Relationships between vegetation characteristics and soil erosion in the rainforest zone of Southern Nigeria

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Abstract
This study was carried out to examine the relationships between vegetation characteristics and soil erosion (runoff and sediment loss) in abandoned farmlands of 3-year old, 5-year old, 10-year old and a cultivated farmland in a part of the rainforest zone southern Nigeria. Field measurements of rainfall producing runoff and sediment were carried out from March to November in 2012 rainy and cropping season. Pearson’s correlation result showed that on the cultivated farmland, crown cover positively and significantly correlated with runoff (r = 0.652, p<0.01). The vegetation characteristics measured on the respective fallows jointly explained 53.7, 73.1, 89.9 and 86.7 per cent of the variances in runoff on the 10-year, 5-year, 3-year and farmland plots respectively. Pearson’s correlation result further showed that sediment loss on the 5-year fallow could be explained by girth (r = 0.807, p<0.01), while on the farmland plot, high, positive and significant association existed between sediment loss and crown cover (r = 0.835, p<0.01). The vegetation characteristics were also jointly responsible for 48.4, 84.3, 95.1 and 85.9 per cent of the variances in sediment loss on the 10-year, 5-year, 3-year and cultivated farmland plots respectively. The study revealed that the role of vegetation characteristics in minimizing soil erosion increased with increasing age of fallow.

Keywords: Fallow vegetation, Soil erosion, Pearson’s correlation, Vegetation characteristics

Introduction
Farming activities result in vegetation change. The change affects vegetation composition and structure, and this has implications on soil erosion and its associated losses (sediment and nutrient loss) (Iwara, 2013). The clearing of vegetation for food crop cultivation makes the soil susceptible to soil erosion especially when the vegetation is not properly established to afford the soil adequate cover resulting in nutrient loss (Iwara, 2014). Soil erosion intensity and amount of sediment loss differ from one location to the other as a result of the differences in vegetation characteristics, differences in topography and soil types, differences in rainfall intensity and volumes among others. In abandoned farmlands, vegetation helps in suppressing soil erosion mostly during the process of natural nutrient restoration. The erosion-suppressing effectiveness of vegetation characteristics across different fallow communities depends largely on the age of fallow and the type of vegetation (Iwara, 2013). In areas where vegetation is sparse, the amount of sediment and nutrient loss could be massive; this can have tremendous effects on optimum nutrient accretion in the soil. Soil erosion results in the loss of topsoil which unchecked could translate into decrease in crop yield for subsequent farming (Arwunudiogba, 2000; Wijitkosum, 2012); and could make land become infertile and unproductive for farming when the topsoil which constitutes the fertile layer of the soil is washed away. Basic soil nutrients required for plant growth such as nitrogen, phosphorus, potassium and calcium are lost when topsoil is eroded (Pimentel and Kounang, 1998).

Lal (1980) and Young (1989) stated that eroded topsoil or sediment contains about three times more nutrients than the soil left behind, because the enriched portion of the soil is loss. Thus, the overall productivity and potential of the soil to support agricultural production is affected as a result of the depletion of nutrient resources (Pimentel and Kounang, 1998). They further argued that if soil conservative measures are not put in place, maximum nutrient input in a fallow farmland may be interrupted and delayed. With the increasing human population and shortening in fallow period, a piece of land may not have the required nutrient base to enhance crop yield as a result of the constant loss of nutrient elements. The loss in organic matter laden

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topsoil degrades soil structure and could result in the depletion of essential nutrients contained in the organic matter (Libert, 1995; Wijitkosum, 2012).

