Soil-Loss Tolerance of Some Nigerian Soils in Relation to Profile Characteristics[1]

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ABSTRACT

The soil-loss tolerances of five important agricultural soils covering three orders (Inceptisols, Alfisols and Ultisols) in southern Nigeria were evaluated using the following criteria: nutrient distributions within the soil profiles; productivity of the Ap and B horizons with and without inorganic fertiliser amendments; relative yield recovery on desurfaced soils in the field with and without inorganic fertiliser amendments; and present soil depth and rate of new soil formation. Soil-loss tolerance differed according to the assessment method used. An average ranking of the soils using data from the various assessment methods showed an order of tolerance of Inceptisols > Alfisols > Ultisols, which differed slightly from the fertility status order of the soils. This indicates that the productivity of these soils more than their nutrient status has a greater influence on their tolerance to erosion. The merits of this approach of evaluating soil-loss tolerance are discussed.

COMPENDIO

Se han determinado los límites de tolerancia a la erosión en cinco importantes suelos agrícolas del sur de Nigeria, que cubren tres órdenes distintos (Inceptisols, Alfisols, Ultisols), adoptando los siguientes criterios: distribución de nutrimentos en el perfil del suelo; productividad de los horizontes Ap y B con o sin fertilización inorgánica; relativa recuperación de la cosecha en el campo, en suelos erosionados superficialmente, con o sin fertilización inorgánica; profundidad actual; y tasa de neoformación del suelo. El límite de tolerancia a la erosión del suelo difiere según el método de determinación que se ha utilizado. Se puede establecer un grado medio de erosión de los suelos, a partir de los datos de las diferentes determinaciones, observando un grado de tolerancia en este orden: Inceptisols > Alfisols > Ultisols que difiere poco del estado de fertilidad del suelo. Esto indica que en relación con la tolerancia a la erosión, la productividad de estos suelos es más importante que su estado nutricio intrínseco. Se discute el valor de esta evaluación tentativa de los límites de tolerancia a la erosión.

INTRODUCTION

The acceptable limit of erosion known as "soil-loss tolerance" is defined as the maximum rate of soil erosion that will economically and indefinitely permit sustained crop productivity (20). The extent to which erosion is a problem in any locality depends on whether these limits are exceeded naturally. While value judgements play a considerable role in arriving at these limits, certain soil profile characteristics, notably nutrient distribution within the profiles, rooting depth and physico-chemical properties of the subsoil horizons are taken into consideration (6). Bauer (2) also emphasized that erosion can only be considered very serious in any locality if the residual soil productivity cannot be restored by improved soil management practices.

According to Lal (8), where the fertility levels and the physical conditions of the removed topsoil are identical with those of the exposed subsoil as in the deep Andisols and Inceptisols of volcanic origin in Hawaii and Puerto Rico, crop yields may not be depressed as a result of soil erosion. In this case more on-site erosional losses may be tolerated from such a soil. If, however, the nutrients are concentrated in the

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top 0 - 5 cm of the soil as in the shallow Oxisols, Ultisols and Alfisols in West Africa, topsoil loss will lead to drastic decline in soil productivity.

Attempts to quantify the soil-loss tolerance of tropical soils are few. Lal (8) obtained average annual soil-loss tolerance values of eight shallow, gravelly soils in western Nigeria ranging from 0.2 to 2.0 t ha^{-1} yr^{-1}. This contrasts with the acceptable rate of between 5 and 15 t ha^{-1} yr^{-1} reported for soils of temperate regions (20). This paper reports on the relative soil-loss tolerance of some important agricultural soils in southern Nigeria, evaluated by four different methods.

MATERIALS AND METHODS

The location, vegetation, soils and climate of the study sites are shown in Table 1. The Ikenne and Ilora locations are in the southwest, while Nsukka and Onne are in the southeast of Nigeria. These sites cover the main rainfall zones, vegetation belts, soils and geologic materials found in southern Nigeria. The Nsukka I site (Inceptisol) occupies the summit while Nsukka II (Ultisol) occupies the valley bottom of a toposequence.

