Runoff and Soil Loss of Vegetative Fallow and Farmland of South-Eastern Nigeria

Iwara, A.I.

ABSTRACT

The effects of two different land uses-namely, 10 year-old vegetation fallow land and farmland—on soil erosion and soil loss were investigated in a part of the rainforest zone of Nigeria. Measurements of 61 sites where rainfall had produced runoff and 54 sites where rainfall had generated soil erosion were carried out from March to November in the 2012 rainy season. The average runoff amounts for the 10 yr-old and farmland plots were 0.11 mm and 0.41 mm, respectively. The average soil loss for the 10 yr-old vegetation fallow land and farmland plots was 12.43 kg.ha⁻¹ and 127.68 kg.ha⁻¹, respectively. The differences in runoff and soil loss between the treatments were highly significant (P < 0.001). The study showed that soil erosion had occurred on the 10 yr-old vegetation fallow plot even with greater aerial coverage conditions resulting in the loss of nutrient-rich topsoil, though the plot had significantly reduced runoff and soil loss compared with the farmland plot. The significant reduction in soil loss with increasing rainfall events on the 10 yr-old plot was indicative of the importance of vegetation in promoting good hydrological functioning in the area. The finding from the statistical analyses identified rainfall as the principal cause of losses on the 10 yr-old fallow plot, while on the farmland, rainfall and tree girth were the main causes of soil erosion. The continuous loss of nutrient-rich topsoil, if not checked, may affect the ability of the degraded soil to replenish lost nutrient for subsequent farming. However, to reduce the rate of losses of both runoff and soil on cultivated farmlands, all trees should not be cut down during farming operations as is practiced in this part of the world. Keywords: soil erosion, soil loss, rainfall, vegetation fallows, farmland

INTRODUCTION

The dynamics of runoff and soil loss during fallow periods in cropping are not well documented in the literature of forest ecology. Soil erosion studies in fallow vegetation of different ages provide an understanding on how nutrient is depleted in the soil during the process of nutrient restoration. This process enables sustainable land management practices to be put in place during natural nutrient restoration in order to improve the soil capability for improved agricultural production (Pimentel, 2006). Soil erosion is a global problem with a far reaching effect on the land as a viable resource for food production. Soil erosion depletes the soil of essential nutrients making it unsuitable for agricultural production. Agricultural activities in the tropics are characterized by the complete clearing and burning of forest, thereby making the soil susceptible to soil erosion (Avwunudiogba, 2000). The loss in vegetative cover results in runoff, sediment and nutrient loss (mostly with the heavy

Department of Geography, University of Ibadan, Ibadan, Nigeria. E-mail: iwaradream2010@yahoo.com

rainstorms that follow land clearing) which could result in the soil losing its potential (Lal, 1989). Vegetation characteristics in different successional fallow stages play vital roles in protecting the soil from the direct impact of raindrops, regulate soil erosion processes, suppress the movement of surface runoff and allow rainwater to infiltrate the soil. Soil erosion is a global problem and in tropical Africa it represents a serious problem (Lal, 1989) resulting in diminishing soil fertility.

Soil erosion could cause land to become infertile and unproductive for farming when the topsoil which constitutes the fertile layer of the soil is washed away (Avwunudiogba, 2000). Such land may then not have the productive capacity to support efficient food crop production. The rainfall energy that generates runoff resulting in sediment loss may be minimized with the existence of dense vegetation, as the vegetation provides protective cover for the soil, thereby reducing the rate of nutrient loss during periods of nutrient restoration (Wijitkosum, 2012). However, in areas where vegetation is sparse, the rate of soil and nutrient loss may be enormous, thereby delaying the time of optimum nutrient accretion in the soil. The erosion-suppressing effectiveness of vegetation parameters depends largely on the age of site abandonment and the type of vegetation. High plant density and the development of dense canopy cover during ecological succession help in increasing the hydroscopic level of water in the soil, improve the canopy hydrological effects of plant communities and suppress the runoff velocity and peak discharge (Li et al., 2004). Thus, understanding the process of soil erosion in successive fallow periods enables the rate of nutrient loss to be ascertained and measures adopted to minimize the loss during nutrient restoration (nutrient recovery).

