# Evaluation of the Variability in Runoff and Sediment Loss in Successional Fallow Vegetation of Southern Nigeria

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**Abstract**

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The effects of three different ages of natural fallow vegetation on runoff and sediment loss were investigated in a part of the rainforest zone of Nigeria. Measurements of runoff amount and sediment loss were made for the months of March to November in 2012 rainy season using runoff plots of 40 m$^2$. The average runoff amount for the 5-year-old, 3-year-old, and farmland plots were 0.47, 0.26, and 0.41 mm respectively. The average sediment loss on the 5-year-old, 3-year-old, and farmland plots were 209.24, 50.54, and 124.68 kg/ha, respectively. The lowest losses for both runoff and sediment were recorded on the 3-year-old plot, while the 5-year-old plot experienced the highest losses. The variations in runoff and sediment loss among the treatments were significant at $P < 0.001$. The results evidently showed that rainfall was principally responsible for the erosional losses on all the fallow treatments, and that ground cover (density of herbs) and girth helped to reduce sediment loss on the 3-year-old and farmland surfaces, respectively. The high amount of erosional losses experienced on the 5-year-old fallow than on the 3-year-old fallow and farmland plots imply that fallow that is not adequately protected by ground cover experiences accelerated soil erosion. The continuous loss in topsoil rich in plant nutrients may prolong the optimal capacity of the soil to regain its loss nutrient for subsequent food crop cultivation.

**Keywords**: erosional losses; soil erosion; rainfall; vegetation components; vegetation fallows

In Nigeria and other parts of Africa, agriculture – basically food crop cultivation – constitutes the stronghold of the economy. Large expanse of forest is usually cleared to make way for food crop cultivation, and after harvest, the piece of land is deliberately allowed to fallow in order to replenish its loss nutrient through the natural process of nutrient cycling. This process results in bush fallowing of different ages (Binelli *et al.* 2012). However, before the abandoned piece of land becomes matured for subsequent farming, it undergoes several stages of vegetation change (Haripal & Sahoo 2011). The newly abandoned farmland having lost its vegetation to farming activities becomes highly susceptible to accelerated water erosion resulting in sediment and nutrient loss (Pimentel 2006). The continuous loss in topsoil, which is rich in organic matter and nutrient, may affect the natural process of the soil to recover to its optimal capacity that is suitable for agricultural production (Iwara 2011). Soil erosion

is a global problem with a far reaching effect mostly on land as a viable resource for food production. In tropical Africa, it constitutes a serious problem (Lal 1989) because it depletes the soil of essential nutrients making it unsuitable for agricultural production. Capital Regional District (2012) noted that it takes over hundreds to thousands of years for topsoil to be formed through complex interactions among the bacteria, fungi, worms, and insects that live among the roots of plants which help to break down organic matter. But, when the topsoil, which constitutes the fertile layer of the soil, is washed away by water erosion, the land becomes infertile and unproductive for farming. Such a land may not have the productive capacity to support efficient food crop production as a result of the loss in topsoil nutrient.

The potential for soil erosion depends on many factors. Lu *et al.* (2007), Jiao *et al.* (2009), and Ezemonye and Emeribe (2012) opined that rainfall, soil type, landscape, crops, farm management, and

topographic characteristics determine runoff and erosion potential from agricultural lands or forest regrowth. In the tropics, rainfall is the principal determinant of soil erosion. 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 understand the incidence of erosion (Oyegun 1980; Daura 1995). These rainfall components have the ability to remove earth materials from different surfaces by loosening the soil structure. In addition, studies on soil erosion consider mainly vegetation cover as a factor that influences the volume of runoff and sediment vis-à-vis nutrient loss; these studies neglect other vegetation characteristics such as crown cover, basal cover, tree diameter or girth, litter depth, root mass, and root system as well as species composition that could have some influence on soil erosion processes (Chirino *et al.* 2006; Wijitkosum 2012). The identification of vegetation characteristics for soil erosion modelling is important for understanding rainfall and its potential impact on local agricultural and soil fertility.

