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Erodibility Assessment of Soils Using Rainfall Simulation in Yandev, Gboko, Benue State, Nigeria

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Abstract

Field experiments were carried out at the Teaching and Research Farm of the Akperan Orshi Polytechnic, Yandev (AOPOLY) (Latitude 7ºo45' – 8ºo00'N and Longitude 8ºo36'– 8ºo45'E) in December, 2022. The susceptibility of soils to detachment and transport by water was investigated at five minutes intervalusing field erosion plots under rainfall simulation condition. Soil erosion plots (runoff plots) were set up under a slope gradient of 3.5 %. Two soil management practices used were the bare fallow (control) and grass/maize residue and were replicated three times using analysis of variance test based on randomized complete block design (RCBD). Soil samples were taken from 0 – 30 cm depth in each plot for laboratory analysis prior to the rainfall simulation. Runoff and soil loss were collected in the buckets placed inside the outlet pits of the erosion plots and measured after each rainfall event at five minutes interval. The mechanical analysis of the study site indicated sandy loam texture with low value of soil organic matter (0.97%). Soil pH was 7.6. Runoff, sediment yield and infiltration rates indicate significant (p<0.05) differences between the two treatments. High losses of runoff, soil and lower infiltration rates were observed under the bare fallow plots compared to grass/maize residue plots.The results of particle size distribution of the eroded soils were not significant between the two treatments. The most erodible textural class was sand, followed by silt and clay.

Key Words: *Erodibility, Rainfall, Simulation, Soil Properties, Infiltration*

Introduction

Soil erosion by water starts when raindrops strike the bare soil surfaces. It involves the detachment and transportation of soil particles (Obi, 2000; Barthes *et al*., 2001) followed by deposition (Obi, 2000; Barthes *et al*., 2001). Therefore, the fundamental erosion processes are detachment by raindrop impact and flow. Displacement by raindrop impact, transport and deposition by flow (Foster, 1990; Obi, 2000). Detachment processes remove soil particles from the soil mass producing sediment while transport processes move sediment from its point of origin.

The main mechanisms of detachment are the disintegration of aggregates by slaking, cracking, dispersion and shearing by raindrop impact and runoff (Barthes *et al*., 2001). Shearing as well as transport by splash and runoff depend largely on kinetic energy of raindrops and runoff, but also on properties of the soil itself (Barthes *et al*., 2001). As runoff increases according to the slope length, it's shearing and transport capacities also increase, and erosion evolves from sheet erosion to more severe rill erosion.

Soil erodibility is described as the susceptibility of a soil type to erosion and it is the reciprocal of soil resistance to erosion. Soil erodibility (K) is among the six factors in the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) and the Revised Universal Soil Loss Equation (RUSLE) (Renard *et al.*, 1997) for erosion prediction (Yin *et al.*, 2007). Soil erodibility, the resistance of the soil to both detachment and transport, is a function of soil texture, structure, permeability, organic matter content and the management of soil (Hudson, 1995; Morgan, 1995).

Early research work by Roose (1975) extensively analyzed the erodibility of the West Africa using rainfall amount alone, although he excluded areas which lacked adequate data (Manaerts *et al.*, 2000). Several studies on soil erodibility conducted in Nigeria by Obi (1982), Igwe *et al*. (1999), Ukah *et al*. (2001), Ajon *et al*. (2017) have indicated the high erodibility and variability of tropical rains. Tropical soils are more erodible than those in the temperate latitudes. Ukah *et al*. (2001) carried out research on soil loss assessment in Gboko Local Government Area of Benue State including Yandev area but all were based on the use of soil loss prediction models.

From available literature, much has not been done on the evaluation ofsoil erodibility in the north central region of Nigeria. Erosion studies here have been based on the extrapolation of data from other climatic regions owing to paucity of auto-recording rainfall data. It is inadvisable to extrapolate erodibility indices to other rainfall areas because of the difference in physiographic conditions.The aim of this study was to assess rainfall erodibility and the extent of runoff and sediment yield under rainfall simulation in Yandev area of Benue State, Nigeria.

MATERIALS AND METHODS

Study Area

The experiment was conducted at the Teaching and Research Farm of the Akperan Orshi Polytechnic, Yandev in December, 2022. The area is located at about 4 km north – east of Gboko Town along Gboko – Makurdi road in Gboko Local Government Area of Benue State. The study area is bounded by longitudes $8^0$36' and $8^0$45'E and latitudes $7^0$45' and $8^0$00'N.

The climate of the study area is tropical savanna. The minimum temperature is 25^0C and maximum is 33.5^0C. The mean monthly temperature is 27.3^0C. The total annual rainfall varies between about 900 and 1200mm. The study area has distinct dry and wet seasons. Rainy season starts in March/April and ends in October/November.