The degrading power of soil erosion depends on many factors such as rainfall, soil type, landscape, crops, farm management and topographical characteristics (Jiao *et al.*, 2009; Ezemonye and Emeribe 2012). In the tropics, the degrading force of soil erosion is caused by rainfall; geomorphologists have used several attributes of rainfall such as rainfall intensity, drop size, duration of fall, annual total amount and frequency of fall, kinetic energy and terminal velocity among others to study soil erosion (Daura, 1995). A majority of the studies in the literature on soil erosion and soil loss were principally based on cropping system and plantations (Oyegun, 1980; Lal, 1983; Odemerho and Avwundiogba, 1993; Daura, 1995; Haridjaja, 2012); others have focused on soil erosion, soil and nutrient loss under individual tree/shrub species in vegetation patches (Zhenlong, 2004; Vásquez-Méndez et al., 2010). However, studies that attempted to understand the process of soil erosion and soil loss during the period of nutrient restoration in vegetation fallows are poorly documented in the literature. The aim of the current study was to evaluate the dynamics of soil erosion and soil loss in vegetation fallow periods in a part of the rainforest belt of south Southern Nigeria. The specific objectives were: to determine the amounts of runoff and soil loss using runoff plots on a 10 yr-old vegetation fallow plot and on farmland; to measure the differences in vegetation characteristics (vegetation cover, ground cover, basal cover, tree size, litter depth and tree/shrub species composition) between the fallow periods; and to build predictive models for evaluating runoff and soil losses using vegetation characteristics.

MATERIAL AND METHODS

Study area

The study was carried out in Agoi-Ekpo (5°50'0" N and 8°16'0"E; Maplandia.com, 2005), one of the villages in the Yakurr Local Government Area of Cross River State (Figure 1). The relief of the area is gentle except in places where granite rises above the general level of the surface. Agoi-Ekpo lies within the hot-wet equatorial belt of the tropics. It exhibits the characteristics of the humid tropics which are high temperature, heavy

rainfall and high relative humidity; annual rainfall in the area ranges from about 1524 to 2699 mm; the mean annual temperature is high (about 27 °C with little variation); the relative humidity is relatively high (over 80%) with high seasonal and daily variations of about 55% (Iloeje, 2009). Vertisols are the main soil type found in the area and the geology/parent material is of cretaceous sediments (Oden et al., 2012) while the topography of the study sites is near level (3 degrees). The area has luxuriant forest vegetation, and about 70% of the vegetation is still thick. As a result of the luxuriant vegetation characteristics, wild birds, animals, insects and butterflies among others abound in the area. Numerous non-timber forest products such as fruits and herbs among others are also abundant in the area. The major socio-economic activities of people in the area are farming, hunting and logging. Other activities in the area include gathering of non-forest timber products, fishing, wine tapping and trading; the paramount white collar jobs include teaching and civil service. Agriculture and residential housing are the common land use types.

Site sampling

Vegetation fallow areas (10 yr-old vegetation fallow land and newly harvested farmland) were identified and sampled using information on land use history (fallow ages) provided by the local farmers. On each identified fallow community, 10 plots of 20×20 m were randomly established (Figure 1). The established plots were used to obtain vegetation data consisting of: vegetation cover, basal cover, girth, tree/shrub species composition, ground cover and litter depth. In the same way, a plot for vegetation sampling for each fallow community was randomly selected from which the runoff plot was constructed. Thus, for each type of land use, one runoff plot of 10×4 m was constructed; from this runoff plot, surface runoff and soil loss were obtained. Vegetation on the 10 yr-old fallow plot was basically trees with a few stands of shrubs, while vegetation on the newly harvested farmland was basically made up of cassava and a few shrubs and tree species. The vegetation canopy structure was not dense.



