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Runoff-infiltration processes and some physical properties of Degraded Ultisol under different soil and crop management practices in Nsukka, South Eastern Nigeria.

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Information on runoff and infiltration processes is important for sustainable management and conservation of soil and water resources for increased productivity on Nigerian agricultural lands. A research was conducted in the runoff plots (20 m x 3 m) at the University of Nigeria Nsukka Teaching and Research Farm to evaluate runoff and some hydrophysical properties of Nkpologu sandy loam soil under different cover and soil management practices. The management practices were bare fallow (BF), groundnut (GN), and sorghum (SM) cultivation with 10 t/ha poultry manure. Soil samples for analysis were taken at 0-15 cm depth at the end of each cropping season. Runoff and infiltration measurement were done under different soil and crop management practices. There was significant ($P < 0.05$) effect of soil and crop management practices on bulk density (BD), total porosity (TP), and macro-porosity (MP), except micro-porosity (MIP). The highest values for BD (1.61 kgm^{-3}), TP (49.9 %), MP (6.42 %), and MIP (42.85 %) were obtained under the BF. The lowest BD (1.35 kgm^{-3}) and MP (6.42 %) was recorded under GN, whereas SM recorded the lowest TP (42.10 %) and MIP (36.58 %). The soil and cover management practices significantly influenced the infiltration characteristics, runoff, and soil loss measured ($P < 0.05$). The final steady infiltration rates ranged from 287 mm h^{-1} under BF to 468 mm h^{-1} under GN cover plot, while the cumulative infiltration at the end of 2 hours ranged from 14,460 mm under the BF to 64,500 mm under the SM plot. The highest runoff and soil loss values respectively for both monthly (8.72 mm; 661 $kgha^{-1}$) and daily (1.554 mm; 126 $kgha^{-1}$) evaluations were obtained under the BF whereas the lowest values for monthly (1.95 mm; 31 $kgha^{-1}$) and daily (0.38 mm; 5 $kgha^{-1}$) evaluations were obtained under GN. The study has shown that this soil is fragile, erodible, and susceptible to different forms of degradation, especially soil erosion. Adequate soil and crop cover management practices are indispensable to minimize further degradation, and to enhance sustainable management of soil and water resources for improved productivity.

Key words: Runoff, Soil loss, infiltration characteristics, sustainable management, degradation.

INTRODUCTION

Soil erosion which is one of the most important forces of soil degradation in most arable soils of the world leading to productivity deterioration has posed great challenges to human existence. This will be worsened by the present challenge of climate change and variability which is expected to affect soil and water resources in agricultural lands and in many environments through changes in temperature and precipitation patterns that influences runoff and erosion rates (Soil and Water Conservation Service (SWCS), 2003). Nearing (2001) affirmed that the most important effect of climate change on soil erosion and surface runoff will come from climate-induced changes in the volume and erosive power of rainfall. This will aggravate accelerated soil erosion which is the predominant ecological problem in the humid tropics and in particular, south-eastern Nigeria. The soils of south-eastern Nigeria are mainly ultisol and alfisol naturally prone to erosion i.e highly erodible, due to their fragile nature and are classified as structurally unstable (Oguike and Mbagwu, 2009; Idowu and Oluwatosin, 2008). The negative impacts of soil erosion due to inappropriate land management on soil and water resources has been reported by some researchers (Nyakatawa *et al*., 2001, Isikwue *et al*, 2001, and Isikwue, 2005). It has also been reported that runoff leads to soil loss (Le Bissonnais et al., 2005) mostly on rainfed crop lands and nutrient movement from soil surface (Lal, 1998; Simard *et al*., 2000; Ng Kee Kwong *et al*., 2002), and consequently declining soil productivity and crop yield (Vaezi *et al*, 2010).

Runoff is generated by rainstorms and its occurrence and quantity are dependent on the characteristics of the rainfall event, i.e. intensity, duration and distribution. SWCS (2003) noted that the amount and intensity of precipitation affect the amount of soil that can be eroded and the volume and flow rate of surface runoff. According to Horton, 1933 and Haan *et al*., 1994 reported in Haggard *et al.,* 2005, the major abstraction from rainfall during surface runoff producing events is infiltration, which is a complex process with spatial and temporal variability. He noted that infiltration rate is dependent upon several soil properties and site characteristics that ultimately affect surface runoff production from the landscape. The most common soil properties affecting infiltration, and thus surface runoff production, are bulk density, degree of structure or aggregation, presence of macropores and saturated hydraulic conductivity. Sauer and Logsdon (2002) also reported the influence of coarse soil fragments on infiltration and surface runoff production. Besides the site characteristics such as climatic and topographic factors which are beyond the power of man to control, vegetation and soil factors can easily be manipulated to control surface runoff and soil losses.

