Effects of Fallow Genealogical Cycles on the Build-up of Nutrients in Soils of the Cross River Rainforest, South-Southern Nigeria

*Offiong, R. A.[1] and Iwara, A. I.[2]

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Abstract

The study examined the effect of fallow generational cycles on the buildup of nutrients in the soil. Fallow sequence of 1st, 2nd, 3rd, 4th and 5th generations were studied. The quadrat approach of sampling was employed to collect soil samples (surface and subsurface) from five plots of 10m x 10m across the five fallow generational cycles. Result showed that the mean proportions of organic matter (OM), total nitrogen (TN), cation exchange capacity (CEC) and available phosphorus (Av. P) increased substantially in the 1st and 2nd generation of fallows probably due to reduced cropping frequency. The PCA result further revealed that topsoil available phosphorus, topsoil exchangeable sodium and topsoil exchangeable potassium constituted the most significant soil properties that progressively increased across the fallow generations. As usual, nutrients in the fallow generations were confined to the topsoil. The increase in soil nutrients was attributed to the increased in tree size, vegetation cover and adequate ground cover which helped to conserve and build-up essential nutrients in the soil by minimizing the loss of nutrients through soil erosion. The study suggested that for efficient conservation practices, fallow land mostly the 1st generation fallow which was fast approaching climax should be considered for reserve. For this to be feasible, alternative means of livelihoods should be provided to reduce the wanton destruction, concentration and dependence on forest resources for sustenance.

Key words: *Fallow Genealogy, Vegetation Development, Soil, Physical Property, Chemical property, Disturbance frequency*

Introduction

The destruction of forest for agricultural (mostly food crop cultivation) and non-agricultural (residential, road construction and industrial expansion) purposes usually brings about tremendous changes in soil and vegetation components as well as results in the development of different fallow vegetations. These changes are apparently influenced by the frequency and pattern of disturbance. The destruction of vegetation mostly through shifting cultivation leads to regeneration of fallow vegetation with diverse tree and shrub species (Smith and Scherr, 2002). Fallow according to Styger and Fernandes (2005) refers to a resting period for disturbed agricultural land between two cropping cycles during which soil fertility is restored. Fallows have more roles than just fertility (Styger *et al.,* 1999), as they offer economic prospects with regard to their carbon sink function, nutrient restoration; provide cash income in times of immediate need and help to balance food supply. Furthermore, fallows produce wood, fibers, and medicinal plants for households and can serve as pastures for livestock. For resource-poor farmers with constraints on their labour, inputs, and access to new techniques, fallows are economically often a good option for optimizing agricultural production, especially when non-crop products can be harvested (Kupfer *et al.,* 2006).

Fallows or forest regeneration or regrowth as the case may be, is a common terminology in ecological studies as it pertains to the re-establishment of forest after a period of disturbance (food crop cultivation). On this note, majority of the studies in the literature (Nye and Greenland, 1960; Aweto, 1981b; Agboola, 1994; Fernandes *et al.,* 1997; Brand and Pfund, 1998; Feldpausch *et al.,* 2004; Addo-Fordjour *et al.,* 2009) considered fallows based principally on succession time or number of years a piece of land is deliberately allowed to fallow, to replenish its loss nutrient. The principal focus of majority of these studies is to characterize soil or vegetation components and in most cases both components (Aweto, 1981c; Hughes *et al.,* 1999; Feng *et al.,* 2007) to understand the changes that have taken

[1]*Dept. of Geography & Environmental Studies, University of Calabar, Nigeria*
[2]*Dept. of Geography, University of Ibadan, Nigeria*
Corresponding email: raphyxx@yahoo.com

place in relation to fallow periods. However, the number of times a piece of land is cultivated in the past 70 years has not attracted research attention. The reason for this is not far-fetched, which perhaps may be attributed to the increase in global population and pressure on available land. This paper therefore attempts to invoke provoking contentions as well as introduce a new thought of research on fallow management and its effects on soil nutrient restoration.

Fallow genealogy as used in this context refers to the number of times a piece of land is cultivated in the past seventy years. In this regards, a piece of land that has been cultivated once in the past 70 years, is termed 1st generation fallow, one that is cultivated twice is termed 2nd generation fallow and so on. Though, these types of fallow genealogies/generations are not easy to come by in some parts of the tropics, except in areas where the forest vegetation has not been wantonly exploited, probably due to low population and availability of large expanse of forested land. Soil fertility restoration for ecosystem productivity and sustainability is perhaps the rationale for deliberately allowing disturbed hectare of land to regain its loss nutrient. Low soil fertility is increasingly recognized as a fundamental biophysical cause for declining food security among small-farm households in sub-Saharan Africa (Sanchez *et al.,* 1997; Mafongoya *et al.,* 2005), therefore exploring areas with immense forest resources and minimal disturbance will go a long way to improve food security as well as serve as conservative spots for biodiversity preservation. The implications include reduction in on-site land degradation (control of soil erosion and nutrient loss among others) and off-site environmental degradation (eutrophication of water bodies, sedimentation of water channels among others).