Studies have acknowledged the effects of vegetation characteristics on soil erosion. Aweto (1981) found tree size and vegetation cover as well as tree density to influence water holding capacity vis-à-vis prevent the leaching of soil nutrient. Daura (1995) found that plant residues and vegetation cover increase the porosity of the upper horizon of the soil and hence its infiltration capacity. Soil erosion is found to increase on sites with low or reduction in surface cover (Su et al., 2010). Plant girth helps to intercept raindrops thereby serving as a physical barrier to water movement (Iwara, 2014). Puigdefàbregas (2005), Wei et al., (2007) and Vásquez-Méndez et al., (2010) stated that vegetation composition and structure 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. It also plays an important role in providing and holding nutrients in the soil and maintaining soil structure. Studies carried out by Zhenhong (2004) and Zhenhong et al., (2006) further revealed that plant diversity reduces the risk of nutrient loss in runoff and that soil erosion decreased with increase in species. Similarly, Ali et al., (2007) stated that high plant density and the development of dense canopy cover across the various stages of ecological succession help in improving the canopy hydrological effects of plant communities and suppress runoff velocity.

The rainfall energy that generates runoff resulting in sediment loss may be minimized with the existence of dense land cover potentials mostly vegetation and ground cover (density of herbs). Few documented studies are however, available on soil erosion in abandoned farmlands. Majority of the available studies examined soil erosion and sediment generation in cropping system and plantations (Odemerho and Awundigba, 1993; Daura, 1995; Neergaard et al., 2008; Makanjuola et al., 2011). But soil erosion studies on abandoned farmlands of varying ages are not adequately documented in the literature of forest ecology. The study by Ries and Langer (2001) attempted but considered only two fallow vegetation (young and old fallow), and small mobile nozzle type rainfall simulators were employed to investigate the conditions of runoff generation and soil erodibility in abandoned fields in the Central Ebro Basin, Spain. The study did not examine the interrelationships between vegetation characteristics and soil erosion; and it only gave account of vegetation cover in suppressing runoff, but neglected other vegetation characteristics like tree density, species composition and density of herbs among others. The study revealed that material delivery (sediment yield caused by erosion) did not significantly decrease with increasing vegetation cover, only however, with vegetation cover of over 60% did material output decrease significantly.

Similarly, Zhenhong (2004) and Zhenhong et al., (2006) examined the relationship between plant species diversity and soil erosion on different secondary succession phases of a semi-humid evergreen broad-leaf forest in China. The study revealed that plant diversity improved the canopy hydrological effect of plant communities and that plant diversity acted on surface runoff and soil erosion control as well as reduced the risk of phosphorus loss in runoff. The result also showed that soil erosion decreased with increase in species and the relationship showed a negative exponential function between soil erosion and plant species diversity. The study did not give quantitative account of other vegetation parameters like basal cover, tree height, tree density and tree size among others that could have influence on soil erosion. The present study examined how vegetation characteristics help control soil erosion in fallow vegetation and cultivated farmland in southern Nigeria. The objective of the study was to examine the relationship between vegetation characteristics (crown cover, ground cover, basal cover, girth, litter depth, tree/shrub density and density of herbs) and soil erosion (runoff and sediment loss) in different fallow communities.
Material and methods

**Study area**

The study was carried out in Agoi-Ekpo, one of the villages in Yakurr Local Government Area of Cross River State. Its geographical coordinates are 5° 50’ 0" North and 8° 16’ 0" East (Maplandia.com, 2005 cited in Iwara, 2013). The area falls within the lowland of south-eastern Nigeria called the Cross River plain (Iloeje, 2009). The relief is gentle except in places where granite rises above the general level of the surface (Iloeje, 2009). Agoi-Ekpo lies within the hot-wet equatorial climate of the tropics. Rainfall far exceeds 3,500 mm annually (Oku and Armon, 2006). Temperature in the study area is generally high. 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 soils type found in the area. The geology is of cretaceous sediments (Oden et al. 2012 cited in Iwara, 2013; 2014). The relief is gentle except in places where granite rises above the general level of the surface. The area has luxuriant forest vegetation, and as a result of the luxuriant vegetation characteristics, several wild birds and animals, insects, butterflies etc abound in the area.

![Figure 1: Study area and sampling points](image)

**Types and sources of data**

The study basically used primary data. Primary data included data on surface runoff, data on sediment loss and data on vegetation characteristics (crown cover, ground cover, tree/shrub density, density of herbs, basal cover, tree size and litter depth) as well as data on land use history (number of years of the fallow vegetation). Data on vegetation characteristics were obtained from ten 20m x 20m plots randomly distributed in the different fallow communities; data on surface runoff and sediment loss were obtained through the establishment of one 40 sq. metres (10m x 4m) runoff plot in the 20m x 20m plots used to collect vegetation data in each identified fallow category and farmland. Data on land use history was obtained from farmers (landowners) in the area through oral interview.