Studies on the variability and trend in soil erosion and sediment loss in successional fallow vegetation are not well documented in the literature, suggesting that not much research has been done. Majority of the studies on ecological succession focused mainly on nutrient accretion and changes in vegetation characteristics in relation to succession time (Aweto 1981; Sarmiento *et al.* 2003; Addo-Fordjour *et al.* 2009). However, studies that attempt to understand the process of nutrient depletion during the period of nutrient restoration in fallows of varying ages are not readily available in the literature. The bulk of available studies on soil erosion and sediment loss examined the changes in cropping system and plantations (Lal 1983; Daura 1995; Makanjuola *et al.* 2011; Haridjaja 2012); as well as on individual tree/shrub species in vegetation patches (Zhenlong 2004; Vásquez-Méndez *et al.* 2010). Soil erosion studies in fallow vegetation of different ages provide an understanding on how erosion occurs resulting in topsoil nutrient loss, thereby depriving the soil of essential nutrients during the process of natural nutrient restoration. Such study enables sustainable land management practices to be put in place during the process of natural nutrient restoration, in order to improve the soil potential for agricultural production. The aim of this study was to understand the dynamics of soil erosion and sediment loss in different successional fallow communities in a part of the rainforest belt of southern Nigeria.

## MATERIAL AND METHODS

**Study area**. The study was carried out in Agoi-Ekpo, one of the villages in Yakurr Local Government Area of the Cross River State (Figure 1). Its geographical coordinates are 5°50'0''N and 8°16'0''E (Maplandia. com 2005). It is a typical nucleated rural settlement with a population of about 11 406 (Projected Population Figure) inhabitants. The area falls within the lowland of south-eastern Nigeria called the Cross River plain. The relief is gentle except in places where granite rises above the general level of the surface. Agoi-Ekpo lies within the hot-wet equatorial climate of the tropics. It exhibits the characteristics of the humid tropics which are high temperature, heavy rainfall, and high relative humidity. Rainfall amount in the area ranges about 1524–2699 mm annually. The mean annual temperature is high, being about 27°C with little variations. 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 (Cross River State Ministry of Agriculture 2012). The geology/parent material is of Cretaceous sediments (Oden *et al.* 2012) while the topography of the study sites is within 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, several wild birds and animals, insects, butterflies, etc. 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 socioeconomic activities in the area include gathering of non-forest timber products (NTFP'S), fishing, palm wine tapping, and trading; the paramount white collar jobs include teaching and civil service. Agriculture and residential land uses are the common land use types.

**Site sampling**. The procedure for data collection involved a reconnaissance survey during which fallow communities of different ages ranging from (a) farmland, (b) 3-year-old fallow, and (c) 5-year-old fallow were identified and sampled using information on land use history (fallow ages) provided by the local farmers. The farmland had cassava allowed to mature after yam had been harvested; and throughout the duration of the experiment, it was not weeded. In each identified fallow community, 10 plots of 20 × 20 m in size were randomly established. The established plots were used to obtain vegetation data such as crown cover, basal cover, girth, density of trees/
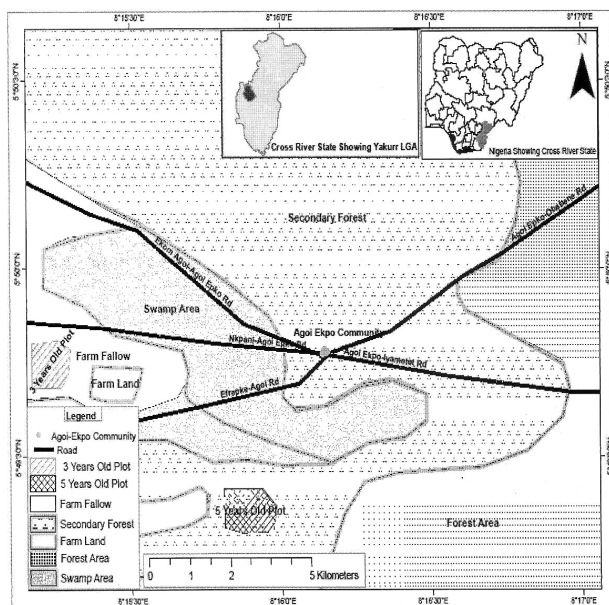
Figure 1. Map showing Agoi-Ekpo and sampling locations