Since, the generation of fallows identified in this study was cultivated once, twice or thrice as the case may be in the past 70 years, net loss of nutrients from the topsoil is completely minimized, due to the increase in litter fall. Styger and Fernandes (2005) noted that in the early stages of a fallow when biomass is increasing and nutrient uptake is rapid, there may actually be a net loss of nutrients from the topsoil. They further argue that it is only later in the fallow development, when litter fall greatly exceeds the increase of nutrient uptake into biomass, that the amount of nutrients in the topsoil may be increased and restored. This perhaps is obvious as the decrease in the frequency of disturbance (continuous land cultivation for food crop cultivation) speeds up the recovery capacity of a once disturbed ecosystem, thereby triggering nutrient fluxes.

Statement of problem

Globally, forest destruction especially for the cultivation of food crop is usually accompanied by unprecedented changes in soil and vegetation components. The loss in forest vegetation/cover makes the soil susceptible to soil erosion, thereby facilitating soil and nutrient loss. The continuous loss in soil nutrient due to the loss in vegetal cover affects the productivity capacity of the soil to sustain increased food production. However, the destruction of forest though accelerates soil erosion problems, but at the long-run leads to the development of different successional and generational vegetation depending on the fallow age and the number of times a piece of land is cultivated. The gradual change in fallow time brings about drastic development of forest regrowth with inherent effect on the buildup of nutrient through the accumulation of biomass which in situ decomposes to add nutrient to the soil. The development of forest also affords the soil adequate cover and protection from harsh climatic conditions mostly the erosive force of rainstorm.

Indeed, the growth in vegetation over time helps to improve the soil structure as well as ensure the soil eco-balance and nutrient fluxes. This perhaps is only feasible when a once disturbed ecosystem or piece of land is allowed to fallow, during which the soil regains its fertility. Previous studies as noted above considered fallows based principally on succession time or number of years a piece of land is deliberately allowed to fallow. The principal focus of these studies is to characterize soil or vegetation components and in most cases both components to understand the changes that have taken place in relation to fallow periods. But, the number of times a piece of land is cultivated in the past 70 years has not attracted research attention. This paper therefore evaluates the dynamics and build-up of nutrients in different generations of fallows. The paper is timely as the quest for soil fertility restoration is on the front burner with regards to the changing trends in the global climate and food security. Furthermore, this study provides baseline information on fallow genealogical cycle and its resultant effects on the soil.

Hypotheses

The study hypotheses that:

- There are significant variations in the buildup of nutrients across different generation of fallows.
- Nutrients in fallow soils increase substantially in relation to the number of times a piece of land is cultivated.

Materials and Method

Study Area

The study was carried out in Oban Group Forest in Akamkpa Local Government Area, Cross River State. Geographically, the area lies between longitude 8^0 060' and 8^0 50'E and latitude 5^0 00' and 5^0 57'N. The climate is characterized by a double maxima rainfall beginning in the month of March to August, then August to October, reaching its peak in the month of July and September; the annual rainfall in about 2000-3000mm (Offiong, 2005). The average temperature here is about 27^0 C; relative humidity is between 80%. The tropical maritime and tropical continental air masses are common in the area. The area is characterized by luxuriant evergreen forest vegetation with few patches of secondly forest which constitutes the fallows. The rainforest consists of broad leaf species, amounting to 60-100 species per sq km. Many trees grow to the height of 30m - 60m tall. Many of the trees have large buttresses, smooth balks, columnar holes and thick woody climbers. Several species of birds, mammals, reptiles and insects are found in the area. The soils of the area are mainly loamy-sand and clay-loamy soils (Offiong, 2005). The terrain is undulating flood plain found around the Ikpan River.

Sampling procedure and data collection

The procedure of data collection began with a reconnaissance survey to the area, during which fallow generations ranging from 1st, 2nd, 3rd, 4th and 5th were identified and delineated for soil sampling. Identification of fallow generations was done by the local farmers, as they remembered the number of times a particular fallow was cleared and cultivated in the past 70 years. In each generation of fallow, a belt transect of 80m was established, from which soil samples were randomly collected from 5 plots of 10m x 10m out of the 8 laid. In each plot, 5 surface (0-15 cm) and subsurface (15 – 30cm) soil samples were randomly collected with a soil auger and then composited.

