fact, Rehm (1978) observed that in the Cameroons, the removal of 2.5 cm of topsoil caused a 30% drop in maize yield, while, when 7.5 cm was removed, the exposed subsoil became completely unproductive. Yost et al., (1983) reported similar results for desurphased soils in Hawaii. Most reports confirm that topsoil loss by whatsoever means in fragile tropical soils, under low input based farming systems results in severe yield declines (Miller, 1976, Langdale et al; 1979, Oti et al., 1999, den Biggellaar; 2004.)

Loses in agricultural productivity are not known for most areas prone to accelerated erosion, like Southeastern Nigeria (Lal, 1995), even though its effect tends to be location and crop specific. den Biggelaar, (2004) in a comprehensive review of the Global impact of soil erosion on productivity, identified only 9 reported studies on ultisols.

One of the major reasons for the scarcity of information on erosion – productivity relationships is the difficulty in conducting such experiments, especially in establishing the cause-effect dynamic. Also methods of assessment often produce estimates that differ by a factor of 3 to 5 (Lal, 1994). Apart from modeling, the two main experimental approaches commonly used in erosion/productivity studies are

(i) Desurfacing to simulate varying degrees of erosion (Lindstorm et al., 1986; Lal, 1987a; Pierce, 1991; Thompson et al., 1991). While this method is rapid, simple, and cheap, and gives information for many situations, its major limitation is that the results have only relative value.

(ii) The erosion phase technique based on past in situ erosion. While not completely error-proof, it assesses erosion as it has occurred under natural forces.

The results reported in this paper are a part of a large body of research work conducted between 1996 – 2002, to evaluate erosion's impact on the productivity of the Ultisols of Owerri ecological zone, establish cause-effect relationships, quantify yield decline trends of selected crops; and compare the two methods of assessment. The specific objective of this was to

a. assess the appropriateness of using desurphasing techniques to estimate erosion induced maize yields decline and

b. to compare the results with the erosion phase approach reported in paper I.

MATERIALS AND METHODS

In spite of obvious limitations, artificial removal of topsoil remains a standard procedure for erosion induced productivity decline studies (Batchtell et al., 1956, Sandler, 1980; Lal, 1976).

Study Location, land preparation and field layout

This study was situated on the non-eroded (NE), landscape within the same contiguous field used for the erosion phase experiment reported in paper I. Care was taken to demarcate the field as uniform as possible in topography and soil type (variation in slope within the experimental plots was less than 0.5%).

The site was under 4-5years fallow, land clearing was done by the traditional slash and burn method in March 1998. Wood debris was removed from site after burning.

The experimental plots were arranged in a simple Completely Randomized Design (CRD) format with depth of topsoil removed (0, 2.5, 5.0, and 7.5 cm) as the only treatment. After marking out plots of sizes 10 m x 10 m, specified soil depths were removed at random. Since the field was essentially a flat plateau with a mean A- horizon depth 45 cm, of uniform topography, the CRD was considered sufficiently sensitive and appropriate. Moreover, to simplify comparisms with the erosion phase data of paper I, the same experimental design was replicated four times. There was a total of 16 plots, each enclosed by small dykes to prevent run-on and run-off.

Excavation of desired depths was manually done with hand shovels.

First Season Maize Cropping (April – July, 1998)

Early maturing maize variety IITA farz 27 was sown on the 24th of April 1998. Plant spacing was 25 cm x 75 cm giving a total plant population of 50, 000 plants per hectare. All farming operations were done at the same time and sequence as for maize planted on natural eroded plots of paper I.

Second Season Maize Cropping (April – July, 1999)

After routine land clearing activities (slash and burn), plants were demarcated by remolding of the separation dykes. A blanket dose of 120kg/ha of compound NPK (20:10:10) was applied by the broadcast method. Surface crusts were manually broken with a garden fork and fertilizer worked into soil.

Maize variety farz 27 was sown on the 3rd of April 1999, at a population density equivalent of 50, 000 plants per hectare. All routine farm maintenance activities – thinning down, weeding, etc were same as for the erosion phase experiment of paper 1.

Harvest and Yield Computations

At four, six and eight WAP, plants were sampled for height measurements and total dry matter yield accumulation assessments (TDMY). Leaf Area Index (LAI) was also assessed. Details of methodology was described in paper 1. Experiment ended at 14 WAP with the final harvest of mature cobs.