Figure 1 Agoi-Ekpo showing location of runoff plots.

Design and installation of runoff plots

Only sites with uniform soil and topographical characteristics were sampled with the aid of soil and topographic maps of the area as well as a global positioning system device (GPS). For each selected site, the runoff plot was constructed on an area where the slope did not exceed 3⁰. Two runoff plots (one on the 10 yr-old vegetation fallow and another on the farmland) were constructed bounded by a wooden plank extending 10 cm below and protruding 15 cm above the ground. All plots were 10m long and 4m wide giving a total area of 0.004 ha. At the lower end of each plot, a gutter for runoff collection was constructed and a 250 L container drum was installed to collect the runoff after each rainstorm. A plastic PVC pipe performed the function of conveying the runoff and sediment into the collection container.

Rainfall, runoff and soil loss estimation

Rainfall was measured with a simple rainfall gauge and the amount was measured every morning at 0900 hours using a measuring cylinder. The rain gauge was located 40 m from the runoff plots. Rainfall data were collected in the rainy season period of March to November 2012 covering a total of 77 rainfall events. In this study, analysis was carried out for 61 rainstorms that generated runoff as well as for 54 rainstorms that eroded sediment. Runoff and sediment loss data for the two treatments were obtained after every rainstorm. The runoff amount was measured following procedures described by Zheng (2005) and Adediji (2006). After the runoff had been collected in the storage container, the volume in the container was then measured using a 15 L plastic bucket. The soil that had settled at the bottom of the collection container was then obtained by adding some amount of the runoff water, vigorously stirring and collecting it in the plastic bucket, after which, the soil was emptied into polythene bags with labels. The runoff and soil collection

containers were cleansed after every runoff and soil measurement operation. The soil was air dried and weighed in grams using an electronic balance (Serial No: 7129350674; OHAUS Corporation; New York, NY, USA). The units of runoff were converted from liters to millimeters using the equation given by Vadas *et al.* (2002). In addition, soil loss measured in grams was converted to kilograms per hectare using the equation given by Vadas *et al.* (2002). Furthermore, for each rainstorm, the amount of runoff was divided by the rainfall amount and then multiplied by 100 to produce the runoff coefficient (as a percentage) which provided the ratio of runoff per millimeter of rainfall (Siriri *et al.*, 2006).

Estimation of vegetation attributes

Crown cover is that portion of the ground that is shielded by the vertical projection of tree crowns (Jennings et al., 1999), while the basal cover is the portion of the plant stem that extends into the soil (Korhonen et al., 2006). Data on crown and basal cover were measured in percentages using the line intercept method (Cook and Stubbendieck, 1986; Coulloudon et al., 1999). Tree girth (tree size) was determined using the diameter at breast height (1.3 m from the ground) according to Hall and Okali (1979), Girth/tree size at breast height was measured for plants regardless of whether they were a tree or a shrub species providing the diameter at breast height was greater than 0.04m. On farmland, the girth was measured for trees, shrubs and cassava stems. The girth of the cassava stems ranged from 0.04 - 0.09 m. The litter depth in each plot was determined by measuring the amount of accumulated litter in centimeters using a ruler. The procedure involved pushing a 30 cm ruler into the ground until a firm surface was reached (Tievsky, 2005). Tree/shrub species composition including cassava composition was obtained by counting the number of stems of individual species in each plot.

Data analysis

Data obtained were analyzed using tables, averages, simple percentages, independent samples test, Pearson's correlation and stepwise multiple regression analysis. Statistical analysis was carried out using the SPSS software package for Windows (Version 20; SPSS; Chicago, IL, USA).