Laboratory analysis

The soils were put in polythene bags with labels; they were thereafter air-dried and taken to the laboratory for analysis. Soil organic carbon was determined by the method of Walkley and Black (1934); total nitrogen by the Kjeldahl method (Bremner and Mulvaney, 1982) and available phosphorus was determined by the method of Bray and Kurtz (1945). The soils were leached with 1M neutral ammonium acetate to obtain leachates used to determine exchangeable bases and soil cation exchange capacity, while pH value was determined using a glass electrode testronic digital pH meter (Model 511) with a soil: water ratio of 1:2. Soil particle size composition was analysed using the hydrometer method (Bouyoucos, 1926).

Data analysis

Data obtained from the procedures above were analysed using descriptive, univariate and multivariate statistical techniques. Descriptive techniques such as tables, simple percentages and averages were used to represent the data for easy comparison; univariate technique such as One-Way ANOVA was performed on the soil properties to determine if significant variation exist among the sampled generation of fallows, while a multivariate technique through the use of principal components analysis (PCA) was performed to reduce the set of soil variables as well as find the most significant soil properties that increased substantially across the fallow generations.

Results and Discussion

Surface soil properties

Table 1 shows information on the physical and chemical properties of surface soils across the fallow generations. The table showed that the concentration of sand was high in the 2nd and 4th generations with mean values of 82% respectively, while the lowest concentration of sand was obtained in the 1st generation with mean value of 71%. Sand proportion in the fallow generations varied significantly ($p<0.05$). The proportion of silt did not vary ($p>0.05$), as it was the same across the fallow generations with mean values 7.4% respectively. However, for clay, the highest mean value of 13% was obtained in the 3rd and 5th generations, while the lowest mean value of 1.4% was obtained in the 1st generation fallow. There was significant variation in silt contents among the generation of fallows ($p<0.05$). The levels of porosity and moisture content in the soil were high in the 2nd and 3rd generations with mean values of 60g/kg respectively, and in the 5th generation with mean value of 33%, while the lowest values of 56g/kg and 27% were obtained in the 1st generation fallows respectively (table 1). There were significant variations in porosity and moisture contents among the generation of fallows ($p<0.05$). In the same vein, the concentrations of organic carbon (OC) and total nitrogen (TN) varied among the fallow generations ($p<0.05$) with high mean values of 1.27% and 0.31% in the 1st generations; it was closely followed by the 2nd and 3rd generation of fallows with mean values of 1.16% and 0.28% respectively.

The lowest proportions of OC and TN were obtained in the 5th generation with mean values of 0.22% respectively. For exchangeable calcium (Ca) and magnesium (Mg), the highest mean values of 3.09meg/100g and 0.41meg/100g were obtained in the 5th and 2th generations, while the lowest mean values of 2.23meg/100g and 0.33meg/100g were obtained in the 1st and 5th generation of fallows respectively. The proportions of Ca and Mg varied among the fallow generations ($p<0.05$). In addition, the levels of exchangeable sodium (Na) and potassium (K) were high in the 3rd and 2nd generations with mean values of 0.41meg/100g and 0.14meg/100g, while the lowest mean values of 0.07meg/100g and 0.06meg/100g were obtained in the 5th generation respectively. There were significant variations in the contents of Na and K among the generation of fallows ($p<0.05$). The highest concentrations of cation exchange capacity (CEC) and Av. P (available phosphorus) were in the 3rd and 1st generations with mean values of 5.60meg/100g and 101.28mg/kg^{-1}, while the lowest mean values of 4.00meg/100g and 1.49mgkg-^{1} were obtained in the 1st and 4th generations respectively. The proportion of CEC in the fallow generations did not vary ($p<0.05$), while Av. P proportion varied significantly among the generation of fallows ($p<0.05$). The levels of pH and electrical conductivity were high in the 2nd and 3rd fallow generations with mean values of 4.7 and 0.47 dsm-^{1}, while the lowest mean value for pH was obtained in the 1st generation (4.46), and for EC, the lowest mean value of and 0.07 were obtained in the 1st and 2nd fallow generations respectively (table 1).