Soil Sampling/Analysis

Initial Soil properties of study site (NE) is reported in paper I. The specific effects of desurphasing on soil properties was assessed one year after various levels of topsoil had been mechanically removed. Composite soil samples obtained from four subsamples were analyzed in pairs and mean values reported.

Physical properties: Particle size distribution was determined by the hydrometer method of Bouyoucos (1926), as modified by Day (1956), Bulk Density (BD), by core method of Blake and Hartge (1986) using cores of 50 mm diameter and 50 mm height, porosity by the relationship between BD and particle density assumed as 2.65 g/cm3, soil water relation potentials ranging from saturation (0 cm) to tensions of 1000 cm measured by a combination of Tension Table and pressure plate extractors (Klute, 1986). The available water capacity (AWC) was computed as the difference in volume moisture content at field capacity (0.1 bar) and permanent melting point (15 bar). Water stable aggregates (WSA) was determined on 5 to 25 mm aggregate using multiple screen wet sieving procedure of Yoder (1937) as described by Kemper and Roseneau (1986) and mean weight diameter (MWD) was calculated by the method of Van Bavel (1949) and Youker and McGuiness (1956).

Chemical properties: All samples were air-dried, and passed through a 2 mm sieve. Soil pH was measured in a soil suspension with a soil/water and soil/0.1kcl ratio of 1:2:5, using a Beckman pH meter. The soil was extracted with neutral M NH4OAC and exchangeable Ca, Mg, K, Na and other cations determined by atomic absorption spectrophotometry. Cation exchange capacity (CEC) was obtained by summation of NH4OAC – exchangeable bases plus KCL – exchangeable acidity. Potassium Chloride – acidity (H+ and AL+++) was determined by titration with 0.05N NaOH. Total nitrogen (N%) was determined by the Kjeldahl digestion method, soil organic carbon content by the method of wet combustion (Walkley – Black, 1934). Available P was measured by the Bray II method (Bray and Kurtz, 1945). The analytical procedures used followed the guidelines of Daye et al. (1982), methods of Soil Analysis Part II.

Table I. Selected soil physical properties of desurphased plots 1999 (0 – 10 cm soil depth)

Depth of topsoil removed (cm)	Clay	Silt	Fine Sand	Coarse Sand	Bulk density (Mg m^{-3})	MWD (mm)	Water Stable Aggregate					
	(%)						2 mm	1 mm	0.5 mm	0.25mm	<0.25mm	TA
0	12	04	22	62	1.44	0.56	1.90	8.50	36.40	39.10	13.90	85.90
2.5	14	02	18	66	1.50	0.65	2.30	9.58	34.90	39.13	14.35	85.91
5.0	14	04	18	64	1.47	0.62	1.98	6.30	40.03	39.35	12.33	90.26
7.5	14	06	18	62	1.64	0.41	1.70	6.00	38.35	36.85	17.10	82.90

Analysis of variance (ANOVA) was used to evaluate treatment effects on maize performance and mean separation of significant effects was based on the Least Significant Difference (LSD) at 5% probability level.

RESULT AND DISCUSSION

Detailed soil properties of the study site are reported in Tables 1 and 2 of paper 1. Soil physical properties of desurphased plots at the beginning of 1999 (after the 1998 cropping season) are shown in Table 1. Total aggregation remained high (82 – 90%), with a preponderance of medium sized aggregates (75%). Observed bulk density values which ranged from 1.44 Mg m-3 in undisturbed plots to 1.64 Mg m-3 in plots were 7.5 cm of topsoil where excavated, are higher than values of 1.38 to 1.41 Mg m-3, typically recorded for ultisols (Dourado – Neto et al., 2010). Mean weight diameter, even though lowest in plots that lost 7.5 cm of the topsoil (0.41) had irregular trend.

The chemical properties of the experimental plots are as shown in Table 2. The soils were acidic, and in plots were 5.0 cm or more of topsoil was removed, pH was as low as 3.3. The soil had low organic carbon content, total nitrogen, base saturation, CEC and available P. This necessitated the addition of NPK compound fertilizer to avoid total plant failure. The nutrient profile levels are typical for the Owerri ecological zone (Unamba – Oparah, 1985; Unamba – Oparah et al., 1987 and Maduakor, 1997).

