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Relationships between Soil and Vegetation Structural Properties of Secondary Forest Regenerating in Degraded Rubber Plantation in the Niger Delta Area of Nigeria

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Abstract

The effects of soil on vegetation structural attributes (tree density, tree height, tree diameter, basal area and estimated aboveground biomass) of a secondary forest following the abandonment of a degraded rubber plantation in Orogun area of Delta state Nigeria was studied using the multiple linear regression model. Four secondary forests of different age categories (1-year, 5-year, 10-year old secondary forests and a mature secondary forest of about 80 years old) were studied. Vegetation parameters were measured by quadrat method. Forty quadrats (30m x 30m), ten in each secondary forest categories were delineated for soil sampling and for the measurement of vegetation structural properties. Twenty composite soil samples were collected in each secondary forest category and analyzed for organic matter, pH, available phosphorus, total porosity, ECEC (effective cation exchange capacity) and water holding capacity. Vegetation structural properties for each of the quadrats were measured using appropriate field measurement techniques. Multiple linear regression was used to investigate the relationship between the vegetation structural properties and soil properties. The result of multiple linear regression showed that soil organic matter, total porosity, water holding capacity, available phosphorus and ECEC were the most outstanding soil factors influencing the regenerative capacity of the vegetation structural properties in secondary forests.

Key words: Tree height, Tree density, Basal area, multiple regression, ECEC, Water holding capacity.

Introduction

Vegetation and soil display a circularly causal relationship, in that the latter provides support (anchorage, nutrient, moisture and habitat) for vegetation to grow successfully on the one hand, while vegetation provides protective envelop for soil against soil erosion and helps to maintain soil nutrient through nutrient recycling via litterfall and mineralization of litter. Therefore, vegetation and soil are interconnected and exert symbiotic effects on each other. Vegetation performs important functions in an ecosystem at different spatial scales. Vegetation strongly affects soil characteristics, including soil volume, chemistry, and texture, which in response affect various vegetation characteristics, including productivity, structure, and floristic composition (Brant *et al.* 2006).

Soil nonetheless is essential to ecosystem and agricultural sustainability and production because it supplies many of the essential requirements such as water, nutrients, anchorage, oxygen for roots, and moderate temperature for plant growth (Jamieson *et al.* 2002, van der Maarel 2004). Soil performs a very important role in nature, providing nutrients for plant to grow as well as habitat for millions of micro- and macro-organisms (Eni *et al.* 2011). Healthy soil enables vegetation to thrive, releases oxygen, holds water and diminishes destructive storm runoff, breaks down waste materials, binds and breaks down pollutants, and serves as the first course in the larger food chain (Marx *et al.* 1999, Rodriguez-Iturbe 2000). The degradation of the soils and vegetation impact negatively on the soil and vegetation and affect their ability to perform these functions. The reciprocal relationship between soil and vegetation demands a multivariate approach in order to determine important vegetation and soil properties that sustain this reciprocal relationship. Based on this, multivariate analytical techniques (such as multiple linear regression, principal component analysis, canonical correlation analysis, detrended canonical correlation analysis, factor analysis, canonical correspondence analysis and stepwise multiple regression among others) are very useful in the analysis of soil and vegetation as each consists of data corresponding to a large number of variables.

The lowland tropical secondary forest of Orogun in Delta state Nigeria is a secondary forest regenerating from degraded abandoned rubber plantation and food crops agriculture. Plantation agriculture of rubber, which in most instances proved to be little more permanent than bush fallowing, is a major cause of secondary forest in Delta state area of Southern Nigeria. Most of the rubber plantations in Orogun are abandoned today because of soil nutrient impoverishment, animal pests, plant diseases and death of rubber trees arising from inappropriate tapping. Therefore, most of the areas that were occupied by rubber plantations are now occupied by secondary

forests in different stages of regeneration. There is therefore the need to identify the basic soil and vegetation parameters encouraging the regenerative capacity of this once degraded secondary forest and impoverished soil.