Subsurface soil properties

The levels of physical and chemical properties of subsurface soils in the fallow generations are shown in table 2. The table showed that the concentration of sand was high in the 4th generation followed by the 3rd and 5th generations with mean values of 79.2% and 75.2% respectively. There was significant variation in the sand content among the generation of fallows ($p<0.05$). Silt content was high in the 1st and 2nd generations with mean values of 9.4%, it however reduced to 5.4% in other generations. Silt content varied across the fallows ($p<0.05$). Clay content did not vary significantly across the fallows ($p>0.05$), though the 3rd and 5th generation had relatively higher mean values of 19.4% respectively, followed by the 1st and 2nd generation with mean value of 17.4% respectively. The proportion of porosity was relatively the same in the 2nd, 3rd and 4th generations with mean value of 62 g/kg, and reduced slightly in the 1st generation with mean value of 59 g/kg. The content of porosity varied significantly across the fallow generations ($p<0.05$). The level of soil moisture was high in the 1st generation fallowed by the 5th generation with mean values of 31.8% and 30.1% respectively, and reduced to 28% in the 4th generation. Also, soil moisture content varied significantly across the fallow generations ($p<0.05$) (table 2).

More so, the chemical properties of sub-surface soils (table 2) showed that the highest levels of organic carbon (OC) were obtained in the 3rd generation, followed by the 2nd generation fallow with mean values of 0.93% and 0.92% respectively, while the lowest mean value of 0.71% was obtained in the 1st generation fallow. There was significant variation in the concentration of OC across the fallow generations ($p<0.05$) The level total nitrogen was the same in the 2nd, 3rd, 4th and 5th fallow generations with mean values of 0.22%, and reduced to 0.17% in the 1st generation. Total nitrogen content varied significantly across the fallow generations ($p<0.05$) Furthermore, the concentration of exchangeable calcium (Ca) and magnesium (Mg) was high in the 2nd and 1st generations with mean values of 2.61meg/100g and 0.43meg/100g respectively, and reduced drastically in the 1st and 3rd generation of fallows with mean values of 1.91meg/100g and 0.28meg/100g respectively. The proportions of Ca and Mg varied significantly across the fallow generations ($p<0.05$).

Likewise, the proportion of exchangeable sodium (Na) was high in the 3rd, 4th generations with mean values of 0.38meq/100g, and reduced to 0.08meq/100g in the 5th generation; while the proportion of exchangeable potassium (K) was high in the 2nd generations with mean values of 0.07meq/100g, and reduced substantially to 0.03meq/100g in the 4th generation. The proportions of Na and K varied significantly across the fallow generations ($p<0.05$). The highest levels of CEC and Av. P were obtained in the 2nd and 1st generations with mean values of 4.05meg/100g and 13.96mgkg-^{1}, while the lowest proportion of Av. P was obtained in the 4th generation with a mean value of 0.65mgkg-^{1}. The levels of CEC and Av. P in the generation of fallow soils varied significantly ($p<0.05$). pH level was high in the 4th generation and reduced thereafter in the 3rd generation with mean values of 4.7 and 4.5 respectively. The level of pH did not vary significantly across the fallow generations ($p>0.05$). The proportion of electrical conductivity (EC) was extremely low in the 1st generation, but increased steadily thereafter. The proportion of EC varied significantly across the fallow generations ($p<0.05$) (table 2).

Result of PCA

PCA was performed for soil properties with high intercorrelations across the fallow generations. Principal loadings (correlation coefficients) and the variances (eigenvalues) for the soil variables were computed. In the 1st generation fallow, the PCA procedure using varimax rotation (variable maximization) as well as the Kaiser rule of selecting only components with eigenvalues >1(Gaur and Gaur, 2006) extracted three components. The extracted components accounted for 97.7% of total variance in the original data set. Five soil properties with positive and negative values loaded heavily on component 1, they included subsoil silt content (0.95), subsoil exchangeable sodium (0.92), topsoil sand (-0.92), subsoil exchangeable calcium (0.91) and topsoil exchange acidity (0.91). This component was regarded as measuring subsoil silt content. It accounted for 8.25 of the total eigenvalue loading and 37.7% variance in the linear combination of soil properties. The second component also had five soil properties with positive and negative values that loaded heavily on it, these variables included topsoil exchangeable magnesium (0.99), subsoil porosity (-0.98), subsoil available phosphorus (0.97), topsoil organic carbon content (0.95) and subsoil organic carbon content (0.85). This component exemplified subsoil magnesium content and it accounted for 7.25 total eigenvalue loading and 32.9% variance in soil properties. Component three on the other hand had six soil properties that loaded heavily on it. They included topsoil clay (-0.97), subsoil clay (-0.93), subsoil exchangeable magnesium (-0.86), topsoil available phosphorus (0.85), topsoil exchangeable potassium (0.85) and subsoil pH (-0.85). This component represented clay content and it accounted for 5.96 total eigenvalue loading and 27.1% variance in soil properties. The result above showed that subsoil silt content, subsoil magnesium content and topsoil clay content were the significant soil properties that progressively increased in the first generation fallow.

