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Influence of Soil Physico-chemical Properties on the Distribution of Woody Tree/Shrub Species in South-Southern Nigeria

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ABSTRACT Variations in soil physical and chemical properties influence the speciation and distribution pattern of flora in a given environment. Plants species like animals and humans alike are attracted to locations where conditions are favourable to them. The differences in the distribution and abundance of plant species in any environment are therefore indications of the variation in biophysical components of the environment such as soil, water, topography among others. The present study examined the influence of soil properties on the distribution of woody tree/shrub species. Quadrat method was employed to collect soil and vegetation data from fifteen randomly selected plots of 20 m x 20 m. Vegetation result showed that *Elaeis guineensis, Anthocleista vogelii, Alstonia boneii, Baphia nitida, Dialium guineensis, Pycnanthus angolensis, Havea brasillensis, Pentacleithra macrophylla, Musanga cecropioides* and *Anthonata mycrophylla* were the most dominant tree/shrub species in the area. The result of step-wise multiple regression analysis ($P<0.05$) identified the combination of Silt + CEC + BS, Av. P + silt, CEC + OC and silt + CEC as well as individual soil properties of Av. P, TN, silt and CEC as soil variables that influenced the distributional pattern of tree/shrub species in the area. It was concluded that the spatial distribution and densities of tree/shrub species in area was due to the variation in the levels of essential soil nutrients within their range of tolerance.

INTRODUCTION

At different spatial and time scales, biotic organisms respond positively to conditions that are favourable or within their range of tolerance. As such, different organisms mostly plants are known to have different climatic and edaphic requirements. The variations in climatic and edaphic conditions influence the speciation, survival and distribution pattern of flora in a given environment. Plants like animals and humans alike are attracted to locations where the site conditions are favourable to them, which suggest that differences in the distribution and abundance of plant species in any environment are an indication of the variation in soil properties (Graham et al. 2005; Engler and Guisan 2009). A sound understanding of soil properties and their relationships with flora distribution is believed to be highly essential for integrated and sustainable flora management programmes (Udoh et al. 2007). The growth ,therefore, of flora and their geographic distribution is greatly affected by the environment. This is because if any environmental factor is less than ideal, it limits a plant's growth and/or distribution. For example, only plants that adapt to limited amounts of water can live in areas like deserts, while water loving plants are found around water-logged areas.

However, directly or indirectly, most plant problems are caused by environmental stress, and in most cases, poor environmental conditions like insufficient nutrients damage a plant directly which in the long-run limits its abundance at both taxonomic and distribution scales. In other cases, environmental stress weakens a plant and makes it more susceptible to disease or insect attack. Environmental factors that affect plant growth include light, temperature, water, humidity and nutrition (soil fertility). However, understanding the relationship between certain soil properties and specific flora species would act as a guide to farmers, horticulturists and land use planners alike to recognize the likely soil conditions that are suitable for a particular purpose. Such knowledge may be applied in mineral prospecting (Veeranjaneyulu and Dhanaraju 1990) and also as a way to restore areas greatly in sparse supply.

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Several studies have, however, emphasized the influence of varying soil properties on the distribution and abundance of flora species in different locations (Aweto 1981; Ukpong 1994; John et al. 2007; Udoh et al. 2007; Zare et al. 2011; Cannone et al. 2008; Medinski 2007). These studies are, however, not exhaustive as they identified soil properties of certain locations/environments that influence the distribution of flora species. On this note, more studies are needed to identify and understand the dynamics in flora distribution in different ecosystems. Indeed, the surrounding vegetation in Tinapa Business and Leisure resort is a highly regenerative secondary forest characterized by dense and luxuriant forest structure after series of anthropogenic disturbance mostly illegal logging and farming activities. The vegetation of the area over nine years of abandonment as a result of its seizure by the Cross River government is dominated with different tree/shrub species of varying range of speciation, distribution and abundance. Various factors, however, account for the varying distribution pattern of species in the area, while some species are clustered and have wide range of occurrence (relative frequency); others are fairly or randomly distributed and many others are rarely encountered. Understanding soil properties that influence the distribution of flora species in the area is imperative, as it helps to provide baseline information for restoration attempts, mostly as the ecological restoration of planting trees are ongoing in places where vegetation was initially destroyed to erect tourism structures. It is on this background that the present study attempts to identify prominent soil properties that influence the distributional pattern of tree/shrub species in the area.