**Plot description**

The cultivated farmland served as one in a continuum and composed of cassava after yam had been harvested. The vegetation was basically made up of herbs with few stands of trees allowed by the farmers to grow. *Alchornea cordifolia* and *Milletia aboensis* were the most ecologically-dominant tree/shrub species, while *Chromolaena odorata* and *Aspilia africana* were the most dominant herbaceous species in the cultivated farmland. The 3-year old fallow had more of herbs with few stands of shrubs. The predominant herbs were
Chromolaena odorata, Aspilia Africana, Sida actua and Melanthera scanders, while Anthonotha macrophylla and Rauvolfia vomitoria were the most predominant tree/shrub species.

Like the 3-year fallow, the 5-year old fallow also comprised vegetation voluntarily allowed by farmers in the area to grow in order to regain its nutrient for subsequent cultivation. It had more of shrubs with very few trees as well as scanty undergrowth (density of herbs). Alchornea cordifolia, Harungana madagascariensis, Napoleona vogelii, Millettia obanensis and Albizia zygia were the most abundant tree/shrub species, while Paspalum conjugatum, Chromolaena odorata, Centrosema pubescens and Costus afer were the most dominant herbaceous species in the 5-year fallow. The 10-year fallow acted as the control. Like the 3-year and 5-year fallsows, the 10-year fallow also comprised vegetation willingly allowed by farmers to grow in order to reclaim its nutrient for subsequent cultivation. Sterculia tragacantha, Cnestis ferruginea, Baphia nitida, Napoleona vogelii and Alchornea cordifolia were the most abundant tree/shrub species in the 10-year old fallow, while Paspalum conjugatum, Aspilia Africana and Triumfetta rhomboidea were the most dominant herbaceous species.

Site sampling
Abandoned farmland of 3-year old, 5-year old, 10-year old and cultivated farmland were identified and sampled. In each identified fallow community, 10 plots of 20m x 20m in dimension were randomly established. This was intended to examine the geographic spread of the vegetation parameters and to provide a good basis for understanding the ecological demands of many single species (Lawesson et al., 2000). The established plots were used to obtain vegetation data such as vegetation cover, basal cover, girth, tree/shrub species composition, herbaceous composition, ground cover and litter depth. In the same way, a plot used for vegetation sampling for each fallow community was randomly selected from which runoff plot of 10m x 4m was constructed; from this runoff plot, surface runoff and sediment loss were obtained.

Design and installation of runoff plots
Runoff plots of 10m x 4m were constructed in the 3-year old, 5-year old, 10-year old and cultivated farmland. The runoff plots were duly geo-referenced using Global Positioning System (GPS). Vegetation in the fallow plots was principally composed of shrubs with few stands of trees. The plots were constructed on area of slopes not exceeding 3° (i.e. 3 degrees). Runoff amount in liters was measured following procedures described by 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. After which, the sediment was emptied into polythene bags with labels. After which, the sediment was air-dried and weighed in grams using an electronic balance. The units of runoff were converted from liters to millimeters using the formula given by Vadas et al., (2002)

Vegetation sampling and estimation
Data on crown and basal cover were measured in percentages using the line intercept method (Coulloudon et al., 1999). Tree girth (tree size) was determined using diameter at breast height of 1.3m from the ground (Kong et al., 2015). Girth/tree size measurement was done for plants regardless of tree or shrub species with diameter at breast height (dbh) >0.10m. Herbaceous composition was determined using subplots of 1m² (Gilliam, 2007; Ahmad and Ehsan, 2012) On the other hand, litter depth in each plot was determined by measuring the amount of accumulated litter using a ruler and expressed in centimeters. It was achieved by dropping a 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. Also, the line-intercept method was employed to estimate herbaceous cover (Mitchell and Hughes, 1995; Caratti, 2006). This was achieved by stretching a 20m tape on each of the plot floor from which areas not covered by the plants (i.e. open spaces or gaps) were noted and then subtracted from the length of the tape, this gives the total area covered and then multiplied by 100 to give percentage of cover.
Data analysis

Data collected from the field was statistically treated using Pearson’s correlation and multiple correlation analysis (MCA). These techniques (inferential statistics) were used to understand the nature and strength of the relationship between vegetation characteristics and soil erosion.