shrubs, herbaceous/ground cover, density of herbs, and and litter depth. In the same way, a plot for each fallow community was randomly selected from which runoff plot of 10 × 4 m was constructed; from this runoff plot, surface runoff and sediment loss were obtained. As much as possible, all treatment plots (vegetation and runoff plots) were in the same site. Each sampled plots were duly geo-referenced using the Global Positioning System (GPS).

**Design and installation of runoff plots**. At each selected site, runoff plots were constructed on the area of slopes not exceeding 3°. Three runoff plots were constructed on a 3 degree natural slope using a wooden plank extending 10 cm below and protruding for 15 cm above the ground. All plots were 10 m long and 4 m wide giving a total area of 40 m$^2$ (0.004 ha).

The collection container was installed in a 3.5 m deep pit sizing 5 × 5 m. The PVC pipe performed the function of conveying the runoff and sediment into the collection container.

**Rainfall, runoff, and sediment loss estimation**. Rainfall was measured with a simple rainfall gauge. 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 done for 61 rainstorms that generated runoff as well as 54 rainstorms that had eroded sediment. Runoff amount was measured following procedures described by ZHENG (2005) and ADEDEJI (2006). The sediment that settled at the bottom of the container was then obtained by adding some amount of the runoff water, rigorously stirred and collected in the plastic bucket. The sediment was air-dried and weighed in grams using an electronic balance (OHAUS Corporation, New York, USA). The units of runoff were converted from litres to millimetres, while sediment loss measured in grams was converted to kilograms per hectare (kg/ha) using the formulae given by VADAS *et al.* (2002).

## RESULTS

The mean runoff amount across the fallow plots (treatments) ranged from 0.26 to 0.47 mm (Table 1). The lowest runoff was recorded on the 3-year-old plot, while the 5-year-old plot was most effective in runoff. The variation in runoff amount among the treatments was significant at $P < 0.001$ (Table 1). The total sediment losses for the different plots (treatments) are shown in Table 2 from which it follows that the 5-year-old fallow plot experienced the highest sediment loss with mean value of 209.24 kg/ha/year, while the 3-year-old fallow experienced the lowest

Table 1. Fallow systems effects on runoff (mm) pattern during 2012 rainy season

| Fallow plots | Total runoff | Average runoff | Min | Max | SD |
|---|---|---|---|---|---|
| 5-year-old fallow | 28.84 | 0.47 | 0.05 | 1.82 | 0.44 |
| 3-year-old fallow | 15.83 | 0.26 | 0.01 | 0.97 | 0.26 |
| Farmland | 25.30 | 0.41 | 0.02 | 1.33 | 0.36 |

*F*-ratio = 16.089; degrees of freedom = 3/240; significance = 0.000; SD – standard deviation

Table 2. Fallow systems effects on sediment loss (kg/ha) during 2012 rainy season

| Plot treatment | N | Minimum | Maximum | Sum | Mean | SD |
|---|---|---|---|---|---|---|
| 5-year-old sediment | 54 | 0.28 | 2 309.11 | 11 299.05 | 209.2417 | 446.69289 |
| 3-year-old sediment | 54 | 0.00 | 592 | 2 729 | 50.54 | 109.328 |
| Farmland sediment | 54 | 0.31 | 1 141.95 | 6 732.68 | 124.6793 | 209.38022 |

*F*-ratio = 6.355; degrees of freedom = 3/212; significance = 0.000; SD – standard deviation