Maize performance 1998

Plant establishment and Height

The effect of mechanical topsoil removal on plant population and height in 1998 indicates that plant height (a) was both a function of topsoil loss and age. Desurphasing led to stunted growth, and the effect was more evident as the growing season progressed. The order was

Table 2. Selected Soil Chemical properties, preplanting 1999 (0 – 10 cm layer)

Depth of topsoil removed	SOC	TN	BS	pH	ExH^+	$ExAl^{+++}$	TA	CEC	P(Mg kg^{-1})
	(%)				(Cmol kg^{-1})				
0	1.34	0.114	44	4.8	1.0	2.4	3.4	4.3	27.05
2.5	0.79	0.107	46	4.8	0.8	2.0	2.8	4.3	11.9
5	0.71	0.090	45	4.7	0.9	2.5	3.4	3.3	11.9
7.5	0.71	0.098	52	4.6	0.9	2.4	3.3	3.3	11.9
LSD (0.05)	0.18	NS	NS	NS	NS	0.3	0.3	NS	1.62

NS = Not significant at P = 0.05; SOC = Soil organic carbon; TN = total nitrogen; TA = total acidity; BS = base; CEC = cation exchange capacity

0>2.5≥5.0≥7.5 cm. Plant growth and vigor were best on the undisturbed site.

Plant populations expressed as percentage stand count at different ages (b) were drastically reduced by the removal of soil surface layers. There was a progressive dying-off of seedlings which secondary replanting of seeds could not correct. The major impact of topsoil removal was to prevent seedling establishment. While the undisturbed plots maintained consistently high plant populations (100 – 89%), the values were 85 – 30%, 70 – 10%, 50 – 10% for 2.5 cm, 5.0 cm and 7.5 cm depth removal respectively, between 14 DAP and 56 DAP.

The reason for this dramatic effect of topsoil loss on seedling survival is not quite clear but may be related to the truncation of the microbial mechanisms that regulates nutrient dynamics of low – input based farming systems not dependent on artificial soil amendments.

Dry matter biomass, grain yield and yield variables. Table 3 shows maize dry matter, grain and yield variables in 1998. Artificial soil loss led to pronounced significant reductions in the dry matter production of all plant components. There were no significant differences among the three levels of topsoil loss. Once the first 2.5 cm surface soil layer was removed, the productive capacity of the soil declined rapidly.

There was total crop failure on sites from which 5 and 7.5 cm layers of topsoil were excavated. Even on sites from which only 2.5 cm of soil was removed; relative yield was only 8% of the value of the undisturbed soil. Erosion only affected the magnitude of biomass fixation and not the trends, which were similar in all the four sites. Soil regulated factors in the growth and development of maize are more evident in the quantity of dry matter fixed more than in the modification of the sigmoid curve pattern that characterizes the growth of most living forms.

Maize performance 1999

Plant establishment and height.

Desurphasing led to stunted growth and reduced plant populations. The application of compound NPK fertilizer, in 1999 season, improved general crop performance without masking the negative impact of topsoil removal.

The percentage plant establishment was about 80% for 0 cm, 62% for 2.5 cm soil depth, 58% for soil depth and 40% for 7.5 cm soil depth removed 28 DAP.

Dry matter biomass, grain yield and yield variables.

In Table 4 is shown the effect of topsoil remove on dry matter, dry grain, fresh cob, Leaf Area Index (LAI) and shelling ratios. Desurfacing had no impact on some of the yield indicators like shelling ratio (SR), whereas it had significant impact on some others like root weight, total dry matter, grain yields and LAI. Most attributes were similar among 2.5, 5.0 and 7.5 cm depths of desurphased plots. However, significantly higher values were obtained in the undisturbed site. Values were in the order 0>2.5≥5.0≥7.5 cm depths of topsoil removal. Relative grain yields were in the order 100:41:9:6 for 0:2.5:5.0:7.5 cm depths of topsoil lost. The corresponding yield values were 5.17 t, 2.02 t, 0.48 t and 0.29 t/ha respectively.

Differences in grain yields observed among the disurphased treatments and the undisturbed sites were due largely to higher yields of individual maize plants and higher LAI. Plant populations played a secondary role. Shelling ratios (SR) and in fact other plant part ratios were not confounding factors, and are therefore not good indicator variables in the soil loss productivity decline relationships.

