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Soil erodibility as influenced by long term fallow in south western Nigeria

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ABSTRACT

A field experiment was conducted in the humid Southwestern Nigeria to investigate effect of fallowing on soil erodibility. Two sites were selected for the experiment, namely a Secondary Forest (SF) fallowed for about 15 years as site 1 and a degraded site (DS) cultivated continuously for over 10 years as site 2. The total land areas were 525 and 562 m² for site 1 and site 2 respectively. Twenty soil samples were collected from each site at two predetermined depths of 0-15 and 15-30cm. The soil samples were analysed for some selected physico-chemical properties. The two sites were compared with respect to soil physical and chemical properties as a function of soil erodibility. Results showed that the texture of site 1 (SF) was between sandy clay loam (0-15cm) and sandy loam (15-30cm) while that of site 2 (DS) was loamy sand (0-15cm) and sand (15-30cm). The bulk density of SF was lower at each of the two soil depths than that of DS. Soil saturated hydraulic conductivity of the forested site was 1.4 times that of the degraded site. Similar trend was observed for C/N ratio and clay ratio. The soil mean weight diameter of SF (3.2 mm) was significantly higher than that of DS (0.5 mm). Using these data, soil erodibility factor (K) at furrow slice was found to be $8.18 \times 10^3 \text{ Mgh MJ}^{-1} \text{ mm}^{-1}$ for SF and $8.41 \times 10^3 \text{ Mgh MJ}^{-1} \text{ mm}^{-1}$ for DS. Effective cation exchange capacity (ECEC) was significantly higher in SF than that of DS. This result indicated that fallowing conserves soil nutrients and physical properties. It is obvious that fallow reduces soil erodibility from these observations. Therefore, restoration of degraded soil through fallowing should be encouraged among farmers to enhance soil productivity and crop production.

Key words: Degraded soil, fallowing, soil erodibility.

INTRODUCTION

Fallowing is a period during which a piece of land is allowed to rest from cropping in order to fully recover or regenerate its organic matter and plant nutrient contents. Fallow system of farming is based on nutrient cycling which is a cost-free and effort-less generation of soil productivity (Sanchez, 1994). During the fallow period, the secondary forest grows rapidly, tapping nutrients remaining in the soil, accumulating them above ground for 10-20 years. In the traditional bush fallow system, 2 to 3 years of cropping were followed by 10-15 years of fallow in order

to maintain crop yields and meet household food needs (Kumwenda *et al.*, 1995). Fallowing has almost disappeared on most of the arable land in Africa (Kumwenda *et al.*, 1995). Continuous cropping with a consequent downward spiral of soil fertility has led to a decline in crop yields and increased soil erosion. Continuous cropping without fallow or without application of organic and mineral fertilizers as well as the use of heavy machinery for land clearing and cultivation are the major misuses of tropical soils.

Soil productivity is generally increased in terms of physical and chemical properties

when the land has been sufficiently left under fallow usually 10 – 15 years to fully recuperate through fall from plants (Lal, 2004). Fallowing is always relied upon particularly in the tropics to rebuild degraded soils through accumulation of organic matter. Effects of erosion damage are particularly more noticeable on sandy soils that are very fragile to withstand rainfall impacts. Fallowing facilitates restoration and stability of such soils and helps to provide the stable environmental conditions on which sustainable agricultural production depends (Kio, 2000).

Soil productivity in terms of the physical, chemical and biological properties is largely enhanced through litter decomposition from vegetation and flora in the forest. Organic matter is vital to the sustainable management of fertility of tropical soils which contain low activity clay, kaolinite, low inherent fertility and various nutrient deficiencies and imbalances (Agboola, 2000). Over the years, attempts to increase the productivity of tropical soils with different organic materials have not been completely satisfactory (Aluko and Fagbenro, 2000). The fallowed land which contains trees and perennial shrubs intercept precipitation by their crowns, preventing or reducing runoff and soil loss and generally improve and restore soil conditions through the decomposition of their litter (Oshunsanya *et al.*, 2010).