Thus, this study aims to evaluate the runoff-infiltration processes and the associated soil loss under different soil and crop management practices.

MATERIALS AND METHODS

Site Description

The experiment was conducted in the runoff plots of the University of Nigeria, Nsukka Teaching and Research Farm constructed in 1973. The soil has a natural slope of 5%. It is a deep, porous with reddish to brownish colour (ultisol) derived from sandy deposits of false bedded sandstones belonging to Nkpologu series (Akamigbo and Igwe, 1990). The runoff plots measuring 20 m by 3 m were delineated by asbestos sheets which extend above ground on both sides and the upper end to prevent runoff entering from outside. The lower ends were connected to soil-and-water collection bins below the ground level.

The study area is a forest-savanna transition zone or derived savanna located between latitude 06^{o}51'N and longitude 07^{o}24'E, with mean elevation of 400 m above sea level. The plots were established to monitor the effects of different soil/crop management systems on runoff and infiltration processes.

The area is characterized by a humid tropical climate with wet and dry seasons (Obi, 1982). The rainfall is bimodally distributed with annual total of about 1750 mm.The mean annual temperature is 27^{o}C with minimum and maximum of 21^{o}C and 31^{o}C respectively (UNN meteorological station). The average relative humidity rarely falls below 60% during the short harmattan season (between December and January) when temperature may fall below 22˚C.

Cultural Practices and Management Treatments

The management and or cultural practices used for this experiment were tilled groundnut and sorghum, and bare fallow. Tillage was done in the first year to a depth of 15 cm using hoe, and 10 t/ha poultry manure added before planting the test crops. However, in the second year minimal tillage was performed using hoe without further addition of 10 tons ha^{-1} poultry manure before planting the test crops. Weeding operation was done occasionally on the groundnut and sorghum plots to minimize weed competition while the bare fallow was kept weed-free throughout the period.

Different management treatments imposed were as follows;

(i) Bare fallow.

Table 1. Effect of cover management on the pore size distribution, bulk density and hydraulic conductivity**.**

Trt	Total porosity (%)	Macro porosity (%)	Micro porosity (%)	BD (Mg/m^3)
BF	49.27	6.42	42.85	1.61
GN	44.60	5.28	39.31	1.35
SM	42.10	5.52	36.58	1.36
CV %	7.10	21.9	7.2	4.8
$LSD_{0.05}$	2.76	1.082	NS	0.058

Trt= management practices, BD= bulk density, NS= non-significant, $LSD_{0.05}$= least significant difference at 5% probability level, CV= coefficient of variation.

(ii) Groundnut(*Arachis hypogea*) + 10 tons/ha poultry manure + tillage
(iii) Sorghum *(Sorghum almun_)*+ 10 tons/ha poultry manure + tillage

Measurement of runoff water and eroded soil material

Measurement of runoff was carried out using graduated cylinder after each rain. The runoff values expressed in millimetres were obtained using the relation

$$\text{Runoff (mm)} = \frac{\text{litres of runoff water}}{\text{Area of plot (m}^2\text{)}}$$

In measuring soil loss, the deposited sediment in the collector was drained when maximum sedimentation was assumed to have taken place, and the wet material was oven dried at 105°C for 24 hours to remove the water content of the sample and weighed afterwards to determine the weight or quantity of soil loss.

Measurement of infiltration characteristics

The double-ring cylinder infiltrometer method/technique, with cylinders/rings of dimensions 30 cm by 30 cm (inner ring), and 30 cm by 40 cm (outside ring), was used to determine the infiltration characteristics of the soils at the designated data points representing the different soil and cover management practices. The infiltration run was done at each location of the selected spots.

Measurement of soil physical properties

On each of the test plots, three undisturbed soil core samples, each of 5.0 cm in diameter and 5.5 cm in length was collected randomly from the top soil (0-15 cm) and used for the determination of bulk density and pore size distribution.