In most parts of the world, studies explaining the relationships between soil and vegetation have been conducted in the past by scholars in the fields of ecology, geography, forestry, and soil science using varying multivariate approaches. For instance, studies on soil-vegetation relationships of saline localities have been carried out in different parts of the world (Li 1993, Bui and Henderson 2003, El-Ghani and Amer 2003, Li *et al.* 2008); studies on soil-vegetation relationships in tropical rainforests have also been conducted in different parts of the tropical world (Feng *et al.* 2007, Du *et al.* 2007). In Nigeria, studies on soil-vegetation interrelationships in the rainforest zones focused on: (1) secondary forests following shifting cultivation system of agriculture (Aweto 1981a), (2) coastal mangrove swamps (Ukpon 1994) and (3) the Tinapa Resort of Cross River state-which is a secondary forest following series of anthropogenic disturbances outstandingly food crop cultivation, fuelwood exploitation, and illegal logging activities (Eni *et al.* 2011). There appears to be no study on the relationships between soil and vegetation structure of secondary forests regenerating from degraded abandoned rubber plantation in Nigeria and other parts of the world. This study sets out to fill this gap. The aim is to identify significant vegetation structural properties that help to restore the fertility of the soil for agricultural productivity and to identify the soil properties that help to sustain the regeneration of vegetation structural properties.

Materials and methods

The study area (Orogun) which is part of the low deltaic plain of southern (Niger Delta) Nigeria is bordered to the north by Abraka in Ethiope East Local Government, to the south by Emevor Isoko North Local Government and to the west by Kokori in Ethiope East local Government and to the east by Abbi and Amai in Ukwuani Local Government Areas respectively (Fig. 1). The study area is located between latitudes 5⁰26'N and 5⁰48'N and between longitudes 5⁰51'E and 6⁰12'E. Other details of the study area are contained in Ichikogu (2011a, b, c).

mature forest had the same parent material and were on comparable flat crestral interfluve sites to ensure that catenary variations in soil properties were minimized.

Within each of the secondary forest age categories, ten sample plots of 30 metres X 30 metres were delimited for investigation. Soil sampling follows the procedure described by Boone et al (1999). Soil samples were collected from five points which were located randomly within the 30 metres X 30 metres plots at predetermined depths of 0-10cm and 10-30cm (which shall be referred to as top-soil and sub-soil in subsequent sections) using a core sampler. The approach of sampling from predetermined depths was adopted in order to ensure comparability among samples collected from different sample quadrats in geographically separate locations since the thickness of the soil profile vary from place to place (Ichikogu 2011a). The limit of the top 30cm of the soil was chosen for two reasons. Firstly, the limit of the visible humic horizons usually lies here and secondly, numerous observations of root distributions and direct measurement of labeled-phosphorus uptake (Nye and Foster 1960) indicates that in humid regions nearly all the feeding of the annual crops which replace the fallows takes place within this zone. A total of 100 soil samples were collected from each age category on the basis of 50 samples from topsoil and 50 samples from subsoil. These samples of soil were mixed into a composite of 10 composites for each soil depth (on the basis of five samples constituting a composite sample) for chemical analysis. Since there were three age categories and a mature forest, a total of 80 soil composite samples were used for chemical and physical analysis. Eighty composite samples collected were air-dried, crushed thoroughly mixed and passed through a 2mm mesh sieve in readiness for analysis.

Mature forest in Orogun

10-year old fallow in Orogun



5-year old fallow in Orogun



1-year old fallow in Orogun



Plate 1: Fallows and secondary forests in different stages of regeneration

The soil properties analyzed are soil organic matter, bulk density, and total porosity, water holding capacity, soil pH, available phosphorus and effective cation exchange capacity. Soil pH was determined potentiometrically (Aweto, 1981a). To determine the soils water holding capacity, 5 soil samples were collected at 0-10 cm and 10-30 cm soil depths respectively in each of the 30 X 30 metres plots, air dried and taken to the laboratory for analysis. The soil water holding capacity was determined as the difference between field capacity (FC) and permanent wilting point (PWC). Bulk density was analyzed by the core method. Total porosity values were calculated from bulk density values using an assumed particle density value of 2.65g/cm^3 (Vomocil 1965). Available phosphorus was determined by leaching the soil with Bray and Kurtz solution (0.025M HCL to 0.03MN H_4F). The concentration of available phosphorus was determined calorimetrically with “spectronic 20” spectrophotometer after the colour had been developed in soil extract using the ascorbic acid method (Molindo, 2008). Effective cation exchange capacity was determined by the summation method (Chapman, 1965); summation of the exchangeable cations in Ichikogu (2011a). The Walkley-Black method was used in this study to determine the soil organic carbon content, while the soil organic carbon was converted to soil organic matter by multiplying the organic carbon values by a factor of 1.729 (Walkley and Black 1934).