Soil chemical analyses

Three profile pits were dug at each of the Onne, Ikenne and Ilora sites while two profile pits were dug at each site in the Nsukka location. Soil samples were taken from each of the profiles at intervals of 10 cm up to the 50 cm depth and then at 50 - 70 cm and 70 - 100 cm depths. All samples from the same depth in the same location were composited, air-dried at room temperature, sieved through a 2 mm mesh and the fine-earth fractions used for the chemical analyses. Total nitrogen was analyzed by the Kjedahl digestion method, organic carbon by dichromate oxidation, available phosphorus by the Bray-1 method, exchangeable Ca, Mg, and K by the 1N NH_4-acetate extraction, KCl-acidity (Al^{3+} + H^+) by titration with

Table 1. The physical environment of the study sites.

Parameter	Nsukka I	Nsukka II	Onne	Ikenne	Ilora
Latitude Longitude	06°52'N 07°24'E	06°52'N 07°24'E	04°51'N 07°01'NE	06°52'N 03°43'E	07°50'N 03°58'E
Elevation (m)	400	400	near sea level	60	250
Texture of topsoil	Clay	Sand clay loam	Sandy loam	Sandy clay loam	Sandy clay loam
Vegetation	Derived savannah	Derived savannah	Superhumid forest	Humid forest	Derived savannah
Soil series	Uvuru	Nkpologu	Onne	Alagba	Egbeda
Classification (soil taxonomy)	Lithic dystropepts	Oxic paleustults	Oxic paleudults	Oxic paleustalfs	Oxic paleustalfs
Parent material	Upper coal measures	Colluvium overlying false-bedded sandstones	Coastal sediments	Araneceous sedimentary rocks	Basement complex rocks
Presence of gravel (> 2 mm) within 1 m depth	Yes	No	No	No	Yes
Rainfall (mm)	1 600	1 600	2 580	1 400	1 150
Mean solar radiation ($GCal/cm^2$/day	265	265	307	387	424
Thickness of Ap horizon (cm)	32	10	9	30	8

0.05N NaOH and pH (in 1:2.5 soil/water suspension) potentiometrically. Effective cation exchange capacity (ECEC) was obtained by summation of NH_4OA C-exchangeable bases and the KCl-exchangeable acidity. These methods are described by Jackson (4).

Evaluation of relative soil-loss tolerance

The first method involved averaging the nutrient contents of the different horizons within each soil profile and ranking the soils on a scale of 1 to 5 (1 = least fertile, 5 = most fertile). The underlying assumption here is that the higher the fertility status the higher the potential of the soil to tolerate soil loss.

The second method involved artificially removing a 0 - 5 cm soil sample in all locations and comparing their productivity with those of the undisturbed topsoils with or without addition of inorganic fertilisers. The indicator crop was maize (*Zea mays* L. var. TEPB) and nitrogen and phosphorus fertilisers, applied at the rates of 120 kg N/ha and 60 kg P/ha respectively, were the only nutrients used. The Nsukka and Onne soils with low pH were limed to a pH of about 6.0 before planting. Relative rather than absolute yield data computed as

$$Y_R = 100\ (Y_i Y_o^{-1}) \qquad (1)$$

were used for comparing the erosion tolerance of the soils so as to minimize the effects of the ecological differences of the locations on the yield of the test crop. In this equation, Y_R is per cent yield recovered, Y_i is grain yield on cut surface treatment and Y_o is grain yield on corresponding undisturbed topsoil treatment. The higher the Y_R the more tolerant the soil is to erosion.

In the third method, the productivity of the Ap and B horizons of the soils were compared in the greenhouse with and without inorganic fertilisers. The inorganic fertilisers were 60 ppm N, 15 ppm P, 20 ppm K and 20 ppm Mg, applied as solutions of ammonium sulphate, sodium dihydrogen phosphate, potassium sulphate and magnesium sulphate, respectively. The Onne and Nsukka soils were also limed to a pH of 6.0 before planting maize. The relative yield recovery was computed as the ratio of dry matter yield from the B horizon to that from the corresponding Ap horizon treatment.