MATERIALS AND METHODS

Study Area

This study was carried out in Tinapa business and leisure resort in Cross River State, Nigeria. Tinapa business and leisure resort lies between latitude 05° 022′ and 05° 042′ N and longitude 08° 072′ and 0° 022′ E. The area falls approximately along the coastal fringes of Cross River State where the rainy season lasts for about 10 months, with dry months having less than 60 mm of rainfall. The nearness of the area to the Atlantic Ocean has a moderating effect on its temperature with highest average daily maximum of 35 ^{o}C and recorded mean actual temperature of 26 ^{o}C (Akpabio et al. 2006). The area has an average relative humidity of 80-90% at 10am during the wet season and is well-drained that storm water disappears 30 minutes after a typical rainstorm (Eze 2008). The soils in Tinapa are ferrallitic with dominant colour of yellowish-brown (Soil Map of Nigeria 1964); and are generally deep, porous, and weakly structured and well drained. The vegetation of the area is a mixture of mangrove and tropical rainforest. The rainforest is further subdivided into the lowland rainforest and the freshwater swamp forest. The mangrove swamp is found in the southern fringe of the area, and stretches from the freshwater limits to the ocean beaches (Iwara 2009). The present study was carried out in the lowland rainforest zone about 3 km from the tourism hub. The rich and luxuriant vegetation of the area has been subjected to severe degradation for the construction of tourism facilities like Studio Tinapa, Nollyhood Tinapa, Amba hotel, recreational centre, shopping complexes and administrative blocks and roads among others. Buffer vegetation is found some distance away from the tourism environment.

Soil Sampling

The quadrat approach (systematic line transect) through the establishment of plots across the forest floor was employed to collect soil and vegetation data. Three belt transects of 140m in length with a distance of 15 meters in between were laid in the lowland belt of the forest. Seven plots of 20m x 20m in dimension were established in alternate direction along each transect, while five (5) plots from each transect were randomly selected and used to obtain soil and vegetation data. The vegetation data determined included population of tree/shrub species with woody stems ≥10 centimeters (cm) dbh (DBH 137cm from the ground) were identified and counted. In each plot, tree/shrub density and percentage distribution were determined. In the same way, fifteen (15) soil samples were collected using a soil auger at rooting depth of 30cm. The soils were put in polythene bags with labels; they were air-dried and passed through a 2 mm sieve in order to separate the soil from stones. Thereafter, particle size composition was determined using the hydrometer method (Bouyoucos 1926); organic carbon by the Walkley-Black method (1934); total nitrogen by the Kjeldahl method (Bremner and Mulvaney 1982); available phosphorus was determined by the method of Bray and Kurtz (1945). The soils were leached with 1N neutral ammonium acetate to obtain leachates used to determine exchangeable bases adapted from the method described by Daly et al. (1984). Soil cation exchange capacity was determined by the summation method; while pH values were determined using a glass electrode testronic digital pH meter with a soil: water ratio of 1:2.

Data Analysis

Two data matrices representing soil and vegetation characteristics were constructed and the SPSS for windows (Ver. 17.0) software package was used for statistical analysis mainly averages, standard error, percentages and multiple regression analysis (MRA). MRA using the stepwise approach was performed in order to determine the relative contributions of soil physical and chemical properties to the variation in the distribution pattern of tree/shrub species in the area. Accordingly, soil properties and values were entered in simultaneously and their strength assessed. Thus, only significant predictor variables (soil properties) were retained and included in the model. The retained predictor variables were used to make inference as variables influencing tree/shrub species distribution. On the other hand, ten dominant tree/shrub species selected as criterion variables were determined based on their density and relative distribution (relative frequency). Density was determined as the number of tree/shrub species per ha (Kathiresan 2007 and Adams et al. 2007; Udoh et al. 2007), and relative distribution was frequency of occurrence of tree/shrub species divided by the total frequency of all species.

RESULTS

Physical Properties of Soil

The soil particle size composition of soil in the area is shown in Table 1. The soil was principally sandy; with sand constituting more than 70% of the inorganic mineral fragment. The soil was loamy-sand having been derived from granitic parent materials.