Table 3. Stepwise multiple regression result of significant predictor variables (runoff and sediment loss)

| Fallow plots | Retained variable (s) | $R^2$ | *F*-values* | Regression equations |
|---|---|---|---|---|
| **Runoff** | | | | |
| 5-year-old | *Rf* | 0.75 | 23.525 | $y = 0.008 + 0.86Rf$ |
| 3-year-old | *Rf* and *CC* | 0.83 | 29.970 | $y = -0.665 + 0.81Rf + 0.39CC$ |
| Farmland | *Rf* and girth *G* | 0.87 | 23.860 | $y = 0.437 + 0.95Rf - 0.38G$ |
| **Sediment loss** | | | | |
| 5-year-old | *Rf* | 0.86 | 48.321 | $y = -22.525 + 0.926Rf$ |
| 3-year-old | *Rf, RUF,* and *BC* | 0.78 | 133.89 | $y = -29.764 + 0.420Rf + 0.549RUF + 0.172BC$ |
| Farmland | *Rf* | 0.86 | 47.25 | $y = -58.519 + 0.926Rf$ |

*significant at 1% confidence level; *Rf* – rainfall amount (mm); *G* – girth (m); *CC* – crown cover (%); *RUF* – runoff volume (mm); *BC* – basal cover (%)

amount of eroded soil with mean sediment value of 50.54 kg/ha/year followed by the farmland with mean value of 124.68 kg/ha/year. The differences in sediment loss among the plots were attributed to the variation in the crown cover, and ground cover (density of herbs). The low sediment loss recorded on the 3-year-old fallow plot may be a result of the reduction in run-off and enhancement of rainfall infiltration; while the very high sediment losses on the 5-year-old and farmland plots may be blamed on the existence of canopy gaps with low ground cover percentage. The amounts of sediment loss observed across the fallow treatments are above the values reported by Daura (1995), in the Guinea Savannah Zone of Nigeria. The differences in rainfall amounts and treatments used may be responsible for the variation. In this study, 54 rainstorms that generated measurable sediment were evaluated, while the study by Daura recorded 43 rainfall events that generated sediment.

Stepwise multiple regression results revealed that on the 5-year-old plot, rainfall was the only predictor variable responsible for the runoff volume. On the 3-year-old plot, rainfall and crown cover were primarily responsible for of the observed variation in runoff depth. Likewise, on the farmland, rainfall and girth were noteworthy in explaining runoff depth. Hence, across the fallow plots, rainfall exerted the most influence in explaining runoff volume. For sediment loss, rainfall was identified as the only factor responsible in explaining sediment loss on the 5-year-old fallow and farmland respectively, whereas rainfall, basal cover, and runoff volume were potent factors on the 3-year-old plot (Table 3). Rainfall, basal cover and runoff volume were actively responsible for the amount of sediment loss recorded on the 3-year-old fallow. Among these three variables, runoff volume was the principal determinant of sediment loss, followed closely by rainfall amount.

The least but significant predictor variable facilitating sediment loss on the 3-year-old fallow was the basal cover. The positive sign observed between sediment loss and basal cover on the 3-yearr-old fallow is expected because the 3-year-old fallow plot was principally dominated by herbs with few stands of shrub species. This has implication on the structure of the basal cover, and its inability of the root system to loosen the soil layer to enhance infiltration.

**DISCUSSION**

The study revealed that greater proportion of the annual rainfall was absorbed by soils on the 3-year-old fallow plot due to its dense ground cover percentage (characterized by high density of herbs). The 5-year-old plot yielded the highest losses of both runoff and sediment, while the 3-year-old plot had the lowest. The observed differences in both runoff and sediment loss on all the plots were statistically significant. The farmland and 5-year-old fallow plots displayed similar trend in erosional losses (runoff and sediment loss) which may be attributed to the sparse vegetation cover characterized by canopy gaps, and scanty ground cover. The drastic reduction in erosional losses on the 3-year-old plot was attributed to the rainfall energy interception by the dense ground cover (high density of herbs), thus increasing water infiltration and storage. This implies that increase in ground cover effectively minimizes erosional losses on fallow soils (Ali *et al.* 2007). Similar finding was reported by Almas and Jamal (1999) and Ali *et al.* (2007) when they observed that dense ground cover cover helps to reduce soil surface sealing by raindrop impact and thus maintains higher infiltration rate and low runoff.