Results

Relationships between vegetation characteristics and runoff

Vegetation is known to influence runoff volume (Daura, 1995; Vásquez-Méndez et al., 2010; Pimentel and Burgess, 2013). Table 1 gives Pearson’s correlation result of the relationships between vegetation characteristics (crown cover, basal cover, litter depth, girth, tree/shrub density, ground cover and density of herbs) and the runoff on the fallows and cultivated farmland. On the 10-year, 5-year and 3-year fallow plots as well as the cultivated farmland, some vegetation characteristics showed inverse and insignificant relationships with runoff volume. On the 10-year fallow plot, low inverse correlation coefficients of -0.037 to -0.366 were observed between tree/shrub density, basal cover, girth, density of herbs, crown cover, litter depth, ground cover and runoff. On the 5-year fallow plot, low and inverse relationships were observed between tree/shrub density, herbaceous cover, crown cover, basal cover, density of herbs and runoff. The correlation coefficients for these vegetation variables and runoff ranged from -0.002 to -0.441. The 3-year fallow plot showed inverse correlation between tree/shrub density, girth, litter depth and runoff with correlation coefficients ranging from -0.054 to -0.530. On the cultivated farmland plot, low and inverse relationships were observed between tree/shrub density, girth, basal cover, density of herbs and runoff. The correlation coefficients for the respective vegetation variables and runoff ranged from -0.159 to -0.336. In addition, on the cultivated farmland, crown cover positively and significantly correlated with runoff \( r = 0.652, p<0.05 \). The inverse relationships observed on the respective fallow and cultivated farmland plots are indicative of the role of vegetation attributes in suppressing runoff.

Table 1: Correlation between runoff and vegetation components in fallows

<table>
<thead>
<tr>
<th>S/no</th>
<th>Predictor variables</th>
<th>10-year fallow</th>
<th>5-year fallow</th>
<th>3-year fallow</th>
<th>Farmland</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>TSD</td>
<td>-0.037</td>
<td>-0.271</td>
<td>-0.530</td>
<td>-0.222</td>
</tr>
<tr>
<td>2</td>
<td>G</td>
<td>-0.175</td>
<td>0.456</td>
<td>-0.134</td>
<td>-0.159</td>
</tr>
<tr>
<td>3</td>
<td>HC</td>
<td>-0.366</td>
<td>-0.251</td>
<td>0.215</td>
<td>0.056</td>
</tr>
<tr>
<td>4</td>
<td>CC</td>
<td>-0.363</td>
<td>-0.441</td>
<td>0.411</td>
<td>0.652*</td>
</tr>
<tr>
<td>5</td>
<td>LD</td>
<td>0.365</td>
<td>0.267</td>
<td>-0.054</td>
<td>0.156</td>
</tr>
<tr>
<td>6</td>
<td>BC</td>
<td>-0.068</td>
<td>-0.002</td>
<td>0.162</td>
<td>-0.251</td>
</tr>
<tr>
<td>7</td>
<td>DH</td>
<td>-0.247</td>
<td>-0.299</td>
<td>0.273</td>
<td>-0.336</td>
</tr>
</tbody>
</table>

*Correlation coefficient is significant at 0.05 level

TSD - Tree/shrub density  
G - Girth (m)  
HC - Herbaceous cover (%)  
CC - Crown cover (%)  
LD - Litter depth (cm)  
BC - Basal cover (%)  
DH - Density of herbs