In the 2nd generation fallow, three components with eigenvalues >1 were extracted and they accounted for 96.8% of total variance in the original data set. Seven soil properties with high positive and negative values loaded on component 1, they included topsoil moisture content (0.95), topsoil available phosphorus (-0.95), subsoil exchange acidity (-0.921), subsoil available phosphorus (0.87), subsoil moisture content (-0.87), topsoil total nitrogen (0.83) and topsoil organic carbon (0.83). This component measured topsoil moisture and phosphorus contents. It accounted for 8.88 of the total eigenvalue loading and 38.6% variance in the data set. Component two had six soil properties that loaded heavily on it, these variables included topsoil exchangeable magnesium (-0.99), topsoil exchangeable sodium (0.99), topsoil exchange acidity (0.97), subsoil exchangeable potassium (0.97), topsoil cation exchange capacity (0.96) and topsoil porosity (-0.88). This component exemplified topsoil exchangeable bases and it accounted for 8.62 total eigenvalue loading and 37.5% variance in soil properties. Component three accounted for 4.78 total eigenvalue loading and 20.8% variance in soil properties. Three soil properties loaded heavily on this component, they included subsoil organic carbon (0.98), subsoil clay content (-0.97) and topsoil exchangeable potassium (0.91). This component measured subsoil organic carbon content. From the result, topsoil moisture and phosphorus contents, topsoil exchangeable bases and subsoil organic carbon content were the soil properties that gradually increased in the 2nd generation fallow.

In addition, three components that accounted 98.3% of total variance in the original data set were obtained in the 3rd fallow generation. On component one, seven soil properties which included topsoil total nitrogen (-0.98), topsoil clay content (-0.98), subsoil porosity (0.97), subsoil available phosphorus (0.93), topsoil pH (0.92), subsoil magnesium (0.92) and subsoil CEC (-0.86) loaded on it. This component measured topsoil nitrogen content. It accounted for 9.71 eigenvalue loading and 42.2% variance in the data set. Component two had eight soil properties, they included topsoil sand (0.95), topsoil CEC (-0.94), topsoil exchangeable magnesium (-0.94), topsoil exchangeable sodium (-0.94), subsoil sand (0.94), subsoil moisture content (0.93), subsoil silt content (0.88) and subsoil organic carbon content (-0.88). This component represented topsoil sand content, it accounted for 8.65 total eigenvalue loading and 37.6% variance in soil properties. The third component accounted for 4.26 eigenvalue loading and 18.5% variance in soil data structure. However, only topsoil exchangeable calcium (-0.87) loaded heavily on this component. It measured topsoil exchangeable calcium. This indicated that topsoil nitrogen content, topsoil sand content and topsoil exchangeable calcium were principal soil properties that increased significantly in the 3rd generation fallow.

Like in the first-three generations, in the fourth generation fallow, three components that accounted 97.6% of total variance in the original data set were extracted. On component one, ten soil properties loaded heavily, they included topsoil moisture content (0.99), topsoil organic carbon content (0.99), subsoil silt content (0.99), subsoil exchangeable sodium (0.97), subsoil CEC (0.97), subsoil porosity (0.96), topsoil exchangeable potassium (0.96), topsoil clay content (0.87), subsoil exchangeable calcium (-0.86) and subsoil total nitrogen content (0.88). This component measured subsoil moisture content; it accounted for 11.24 eigenvalue loading and 51.10% variance in the data set. Component two had three soil properties, they included subsoil exchangeable magnesium (0.98), subsoil sand content (0.88) and subsoil porosity (0.80). This component represented subsoil exchangeable magnesium content; it accounted for 5.19 total eigenvalue loading and 23.58% variance in soil properties (table 6). The third component accounted for 5.04 eigenvalue loading and 22.89% variance in soil data structure. However, five soil properties namely topsoil exchangeable magnesium (0.93), subsoil available phosphorus (-0.87), topsoil CEC (0.84), topsoil exchange acidity (0.83) and subsoil exchange acidity (0.83) loaded heavily on it. The component measured topsoil exchangeable magnesium content. The result indicated that subsoil moisture content, subsoil exchangeable magnesium content and topsoil exchangeable magnesium content were soil properties that increased progressively in the 4th generation fallow.