The stepwise regression result further showed that on the 5-year-old fallow, only rainfall was significant in

explaining runoff depth, while on the 3-year-old plot, rainfall and crown cover were significant in explaining runoff depth. Crown cover reduces raindrop effect on the soil by intercepting raindrops and absorbing much of the energy (Li *et al.* 2004). On the farmland, rainfall and girth were significant in explaining runoff depth. The inverse relationship between girth (tree size) and runoff on the farmland is apparent as cassava stems and those of trees/shrubs help to intercept rainwater as well increase infiltration by loosening the soil layer. The density of cassava with few shrubs and trees constituted a physical barrier to the erosive forces of raindrops. The study revealed that sediment loss on the 5-year-old fallow and farmland was influenced by rainfall amount. The study observed rainfall to be chiefly responsible for the erosional losses experienced on all the plots. This supports the fact that rainfall is the principal determinant of soil erosion in the tropics. This is affirmed by Daura (1995) and Lal (1989) that rainfall is generally accepted as the most important climatic parameter controlling runoff and associated losses on agricultural land. According to Lal (1989), rainfall is a global problem, but in tropical Africa, it represents a serious problem resulting in the diminishing of soil fertility.

The basal cover on the 3-year-old fallow could not minimize sediment loss because of the low density of tree/shrub caused by farming activities (slash, clear cutting and burning practice of land preparation) carried out before its abandonment. This affected the rapid establishment of shrubs/trees which would have helped to loosen the soil to enhance infiltration. In general, the change in vegetation characteristics was observed to have substantial effects on the amount of runoff and sediment loss experienced on the plots, as there was a gradual reduction in soil erosion with the growth in vegetation attributes (mostly herbaceous/ground cover) on the 3-year-old fallow and farmland plots. The rapid increase in herbaceous cover as well as the sprouting of cassava on the cultivated farmland following the full commencement of the rains helped to reduce runoff depth and sediment loss in the latter stage of the experiment. The increase in ground cover on the 5-year-old fallow plot was slow, with almost no noticeable difference between the ground cover (density of herbs) in March when the experiment commenced and in November when it ended. Also, the crown cover on the 5-year-old fallow was characterized by canopy gaps probably as a result of shrub density. Perhaps, the scanty ground cover and canopy gaps may be responsible for the high losses in both runoff and sediment experienced on the 5-year-old fallow.

## CONCLUSION

The study has shown that runoff and topsoil loss still occur in fallows with dense vegetation cover, though the losses vary significantly among the fallow ages and farmland. The 5-year-old fallow and farmland plots yielded the highest runoff with 41.2 and 36.4% of the total losses, while the 3-year-old plot had the lowest runoff of 22.4%. Also, the 5-year-old fallow and cultivated farmland plots yielded the highest sediment loss with 54.4 and 32.5% of the total losses respectively, while the 3-year-old plot had the lowest sediment loss of 13.1%. The analysis of total nutrient loss verifies the assertion in the literature that nutrient element loss from a field is dependent on the amount of sediment loss. These results clearly show that vegetation to some extent helps to reduce soil erosion on fallow surfaces. The high amount of losses experienced on the 5-year-old fallow than on the 3-year-old fallow and farmland plots are unexpected. This therefore implies that fallow that is not adequately protected by vegetation especially ground cover experiences accelerated soil erosion problem resulting in the loss of enriched soil and organic matter. To minimize the continuous loss of enriched topsoil in fallows with scanty ground cover, mulching should be practiced; and trees should be allowed in farmlands instead of felling them completely as practiced in this area.

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