The soil fertility of a fallowed land (freshly cleared of its vegetation) enhances crop production. The extent, to which crop production is enhanced, however, depends on the period for which the land has been left under fallow. The most fertile soils are thus those under forest vegetation (primary and secondary forests) for a long period of time where nutrient recycling and biotic activities have created optimum chemical and physical soil environment. However, once the forest has been cleared and put to agricultural production, soil degradation

sets in. The quality and productivity of the soils decline very rapidly owing to a combination of rapid decomposition of soil organic matter, soil and water erosion and continuous cultivation without a corresponding organic and inorganic fertilizer application.

Literature has however shown that effects of land fallowing have usually been evaluated in terms of nutrient accumulation only and rarely combined with soil erodibility indices. This study was conducted to investigate effects of fallowing on soil erodibility in Southwestern Nigeria using nutrient accumulation and some soil erodibility indices.

MATERIALS AND METHODS

Two sites located within University of Ibadan teaching and research farm were, selected for the study. University of Ibadan (7°21'N 3°54'E) falls within the Derived Savanna of southwestern Nigeria, Ibadan has a tropical humid climate with mean annual rainfall of 1289.2 mm recorded over a period of 16 years (Alabi and Ibiyemi, 2000). There are two growing seasons; early season (March/April to August) and late season (mid-August to October/November). Ibadan has an average temperature of 27°C. The percentage sunshine ranges between 16 % in August and 59 % in February and December with an average of 44 %.

The soil of the study sites is an Alfisol of the order Oxic Paleustalf (ISSS, 2003) and classified locally as Iwo series (Smyth and Montgomery, 1962). Site 1 was a secondary forest (bush re-growth), which had been under fallow (bush re-growth) for about 15 years as at the time sampling was made and covers a total land area of 525 m². Site 2 was a degraded soil which had been cultivated continuous for more than 10 years covering an area of 56m² which had been cropped to maize, cassava, potatoes, yams, cocoyam, pepper, tomatoes and vegetables prior to sampling.

Twenty soil samples were randomly collected from pre-determined depths of 0-15 and 15-30cm from each site. Undisturbed soil cores were taken with a cylindrical core sampler (5cm- height and 5 cm-inner diameter) from the two pre-determined depths for physical determination. Bulk density was estimated by dividing the oven-dry mass of the soil by the volume of the soil as described by Grossman and Reinsch (2002). Particle size distribution was carried out on the soils using hydrometer method as described by Gee and Or (2002). Saturated hydraulic conductivity (Ks) was obtained using constant water head permeameter as described by Smith and Mullins (1991). Undisturbed soil samples were also taken for the determination of Organic Matter (OM). This was determined by loss-on-ignition (LOI) as described by Cambardella *et al.* (2001). Air dry soil samples were oven dried at 105°C to a constant weight while 5g of oven-dry sample was used for LOI by mass difference after 4 hr in a muffle furnace at 500°C. Soil pH was determined both in water and 0.01M CaCl₂ using 1:1 and 1:2 soil – solution ratio, respectively with a Coleman's pH meter. Total N was determined by the Microkjeldahl method (Bremmer, 1965). Available P was extracted by Bray's P1 method (Bray and Kurtz, 1945) and read on the spectrophotometer. The exchangeable cations (K, Na and Ca) were determined by the flame photometer while Mg was read from the Atomic Absorption Spectrophotometer (AAS). Effective Cation Exchangeable Capacity (ECEC) was determined as the summation of exchangeable bases and exchangeable acidity (IBSRAM, 1994), while percentage base saturation was calculated as follows:

$$\begin{aligned} \text{\%Base Saturation} \\ &= \frac{Ca + Mg + K + Na}{ECEC} \\ &\times 100 \end{aligned}$$