Maize crops sown in 1999 performed much better than the 1998 crops in all variables evaluated due mostly to the compensating effects of fertilizer application. In sites where 2.5 cm of soil depth was removed for instance dry matter yields in 1998 were only about 20% of the 1999 data.

In general, data from the two maize crops, indicate the following trends:

(i). topsoil removal had severe negative impact on seedling emergence and establishment, unit plant biomass production and other growth parameters were also affected by even the marginal

Table 3. The response of maize biomass and yield indicators to topsoil removal. 1998

Depth of topsoil removed (cm)	Leaf	Stem	Above ground		Dry yield		Freshcob		Shelling ratio (SR)
	———	(g/plant)	———	(kg/ha)	(g/plant)	(t/ha)	(g/plant)	(t/ha)	
A. Actual Values									
0	19.29	23.18	67.46	3290	78.44	3.765	194.70	9.350	0.73
2.5	3.78	3.55	8.47	177	6.43	0.095	40.70	0.651	0.68
5.0	3.00	1.36	4.61	52	00	00	6.78	0.036	-
7.5	1.07	1.07	2.32	17	00	00	4.57	0.024	-
LSD (0.05)	5.62	5.38	20.12	680	-	-	-	-	-
B. Relative Values (%)									
0	100	100	100	100	100	100	100	100	100
2.5	20	23	16	09	08	03	21	07	86
5.0	17	11	10	04	00	00	03	01	00
7.5	07	07	5	02	00	00	02	01	00

removal of 2.5 cm of surface soil. There was total crop failure when 5 cm or more of the topsoil was removed. For an Ultisol in southern Cameroon, Rehn (1978) observed 50% decline (against 92% recorded in these studies) when 2.5 cm of topsoil was removed and complete failure occurred by the scraping off of 7.5 cm topsoil. Mbagwu et al. (1984a) and Lal (1987a) have also reported very drastic reductions in crop yields induced by the removal of 5 cm or more of surface soil layers, in altisols and ultisols.

(ii) Improved residue management and the application of fertilizer in the second season crop led to better plant populations, growth performance, higher biomass production, and greater grain and cob yields in all the treatments. These improvements partially compensated for the loss of topsoil, without completely ameliorating the loss,

(iii) even though the removal of 7.5 cm of topsoil in this experiment did not expose the B horizon of the desurphased plots, yet significant yield declines occurred, attributable to the loss of soil organic matter, soil organisms, the disruption of nutrient cycling dynamics, and greatly diminished available nutrient pools (den Biggelear et al., 2004; Oti et al., 2007), and hence the inability of inorganic fertilizers to totally compensate for crop yield declines.

The linear functions of maize yield decline (Table 5) for each centimeter of topsoil removed mechanically was very high (1.26 t/ha/cm); in 1999, in fact four times higher than the rate for naturally eroded soils (0.29 t/ha/cm). The upper 2 cm of topsoil is the most critical soil layer influencing the overall productivity of these soil systems.

Comparative Analysis of natural versus simulated erosion approach to erosion-induced productivity decline studies.

Results of these studies show long term natural erosion had drastic effects on the reduction of A horizon depth and higher surface soil bulk densities. Topsoil removal had minimal effects on these parameters. Also soil chemical properties and probably soil biological functions were more adversely affected by desurphasing than natural erosion which is a gradual process. The abrupt loss of soil by desurphasing traumatizes the soil system more than the natural erosion process, and therefore, the former tends to have immediate impact on productivity, unlike the more incipient, gradual loss associated with natural erosion.