Furthermore, the joint contributions of the 7 vegetation variables which are crown cover, basal cover, litter depth, girth, tree/shrub density, ground cover/herbaceous cover and density of herbs on runoff volume generated on the various plots were also examined. The results in Table 2 indicated that the joint contribution of these parameters on runoff volume had multiple correlation coefficients (r-Values) of 0.773, 0.855, 0.945 and 0.931 on the 10-year, 5-year, 3-year and farmland plots respectively. The positive correlation coefficients
on all the plots are an indication that as vegetation components increase, runoff volume also increases and vice versa. The vegetation variables were jointly responsible for 53.7, 73.1, 89.9 and 86.7 per cent of the variances in runoff on all the plots, while the remaining 46.3, 26.9, 20.1 and 11.1 per cent of the unexplained variances were attributed to other parameters not considered in the study. In addition, the result of the test for significance of the multiple correlation coefficients using t-test statistics showed that the coefficients were significant at 0.05 per cent confidence level (Table 2). The result therefore implies that vegetation components are directly related to runoff on the various treatments.

Table 2: Multiple correlation between vegetation components runoff and sediment loss

<table>
<thead>
<tr>
<th>Fallow plots</th>
<th>Multiple correlation values</th>
<th>Multiple correlation values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>r-Value (runoff mm)</td>
<td>R² (runoff mm)</td>
</tr>
<tr>
<td>10-year fallow</td>
<td>0.733*</td>
<td>0.537</td>
</tr>
<tr>
<td>5-year fallow</td>
<td>0.855*</td>
<td>0.731</td>
</tr>
<tr>
<td>3-year fallow</td>
<td>0.948*</td>
<td>0.899</td>
</tr>
<tr>
<td>Farmland</td>
<td>0.931*</td>
<td>0.867</td>
</tr>
</tbody>
</table>

*Multiple R-values significant at 5% confidence level

**Relationships between vegetation components and sediment loss**

Evidence from the literature reveals that runoff volume and sediment yield diminish with increasing vegetation, and this relationship between vegetation and sediment yield is used to validate the effect of vegetation in erosion models (Puigdefabregas, 2005; Vasquez-Mendez et al., 2010) Table 3 shows result of Pearson’s correlation between the vegetation variables and sediment loss. On the 10-year plot, low positive and negative relationships were observed between vegetation components and sediment loss. On the 5-year fallow plot, the amount of sediment yield was significantly and positively related to girth (tree size), but showed negative and insignificant relationships with tree/shrub density, ground cover, crown cover and density of herbs. This indicated that sediment yield on the 5-year fallow plot could be explained by tree size (girth) (r-Value = 0.807, p<0.01). The girth of trees and shrubs on the 5-year fallow was not able to serve as a physical barrier to rainwater; instead it favoured sediment loss.

Also, on the 3yr-old fallow plot, low and insignificant relationships were observed between tree/shrub density, girth, litter depth and sediment yield. Furthermore, on the cultivated farmland plot, high, positive and significant relationship existed between crown cover and sediment loss (r-Value = 0.835, p<0.01). Tree/shrub density, basal cover and density of herbs on the cultivated farmland negatively and significantly correlated with sediment yield. The inverse associations between vegetation characteristics and sediment loss on the respective plots shows that changes in tree/shrub density, girth, ground/herbaceous cover, crown cover, basal cover and density of herbs are inversely related to the quantities of sediment loss. The low correlation reported in this study between vegetation components and sediment loss corroborates those of Sanjari et al., (2009) who also reported low correlation between vegetation components and sediment loss. The correlation result above identifies tree/shrub density to play substantial impact in minimizing sediment loss on all the plots. This is so, as this vegetative component showed negative association with sediment loss on all the plots. Also, on the old fallows (10-year and 5-year), herbaceous cover and crown cover were observed to provide protective cover to the soil against soil erosion. These two vegetation characteristics helped to minimize sediment loss. It could therefore be said that the role of vegetation in minimizing sediment loss increases with the increase in fallow age.
The result of the joint contribution of vegetation components on sediment loss as shown in Table 2 indicated that the joint contributions of these parameters on sediment loss were high on the 5-year, 3-year and cultivated farmland plots with multiple correlation coefficients (r-Values) of 0.915, 0.975 and 0.927 respectively. The positive correlation coefficients are indications that as vegetation components increase, sediment loss increases as well and vice versa. The vegetation variables were jointly responsible for 84.3, 95.1 and 85.9 per cent of the variances in sediment yield on the 5-year, 3-year and cultivated farmland plots respectively, while the remaining 15.7, 4.9 and 14.1 per cent of the unexplained variances were attributed to other parameters not considered in the study. For the 10-year fallow, the vegetation variables were jointly responsible for 48.4 per cent of the variances in sediment yield, while the remaining 51.6 per cent of the unexplained variances were attributed to other parameters. In addition, the result of the test for significance of the multiple correlation coefficients using t-test statistics shows that the coefficients obtained on the 10-year, 5-year, 3-year and cultivated farmland plots were significant at 0.05 per cent confidence level respectively (Table 2).