Laboratory Method

Bulk density was determined by core method as described by Anderson and Ingram (1993). Pore size distribution was determined using the water retention data (Plint and Plint, 2002) in which the microporosity (Mp) was taken to be the soil moisture content at 60 cm (water) tension.

Statistical Analysis

The analysis of variance (ANOVA) for a completely randomized design (CRD) was carried out using a Genstat Discovery Edition version 5.0 (GENSTAT, 2003) on windows 7 and the mean difference of the effects of different crop growth on runoff, soil and hydrophysical properties measured were compared using the Fischer's least significant difference (F-$LSD_{0.05}$) as described by Obi (2002).

RESULT AND DISCUSSION

Pore size distribution and bulk density (BD)

Pore size distribution

The pore size distribution and bulk density are shown in Table 1. The different soil and cover management practices significantly ($P < 0.05$) influenced the total porosity. However, the total porosity obtained under GN is not significantly different from that obtained under SM. Contrary to Obi and Nnabude (1987), the least value was obtained under the sorghum plot. The high value obtained under BF and GN respectively could be attributed to the organic matter content of the soils, activities of soil fauna such as termites and roots that created larger pores.

Macroporosity was also significantly (*P<0.05*) affected by cover management practices. Obi (1999) reported that grass and legume covers increased macroporosity by 21.1 %. The highest value (6.42%) was obtained under bare fallow whereas the least value (5.3%) was obtained under groundnut plot. The lower values obtained under GN and SM plots could be attributed to the disturbance of the soil caused by tillage during the planting and harvesting operations done in the preceeding seasons. Nimmo *et al*., (2002) reported that soils after initial tillage quickly revert back to their original state and sometimes becomes more compacted compared to their initial state. Moreover, soil physical and hydraulic properties due to tillage revert back to the original state as a result of natural reconsolidation due to wetting and drying cycles (Green *et al*., 2003) created by rain events during the crop season.

The different cover management practices did not significantly (*P<0.05*) influence the microporosity (Table 1). This result agrees with the work of Amana *et al.*, 2010 who reported a non-significant influence of vegetation cover on microporosity. The lowest value of 36.58 % was recorded under SM plot against 42.85 % recorded under the bare soil. Obi (1999) reported a 13.6 % decrease in microporosity under grass and legume covers over the value for the bare soil on a sandy clay loam soil. The differences in cover protectiveness, root system development, biomass and faunal activities would, to some extent, explain the observed differences in microporosity under different cover management practices. The significant effect recorded by total porosity under different cover management practices may be due to their effect on macroporosity.

Bulk density

The soil bulk density was significantly (*P<0.05*) influenced by the different cover management practices (Table 1). The average bulk densities of the surface soil (0-20 cm) ranges from 1.35Mg/m^3 under GN cover to 1.61 Mg/m^3 under BF. Amana *et al*., (2010) recorded a high bulk density value of 1.65 Mg/m^3 under BF soil in 2005. The significant (*P<0.05*) reduction in the bulk density under GN and SM cover management practices can be attributed to a combination of the initial tillage or previous cultivation in the first cropping season, and high root density and organic matter accumulation. Bulk density has been widely reported as an important soil factor in root growth and proliferation. The bulk density under bare fallow was high and a little below the critical optimum value capable of impeding root growth and development and can be attributed to no tillage. Cannel *et al*., (1980) and Greenland (1981), reported increase in bulk density under zero or no tillage. The bare fallow was additionally compacted as result of direct rainfall impact due to no cover, and moreso, due to absence of root activity.

Infiltration rates and Cumulative infiltration

Infiltration measurements were made at the end of the second cropping season to study the influence of the various crop cover management practices on this important soil structural phenomenon. Both infiltration rate and cumulative infiltration were lowest in the BF compared to the plots cultivated with GN and SM (Figure 1 and 2). The final infiltration rates ranged from 287 mm h^{-1} in the BF to 468 mm h^{-1} in the GN cover plot while the cumulative infiltration at the end of 2 hours ranged from 14,460 mm under the BF to 64,500 mm under the SM plot. Obi (1999) also reported the lowest cumulative water infiltration values under the BF treatment. The final infiltration rate at 2 hours followed the order GN > SM > BF while the cumulative infiltration at 2 hours followed the order SM > GN > BF. The excessive rates under the SM cover could be attributed to the combined effect of dense network of roots and the activities of termites and ants whose channels were evident and pronounced in the plots. Similar observation was made by Obi (1982), and by Wilkinson (1975) Wilkinson and Aina (1976).