Soil erodibility indices such as carbon to nitrogen ratio (C/N) and clay ratio were also determined. The clay ratio was determined as indicated below:

$$\text{clay ratio} = \frac{\% \text{ sand} + \% \text{ silt}}{\% \text{ clay}}$$

In addition, soil erodibility factor (K) was calculated using the universal soil loss equation (USLE):

$$K = 2.8 \times 10^{-7} M^{1.14} (12 - a) + 4.3 \times 10^{-3} (b - 2) + 3.3 \times 10^{-3} (c - 3)$$

Where K is the soil erodibility factor (Mgh MJ⁻¹mm⁻¹), M is the particle size parameter (% silt + % very fine sand) x (100 – % clay), a is the percent soil organic matter (SOM), b is the soil structure code (1 for every granular structure; 2 for fine granular structure; 3 for medium or coarse granular structure and 4 for blocky, platy or massive structure). Therefore, the structure code for the medium granular studied Iwo soil series at Ibadan is 3 and c is the profile permeability class factor (range between 1 for rapid and 6 for very slow (Lal and Elliot, 1994; Lal, 1988).

All data obtained were fitted into general linear model, while treatment effects (degraded and secondary forested data) were compared using analysis of variance and assuming a randomized complete block design (SAS, 2002).

RESULTS AND DISCUSSION

Soil Physical Properties as influenced by length of fallow

Particle size distribution of Secondary Forest (SF) and Degraded Soils (DS) were significantly ($P < 0.05$) different at different soil depths. Secondary forest had sandy clay loam and sandy loam texture at 0-15 cm and 15-30 cm soil depths respectively while DS had loamy sand and sand as texture for 0-15 cm and 15-30 cm soil depths, respectively (Table 1). Results showed that the degree of fineness of soil particles was highest under SF and least

under DS, suggesting that accumulation effects of litter decomposition from vegetation over long period of time under fallowed land had resulted to better soil texture capable of supporting the cultivation of crops. This is in agreement with Ogunlade and Iloyanomon (2009) that showed that clay particles increased with increase in the age of cocoa plantation in Nigeria and attributed this to higher amount of leaf litter generated and decomposed under cocoa plantation. Soil bulk density values were significantly ($p < 0.05$) lower under SF than DS by a range of 27.3 to 30.0%, indicating that SF soils contained decomposed plant materials (litter fall) which had mineralized resulting in higher proportion of fine soil particles that resulted to lower bulk density values under SF. Higher bulk density values obtained from DS was due to fine particles that have been washed away by runoff leaving behind coarse particles such as gravel and sand that resulted to higher bulk density values. Soils with higher percentage of gravels, a characteristic of a well degraded soil, will not only act as

sieve to nutrient solution but also as impediment to crop root growth, root elongation and root enlargement. This impediment is seriously felt on crop productivity when such land is planted with root and tuber crops by reducing the quantity and quality of root crops. Saturated hydraulic conductivity values obtained from soils under SF were significantly higher ($P < 0.05$) than DS (Table 1) suggesting that it will take a longer period for water erosion to gather momentum under SF even when freshly cleared for farming. This is due to the fact that there is significant linear relationship between saturated hydraulic conductivity (SHC) and infiltration rate (Reynolds and Elrick, 1990) that is, the higher the SHC the higher the infiltration rate resulting to lower surface runoff. Therefore, SF soils are well structured, with high water retention for good growth and development of crops compared with DS which are poorly structured with low water retention which could lead to poor crop yields.

Table 1: Comparative mean values of physical properties of a secondary forest and degraded soils at different soil depths in Ibadan

Land Management	Soil depth (cm)	Sand gkg ⁻¹	Silt gkg ⁻¹	Clay gkg ⁻¹	Textural class	BD g cm ⁻³	SHC cm hr ⁻¹
SF	0-15	610.0b	120.4b	269.6a	Sandy clay loam	1.12a	155.7a
	15-30	636.0b	220.1a	143.9b	Sandy loam	1.27a	139.0b
DS	0-15	800.5a	126.8b	72.7c	Loamy sandy	1.50b	108.0b
	15-30	890.9a	53.5c	55.6c	Sandy	1.54b	106.5b

SF = Secondary Forest, Degraded Site, BD = Bulk Density, SHC = Saturated Hydraulic Conductivity, Means in the same column followed by the same letters are not significantly different at $p < 0.05$ using Duncan's Multiple Range Test.