Table 1: Physical properties of soils [a]

Soil properties	*Values*
Clay (%)	4.62±0.41
Silt (%)	10.93±0.77
Sand (%)	84.45±1.06

[a] values are means ± standard errors.

Chemical Properties of Soils

The chemical properties of soils are shown in Table 2. The mean proportions of organic carbon (OC) and total nitrogen (TN) were1.73% and 0.40% respectively; while the mean value of cation exchange capacity (CEC) in the soil was 10.05meq/100g. The high contents of OC, TN and CEC in soil of the area may be attributed to the rate of nutrients returned to the soil through the fall and subsequent decay of litter made possible by the high temperature and precipitation in the area. The mean proportions of exchangeable bases, particularly exchangeable calcium, magnesium, sodium and potassium were low ranging from 0.09 to 1.40 meq/100g. The low proportions of exchangeable bases in the soil of the area were attributed to the high rainfall in the area (Table 2). These basic cations according to Foth (2006) become insufficient in the soil for plant uptake as a result of continuous leaching caused by increased precipitation. In addition, the high proportion of Av. P in the soil was due to the application of fertilizers to improve the soil nutrient by farmers prior to the acquisition of the land, by the Cross River State government in 2002. Chidumayo and Kwibisa (2003) reported similar result when they observed higher Av. P in cultivated plots than in mature woodland and fallow plots, and attributed the increase to the application of P-fertilizers to crops by farmers.

Table 2: Chemical properties of soil[a]

Soil properties	*Values*
Organic Carbon (%)	1.73±0.08
Total Nitrogen (%)	0.40±0.02
Exch. Calcium (Meq/100g)	1.38±0.05
Exch. Magnesium (Meq/100g)	0.74±0.01
Exch. Sodium (Meq/100g)	0.09±0.00
Exch. Potassium (Meq/100g)	0.17±0.00
CEC (Meq/100g)	10.05±0.59
Av. P (Mg kg)	68.80±4.26
pH	3.15±0.07

[a] Values are means ± standard errors.

Composition of Tree/Shrub Species

A total of 23 tree/shrub species belonging to 13 families were encountered across the 15 plots. *Fabaceae* was the most ecologically dominant family with 114 stems, followed by *Rubiaceae* with 84 stems and then *Euphorbiaceae* and *Apocynaceae* with 70 and 41 stems respectively; while *Sapotaceae*, *Irvingiaceae* and *Anacardiaceae* were the least families with 9 and 10 stems respectively (Table 3). Tree/shrub species in the area indicated relative selectivity in which they occurred as only two of the encountered species precisely *Anthocleista vogelii* and *Dialium guineensis* were present in the 15 sampling plots. 10 tree/shrub species based on their density and relative frequency were selected to examine the relative effect of soil properties on their occurrence. The 10 most abundant species were *Elaeis guineensis, Anthocleista vogelii, Alstonia boneii, Baphia nitida* and *Dialium guineensis* with densities of 1150 ha^{-1}, 1050 ha^{-1}, 1050 ha^{-1}, 725 ha^{-1}, and 675 ha^{-1} as well as relative frequencies of 6.36%, 6.82%, 6.36%, 5.45% and 6.82% respectively. Others were *Pycnanthus angolensis, Havea brasillensis, Pentacleithra macrophylla, Musanga cecropioides* and *Anthonata mycrophylla* with densities of 675 ha^{-1}, 675 ha^{-1}, 600 ha^{-1}, 650 ha^{-1} and 575 ha^{-1} respectively. The relative frequencies for these species were 4.09%, 5.91%, 4.55%, 6.36% and 4.55% respectively (Table 3). These selected species showed wide range of distribution compared to others that were site selective.