Runoff and soil loss

The effect of soil and cover management practices on daily and monthly runoff, and soil loss respectively were presented on Table 2. There was significant (p <0.05) effect of soil and cover management practices on both runoff and soil loss measured. The highest monthly runoff (8.72 mm) and monthly soil loss (661 kgha^{-1}) were obtained under the BF plot while the least values (1.95 mm; 31 kgha^{-1}) were obtained under the GN plot (Table 2). The same trend was followed by runoff and soil loss measured daily under the different soil and cover management practices with the highest values for runoff (1.554 mm) and soil loss (126 kgha^{-1}) recorded under the BF and lowest values (0.38 mm; 5 kgha^{-1}) recorded under GN plot (Table 2). The high runoff and soil loss values obtained under the BF could be attributed to the impact of raindrop on the soil and hydrophysical properties measured as shown by the high bulk density (1.61 kg/m^3) (Table 1) and lower infiltration characteristics (Fig 1 and 2). The variation in the effect of soil and crop management practices were pronounced on monthly soil loss (CV %, 93.9) compared to the monthly runoff (CV %, 24.6) (Table 2). This variation was however, higher (CV, 44.1 %) for daily runoff, and more pronounced (CV %, 135.1) for daily soil loss (Table 2). The result clearly showed that the variations in runoff and soil loss

Table 2. Effect of cover management on Monthly/Daily Runoff and Soil Loss

Management practice	Monthly Runoff (mm)	Monthly Soil loss (kgha^{-1})	Daily Runoff (mm)	Daily Soil loss (kgha^{-1})
BF	8.72	661	1.554	126
GN	1.95	31	0.380	5
SM	3.77	105	0.703	21
CV%	24.6	93.9	44.1	135.1
$LSD_{0.05}$	1.152	242.5	0.377	66.5

BF= bare fallow, GN= groundnut, SM= sorghum, NS= non-significant, $LSD_{0.05}$= least significant difference at 5% probability level, CV (%) = coefficient of variation.