Vegetation biomass parameters such as tree height, tree diameter and tree density and basal area were measured in five sub-plots selected in each 30 metres X 30 metres plot. For the purpose of the field investigation, a tree was defined operationally as woody plant of erect habit with a minimum breast height diameter (i.e. at the height of 1.5m above the ground) of 2cm. For the measurement of tree diameter, the circumferences of the tree trunks were measured at breast height with flexible measuring tape around the trunk of the trees. The circumference measurements were then converted into diameter values by dividing circumference values by 3.142 (that is, Π). The diameters of saplings in the 1-year old secondary forest plots were determined at the ground level as was done by Aweto (1981a). Tree basal area was measured by using the equation based on the formula for the area of a circle (Area = Πr^2).

Where:

r = radius

$\Pi = 3.142$

And the formula for radius (r) = $\frac{\text{diameter}}{2} = \frac{\text{DBH}}{2}$

Therefore:

Tree basal area = $\frac{(\text{DBH})^2 \Pi}{200}$

Where

DBH = Diameter at breast height in centimetres.

After calculating the individual tree basal area using the above formula the total tree basal area per hectare was obtained by multiplying the average individual tree basal area by the total number of trees per hectare.

The height of trees was measured by measuring the angle of the tree tops and the distance from the point of observation with Abney level and measuring tape respectively (i.e. the angle of the tree was measured using the Abney level while the tape was used to measure the distance from the point of observation to the tree). Based on these measurements, tree height was calculated using the formula:

$H = X \tan \Theta$

Where

H = Height of tree

X = Distance of observer from tree

Θ = Angle of tree top from observer

The tree density was obtained by counting the number of individual that have attained tree status in each 30 metres X 30 metres plot and subsequently converting the values to tree density per hectare.

Data analyses

Multiple regression was used to model the relationship between soil organic matter, pH, ECEC, water holding capacity, total porosity and available phosphorus on vegetation structural properties (tree height, tree density, tree diameter, tree basal area and estimated aboveground biomass) using the panel/pooled regression tools in the E-views software package. To do this the ten soil composite samples analyzed in the laboratory for the 1-year old fallow form sample number 1 to 10, those of the 5-year old fallow, 10-year secondary forest and mature forest form sample 11-20, 21-30 and 31-40 respectively, which were used in the regression, while the values of each of the soil structural properties for each of the ten quadrats in the 1-year old fallow, 5-year old fallow, 10-year old secondary forest and the mature forest form sample number 1-10, 11-20, 21-30 and 31-40 used in the regression analysis (i.e. soil physicochemical properties under each quadrat was recorded against the corresponding vegetation structural property values for that quadrat for the regression analysis). The independent variables (soil parameters) were tested for multicollinearity using the criteria of Hauser (1974).

Results

Table 1 shows the mean values of the vegetation structural properties in each of the secondary forest categories and the mature forest. Table 2 shows the mean values of the soil physico-chemical properties used for the stepwise regression analysis.

Relationships between soil properties and vegetation structural properties – multiple linear regression

The relationships between vegetation structural properties and soil properties are shown in the regression models below:

Basal Area of Vegetation

Regression of basal area on the seven soil variables produced a regression model of the form:

$$\text{LOGBA} = -18.96 + 5.64\text{ECEC} + 1.01\text{TP} + 0.22\text{SOM} + 0.39\text{WHC}$$

Where:

LOGBA = Logarithm of Basal area

ECEC = Effective cation exchange capacity

TP = Total porosity

SOM = Soil organic matter

WHC = Water holding capacity

Analysis of variance test for the significance of the regression coefficients yielded an 'F' ratio of 138.116 which is significant at 0.01 levels of significance. The six soil parameters jointly explain 95.33% of the variation in vegetation basal area. However, 't' test for the significance of each of the soil variables towards the explanation of the variation in basal area shows that five out of the six soil parameters entered into the regression are significantly correlated with basal area. These five soil parameters are: soil organic matter, total soil porosity, soil water holding capacity, effective cation exchange capacity and soil available phosphorus.

Soil pH is correlated with basal area but the 't' value is not significant at 0.05 level of significance of the 't' statistics. The soil pH is therefore not significantly correlated with vegetation basal area.