Influence of Soil Properties on Some Dominant Tree/Shrub Species

The result of step-wise multiple regression analysis of the joint contribution (R^2) of soil properties to the relative occurrence and density of 10 dominant tree/shrub species are shown in Table 4. The result shows that out of the 10 dominant vegetation variables (tree/shrub species) entered consecutively into the model, only five were significant, that is, showed some form of relationship with the predictor variables. Also, out of the 12 predictor variables (soil properties) simultaneously entered into the model, only five showed significant effects on the distribution of species; the joint contribution of the soil properties indicated that silt + CEC + BS, Av. P + silt, CEC + OC and silt + CEC contributed to the distribution of flora species in the area. This

Table 3: Density and relative distribution of tree/shrub species in the area[b]

Tree/shrub species	*Families*	*No. of stems ha^{-1}*	*F*	*R_f(%)*
Elaeis guineensis[b]	*Arecaceae*	1150	14	6.36
Anthocleista vogelii[b]	*Rubiaceae*	1050	15	6.82
Dialium guineensis[b]	*Fabaceae*	675	15	6.82
Rauvolfia vomitoria	*Apocynaceae*	500	8	3.64
Pycnanthus angolensis[b]	*Mystricaceae*	675	9	4.09
Baphia nitida[b]	*Fabaceae*	725	12	5.45
Alstonia boneii[b]	*Rubiaceae*	1050	14	6.36
Anthonata mycrophylla[b]	*Fabaceae*	575	10	4.55
Irvingia gabonensis	*Irvingiaceae*	250	4	1.82
Morinda lucida	*Fabaceae*	475	7	3.18
Pentacleithra macrophylla[b]	*Mimosoidea*	600	10	4.55
Bridelia ferruginea	*Euphorbiaceae*	425	11	5.00
Havea brasillensis[b]	*Euphorbiaceae*	675	13	5.91
Brachystegia eurycoma	*Fabaceae*	200	5	2.27
Funtumia elástica	*Apocynaceae*	525	11	5.00
Mangifera indica	*Anacardiaceae*	250	6	2.73
Dacryodis edulis	*Sapotaceae*	225	4	1.82
Ceiba pentandra	*Bombacaceae*	375	9	4.09
Antidesima vogeliana	*Stilaginaceae*	425	9	4.09
Musanga cecropioides[b]	*Moraceae*	650	14	6.36
Uapaca guineenis	*Euphorbiaceae*	400	8	3.64
Alchornea cordifolia	*Euphorbiaceae*	250	7	3.18
Albizia zygia	*Fabaceae*	200	5	2.27
Total	Σ 13 families	12325	220	100.00

R_f = Relative frequency [b]Dominant tree/shrub species is obvious as silt, BS, Av. P, CEC and OC are essential macro nutrients that influence flora distribution; Av. P (available phosphorus) is an essential nutrient for plant growth, and is a primary fertilizer element, this element in the area was enhanced due to the application of fertilizers to improve the soil nutrient by farmers prior to the acquisition of the land, hence its joint and significant determinant of species distribution. CEC is an important property of soil because it is a useful indicator of soil fertility and nutrient availability for flora growth (Hazelton and Murphy 2007). The result further shows that for *Anthocleista vogelii*, total nitrogen (TN) was the only soil property that significantly ($p<0.01$) contributed 48% to its occurrence; for the occurrence of *Baphia nitida*, two effects were noticed, first, cation exchange capacity (CEC) was retained as the only soil property that significantly contributed and influenced its relative distribution (31%). Secondly, the rate of occurrence was however significantly ($p<0.01$) increased to 61% with the addition of organic carbon (OC). This indicated that the combination of CEC + OC increased the relative frequency and density of *B. nitida*. This is apparent as both nutrients are essential for plant growth, and high amount in the soil helps to improve soil quality which in the long-run encourages plant growth and sustainability (Aweto 1981; Aweto and Dikinya 2003).