In the fifth generation fallow, three components that accounted 97.2% of total variance in the soil data structure. On component one, eight soil properties loaded heavily, they included topsoil pH (0.97), subsoil sand (0.97), topsoil sand (0.96), subsoil silt content (0.92), subsoil exchangeable potassium (0.92), subsoil clay content (-0.87), topsoil available phosphorus (0.86) and topsoil exchange acidity (-0.85). This component exemplified topsoil acidity/alkalinity content; it accounted for 8.78 eigenvalue loading and 41.82% variance in the data set. Component two had six soil properties, they were subsoil exchangeable calcium (0.99), subsoil CEC (0.99), and subsoil exchangeable magnesium (0.99), topsoil clay content (-0.90), subsoil exchangeable sodium (0.90) and subsoil moisture content (-0.88). This component measured subsoil exchangeable calcium content; it accounted for 7.51 total eigenvalue loading and 35.75% variance in the soil data. The third component accounted for 4.12 eigenvalue loading and 19.64% variance in soil data structure. However, three soil properties namely topsoil exchangeable calcium

(-0.98), topsoil silt content (-0.97) and subsoil total nitrogen (-0.88) loaded heavily on it. The component represented topsoil exchangeable calcium content. The result revealed that topsoil acidity/alkalinity content, subsoil exchangeable calcium content and topsoil exchangeable calcium content were soil properties that substantially increased in the 5th generation fallow.

Soils of fallow generations were textually homogenous being loamy-sand. The high concentration of sand in the fallow generations was attributed to the advanced degrees of weathering caused by the high rainfall in the area (Attoe and Amalu, 2003). The level of silt was substantially high in the 1st generation than in soils of other generations, indicating nutrient enrichment. Silt, according to Ukpong (1994) is a physical site quality associated with nutrient availability, mostly CEC and organic carbon. Also, the levels of clay varied slightly across the generation of fallows. The high level of clay in the generation of fallows mostly the 3rd generation according to Iwara (2009) may be attributed to the high rate of organic matter decomposition as a result of its few tree density and gaps in canopy cover, which do not protect the soil against weather conditions and solar radiation hence, the rapid rate of organic decomposition. Clay is known to be involved in almost every reaction in soils which affects plant growth. According to Page (1963) both chemical and physical properties of soils are controlled to a very large degree by properties of clay. Clay is the active part of the soil both chemically and physically. The importance of clay on the availability of nutrients in the soil has been noted by scholars, for example, Aweto (1981c) notes that the proportion of clay in the soil strongly affects tree regeneration since clay enhances soil water-retaining and nutrient-holding capacities.

The similarity in the textural composition of soils in fallow generations clearly revealed they were derived from the same parent material and enjoyed the same environmental conditions (Aweto, 1981c; Abua *et al.,* 2010; Eni *et al.,* 2011). The soils of the area were highly porous, indicating they were well aerated. Moisture content was high in soils of the 5th and 4th generation. This could be as a result of the fact the younger generations had more ground cover crops, foliage and fibrous roots as compared to the older generations (Aweto, 1981b); these characteristics ensured adequate hydrological balance. In sum, the result showed that the soils of the fallows were well drained. The levels of organic carbon (OC) and total nitrogen (N) were high in the 1st generation and decreased abruptly thereafter. The high proportion of OC and N in the 1st generation fallow was attributed to the increase in the amount of biomass (above and below) returned to the soil as well as the favourable soil moisture and temperature regimes which facilitated the rate of litter decomposition (Aweto, 1981c; Lal, 2005; Ross *et al.,* 2002). Another likely reason was the reduced frequency of disturbance (number of times the fallow was cultivated). The decrease in proportion of OC and N following the frequency of disturbance has been reported in earlier studies, for instance Knoepp and Swank (1997) observed in their study that OC and N proportion generally declined during the first year following the whole tree harvest, but remained stable years after when disturbance was minimized.

However, the depletion of OC and N in the 5th generation fallow was presumably due to the decreased in litter inputs, shift in the abundance of woody and herbaceous vegetation, changes in depth distribution of plant roots, altered soil water and temperature regimes which accentuated decomposition of biomass (Davidson and Ackerman, 1993). Nevertheless, the level of soil nutrients, especially the exchangeable bases varied considerably across the fallow generations. The high concentration of exchangeable calcium (which increases with nutrient intake or litter breakdown in soils) in the 5th generation could be attributed to its high undergrowth which did not disrupt the organic matter cycle to environmental condition – surface run-off of nutrient. With exception to available phosphorus, the levels of exchangeable bases were generally low due to varying vegetation characteristics across the fallows. The level of cation exchange capacity (CEC) was relatively similar across the fallow generations due to the increases in cover, tree size and the number of legumes (Aweto, 1981b; Lal, 2005). The increase in vegetation cover and tree size implies that raindrop intensity is reduced, loss of soil nutrient through runoff is also minimized and more litter is produced which in situ decomposes to form nutrient. In addition, the high contents of available phosphorus in the 1st generation fallow soil was attributed to its age of abandonment and the effects of different tree species on the soil nutrient, as well as the high ground water table which reduced the degree of leaching. The pH levels were the same across the fallow generations being acidic. The acidic nature of soils in the fallow generations may be attributed to the high rainfall, which is sufficient to leach basic cations especially calcium from the surface horizons of the soils (Foth, 2006; Abua *et al.,* 2010).