RESULTS AND DISCUSSION

Vegetation characteristics in the fallow plots

The vegetation characteristics of the studied fallow vegetation are shown in Table 1. A total of 1,681 tree/shrub species with a mean value of 168 stems per plot was recorded across the 10 yr-old vegetation fallow, while on the farmland plot, 282 cassava stems/shrub/tree species with a mean value of 28 stems per plot were counted. This implied that the 10 yr-old fallow plot was denser and more diverse than the farmland. The low number of tree/shrub species encountered on the farmland may be blamed on the system of land preparation in the area which is characterized by the cutting and burning of trees. This affects the regenerative capacity of trees on the farmland plot. Crown and ground cover percentage values for the plots were 91.1 and 29.64% for the 10 yr-old fallow plot and 53.45 and 42.15% for the farmland plot, respectively. These cover percentages show the degree of protection against soil erosion and the generation of runoff on the studied fallow vegetation. The crown and ground cover percentages differed significantly between the fallow plots. In addition, tree girth differed significantly between the fallow plots with mean values of 0.29 and 0.08 m for the 10 yr-old and farmland plots, respectively. Litter depth was considerably higher on the 10 yr-old fallow plot than on the farmland plot with mean values of 5.1 and 1.4 cm, respectively. Litter depth helps in suppressing the erosion effectiveness of rainstorm by forming a matted surface thereby limiting runoff velocity (Choi et al., 2007). The low litter depth recorded on the farmland may be attributed to the practice of clear weeding which strips the soil of plant residues as well as the low diversity of tree species, as it is mostly composed of cassava. Furthermore, the basal area was higher on the 10 yr-old fallow than on the farmland with mean values of 17.9 and 7.1%, respectively. This has implications on the ability of stems to absorb rainwater which is released afterward to the soil as stem flow.

The girth of trees/shrubs was higher on the 10 yr-old fallow plot than on the farmland plot (Table 1). Plants with a larger girth are able to intercept more raindrops and this thereby serves

Vegetation component	n	Min	Max	Sum	Mean	SD
Tree/shrub composition on 10 yr-old fallow	10	158	179	1681	168.1	7.1
Cassava/Tree/shrub composition on farmland	10	25	31	282	28.2	2.2
Girth (m) on 10 yr-old fallow	10	0.2	0.3	2.9	0.3	0.04
Girth (m) on farmland	10	0.05	0.11	0.8	0.1	0.02
Ground cover (%) on 10 yr-old fallow	10	27.2	32.5	296.4	29.6	1.6
Ground cover (%) on farmland	10	39.7	43.9	421.5	42.1	1.4
Crown cover (%) on 10 yr-old fallow	10	88.9	93.3	911.1	91.1	1.7
Crown cover (%) on farmland	10	50	61	535	53.5	3.7
Litter depth (cm) on 10 yr-old fallow	10	4	6	51	5.10	0.7
Litter depth (cm) on farmland	10	1	2	14	1.40	0.5
Basal cover (%) on 10 yr-old fallow	10	15.8	19.4	179.0	17.9	1.0
Basal cover (%) on farmland	10	7	8	71	7.1	0.4

Table 1Vegetation characteristics in fallow plots.

n = Number of sample plots, Min = Minimum, Max = Maximum.

as a physical barrier to water movement and raindrops (Zhang *et al.*, 2010). Interception by plant stems and flow down the stem diminishes the rainfall energy resulting in concentration of water at the base of stems (De Ploey, 1984; Martinez-Meza and Whitford, 1996). This process facilitates deeper infiltration; hence, the tree girth may act as a barrier to the erosive force of rainfall. Previous results showed that there is a significant difference in soil erosion and runoff among different types of vegetation (Zhenhong, 2004; Li *et al.*, 2006). The association between crown cover, ground cover and runoff on the 10 yr-old fallow is shown in Figures 2a and 2b.