Tree Density

Regression of tree density on the six soil parameters produced a regression model of the form.

$$TD = -3.48 + 2.14SOM + 10.25ECEC + 0.63TP + 0.84WHC$$

Where

TD = Tree density

All the other variables are as defined earlier

From the regression in table 4, all the variables considered except soil pH bear positive relationships with tree density. However, the influence of pH and available phosphorus in explaining variation in tree density are not statistically significant. The positive and significance contributions of soil organic matter, effective cation exchange capacity, total porosity and water holding capacity in explaining variation in tree density is consistent with the findings of many previous studies (e.g. Aweto 1981, Sanchez 1991, Raphael *et al.*, 2000).

Tree Height

Regression of tree height on the six soil parameters produced a regression model of the form:

$$TH = 2.44 + 0.843SOM + 0.146WHC + 6.70ECEC + 1.60TP$$

Where

TH = Tree height

All the other variables are as defined earlier

All the six soil variables jointly explain 62% of the variation in tree height. All the soil variables except pH have positive relationships with tree height. Three soil variables – soil organic matter, effective cation exchange capacity and water holding capacity are statistically significant in explaining variation in tree height, while the remaining three- total porosity, pH and available phosphorus are not statistically significant in explaining variation in tree height.

Tree Diameter

The regression of tree diameter on the six soil explanatory variables yielded an 'F' value of 103.24 which is significant at 0.0001 levels of the 'F' statistics. The six soil explanatory variables jointly explain 66.38% of the variation in tree diameter. The regression of tree diameter on the six soil parameters produced a regression equation of the form:

$$\text{LogTDA} = 26.85 + 2.01SOM + 1.57ECEC + 5.78WHC + 0.07TP + 0.004P$$

Where

LogTDA = Logarithm of tree diameters

All the other variables are as earlier defined.

The six soil variables except soil pH have positive relationships with tree diameter. However, the influences of pH and available phosphorus in explaining variation in tree diameter are not statistically significant. The influences of soil organic matter, total porosity, water holding capacity and effective cation exchange capacity are positive and statistically significant at $P < 0.05$. This findings is consistent with those of Aweto (1981a) (who reported positive and significant relationships between these soil variables and tree size) and that of Bakhtiar and Ali (2011).

Moving away from the individual regression models, we now turn to the goodness of the models in general. From the results presented in tables 3-6, and going by the diagnostic statistics of the models namely R-squared, and 'F' statistics, it can be inferred that the models constructed adequately explain the relationships between soil physio-chemical properties and vegetation structural parameters.

The data collected were pooled and analyzed using the panel/pooled regression tools in the E-views software package. The results obtained show that soil organic matter, water holding capacity, total porosity and effective cation exchange capacity are

significantly related to the vegetation structural parameters (tree height, tree density, tree basal area and tree diameter). While the soil pH and available phosphorus are not statistically significantly related to the vegetation parameters.

Discussion

The result of multiple regression analysis shows that vegetation structural parameters (tree height, tree diameter, tree density and basal area) are significantly related to soil physico-chemical properties. The signs of the regression analysis suggest that the vegetation structural parameters are negatively related to soil pH and soil bulk density. This is not strange because increase aboveground biomass, tree density, tree basal area, tree diameter and tree height result in increase litter fall and increase root concentration in the soil resulting in increase microbial activities and rapid withdrawal of soil nutrients (exchangeable cations) by plants thereby leading to decrease in soil pH.

It is often assumed that forest biomass is related to soil nutrient status (Aweto 1981); this study corroborates that assumption as revealed by the significant correlation between aboveground biomass and the soil physico-chemical properties. However, this assertion should be taken with caution. It is noteworthy that, despite its huge biomass, the 10-year fallow has soils that have lower concentration of nutrients whilst the soils under the small aboveground biomass 5-year old secondary forest have comparatively high concentrations of soil nutrients probably due to rapid nutrient immobilization by the growing vegetation that is associated with transition from pseudo-woody fallow by the fifth year to woody secondary forest by the tenth year. In contrast the mature forests have comparatively higher aboveground biomass and soil nutrients than both the 10-year and 5-year old secondary forests. Many factors, including different patterns of regeneration, might influence forest structural properties. A proportional relationship between soil nutrient concentrations and forest structural properties would be more likely in young secondary forests (as long as other factors are not limiting) than in mature secondary forests with efficient nutrient cycling and long term nutrient accumulation in living matter from the soil. This also was the opinion of Toky and Ramakrishnan (1983) who reported rapid depletion of soil nutrients by the 10th year of fallow.