Chemical Properties as Influenced by the Length of Fallow

Secondary Forest (SF) soil pH in 0.01M CaCl₂ averaged 6.8 which is very close to neutral while the soil pH in degraded site averaged 4.4 which is acidic as presented

in Table 2. Soil organic carbon and total N in SF were significantly consistently higher within 0-15cm soil depth than within 15-30cm by 31.1 % and 35.3 %, respectively. This showed that 0-15cm

depth was richer in soil nutrients than 15-30cm due to litter accumulation and decomposition taking place at soil surface while only a little portion of released nutrients and low molecular weight humified organic matter are washed into lower soil layer. Soil organic C and total N within 0-15cm depth in SF determined are 73.5 and 20.0 gkg⁻¹, respectively. According to Obigbesan (2000), these concentrations were above sufficiency level. He therefore suggested that there was no need to apply fertilizer if such land were to be planted to crops because the soil already contained adequate nutrients to sustain crop production. Degraded soils on the other hand, contained 9.90 and 0.99 gkg⁻¹ respectively of soil organic C and total N within 0-15cm which were far below the sufficiency level, indicating that cropping without fertilizer on such soils would be uneconomical. Available P, Ca, Mg and K were significantly and consistently higher under SF than DS by 54.4, 58.2, 71.6 and 69.6% respectively in the surface soil (0-15cm).

The result further showed that exchangeable acidity and effective cation exchangeable capacity from SF were significantly higher than DS (Table 2). Exchangeable acidity obtained from SF and DS were in ratio of 2.8: 1. Corresponding ECEC was in ratio 2.3:1 suggesting that ability of forested soil to retain nutrients and prevent leaching of nutrients is prominent. This result suggests that organic farming systems could be successfully practiced if the land could be fallowed to allow it to replenish its organic matter and nutrient content without using artificial fertilizers particularly in areas where population per unit land area is low. Fallowed land is a reservoir of nutrients (Lal, 2010) which can put organic agriculture on a sustainable basis.

Table 2: Comparative mean values of chemical properties of a secondary forest (SF) and degraded soils (DS) at different soil depths

Land management	Soil depth (cm)	pH (H ₂ O)1:	pH (CaCl ₂)2:	Total N gkg ⁻¹	Org. C gkg ⁻¹	Avail P mgkg ⁻¹	Ca mgkg ⁻¹	Mg cmolkg ⁻¹	K cmolkg ⁻¹	Na cmolkg ⁻¹	Ex. Acidity	ECE C	%BS (g 100g ⁻¹)
SF	0-15	7.5a	6.8a	34.02a	87.05a	25.13a	3.39a	2.16a	2.58a	0.21c	0.28a	8.62a	30.79d
	15-30	7.5a	6.7a	22.00b	59.96b	22.08a	2.21a	1.85a	1.43b	0.43b	0.16b	6.08b	38.00b
DS	0-15	6.5a	4.4b	6.13c	11.32c	11.27b	1.25b	0.63b	0.52c	0.52b	0.08c	3.40c	42.50a
	15-30	6.5a	4.3b	5.85c	8.49c	8.83b	1.09b	0.51b	0.35c	0.70a	0.08c	2.73c	34.13c

Means in the same column followed by the same letters are not significantly different at p<0.05 using Duncan's Multiple Range Test.

