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Ecological Characteristics of Para Rubber (*Hevea brasiliensis* Muell. Arg) Productivity in the Niger Delta Region of Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author BWB designed the study, wrote the protocol, and wrote the first draft of the manuscript. Author IMA performed the statistical analysis. Author EA performed the soil analysis and interpreted the results, and author EEE managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The Niger Delta region is the rubber belt of Nigeria, and rubber production in the area which is dominated by smallholder plantations, is characterized by low latex yield, due mainly to ageing plantations, unsuitable agronomic practices and high cost of labour. Differences in soil and weather attributes of the area require that farmers adopt location-specific management practices in order to increase yield. Consequently, the relationship between medium-term latex yield of rubber and soil and weather attributes were studied in three rubber growing areas of the Niger Delta, with a view to assessing the fertility status of soils supporting rubber and determining the critical weather factors so as to make recommendations on best management practices. Weather data for estate

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plantations located in Calabar (latitude 5º 7' N and 8º 18' E), Nko (latitude 5º 5' N; 8º 11' E), and Uyo ((latitude 5º 0' N; 7º 10' E), spanning a period of 20 years (1993-2012), were obtained from the Nigerian Meteorological Service (NIMET) and subjected to multiple linear correlation and regression analysis with archival latex yield data from the various estates covering the same period. The minimum amount of rainfall received was 2148.7 mm/annum spread over a period of 135 days at Nko, while a maximum of 3968.7 mm/annum of rainfall spread over 143 days was received in Calabar. Rainfall intensity varied widely across the three locations, while the relative humidity was high, but similar across the locations and the highest ambient temperature of about 32ºC was at the Nko plantation. There was high correlation between weather variables and latex yield. The high negative correlation of latex yield with rainfall in Calabar and Uyo suggest that these areas experience excessive rainfall which might result in the prevalence of fungal diseases and frequent disruption of tapping operations. Maximum temperature correlated negatively with yield at Nko implying that measures to reduce evapo-transpiration such as mulching the base of trees and cover cropping should be adopted in this area. The soil texture was sandy loam in Calabar and Uyo, and sandy clay loam at Nko, and although the pH across the estates was within the recommended range of 4.0 - 6.5, the soils at Calabar and Uyo requires liming for sustained high productivity.

Keywords: Niger Delta; rubber; weather; soil texture; soil fertility.

1. INTRODUCTION

Natural rubber (*Hevea brasilliensis* Muell. Arg) cultivation and processing are important aspects of the socio- economic life of the people of the Niger Delta region of Nigeria; the rubber-belt of the country where extensive plantations of the tree crop are found. This area is also the oil palm and crude oil producing belt of the country, and as a consequence, there is competition for land and labour resources. Rubber cultivation is labour intensive and is therefore capable of creating employment opportunities and contributing to Nigeria's external trade [1]. It is estimated that there are about 18 million hectares (ha) of land suitable for cultivation of natural rubber in Nigeria [2,3], out of which about 247,000 ha is under rubber with only 154,000 ha found under tapping [4].

Nigeria was a leading producer of natural rubber before crude oil was discovered and exploited in commercial quantities by the end of the 1950_s. For instance, between 1957 and 1960, the country was the largest producer of the commodity in Africa and sixth largest in the world, contributing about 3 percent of global output [5]. However, production declined progressively for several decades and has only been recently stabilized [6] such that the country is now estimated to produce about 90,000 metric tons per annum [4]. The decline in production was attributed to ageing plantations, difficulty in land acquisition resulting in establishment of plantations in marginal areas, poor agronomic practices, shortage and high cost of labour, poor rubber prices, and inadequate storage facilities [7,8].

Rubber grows over a wide range of conditions and environmental factors other than climate affect the survival of the tree. The optimal climatic conditions for the genus *Hevea* are a rainfall of 2000 mm or more, evenly distributed with no severe dry season and with 125-150 annual rainy days; a maximum temperature of about 29- 34ºC, minimum of about 20ºC and monthly mean of 25- 28ºC; high atmospheric humidity of about 80%, with moderate wind, and bright sunshine for about 2000 hours in a year, at the rate of six hours a day in all months [9]. The rainfall requirement depends on its distribution, length of dry season and water retention capacity of the soil. Under favourable soil conditions, rubber could tolerate a dry season of 4-5 months, during which less than 100 mm of rain is received within this period, or 2-3 months with rainfall less than 50 mm [10]. Extreme weather in terms of long and intense dry spells and heavy rains can substantially reduce harvesting intensity through a reduction in tapping intensity. [11] reported that the critical weather factors in Nigeria to consider in selecting a site for rubber cultivation are maximum ambient temperature and relative humidity at 0900 hours GMT.

The specific climatic requirements of the plant invariably precluded its cultivation from vast areas of Nigeria, but in recent times and in order to meet the growing demand for natural rubber, facilitate crop diversification in traditional rubber-growing areas and upgrade the living standards in non-traditional rubber growing areas, cultivation of the tree is being expanded to sub-optimal areas [12,13], including Taraba and Kaduna States in central Nigeria [14]. Such areas experience stress situations including temperature extremes, prolonged dry periods and low relative humidity. The objective of this study was to identify the critical weather factors and assess the fertility status of soils supporting rubber trees in three contrasting locations of the Niger Delta with a view to recommending best management practices to farmers therein and in proposed new developments.