Conclusion

In general, this study highlighted the interactions between soil physico-chemical properties and vegetation structural properties of secondary forests regenerating from degraded abandoned rubber plantation in south-southern Nigeria. It revealed that soil organic matter, total porosity, water holding capacity, available phosphorus and effective cation exchange capacity significantly affect vegetation structural properties. Based on these results, in the management of secondary forest regenerating from degraded plantation specific consideration should be given to

changes in soil physico-chemical properties. It is suggested that if the structural properties of the vegetation is to be improved, the fertility of the soil is to be sustained or enhanced, and the degeneration of the secondary forests regenerating from degraded abandoned rubber plantation is to be circumvented secondary forest regenerating from degraded abandoned plantation should be left for at least five to ten years to grow fallow before they are recultivated.

Table 1: Soil physico-chemical characteristics (Topsoil), N =10

Soil properties	1-year old	5-year old	10-year old	MF
OM	2.12	3.09	4.74	5.10
WHC	40.29	48.16	61.17	64.04
TP	56.11	56.98	59.13	61.89
pH	6.14	5.81	5.3	6.0
P	4.91	8.81	4.57	11.6
ECEC	7.14	9.07	8.04	10.18

Note: OM = Organic matter (%), WHC = Water holding capacity (%), TP = Total porosity (%), P = Available phosphorus (Mg/g), MF = Mature forest.

Table 2: Mean tree density (number of trees DBH > 2 cm /ha), tree height (in metres), tree diameter (in cm), Tree basal area (in m²ha⁻¹)

Vegetation parameters	Fallow age Categories			MF
	1-year fallow	5-year fallow	10-year fallow	
Tree density	56	1488	2840	2168
Tree height	1.74	4.18	6.44	8.77
Tree diameter	1.03	4.75	9.23	20.65
Tree basal area	0.16	2.76	18.21	72.99

Table 3: Ordinary least square multiple regression of basal area on the six soil explanatory

Independent variables	B coefficient	Std error	T value	Significant level of t	R ²	F value
ECEC	5.6432	0.9816	5.74898	0.0000	0.9533	138.116
TP	1.010241	0.4814	2.0985	0.0316		
SOM	0.2243	0.1042	2.1526	0.0102		
WHC	0.3946	0.1858	2.1238	0.0146		
P	-1.4897	0.8044	-4.1050	0.0001		
pH	-1.3060	0.7564	-1.7266	0.0939		
Constant	-18.9600	6.9426	-2.7310	0.0092		

Table 4: Ordinary least square multiple regression of tree density on the six soil explanatory variables

Independent variables	B coefficient	Std error	't' value	't' significant level	R ²	F value
SOM	2.1422	0.7001	3.0598	0.0023	0.8946	41.133
ECEC	10.2536	3.0422	3.3705	0.0006		
TP	0.6324	0.3292	1.9210	0.0321		
WHC	0.8421	0.3342	2.5197	0.0134		
pH	-2.2436	1.3963	-1.6068	0.0864		
P	0.3624	0.8616	0.4206	0.6026		
Constant	-3.4813	12.6965	-0.2742	0.8022		

Table 5: Ordinary least square multiple regression of tree height on the six soil explanatory variables

Independent variables	B coefficient	Std error	't' values	't' significant levels	R ²	F
SOM	0.7913	0.2010	3.9368	0.0001	0.6203	17.341
ECEC	7.0203	2.1042	3.3363	0.0005		
WHC	0.1711	0.0132	12.9621	0.0000		
TP	1.5633	2.0011	0.7812	0.3827		
pH	-1.5004	1.2161	-1.2338	0.2457		
P	0.6382	0.8233	0.7752	0.3934		
Constant	2.7354	11.1891	0.2445	0.8341		

Table 6: Ordinary least square multiple regression of tree diameter on the six soil explanatory variables

Independent variables	B coefficient	Std error	't' values	't' significant levels	R ²	F
SOM	1.0240	0.6001	1.7063	0.0932	0.6638	103.2436
ECEC	0.7524	0.0426	17.6618	0.0000		
WHC	4.8716	1.9924	2.4451	0.0241		
TP	0.0621	0.0086	7.2209	0.0000		
pH	-0.0064	0.3923	-0.0163	0.9836		
P	0.0042	0.0018	2.3333	0.0283		
Constant	14.8502	8.3647	1.7753	0.0821		

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