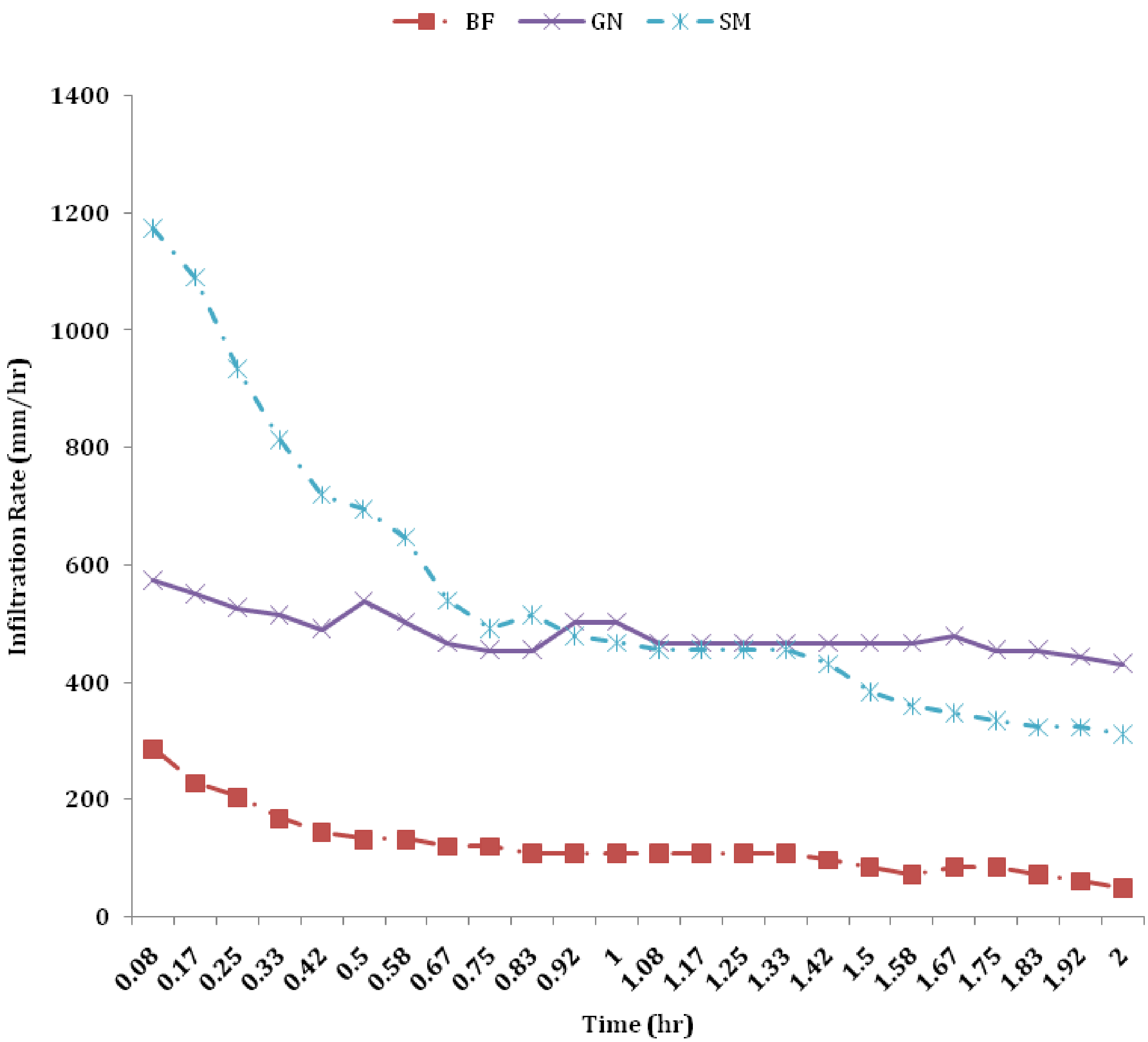


Figure 1. Graph of infiltration rate against time under different cover management practices