There was an inverse relationship between the crown cover and runoff on the 10 yr-old fallow plot, indicating a decrease in runoff with an increase in vegetation cover. This result is indicative of the importance of vegetation cover in regulating runoff processes. The direct relationship experienced for ground cover is expected considering its scant density on the fallow plot. This was consistent with earlier and related studies (Daura, 1995; Bautista *et*



Figure 2 Fallow plot: (a) Crown cover-runoff relationship and (b) Ground cover-runoff relationship. $(R^2 = \text{correlation coefficient, ns} = \text{not significant at 0.01 alpha level.})$

al., 2007). Nevertheless, the results showed that 16.4 and 4.3% (Figures 2a and 2b) of the runoff experienced on the 10 yr-old fallow was caused by the vegetation components of crown and ground cover, respectively. This means that an increase in the vegetation component may not completely stop runoff as noticed on the 10 yr-old plot. Eze (1996) noted that vegetation in the humid tropics does not completely shield the ground surface from erosion, as soil erosion still occurs due to the high intensity and energy load of the rainfall even when canopy coverage approaches 100%. Similarly, Ries and Langer (2001) observed that material delivery (sediment yield caused by erosion) did not significantly decrease with increasing vegetation

cover. The association between canopy cover, ground cover and runoff on the farmland plot is shown in Figures 3a and 3b. There was an inverse relationship between ground cover and runoff, while crown cover showed a direct relationship, indicating an increase in runoff with an increase in vegetation cover. This indicates that on the farmland plot, vegetation cover is less effective in the control of runoff than ground cover. An increase in ground cover (the rapid growth of herbaceous species, mostly *Chromolaena odorata*) with the rains helped to minimize runoff but an increase in vegetation cover (even with the sprouting of cassava leaves) did not significantly reduce runoff depth.



Figure 3 Farmland plot: (a) Crown cover-runoff relationship and (b) Ground cover-runoff relationship. $(R^2 = \text{correlation coefficient}, ns = \text{not significant at 0.01 alpha level.})$

Furthermore, soil loss was lower on the 10 yr-old fallow plot with greater canopy and ground cover conditions, as observed in Figures 4a and 4b.

The linear relationship shows that soil loss decreased with increasing canopy cover condition. It also indicates that crown cover was more effective in suppressing soil loss on the 10 yr-old fallow plot than the ground cover condition. The results however, mean that fallow vegetation with greater aerial coverage provided better protection to the soil against the erosive forces of rainfall. Canopy cover helps in rainfall interception as well as reduce raindrop energy, while ground cover facilitates rainfall infiltration into the soil and reduces overland flow velocities and hydraulic shear stresses, thereby minimizing the soil erosion potential (Erpul et al., 2002). Nevertheless, on the farmland plot, ground cover was more effective in suppressing runoff than crown cover, as it showed an inverse relationship (Figure 5b). Crown cover condition showed a positive association with soil loss (Figure 5a). This implies that the aerial coverage conditions in the farmland plot did not reduce the rate of soil loss. Crown cover is identified as the principal aerial structure that caused 5% of the loss in farmland topsoil (Figure 5a). This further means that the aerial coverage conditions in the farmland plots had not properly matured and become established to decrease topsoil loss. Hence, the significant reduction in soil loss with increasing rainfall events on the 10 yr-old plot is indicative of the importance of vegetation in promoting hydrological functioning in the



Figure 4 Fallow plot: (a) Crown cover-soil loss relationship and (b) Ground cover-soil loss relationship. $(R^2 = \text{correlation coefficient, ns} = \text{not significant at 0.01 alpha level.})$

environment (Vásquez-Méndez et al., 2010).

Generally, fallow areas with greater canopy and ground conditions (mostly during the process of nutrient restoration) experience a reduction in runoff and soil loss. Furthermore, improvement in the soil surface conditions that helps to facilitate rainfall infiltration on the 10 yrold fallow plot is to a greater extend influenced by the roots of trees and high organic matter content. Similarly, Neary *et al.* (2009) in their study observed that in vegetation patches, the changes in soil surface conditions occur as a result of the contribution of organic matter by the litter and the development of roots by both annual and perennial species.

Rainfall

Sixty-one significant rainstorm events were registered during the cropping and rainy season of 2012, accounting for a total rainfall amount of 13,590 mm (Table 2).

As noted above, 77 rainfall events were recorded, but only 61 of the rainstorms generated runoff. The runoff recording period started in March and ended in November 2012 (Figure 6a).