The fourth method involved the use of Skidmore's (18) generalized equation which is a modification of the Smith and Stamey (19) procedure. This relationship for defining soil-loss tolerance limits is a function of the present soil depth and rate of soil renewal and is given as,

$$T\ (x,y,t) = T_1 + (T_2 - T_1)/2 + [(T_2 - T_1/2] \qquad (2)$$

$$\cos\{\pi + [(Z-Z_1)/Z_2-Z_1)]\ \pi\}$$

where T(x,y,t) is tolerable soil-loss rate at point (x,y), and T_1 and T_2 are lower and upper limits of allowable soil-loss rate. T_1 is the soil renewal rate, Z_1 and Z_2 are minimum and optimum soil depths. Z is the present soil depth, that is the effective rooting depth. The estimated annual rate of new soil formation (T_1) for Ultisols in Africa is 0.011 - 0.045 mm (10, 15) and that of Alfisols is 0.07 mm (3). Soil-loss tolerance values obtained from this method depend on soil depth and do not consider the fertility status or productivity of the soil. They are used to develop broad soil conservation programmes.

RESULTS

Nutrient profiles

Generally there is a decrease in the concentrations of the nutrients with depth on all soils (Table 2). Most of the nutrients are concentrated in the 0 - 20 cm depth (which for these soils is the plough layer). Except the Ilora soil which had about 25 per cent of total carbon concentrated in the plough layer, the rest of the soils had between 40 and 50 per cent of their total carbon contents in this layer. For the other nutrients (total N, Bray-1 P, and CEC) their concentrations in the Ap horizon ranged from 36 - 52, 34 - 50 and 26 - 49 per cent respectively.

In terms of the average nutrient contents of the profiles, no one soil had a monopoly of all the nutrients or characteristics that indicate higher or lower fertility status. But when a ranking of the average profile values of the fertility parameters was established (as shown in Table 3), a fertility status order of Ilora > Ikenne > Nsukka I > Onne > Nsukka II was obtained.

Relative yield recovery

Both the greenhouse and field relative yield data are shown in Table 4. In the greenhouse the topsoil

Table 2. Profile characteristics of the soils.