The vegetation in the study area is Guinea Savannah type, characterized by grasses with few scattered shrubs and trees. The land in the study area is used for cultivation of crops such as yam, cassava, guinea corn, maize, millet, groundnut, soyabean, benniseed, rice, melon, and other vegetable crops. Trees crops such as mango, palm trees, citrus, cashew and other economic trees are also found in the area.

Soil Sampling and Analysis

Some selected soil properties of the study site were determined prior to the rainfall simulation. Three composite soil samples were taken at the depth of 0 – 30cm in each plot. The 3 samples in each plot were air dried, bulked accordingly and gently crushed. A total of 2 soil samples from the two treatments were sieved using 2.0mm sieve for laboratory analysis using standard procedures (Udo *et al*., 2009).

Field Preparations for Rainfall Simulation

Land preparation

The runoff (erosion) plots were cleared manually with hoes. The plots were ploughed manually to a depth of approximately 15 cm with big hoes before rainfall simulation.

Experimental plots, design and treatments

The runoff (erosion) experimental plots were laid out on cultivated lands under a slope gradient of about 3.5% before the rainfall simulation. Runoff plots measuring 2 m x 1 m (i.e 2 m^2) were built or bordered by burnt bricks (blocks) to prevent lateral flows from the plots to the adjacent area. Runoff collection pits measuring 0.5m x 0.5m were constructed at the lower outlet (downslope end) of the main plots. Each plot separated from the next by 1 m. A total of 6 erosion plots were used for this experiment. The experiment was laid out in a randomized complete block design (RCBD) of two (2) treatments and replicated three (3) times. Treatments used for the experiment were the bare fallow (control) and natural vegetation (ie grasses and maize residue).

Rainfall Simulator

A rainfall simulator having a water chamber volume of 50 litres (50,000 cm^3)was used to achieve 5 minutes stipulated simulation time per erosion plot. The simulator head (12.5cm diameter) connected to water chamber had 49holes of size 4.0 mm for low pressure water passage through the outlet. The rain was applied to the plots set at 3.5% slope gradient through a simulator that was raisedwithin the plots to a height of 1m above the ground. The time taken for eachrainfall simulation run was 5 minutes interval per plot using stop watch. Six erosion plots were used for this experiment. Start- time, outflow of water at particular time intervals and end- time were recorded. A definite intensity could be obtained with this simulator.

Soil Erodibility Determination

The susceptibility of soils to detachment and transport by water was investigated using field erosion plots after maize were cultivated and harvested leaving the maize residue (stubbles) and grasses.

(a) Runoff collection / measurement

Runoff volume and the sediment suspended in it were collected and measured at five minutes interval as soon as runoff started. Runoff was collected in calibrated buckets placed inside the collection pits at the lower outlet (downslope end) of the plots, allowed the sediments to settle at the bottom for two days and carefully decanted the cleared water and measured after each rainfall simulation event. Runoff volume was measured with cylinders calibrated in cm^3 and converted to mm water depth.

Runoff volume = Volume of runoff in cm^3 / Plot area in cm^2 = cm

Where, 1 cm = 10 mm; 1 m^2 = 10000 cm^2

Therefore, plot area of 2 m^2 = 20000 cm^2

The mean runoff coefficient of plot was determined by taking the mean of all individual rainfall events (equation 1).

$$\text{Mean runoff coefficient} = \frac{\sum_{i}^{n} \frac{Q_i}{P_i}}{n} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (1)$$

Where,

Q_i is the direct surface runoff for event i,

P_i is the rainfall amount for event i, and

n is the total number of events

Percentage runoff (rainfall) was calculated thus;

% Runoff = Runoff (cm^3) / Rainfall (cm^3) x 100 %

(b) Sediments measurement

The sediments suspended in runoff were collected and measured at five minutes interval as soon as runoff started.Sediments loss were collected in the buckets placed inside the collection pits at the lower outlet of the plots, allowed the sediments to settle at the bottom for two days. The cleared runoff water was carefully decanted and the sediments were directly measured with weighing balance after each five minutes rainfall simulation event.

(c) Determination of physical characteristics of soil loss

The physical properties (ie particle size distribution) of soil loss from each plot were analyzed individually after every rainfall simulation event to determine the most erodiblesoil textural class. A portion of soil loss sample was collected in containers for analyzing particle size distribution using Bouyoucos method (Udo *et al*., 2009).

(d) Infiltration capacity of the soil

Infiltration rates (ie the amount of water that entered into the immediate soil surface) of the soil were determined as the difference between water applied to the erosion plots and runoff water collected into the buckets from the erosion plots.

Infiltration = Water (cm^3) applied minus runoff water (cm^3) collected.