In addition, silt significantly ($p<0.01$) contributed 48% to the occurrence of *Dialium guineensis*; while for *Musanga cecropioides*, three models explaining its level of occurrence were identified, in the first model, silt significantly ($p<0.05$) contributed 32% to the occurrence of *M. cecropioides* and the second model revealed that silt + CEC significantly ($p<0.05$) contributed 53% to its wide spread in the area, while the inclusion of base saturation (BS) in the third model resulted in 73% of the relative frequency and density of *M. cecropioides* ($p<0.01$) This perhaps implies that the distribution pattern in terms of frequency and density of *M. cecropioides* is influenced by the combination of the three soil properties. This result is expected as silt because of its smaller particle size, is known to have a slower water intake, but a higher nutrient and water holding capacity. Silt, according to Ukpong (1994), is a physical site quality associated with nutrient availability, mostly CEC and organic carbon; and it facilitates forest regeneration. On the other hand, BS determines if the soil has the physical characteristics necessary for anchorage and growth, the BS obtained for soil in the area is suitable for flora establishment due to its low BS and high organic matter that encourages root penetration (USAID 2008). However, for *Anthonata mycrophylla*, just like that obtained for *B. nitida*, two soil properties significantly ($p<0.01$) determined its spatial spread; Av. P (available phosphorus) accounted 51% in the relative frequency and density of occurrence of *A. mycro-phylla* in the area, while the combination of Av. P + silt significantly ($p<0.01$) resulted in 68% of its distribution. From the soil variables identified above, it is pertinent to note that silt + CEC + BS, Av. P + silt, CEC + OC, silt + CEC, Av. P, TN, silt and CEC constituted the main soil variables influencing the distributional pattern of tree/shrub species in the area.

The influence of soil properties on the distribution of flora have been documented by scholars in the past. Aweto (1981) identified organic matter and clay proportion as soil variables that exerted marked influence on the distribution and abundance of tree species; Ukpong (1994) identified nutrient and salinity as fac-

Table 4: Step-wise multiple regression result of significant soil and vegetation variables

Soil properties	*Tree/shrub species*	*R*	*R^2*	*F-values*	*Regression equations*
TN	*Anthocleista vogelii*	0.69	0.48	10.901*	Y = 0.25 + 5.87TN
CEC	*Baphia nitida*	0.56	0.31	5.342**	Y = 3.97 – 0.22CEC
CEC + OC	*Baphia nitida*	0.78	0.61	8.504*	Y = 5.75 – 0.27ECE – 0.550C
Silt	*Dialium guineensis*	0.69	0.48	10.881*	Y = 2.91 – 0.39S
Av. P	*Anthonata mycrophylla*	0.72	0.51	12.714*	Y = -1.44 + 0.04Av. P
Av. P + silt	*Anthonata mycrophylla*	0.83	0.68	11.687*	Y = -1.86 + 0.03Av. P + 0.23S
Silt	*Musanga cecropioides*	0.56	0.32	5.593**	Y = 0.65 + 0.26S
Silt + CEC	*Musanga cecropioides*	0.73	0.53	6.145**	Y = 2.16 +0.29S – 0.16CEC
Silt + CEC + BS	*Musanga cecropioides*	0.85	0.73	8.853*	Y = 4.45 + 0.29S – 0.26CEC – 0.05BS

*Significant at 1% alpha level, **Significant at 5% alpha level tors explaining species variation in mangrove swamps; John et al. (2007) identified soil pH as the strongest soil factor that influenced the distribution of species in three tropical forest; Udoh et al. (2007) identified Mn, clay content and TN as soil factors that influenced species distribution mostly weeds; Zare et al. (2011) identified soil texture, salinity, effective soil depth, available nitrogen, potassium, orga-nic matter, lime and soil moisture as major soil factors responsible for variations in the pattern of vegetation ; Cannone et al. (2008) observed that vegetation was related to the chemistry of the surface-soil layer, including nitrate, organic carbon, C/N ratio and water content, and also the active-layer depth, while Medinski (2007) identified clay + silt, EC and pH to influence the distribution and life form abundance. These results perhaps implied that tree/shrub species were selective of nutrients as well as depended entirely on the spatial heterogeneity of soil in nutrient distribution.

CONCLUSION

The result obtained has apparently shown that tree/shrub species in Tinapa were selective with respect to varying soil properties. It also revealed that silt + CEC + BS, Av. P + silt, CEC + OC and silt + CEC contributed substantially to the distribution and relative occurrence of tree/shrub species in the area. Particularly, silt + CEC + BS, Av. P + silt, CEC + OC and silt + CEC influenced the occurrence of *Musanga cecropioides, Anthonata mycrophylla* and *Baphia nitida*. Other soil properties that influenced the distribution of tree/shrub in the area were Av. P, TN and CEC. This result therefore indicated that the spatial distribution and densities of tree/shrub species in each plot was related to the spatial heterogeneity in soil resource distribution in such a way that the pattern of distribution suggested speciation to different levels of essential resources within their range of tolerance.

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