Parameter	Location	Soil profile depth (cm)							
		0–10	10–20	20–30	30–40	40–50	50–70	70–100	Means
Organic Carbon (%)	Nsukka I	4.20	3.81	2.80	1.93	1.08	0.98	0.73	2.22
	Nsukka II	0.88	0.82	0.72	0.66	0.39	0.27	0.20	0.50
	Onne	1.37	1.02	0.79	0.79	0.69	0.62	0.69	0.85
	Ikenne	1.27	1.12	0.93	0.98	0.92	0.62	0.69	0.93
	Ilora	1.65	1.46	1.46	1.12	1.08	0.69	0.62	1.15
Total Nitrogen (%) x 10^{-2}	Nsukka I	44.10	34.29	25.20	20.27	10.80	9.03	6.79	21.50
	Nsukka II	9.24	8.20	6.84	6.27	3.90	2.51	2.00	5.57
	Onne	13.10	8.40	8.11	10.01	6.90	6.90	6.29	8.53
	Ikenne	14.70	14.71	9.69	10.90	10.01	6.90	7.20	10.59
	Ilora	16.30	14.60	13.82	12.48	10.90	7.81	7.79	11.96
Available Phosphorus (ppm)	Nsukka I	72.3	72.5	51.0	38.9	36.1	36.1	36.3	49.0
	Nsukka II	3.3	0.8	0.5	0.2	0.1	0.1	0.2	0.74
	Onne	4.9	5.2	4.0	3.8	4.0	4.2	4.6	4.40
	Ikenne	4.8	2.8	1.4	0.8	0.4	0.4	0.6	1.60
	Ilora	2.3	1.5	1.2	0.3	0.1	0.1	0.1	0.80
Exch Bases me/100 g soil	Nsukka I	2.23	1.55	0.98	1.20	0.80	0.84	0.80	1.20
	Nsukka II	2.18	0.81	0.77	0.55	0.53	0.76	0.26	0.84
	Onne	0.96	0.70	0.70	0.69	0.48	0.84	0.53	0.70
	Ikenne	4.96	4.48	3.62	2.70	3.90	3.78	3.90	3.91
	Ilora	16.27	4.93	4.81	4.68	4.80	4.28	2.58	6.05
Effective CEC me/100 g soil	Nsukka I	6.34	5.40	4.06	3.36	2.70	2.76	2.46	3.87
	Nsukka II	4.98	3.50	3.69	4.13	2.60	1.86	1.36	3.17
	Onne	3.37	3.37	3.72	3.75	3.80	4.21	3.48	3.67
	Ikenne	5.52	4.91	4.05	3.06	4.41	4.19	4.32	4.35
	Ilora	16.67	5.32	5.22	5.21	5.29	4.57	3.03	6.47
pH (1:2.5H_2O)	Nsukka I	4.4	4.3	4.6	4.7	5.0	5.0	5.0	4.7
	Nsukka II	4.7	4.7	4.6	4.6	4.9	5.3	5.3	4.9
	Onne	4.3	4.6	5.0	5.0	5.0	5.1	5.3	4.9
	Ikenne	6.1	6.2	6.2	5.9	6.1	6.0	6.2	6.1
	Ilora	6.1	6.4	6.3	6.3	6.3	6.4	6.4	6.3
Total (Al + H) Acidity me/100 g soil	Nsukka I	4.40	4.10	3.60	2.70	2.19	2.21	1.86	3.00
	Nsukka II	3.80	3.79	3.41	3.80	2.20	1.40	1.40	2.83
	Onne	2.28	2.56	2.92	2.96	3.22	3.26	2.84	2.86
	Ikenne	0.40	0.30	0.28	0.26	0.32	0.26	0.26	0.30
	Ilora	0.24	0.24	0.26	0.36	0.32	0.14	0.30	0.27

out-yielded the subsoil by a magnitude of 18 - 40 per cent on these soils. Similar results were reported in other parts of the tropics (1, 13, 14, 17). Generally the more fertile the soil, the higher the relative yield.

With the addition of fertiliser, however, the highest response came from the Nsukka II soil which had the lowest relative yield without any amendment. Fertilizer addition could not restore the productivity of the Onne and Ikenne subsoils to those of the topsoil and only barely did so on the Nsukka I and Ilora subsoils.

In the field, the magnitude of yield loss from treatments with the top 0 - 5 cm removed varied from 15 per cent (at Nsukka I) to 70 per cent (at Onne). Such a reduction in yield following artificial desurfacing of just a thin layer of the topsoil is not uncommon on the shallow soils of West and Central Africa (5, 12, 16). The magnitude of yield reduction did not reflect the fertility status trend in Table 3.

Table 3. Ranking of the fertility status of the soil on a scale of 1 = least fertile to 5 = most fertile.

Parameter	Soils				
	Nsukka I	Nsukka II	Onne	Ikenne	Ilora
Organic carbon	5	1	2	3	4
Total N	5	1	2	3	4
Bray-1 P	5	1	4	3	2
Total exch. bases	3	2	1	4	5
Effective CEC	3	1	2	4	5
pH	1	2.5	2.5	4	5
Exch. acidity	1	3	2	5	4
Average ranking	3.3	1.6	2.2	3.7	4.1

Final order: Ilora > Ikenne > Nsukka I > Onne > Nsukka II

The addition of inorganic fertiliser more than restored the productivity of the exposed subsoils of Ikenne, Ilora and Nsukka I to those of the undisturbed topsoil by a magnitude of 10, 28 and 38 per cent respectively. Those of Nsukka II and Onne could not be fully restored. This trend reflects the fertility status of the soils. For the Ultisols (Nsukka II and Onne) subsoils it appears that higher doses of inorganic fertiliser than those used here may be needed to attain full restoration of productivity.

Table 4. Relative yield recovery (%) in the greenhouse and field with and without inorganic fertilizer amendment.