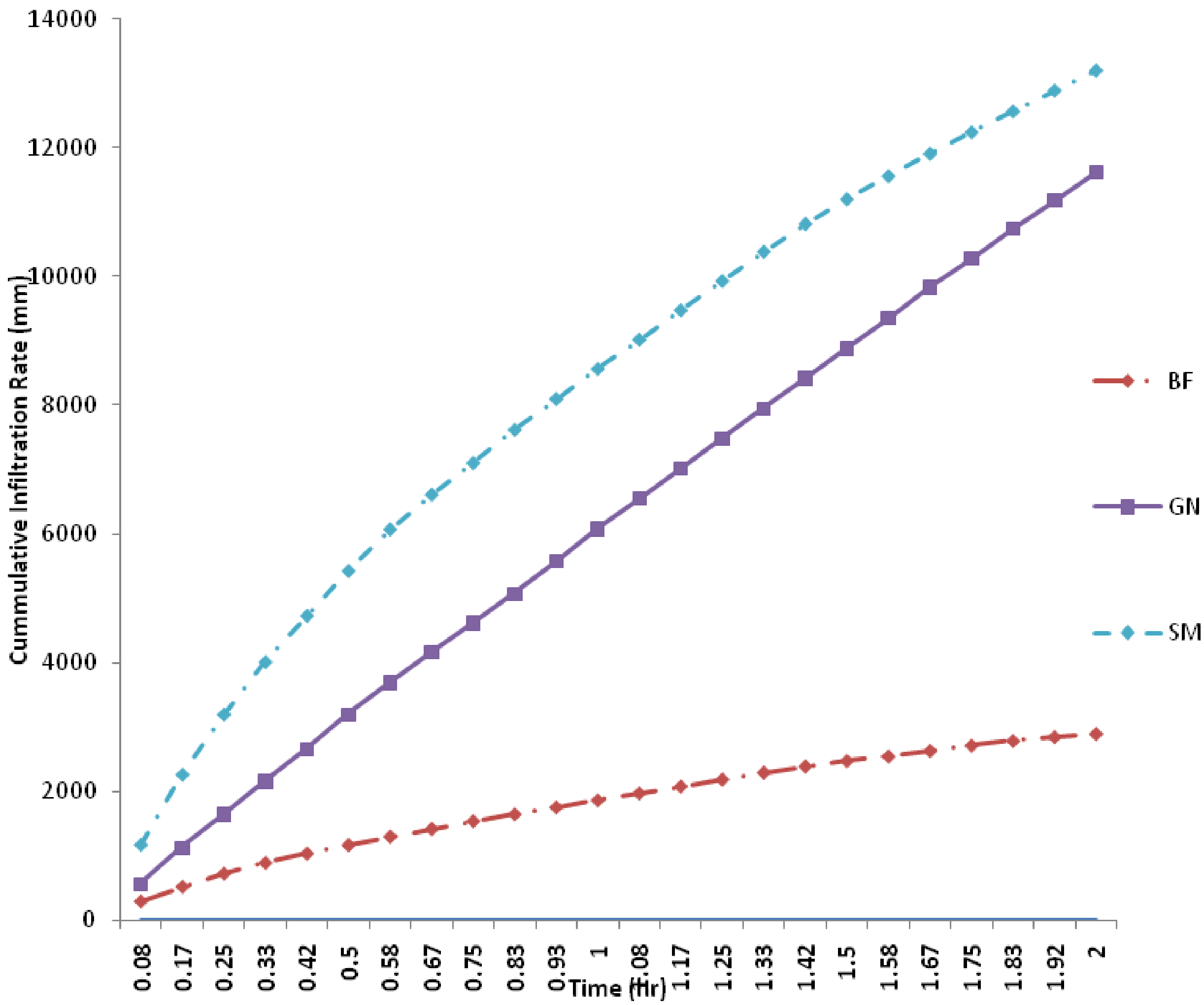
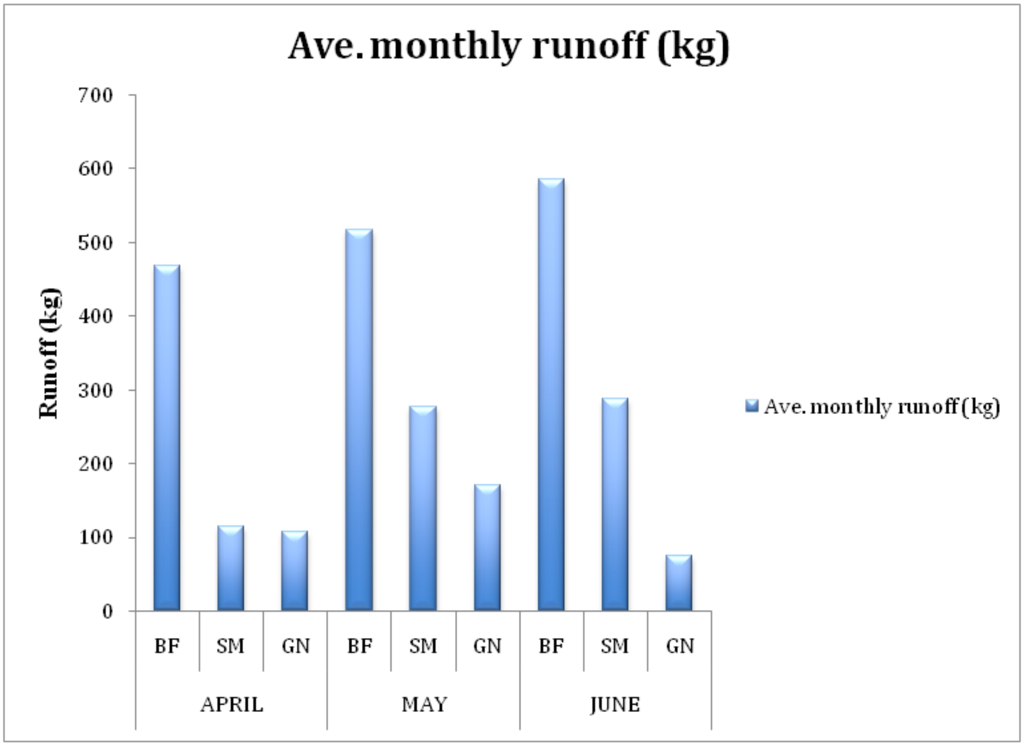


Figure 2. Graph of Cumulative infiltration against Time under different cover management practices.