Infiltration (% rainfall) = Infiltration (cm^3) / Rainfall (cm^3) x 100 %

Statistical Data Analysis

The data collected on runoff and soil loss were analyzed using analysis of variance test based on randomized complete block design (RCBD) using GenStat Release 10.3DE. The means of the erosion parameters (runoff and sediment yield) and infiltration rates were compared between the two treatments.

RESULTS AND DISCUSSION

Soil Properties of the Study Site before Simulation

Soil properties of the study site prior to rainfall simulation indicated that the particle size distribution of the soil was sandy loam texture at the depth of 0 – 30 cm. The proportion of sand was 791 g/kg while that of silt and clay were 110 and 99 g/kg respectively. This soil represents a typical tropical soil which has been continuously and intensively cultivated. Sand is the dominant fine earth fraction follow by silt and clay. The soil is coarse, and, therefore, likely to be prone to erosion and leaching with continuous cultivation. Loss of organic matter is expected to be high due to crop utilization and rapid mineralization without replacement. Soils with a restricted clay fraction, between 9 and 30% are most susceptible to erosion (Morgan 1995).

The soil pH of the study site was slightly alkaline (7.60) during the experiment.The soil organic matter was low and the content was 0.97%. This may be as a result of rapid rate of organic matter decomposition during the rainy season as well as burning of residue after harvest, and intensive and continuous cultivation without proper cover management practices that must have brought about decline in its content in the soil.

Soil Erodibility Assessment

Soil erodibility in this study refers to the measure of the sediment loss through runoff after five minutes of rainfall simulation. The inherent susceptibility of soils to detachment and transport by the various erosive agents is a function of soil properties including among others, textures, aggregate size and stability, organic matter content, clay mineralogy and electrolyte concentrations. The extent of each of these soil properties is different in different soils thereby influencing the degree of vulnerability of a given soil to destructive forces. These are in turn influenced by the interactive by effects of the topographic, cover and rainfall factors.

Runoff collected

The mean runoff collected at five minutes from each of the two treatments during the field experimental periods is presented in Table 1. The results indicate that the mean runoff at the bare fallow plots (control plots) were significantly ($p<0.05$) higher than the grass/maize residue plots, thus showing large variation between the treatments. Runoff as percentage of rainfall is also shown in Table 1. The results show that percentage runoff under the bare fallow plots were significantly ($p<0.05$) higher than those with grass/maize residue plots. The mean value of runoff collected from the bare fallow plots was 4713 cm^3 (2.4 mm) and percentage runoff coefficient was 13.46 %. The plots treated with grass/maize residue had mean values of runoff 1423 cm^3 (0.7 mm) and percentage runoff coefficientof 4.06 %.

Runoff occurs when rainfall intensity exceeds infiltration capacity of the soil (Morgan, 1995). Surface runoff and runoff as percentage of rainfall under the two soil management practices are given in Table 1. The results indicated that the mean runoff collected at the bare fallow was significantly ($p<0.05$) higher than those from grass/maize residue. This implies that cover management practices reduced runoff significantly as compared to the bare fallow. Similar results were reported by Obi (1982) and Ajon *et al*. (2017) who indicated that cover management practice drastically reduced runoff compared to bare fallow (control plots) under various management practices.

Simulated rainfall (quantity of water used) data is shown in Table 1. The total simulated rainfall recorded at each five minutes per plot was 35000 cm^3 of water. Of these quantities a total of 4713 cm^3(2.4 mm)and 1423 cm^3 (0.7 mm) appeared as surface runoff under the bare fallow (control) and grass/maize residue plots respectively. The low surface runoff collected under grass/maize residue treated plots indicated that greater percentage of rain could easily be absorbed by freshly tilled soil and through the plant roots which increased the infiltration capacity of the soil. Higher runoff collected under the bare fallow plots shows that successive rainfall simulation, there were appreciable soil water recharge, compaction and crusting eventually developed with consequent runoff. Higher runoff also could be associated with reduction in the matric potential of the soil due to the saturation of pore spaces with water and surface sealing during the first simulation rainfall events.

Sediment yield

Sediment collected under the two management practices are given in Table 1. The results indicate that grass/maize residue plots reduced soil loss significantly ($p<0.05$) compared to the bare fallow plots. The results show that the higher soil loss was obtained in the bare fallow. The mean value of the soil loss from the bare fallow plots was 0.24 kg/plot (1.2 t/ha) and grass/maize residue plots had 0.15 kg/plot (0.75 t/ha).