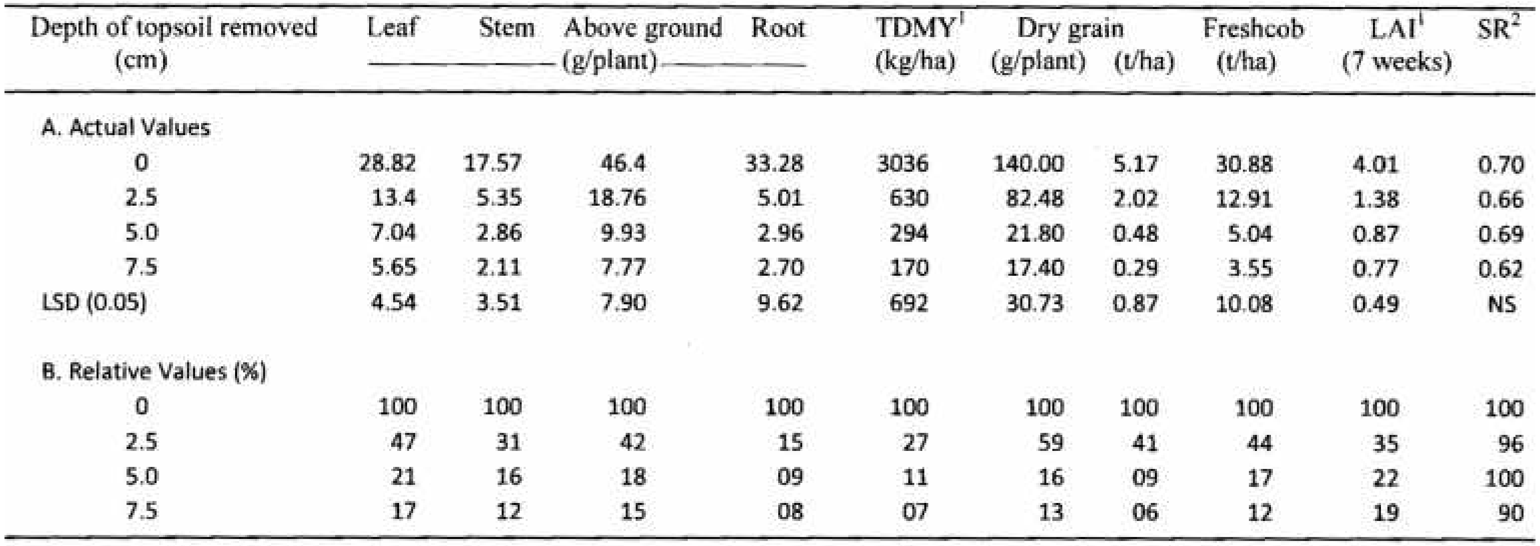
Generally, mechanical topsoil removal delayed seedling emergence and tassling, reduced plant populations, and induced immediate nutrient deficiencies, particularly of nitrogen leading to very stunted growth more than was observed for eroded phases. Gollany et al., (1992), made similar observations. The essential differences between the two approaches is their relative impact on organic matter pools, the dynamics of nutrient cycling, impact on soil biological functions and the diminished available nutrient thresholds. Linear functions of rate of maize yield decline indicates that desurphasing exaggerated the impact of erosion by factor of II for maize grain.

Caution should be exercised on the use of desurphased experiment generated data, particularly in using such information to predict or model soil productivity/soil loss relationships as this technique would appear not to correctly simulate the erosion process. Their use should be minimized and limited to specific situations like when assessing the impact of land clearing machines which scrap off topsoil surfaces.

CONCLUSION

Topsoil removal, led to drastic reductions in maize yield and yield variables, which improved manage-

Table 4. The response of maize biomass and yield indicators to topsoil removal. 1999



Depth of topsoil removed (cm)	Leaf	Stem	Above ground (g/plant)	Root	TDMY^1 (kg/ha)	Dry grain (g/plant)	Dry grain (t/ha)	Freshcob (t/ha)	LAI^1 (7 weeks)	SR^2
A. Actual Values										
0	28.82	17.57	46.4	33.28	3036	140.00	5.17	30.88	4.01	0.70
2.5	13.4	5.35	18.76	5.01	630	82.48	2.02	12.91	1.38	0.66
5.0	7.04	2.86	9.93	2.96	294	21.80	0.48	5.04	0.87	0.69
7.5	5.65	2.11	7.77	2.70	170	17.40	0.29	3.55	0.77	0.62
LSD (0.05)	4.54	3.51	7.90	9.62	692	30.73	0.87	10.08	0.49	NS
B. Relative Values (%)										
0	100	100	100	100	100	100	100	100	100	100
2.5	47	31	42	15	27	59	41	44	35	96
5.0	21	16	18	09	11	16	09	17	22	100
7.5	17	12	15	08	07	13	06	12	19	90

TDMY = Total Dry Matter Yield; LAI = Leaf Area Index; SR = Shelling Ratio.

ments practices and the application of fertilizers did not completely emoliorate. The simulation of erosion effect on soil properties and overall soil function and productivity, through mechanical topsoil removal exaggerates the impact of erosion on productivity, and does not accurately simulate the natural erosion process. Data generated from this technique should be used with caution. The natural erosion phase approach is therefore recommended.

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