Discussion
The relationships between vegetation characteristics and soil erosion (runoff and sediment) indicate that on all the plots, positive and negative relationships exist. The negative associations are indicative of the roles vegetation components play in attenuating the erosive force of raindrops. In a related study, Vásquez-Méndez et al., (2010) observed that vegetation plays an important role in the regulation of hydrological processes. In another study, Puigdefabregas (2005) noted that runoff and sediment loss diminish with the presence and increase in vegetation attributes. However, on the farmland plot, crown cover positively and significantly correlate with runoff volume and sediment loss, while girth on the 5-year fallow positively and significantly correlated with sediment loss. Crown cover reduces the impact of raindrops on the soil by intercepting raindrops and absorbing much of the energy (Li et al., 2004); the percentage of crown cover on the cultivated farmland plot was sparse due to the absence of trees, which made it ineffective in minimizing runoff.

The abundance of cassava leaves on the cultivated farmland did not provide adequate cover to the soil, hence, the observed positive association and high erosional losses. The cover provided by the cassava leaves was not adequate to prevent soil erosion mostly during periods of heavy rainstorm. On the 10-year, 3-year and cultivated farmland, girth shows negative relationships with runoff and sediment loss. Plant girth depending on the size helps to intercept raindrops thereby serving as a physical barrier to water movement. It also serves
as a reservoir that absorbs rainwater. This assertion is in agreement with that of Aweto (1981) when he identified tree size and vegetation cover as well as tree density as the most important vegetation components that influence water holding capacity in relation to preventing the leaching of soil nutrient. The positive association observed between girth and sediment loss on the 5-year old fallow is not surprising because the girth of few trees and mostly shrubs was not well developed to serve as a physical barrier to rainwater. Since it was dominated by shrubs, the girth sizes did not help to effectively attenuate the erosive force of rainwater.

On all the plots, tree/shrub density negatively correlated with sediment element losses. This is expected because the number of trees/shrubs in an area apart from serving as a physical barrier to soil erosion, the development of deep root system helps in erosion control by loosening the soil layer to ease infiltration. Hence, the development of root systems by the trees/shrubs improves the porosity of the topsoil layer thereby facilitating infiltration. Wijitkosum (2012) reported that the formation of dense root network by trees loosens the soil thereby reducing surface runoff. However, the low correlation reported in this study between vegetation characteristics and erosional losses (runoff and sediment loss) corroborates those of Daura (1995), Giordanengo et al., (2003) and Sanjari et al., (2009) who also reported low correlation between vegetation characteristics and erosional losses.

Conclusion
The results have shown that vegetation components play vital roles in minimizing erosional losses, but the extent of the effects varies in relation to fallow ages. This is because the role played is a function of fallow age. On the 10-year and 5-year fallows, a good number of the vegetation components show negative association with runoff and sediment loss, which implies that they are able to minimize erosional losses. Also, vegetation components on the 3-year fallow basically tree/shrub density, girth and litter depth show an inverse association with runoff and sediment loss. However, crown cover on the farmland significantly favours runoff and sediment loss due to the sparse surface cover and the cassava leave is not adequate to give the soil adequate protection from soil erosion especially during periods of heavy rainstorm.

References


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