Soil Erodibility

The result on various soil erodibility indices/factors in relation to soil physical and chemical properties were also evaluated using C/N ratio, clay ratio, soil mean weight diameter (MWD) and soil erodibility factor (K) (Table 3). Carbon to nitrogen ratio for SF and DS was in the ratio of 2.5:1 indicating that litter decomposition rate will be four times higher under DS than SF. There was large variation in the values of clay ratio with respect to soil depth, ranging from 2.7 to 5.9 for SF and 12.8 to 17.0 for DS. This could be ascribed to different levels of soil erosion depending upon the amount of clay that provides stability to soil structure. Soils with high values of clay ratio indicate coarse texture resulted from water erosion impacts as found on DS. The MWD which is a function of soil stability under the impacts of raindrops was higher on SF than DS (Table 3). MWD from SF from DS. Therefore, DS is more susceptible to water erosion than SF. It is also worthwhile to note that MWD at surface (0 – 15cm) was higher than was significantly higher than DS by 85.6 % and 79.3 %, respectively for surface and subsurface soils. Soils from SF are more

stable to impacts of raindrops than soils subsurface (15 – 30cm) for SF while subsurface was higher than surface for DS. This could be ascribed to higher soil organic matter at SF surface soil than subsurface horizon. However, higher MWD on DS subsurface may be attributed to soil compaction. Although, soil erodibility factor (K) was not significant, it was in the order of DS (0 - 15cm) > SF (15 – 30cm) > SF (0 - 15cm) > DS (15 – 30cm). Fallow had no significant effect on soil erodibility factor (K), but the mean K for DS was slightly larger than that of SF (Table 3) indicating higher rate of susceptibility of soils to water erosion under DS. From the vertical aspect, the removal of the more stable surface organic layer exposes the more erodible underlying layer in DS. This was evident by the significantly higher structural stability indices (clay ratio and MWD) of the SF rather than the DS. Non-significant difference in the erodibility factor (K) between SF and DS could be attributed to short term period used in estimating K factor which is shorter than the recommended period of 20 to 22 years required for the estimation of soil erodibility (Wischmeier and Smith, 1978).

Table 3: Soil erodibility indices/factor (k) as influenced by the length of fallow in Ibadan

Land management	Soil depth (cm)	C/N ratio	Clay ratio	MWD (mm)	K*
SF	0-15	2.6a	2.7d	3.5b	8.189×10^{-3}
	15-30	2.7a	5.9c	2.9b	8.260×10^{-3}
DS	0-15	1.8b	12.8b	0.4a	8.412×10^{-3}
	15-30	1.4b	17.0a	0.6a	8.11×10^{-3}

*= no significant difference, SF = Secondary Forest, DS = Degraded Site, K = soil erodibility factor ($\text{Mgh MJ}^{-1} \text{mm}^{-1}$), MWD = mean weight diameter (mm), Means in the same column followed by the same letters are not significantly different at $p < 0.05$ using Duncan's Multiple Range Test.

CONCLUSION

Soil physical properties were greatly improved under secondary forested land. Fine textured soil was found under

secondary forest in contrast to coarse textured soil obtained from degraded soil. Consequently, forested soil bulk density was significantly lower than degraded soil indicating a well-structured soil capable of

retaining water for plants to use. Soil nutrients such as total N, organic C, available P, Ca, Mg and K which are components of soil fertility were significantly high under secondary forest. These afore-mentioned nutrients, according to soil fertility classes established by Uponi and Adeoye (2000), the nutrients were above sufficiency level. This implies that there is no need to apply fertilizer to SF because the forested soil contained adequate nutrients to sustain crop production. Soil erodibility indices as C/N ratio, clay ratio and mean weight diameter showed that forested soils are highly stable and cannot easily collapse under external forces such as ploughing, harrowing and raindrops, indicating that degraded soils are more vulnerable to water erosion than forested soils.

Based on the results obtained in this study, the following recommendations are made:

1. Growing of cover crops during the off-season should be encouraged.
2. Agro-forestry should be practiced
3. Restoration of degraded soils through land use change such as fallowing should be encouraged among the traditional farmers where uncultivable arable lands are still within their reach.

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