Runoff often follows tortuous paths on the grass/maize residue plots, thus decreasing the average flow velocity. Sediments are also obstructed and filtered by the grass/maize residue reducing the overall sediment discharge. Adekalu *et al*. (2007) investigated the mulching effect of mulch on soil loss from three agricultural soils and reported that soil loss decreased with the amount of mulch used. Sediment loss also decreased in mulch treated plots as similarly reported by Poesen and Lavee (1991), Smerts *et al*. (2008) and Ajon *et al*. (2017).

In general, the absolute values (0.24 and 0.15 kg) of sediment yield collected in this rainfall simulation experiment for the two treatments are very low. This could be mainly due to the length of the small erosion plots which are responsible for the flow shearing force resulting in less detachment and transport of soil. Most of the soil detachment in this rainfall simulation study is associated with the impact of raindrops. Therefore, the sediment yield values should only be considered as relative figures. Under normal rainfed conditions, overland flow rates play a significant role in detaching and transporting sediments due to the high velocity of a concentrated flow in channels and rills.

Infiltration capacity

Infiltration is defined as the entry of water into the immediate surface of the soil. Infiltration rate is the time-rate at which water will move into the soil. This may also be defined as the flux passing through the soil surface and flowing into the profile (Obi, 2000).

The changes in infiltration capacity as affected by soil management practices are presented in Table 1. Infiltration rates show significant ($p<0.05$) difference between the two treatments. Higher average infiltration rate was obtained under the grass/maize residue plots (33577 cm^3) while the bare fallow plots had 30287 cm^3 out of the 35000 cm^3 of the total water applied on each plot. This means that the volumes of infiltrated water as percentage of rainfall on the bare fallow and grass/maize residue plots during the five minutes rainfall simulation were 86.54% and 95.94%, respectively of the total water applied. In general, the rates were very high. These high infiltration rates are possible because the soil is porous due to the sanddominant fraction of the soil. The dry season also contributed to the high infiltration rates. Other possible reasons for this have been noted by other workers (Obi, 1982, 2000; Morgan, 1995; Mandal *et al*., 2012; Ajon *et al*., 2017). The decreased in the rate of infiltration under the bare fallow plots could be ascribed to surface sealing and low organic carbon content during the continuous simulation in the dry season. The top 0 – 10 cm of the bare fallow plots were of weak, crumb structure and low organic carbon (0.41 – 0.50 %). Works by Obi (1982, 2000) pointed out that many surface soils with such characteristics were subject to crusting from raindrop impact.

Table 1. Erodibility Test and Infiltration Rates for the five Minutes Rainfall Simulation Runs

Treatment	Time (Min)	Rainfall simulation (cm^3)	Runoff collected (cm^3)	Runoff (% rainfall)	Sediment yield (kg/plot)	Infiltration (cm^3)	Infiltration (% rainfall)
Bare fallow	5	35000	4713	13.46	0.24	30287	86.54
Grass/maize residue	5	35000	1423	4.06	0.15	33577	95.94
LSD (P<0.05)	NS	NS	1035.2	3.232	0.041	1106.3	3.075

Mechanical composition of sediment yield

Particle size distribution of the sediment collected under the two soil management practices is shown in Table 2. The results of particle size distribution of the eroded soils were not significant. In the two treatments, the dominant fraction of the soil loss was sand, followed by silt and clay. For bare fallow plots, the mean proportion of sand was 690 g/kg, while silt and clay were 210 g/kg and 100 g/kg, respectively. Under grass/maize residue plots, the mean proportion of sand was 620 g/kg, silt was 250 g/kg and clay was 130 g/kg. The particle size distributions of the sediment yield were not significant. Sand dominated soil was found to be more susceptible to particle detachment as soil loss compared to silt and clay. This could be due to the relative transportability of coarse and none aggregated sand particles as compared to the fine silt and clay particles. This high erodibility of the sand-dominated soil is in line with Morgan (1995) and Ajon *et al*. (2017) findings. According to Morgan (1995) and Ajon *et al*. (2017), the medium and coarse soil particles are the most easily detached from the soil mass and that high clay particles resist detachment.

Table 2.Mechanical Composition of Sediment Yield

Treatment	Sand (g/kg)	Silt (g/kg)	Clay (g/kg)
T1. Bare fallow	690	210	100
T2.Grass/maize stubble	620	250	130
LSD (P<0.05)	NS	NS	NS

CONCLUSION

Soil erodibility assessment using simulated rainfall at five minutes interval on the bare fallow and grass/maize residue plots revealed runoff and sediment yield decreased with respect to surface cover and slope gradient.

The experiment shows the kind of accelerated erosion that takes place when farm lands are left bare and exposed the soil to rain when the crop residues and bush are burnt after harvest. Therefore farmers should stop the practice of burning of crop residues and bush in the field after harvest to avoid losing of appreciable amount of precious topsoil.

Surface organic cover management is also recommended for sustainable soil management practices in Yandev especially under rainfed conditions.

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