Sixty-one runoff-producing events, accounting for approximately 95% of total rainfall, were evaluated. The smallest precipitation event producing runoff had a rainfall amount of 52 mm and only produced runoff on the farmland (0.04



Figure 5 Farmland plot: (a) Crown cover-soil loss relationship and (b) Ground cover-soil loss relationship. (R^2 = correlation coefficient, ns = not significant at 0.01 alpha level.)

SD

191.92

0.10

mm), while a rainfall amount of 57 mm caused runoff on both fallow areas. The maximum rainfall amount registered for an event causing runoff was 1,012 mm. Kizza et al. (2013) reported similar rainfall values (1,000-2,000 mm) in a rainforest zone of Uganda, while Oku et al. (2012) and Oku

Rainfall amount

10 yr-old runoff

and Armon (2006) observed that in the rainforest zone of Nigeria, annual rainfall far exceeds 3,500 mm. The high rainfall amount registered indicates a high potential to produce runoff and erosion mostly on the farmland plot with sparse vegetation.

222.79

0.11

0.41

13590

6.63

Table 2	Descriptive	statistics of rai	nfall and run	off (mm) bety	ween fallow j	plots.
Varia	able	n	Min	Max	Sum	Mean

42

0.00

Farmland runoff 61 0.02 1.33 25.30 0.36 Difference in means between the 10 yr-old runoff and Farmland runoff has t-value = 6.35; df = 120; Significant at 1% confidence level.

1012

0.49

n = Number of rainstorms that generated runoff, Min = minimum, Max = Maximum.

61

61



Figure 6 (a) Rainfall amount versus time-events and (b) Runoff volume versus time-events of the fallow and farmland plots.

Runoff and soil loss in the 10 yr-old and farmland vegetation fallows

Runoff and soil loss data from the vegetation fallow areas are presented in Tables 2 and 3. The 10 yr-old fallow plot produced considerably less runoff than the farmland plot with total runoff values of 6.63 and 25.30 mm, respectively (Table 2). The aerial structure (vegetation cover, girth) of the 10 yr-old fallow and its high litter depths may have intercepted a significant amount of rainfall, which afterward moved down to the soil, increasing infiltration and diminishing the potential for runoff and erosion (Puigdefábregas, 2005). In addition, the existence of dense tree/shrub species and the subsequent development of their root systems must have made it possible for a significant amount of the rainwater to be absorbed in the soil (Nobel, 1987), thereby reducing the amount available for runoff. This finding is consistent with those of Siriri et al. (2006) who observed that the maintenance of adequate surface cover may serve to conserve soil by reducing the runoff velocity. On the other hand, the high runoff depth recorded on the farmland plot mostly in the early stage of the experiment (March to July) may be attributed to the scant aerial structure of vegetation with canopy gaps as well as the scant undergrowth.

This scant vegetation structure may have impacted on the infiltration rate of the soil as the root system in the plot was not well developed to loosen the soil. Surface sealing in the plot was high which could also be responsible for the high runoff. Reicosky *et al.* (1996) and Ali *et al.* (2007) observed that canopy cover and the development of a root system reduce soil surface sealing by raindrop impact and thus maintains a higher infiltration rate and low runoff. However, the considerable reduction in the runoff depth on the farmland in the later period (July to November) was attributed to the sprouting of cassava leaves and herbs mostly Chromolaena odorata (Figure 6b). a similar observation was reported by Nobel (1987). Statistically, runoff depths differed highly significantly between the vegetation fallows (P < 0.001). Runoff coefficients estimated from the observed data were 11.2 and 2.8% for the farmland and 10 yr-old fallow plots, respectively. The relationship between runoff and rainfall for the fallow vegetation plots is shown in Figure 7a which clearly reveals that the rainfall amount had a direct proportional effect on the runoff in the fallow areas. It showed that on the 10 yr-old fallow plot, about 90% of the runoff depths recorded was caused by rainfall, whereas, on the farmland plot, about 69% of the runoff was accountable to rainfall. This further implied that about 10 and 31% of the unexplained amounts on the two sites, respectively, were attributed to other parameters not necessarily rainfall.