Location	Relative yield (%)			
	Greenhouse		Field	
	Without fertilizer	With fertilizer	Without fertilizer	With fertilizer
Nsukka I	82.3	104.2	85.0	138.2
Nsukka II	58.7	157.9	35.8	72.4
Onne	73.2	86.0	30.3	50.0
Ikenne	75.0	91.0	70.0	110.0
Ilora	77.2	101.0	45.1	128.3

Soil-loss tolerance levels

The annual soil-loss tolerance levels of these soils are shown in Table 5. The weathering and soil formation rates of 0.013 mm for the Ultisols and 0.07 mm for the Alfisols and Inceptisols were assumed for these computations (3, 10). The trend in these values is that the Nsukka I and Ilora soils (with gravelly restricting layers within the 10 - 20 cm depth) had low tolerance values while the others with no such restrictions had higher values. According to Lal (7, 9), decline in soil productivity occurs if soil erosion on these shallow soils exceeds these rates.

Table 5. Estimated soil-loss tolerance limits of some Nigerian soils.

Location	Effective rooting (cm)	Depth above restricting layer (cm)	Soil-loss tolerance (t/ha/yr.)
Nsukka I	10–15	10	0.75
Nsukka II	50–70	100	3.05
Onne	50–60	100	2.00
Ikenne	50–70	100	3.60
Ilora	10–20	10	1.58

DISCUSSION AND CONCLUSIONS

The results show that the order of soil-loss tolerance of these soils differs according to the assessment method employed. According to Wischmeier and Smith (20) the determination and assignment of absolute soil-loss tolerance values requires a multidisciplinary approach in which agronomists, geologists, soil scientists, and economists, among others, play important and complementary roles. Mannering (11) emphasised that this approach lacks any scientific base to predict rates of soil formation and effects of erosion on soil productivity.

In ecologically similar areas, the relative soil-loss tolerance of the main soil series serves to identify areas where even slight erosion may be disastrous to the residual soils in terms of productivity decline. Land users are then advised on the need to manage such soils in such a way as to achieve almost zero soil losses.

Since the methods used differed in their ordering of the soils with respect to soil-loss tolerance, this study has ranked these soils according to their relative soil-loss tolerance (using all the methods described above) on the scale mentioned. The average value of the rankings for each soil represents its relative order. This is shown in Table 6 and indicates an order of tolerance of Nsukka I (Inceptisol) > Ikenne (Alfisol) > Ilora (Alfisol) > Nsukka II (Ultisol) > Onne (Ultisol). This order differs slightly from the ranking of the fertility status in Table 3 and suggests that the productivity of these soils has an overriding influence on their relative degree of tolerance to erosion, rather than their fertility status.

In conclusion, it must be pointed out that this approach gives only a first approximation order of soil-loss tolerance. In areas where soil maps with delineations up to the series level exist, this approach can be used to obtain quick, fairly reliable results. However, its weakness is that it does not give absolute values or limits within which soil conservationists can advise farmers on the adoption of appropriate conservation programmes; and such limits take long periods of experimentation to establish. On the other hand, its strength is that it can be adopted even within relatively small watersheds with different soils to indicate areas where erosion can result in serious productivity decline, and therefore areas where more attention should be given to the implementation of conservation programmes.

Table 6. A soil-loss tolerance ranking of the five soil profiles (on a scale of 1 = least tolerant to 5 = most tolerant) by the various methods.

Methods	Soils				
	Nsukka I	Nsukka II	Onne	Ikenne	Ilora
a Yield recovery in field without fertilizer application	5	2	1	4	3
b Yield recovery in field with fertilizer application	5	2	1	3	4
c Relative yield in greenhouse without fertilizer application	5	1	2	3	4
d Relative yield in greenhouse with fertilizer application	4	5	1	2	3
e Soil depth and renewal rate	1	4	3	5	2
Average ranking	4 0	2 8	1 6	3 4	3 2

Final order: Nsukka I > Ikenne > Ilora > NsukkaII > Onne (Inceptisol) (Alfisol) (Alfisol) (Ultisol) (Ultisol)

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