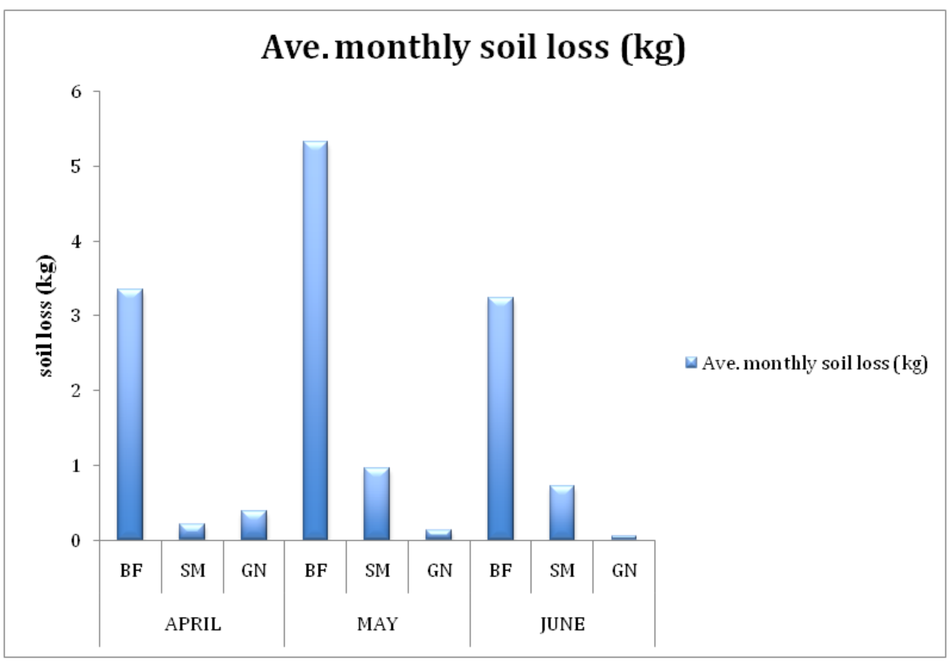
measurements increased by more than 40 % as we move from monthly to daily evaluation. The trend of the three-month measured runoff and soil loss respectively under the different soil and crop management practices are shown in Figure 3 and Figure 4 respectively. It was obvious that 127.25 mm/m^2 of rainfall in June produced the highest runoff under the BF plot compared to 140 mm recorded in the previous month (see appendix 1). However, the amount of soil loss obtained in May was higher than that obtained in June for both BF and SM even but not so for GN. The implication is that rainfall of high intensity i.e. more erosive power fell in May than in June. This is true as reported in SWCS (2003) that the amount and intensity of precipitation affect the amount of soil that can be eroded and the volume and flow rate of surface runoff. However, despite the erosive power of the rain and or its intensity, amount and distribution, runoff and soil loss were reduce to minimum under GN cover management (Fig 3 and 4) which is not significantly ($p<0.05$) different from SM cover management (Table 2). This indicates that runoff and soil loss can be reduced on the studied agricultural land if adequate and/or better crop and soil management practices that provide good covering for fragile soils are adopted.

CONCLUSION

The study has revealed that soil loss, soil erosion and/or runoff occur under different soil and crop management



BF= bare fallow, GN= groundnut, SM= sorghum
Figure. 3. Average monthly runoff under different soil and crop management system.



BF= bare fallow, GN= groundnut, SM= sorghum,
Fig 4: Average monthly soil loss under different soil and crop management systems

practices resulting in the loss of nutrient-rich topsoil. However, the degree of occurrence differed for the different soil and crop/cover management practices examined. Runoff and soil loss were significantly reduced under the groundnut and sorghum plot compared to the bare fallow plot. The significant reduction in soil loss and higher final or steady state infiltration rate under the groundnut and sorghum cover plots compared to the bare fallow plot was an indication that they provided more protective covering for the soil against the raindrop impact, slowed down soil detachment and runoff movement, and improved root activity which promoted better hydrological functioning in the environment. The significant effect of soil and cover management practices on some soil properties studied such as bulk density, porosity e.t.c which influences runoff and infiltration processes further laid credence to the result. Incessant loss of nutrient rich topsoil must be checked to prevent further degradation of the fragile soil resources for subsequent agricultural activities. To reduce the rates of runoff and soil loss, and enhance the hydrological properties and functions of this soil, ecologically sound sustainable management practices for improved agricultural production must be adopted. Clean clearing, bush burning and the practice of sole cropping should be avoided, while the use of organic manure, legumes and cover crops that provides all year round protection for soils and guarantee regular additions of organic materials should be encouraged. Mulching is also advocated at the early stage of the crop growth to enhance soil protection until the crops establish well.

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