More so, the soils under the fallow generation had low electrical conductivity. This indicated that the soils were not saline. The high CEC value across the fallow generations therefore indicated that the soils were able to hold adequate nutrients thereby enhancing the availability of nutrients to plant and micro-organisms. Furthermore, the contents of exchangeable bases (calcium, potassium, sodium and magnesium) were generally low in the generation of fallow soils. The very low concentration of Ca, K and Mg in soil implied the soil was of poor quality, which perhaps necessitated the practice of shifting cultivation and prolonged fallow periods by farmers in the area to augment the soil for improved agricultural production. The sub-surface soils showed that the soils of the region were well drained. Therefore, soils in the rainforest area were not waterlogged, and were highly aerated due to their sandy nature. The level of nutrients like total nitrogen, organic carbon, available phosphorus and cation exchange capacity reduced in substantial proportion in the subsoil (table 2); whereas, the levels of exchangeable bases and pH were slightly the same with those of surface soils. The general reduction in soil nutrients at the depth of 15 – 30cm was because nutrients were mostly concentrated in the topsoil and the high net transfer of nutrient from the sub-surface soil to the surface soil (Aweto, 1981b).

Furthermore, the PCA result revealed that topsoil available phosphorus content, topsoil exchangeable sodium and topsoil potassium constituted the most significant soil properties that contributed to the overall buildup of nutrients across the fallow generations. This therefore reveals that substantial amount of nutrients in the fallow soils are confined to the topsoil, this assertion agrees with those of Aweto (1981b) and Lal (2005), when they observe that substantial amount of nutrient in the soil is confined to the 0 – 15cm of the soil. Available phosphorus and exchangeable potassium are essential macro nutrients needed by plants to enhance growth. The contents of these soil properties in the soil were unconnected to the reduced frequency of disturbance (elongation of fallow), which supported the establishment of forest vegetation with abundant woody and herbaceous species. The increase in vegetation cover and tree size helped to reduce raindrop intensity, minimize the loss of soil nutrient through runoff and helped in nutrient enrichment through the accumulation of biomass which *in situ* decomposed to form nutrient (Ross *et al.,* 2002; Aweto and Dikinya, 2003). Though, exchangeable sodium increased significantly across the fallow generation, it is however considered as a non-essential element for most plant (Aweto and Dikinya, 2003).

Conclusion

The result of the study has apparently shown that the contents of essential nutrients required for crop growth and agricultural productivity such as organic matter, total nitrogen and available phosphorus in the generation soils increase with the number of times the generation of fallow is cultivated. The PCA result further reveals that topsoil available phosphorus content, topsoil exchangeable sodium and topsoil exchangeable potassium constitute the most significant soil properties that increase substantially across the fallow generations. Indeed, the build-up of nutrients is affected by the increase in tree size, vegetation cover and adequate ground cover. These attributes help to conserve essential nutrients in the soil by minimizing the loss of nutrients mostly during periods of heavy rainstorm. The study therefore implies that the elongation of fallow periods and reduction in the continuous use of a piece of land results in the steady accretion of soil fertility. Fallow elongation and reduction in disturbance frequency (continuous cultivation) result in the development of vegetation with attendant effect on soil nutrient restoration. The established vegetation in the long-run produces a lot of litter and protects the soil against nutrient losses through leaching. However, considering the spate of shifting cultivation which is giving rise to excessive loss of vegetation in the area, rotational farming and bush fallowing should be encouraged within the fallow generations. This is as a result of the fact that fallows that have been left for quite a long time such as the 1st & 2nd generations show better soil quality compared to others. Also, for efficient conservation practices, fallow land mostly the 1st generation fallow which is fast approaching climax should be considered for reserve. For this to be feasible, alternative means of livelihoods should be provided by the government and concerned NGOs to reduce the concentration and over dependence on forest resources as mainstay of sustenance.