The maximum sediment loss evaluated per event showed that the farmland had a greater loss than the 10 yr-old fallow with values of 12.4 kg.ha⁻¹ and 124.7 kg.ha⁻¹, respectively (Table 3). The cumulative soil loss for farmland was 6,733 kg.ha⁻¹ and 671 kg.ha⁻¹ for the 10 yr-old plot (Figure 7b). Vegetation on the fallow plots (mostly the farmland) was observed to have a strong effect on surface runoff (Chen *et al.*, 2007; Vásquez-Méndez *et al.*, 2010).

Table 3 Descriptive Statistics of soil loss (kg.ha⁻¹) between the fallow plots.

Variable	n	Min	Max	Sum	Mean	SD
Rainfall amount	54	66	1012	13182	244.11	194.05
10 yr-old fallow soil loss	54	0	231	671	12.43	36.82
Farmland soil loss	54	0.31	1141.95	6732.68	124.68	209.38

Difference in means between the 10 yr-old runoff and Farmland runoff has t-value = 3.88; df = 106; Significant at 1% confidence level.

n = Number of rainstorms with eroded soil, Min = minimum, Max = Maximum.



Figure 7 Runoff-rainfall relationship of the fallow and farmland plots (b) Soil loss versus time-events of the fallow and farmland plots. (R² = correlation coefficient, ** = significant at 0.01 alpha level.)

Statistically, the amount of soil loss differed highly significantly between the vegetation fallow areas (P < 0.001). The relationship between soil loss and rainfall for the fallow vegetation plots is shown in Figure 8 where it can be clearly observed that the rainfall amount had a direct relative effect on the soil loss occurring on the vegetation fallow areas, as on the 10 yr-old fallow plot, about 75% of the eroded soil was caused by rainfall, whereas, on the farmland plot about 84% of the eroded soil was accountable to rainfall. The unexplained amounts (25 and 16%) were attributed to other parameters not necessarily rainfall. The results indicate that a fallow plot with dense and appreciable vegetation structure and surface cover

(in terms of ground cover and litter depth), as occurred on the 10 yr-old fallow plot, is especially effective in diminishing the erosive forces of rainwater and runoff.

Prediction of runoff and soil loss in vegetation fallow

Vegetation characteristics (crown cover, ground cover, basal cover, girth, and litter depth and tree/shrub species composition, respectively) were employed to build predictive models to evaluate the runoff and soil loss in fallow vegetation. Previous studies used rainfall attributes such as rainfall intensity, drop size, duration of fall, annual total amount and frequency



Figure 8 Soil loss-rainfall relationship of the fallow and farmland plots. (R^2 = correlation coefficient, ** = significant at 0.01 alpha level.)

of fall, kinetic energy and terminal velocity among others to understand soil erosion on different land uses mostly cropping systems (Daura, 1995). Stepwise multiple regression analysis was used to understand the influence of the rainfall and vegetation components on the runoff depth and sediment loss. This approach was successful in producing an equation with a small number of predictor variables, but with a high multiple R². It is also suitable for explanatory and predictive purposes. However, out of the seven predictor variables (rainfall, crown cover, ground cover, basal cover, girth, litter depth and tree/shrub species composition) entered into the model to ascertain significant factors that influence runoff on the 10 yr-old plot, rainfall was the only retained and significant explanatory variable (P < 0.01) that explained 78% of the observed variation in runoff depths on the 10 yr-old plot. This shows that runoff depths on the 10 yr-old fallow were positively related to rainfall, as rainfall is the main cause of soil erosion. The regression coefficient was statistically significant at the P <0.01 confidence level and, therefore, remains as part of the mathematical model. The standardized regression coefficient showed that an increase in rainfall would result in 89% of the runoff on the 10 yr-old fallow as shown in Equation 1:

$$Y = 0.006 + 0.89 \times Rf$$
 (1)