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Table 1: Physico-chemical properties of surface soils in the fallow cycles[b]

Soil properties	Fallow generations 1st gen	2nd gen	3rd gen	4th gen	5th gen	F-values
Sand content (%)	70.80±0.24	82.38±0.59	79.54±0.10	82.18±0.64	79.26±0.27	124.017++
Silt content (%)	7.38±0.02	7.38±0.02	7.38±0.02	7.38±0.02	7.38±0.02	0.001 ns
Clay content (%)	1.42±0.07	9.32±0.13	13.30±0.12	9.26±0.10	13.34±0.13	1873.295++
Porosity (g/kg)	56.26±0.24	60.18±0.06	60.10±0.04	58.60±0.32	56.97±0.05	95.268++
Moisture content (%)	27.76±0.05	28.30±0.10	28.26±0.05	31.98±0.07	33.46±0.04	1581.113++
Organic carbon (%)	1.27±0.04	1.16±0.00	1.12±0.01	1.05±0.00	0.22±0.01	8797.412++
Total nitrogen (%)	0.31±0.01	0.27±0.00	0.28±0.01	0.25±0.01	0.22±0.00	40.931++
Exch Ca (Meq/100g)	2.23±0.01	2.71±0.00	2.78±0.00	2.71±0.01	3.09±0.01	2155.477++
Exch Mg (Meq/100g)	0.33±0.01	0.41±0.00	0.35±0.01	0.37±0.00	0.33±0.00	59.851++
Exch Na (Meq/100g)	0.35±0.01	0.35±0.00	0.41±0.01	0.40±0.00	0.07±0.00	1007.860++
Excg K (Meq/100g)	0.08±0.00	0.14±0.00	0.07±0.01	0.08±0.01	0.06±0.01	46.898++
CEC (Meq/100g)	4.00±0.01	4.42±0.01	5.60±0.80	4.35±0.00	4.56±0.00	2.830 ns
Av. P (Mg/kg^{-1})	101.28±0.00	15.18±0.01	2.00±0.01	1.49±0.12	8.61±0.01	5999007.491++
pH	4.46±0.05	4.74±0.05	4.50±0.03	4.56±0.04	4.64±0.05	6.058+
EC (dsm^{-1})	0.07±0.01	0.07±0.01	0.47±0.00	0.41±0.01	0.46±0.01	1837.746++

[b]Values are means ± standard errors.

++ Difference between means is significant at 1% alpha level

+ Difference between means is significant at 5% alpha level

ns: Difference between means is not significant at 5% alpha level.

Table 2: Physico-chemical properties of sub-surface soils in the fallow cyclesb

Soil properties	Fallow generations					F-values
	1st gen	2nd gen	3rd gen	4th gen	5th gen	
Sand content (%)	73.08±0.06	73.08±0.06	75.16±0.05	79.16±0.05	75.16±0.05	2110.247++
Silt content (%)	9.38±0.04	9.36±0.05	5.40±0.03	5.40±0.03	5.40±0.03	3377.371++
Clay content (%)	17.36±0.05	17.38±0.06	19.36±0.14	15.35±0.05	19.34±0.12	0.941 ns
Porosity (g/kg)	58.58±0.01	62.04±0.46	62.15±0.01	61.72±0.01	60.15±0.01	55.860++
Moisture content (%)	31.78±0.06	29.42±0.06	29.70±0.10	28.00±0.32	30.12±0.04	77.780++
Organic carbon (%)	0.71±0.01	0.92±0.01	0.93±0.01	0.82±0.00	0.90±0.01	318.985++
Total nitrogen (%)	0.17±0.00	0.22±0.01	0.22±0.01	0.21±0.01	0.22±0.00	10.473++
Exch Ca (Meq/100g)	1.91±0.01	2.61±0.00	2.13±0.00	2.11±0.00	1.95±0.01	3527.509++
Exch Mg (Meq/100g)	0.43±0.00	0.36±0.01	0.29±0.00	0.30±0.01	0.28±0.01	91.495++
Exch Na (Meq/100g)	0.36±0.01	0.36±0.01	0.38±0.01	0.38±0.01	0.08±0.02	154.543++
Excg K (Meq/100g)	0.05±0.01	0.07±0.01	0.06±0.01	0.03±0.01	0.05±0.01	4.55+
CEC (Meq/100g)	3.75±0.01	4.05±0.01	3.65±0.01	3.81±0.01	3.38±0.01	782.899++
Av. P (Mg/kg^{-1})	13.96±0.01	2.18±0.01	1.27±0.02	0.65±0.00	1.74±0.01	394788.335++
pH	4.6±0.03	4.6±0.03	4.5±0.03	4.7±0.04	4.6±0.07	2.40 ns
EC (dsm^{-1})	0.03±0.00	0.31±0.01	0.37±0.01	0.37±0.01	0.36±0.01	482.573++

bValues are means ± standard errors.

++ Difference between means is significant at 1% alpha level

+ Difference between means is significant at 5% alpha level

ns: Difference between means is not significant at 5% alpha level.