where Y is the predicted runoff depth (millimeters) on the 10 yr-old fallow and Rf is the rainfall amount (millimeters). On the other hand, in the farmland plot, out of the seven explanatory variables simultaneously entered into the model, rainfall and girth were retained and significantly (P < 0.01) explained 87% of the observed variation in runoff depths on the farmland. This indicated that runoff depths on the farmland were positively correlated to rainfall and girth, as rainfall and girth are the main causes of soil erosion. Girth as noted above depending on the plant size helps to intercept raindrops thereby serving as a physical barrier to water movement (Zhang et al., 2010). The regression coefficient was statistically significant at the P < 0.01 confidence level and, therefore, remains as part of the mathematical model. The standardized regression coefficient showed that an increase in rainfall would result in 95% cent of the runoff, while an increase in tree girth would cause about a 38% decrease in runoff depths on the farmland as shown by Equation 2:

 $Y = 0.44 + 0.95 \times Rf - 0.38 \times G$ (2) where Y is for the predicted runoff depth (millimeters) on the farmland, Rf is the rainfall amount (millimeters) and G is the girth (meters). Furthermore, to build predictive models for soil loss in the studied fallow plots, rainfall and runoff depths were added to the vegetation variables. For the 10 yr-old fallow plot, out of the eight explanatory variables entered, only rainfall was retained and significantly (P < 0.01) explained 94% of the observed variation in soil loss. As before, this implies that the loss in eroded soil is principally rainfall dependent. The regression coefficient was statistically significant at the P < 0.01 confidence level and, therefore, remains as part of the mathematical model. The standardized regression coefficient showed that a unit increase in rainfall would bring about 97% cent of the soil loss on the 10 yr-old fallow as shown by Equation 3:

$$Y = -4.58 + 0.97 \times Rf$$
(3)

where Y is the predicted soil loss (kilograms per hectare) on the 10 yr-old fallow and Rf is the rainfall amount (millimeters). In a similar manner, out of the eight explanatory variables entered in the farmland, again rainfall was retained and significantly (P < 0.01) explained 86% of the observed variation in soil loss. The regression coefficient was statistically significant at the P< 0.01 confidence level and the standardized regression coefficient showed that an increase in rainfall would result in 93% of the soil loss on the farmland plot as shown by Equation 4:

$$= -55.52 + 0.93 \times \text{Rf}$$

(4)

Y

where Y is for the predicted soil loss ((kilograms per hectare) on the farmland and is the rainfall amount (millimeters). The model generated above therefore identifies rainfall as the primary cause of losses both in runoff and soil in the fallow vegetation. In the tropics, rainfall has been acknowledged as the principal determinant of soil erosion. According to Lal (1989), it is a global problem, but in tropical Africa, it represents a serious problem resulting in the diminishing of soil fertility. Soil erosion makes the soil unsuitable for agricultural production by eroding essential nutrients. Thus, the amount, frequency and intensity of rains have profound effects on the volume of surface runoff, soil and nutrient losses. This degrades the soil thereby making it unproductive for food crop cultivation.

CONCLUSION

The study revealed that soil erosion occurs in vegetation fallow areas even under substantial aerial coverage conditions resulting in the loss of nutrient-rich topsoil. However, the fallow area with greater canopy and ground cover conditions had significantly reduced runoff and soil loss compared to the fallow area with sparse vegetation attributes. The runoff depth decreased on the 10 yr-old fallow plot resulting also in low soil loss. The significant reduction in soil loss with increasing rainfall events on the 10 yr-old vegetation plot was indicative of the importance of vegetation in promoting hydrological functioning in the environment. The continuous loss in nutrient rich topsoil if not checked may affect the ability of the degraded soil to replenish lost nutrients for subsequent farming. However, to reduce the rate of losses on farmlands, all trees should not be cut down during the farming operation as is practiced in this part of the world. On the other hand, vegetation fallow areas with sparse aerial coverage (mostly crown and ground cover) should be mulched to help protect the soil.

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