2. MATERIALS AND METHODS

This study was conducted in Calabar (latitude 5^o 7' N and 8^o 18' E), Nko (latitude 5^o 5' N; 8^o 11' E), and Uyo (latitude 5^0 0' N; 7^0 10' E), shown in Fig. 1. The study area falls within the tropical rainforest zone, with a predominantly primary forest vegetation, as well as regenerated secondary forest in a few places. Weather data for a twenty-year period (1993 to 2012) obtained from the records of the Nigerian Meteorological Agency (NIMET), as well as latex yield figures spanning the same period obtained from the archives of Akim Akim and Nko rubber plantations in Cross River State, and Akwa Rubber Estates in Uyo, Akwa Ibom State, were used for the study. Best agronomic practices are adopted in managing the plantations, while tapping of rubber latex is by the half spiral panel method (1/2 S) with a tapping frequency of d/3.

Each plantation was demarcated into three blocks of 'Young' (7 to 11), 'Prime' (12 to 24), and 'Old' (> 25) years old trees. In each block, an area of 10, 000 m^2 was demarcated and gridded into ten (10) plots of 100.0 × 100.0 m for the purpose of soil sampling. A 120 cm - deep profile pit was dug in each plot, and sampling of the pits carried out as outlined by USDA-NRCS [15], and modified by [16]. The collected samples were analyzed for physico-chemical properties.

Particle size analysis was done by the hydrometer method as outlined in [17], while soil pH was measured with glass electrode pH meter in soil: water suspension of 1:2.5. It was determined electronically on a direct reading pH meter using the glass electrode with a saturated potassium chloride Calomel reference electrode. The pH meter was calibrated and standardized with buffer pH of 4 and 7. The organic carbon content was determined by the Walkey and Black wet-oxidation method as outlined by [17], while exchangeable cations determined by extracting with neutral normal NH_4OAC. Exchangeable Ca and Mg were determined by the EDTA titration method, while K and Na in the leachate were read using EEL flame photometer. The exchangeable acidity was determined by extracting 5 g of the soil extract with 1N KCl and titrating with 0.5N NaOH using phenolphthalein indicator [18], and the effective cation exchange capacity (ECEC) was taken as the sum of the exchangeable cations (Ca^{2+} + Na^+ + k^+ + Mg^{2+}) and the exchangeable acidity.

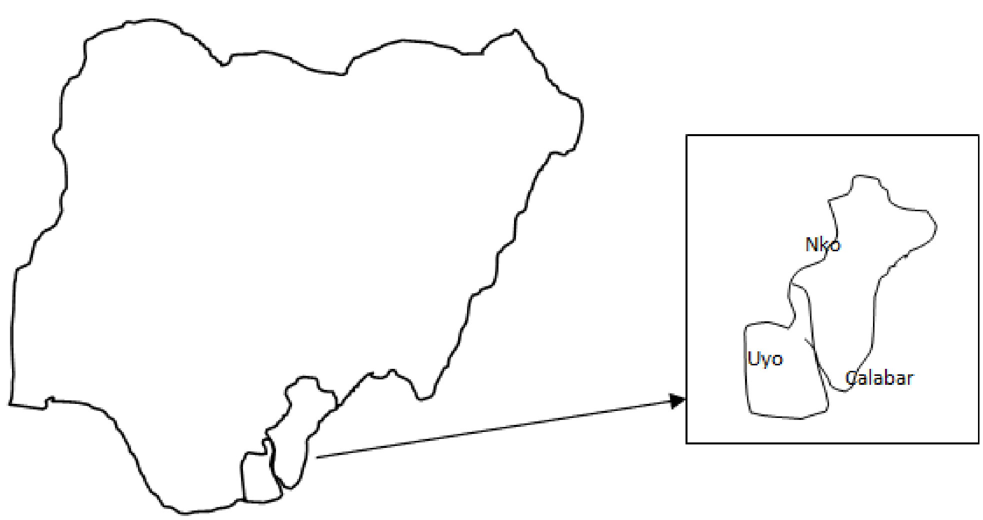

Fig. 1. Sketch map of Nigeria showing Uyo in Akwa Ibom, Calabar and Nko in Cross River States

The per cent base saturation was calculated as follows:

Per cent base saturation (BS) = Ca^{2+} + Mg^{2+} + K^{+} + Na^{+} × 100 ÷ ECEC

The total Nitrogen was determined by Kjedhal digestion and distillation method as described in [19], and available P was extracted by the Bray 2 method [20], and the P read by the [21] method.

The rainfall intensity was derived from the annual rainfall data using the mathematical relationship of [22] as follows:

Rainfall Intensity (mm) = annual amount of rainfall (mm)/annual rainfall duration (days).

The Pearson's product moment correlation and multiple regression model was used to investigate the nature of the relationship between latex yield and weather attributes (i.e. annual rainfall amount, relative humidity at 09 00 hours, and maximum ambient temperature), on the one hand, and latex yield and soil properties on the other. Measures of spread about the mean were based on the coefficient of variability and standard deviation.

3. RESULTS AND DISCUSSION

3.1 Trend Analysis of Some Weather Factors in the Study Area

The trend of the annual cumulative rainfall in the study locations from 1993-2012 showed that the amount of rainfall received across the areas of study was high but variable, and characteristic of the humid tropics. In Calabar where total rainfall was highest, 1993 recorded the least amount of 2511.3 mm while the highest rainfall amount 3968.7 mm fell in 2013. The minimum (1848.7 mm) and maximum (3146.4 mm) amount of rainfall received in Uyo was in 1998 and 2011 respectively, while Nko recorded a maximum annual rainfall of 2717.9 mm in 2009 (Fig. 2).

Rainfall duration in Calabar and Uyo was similar, but higher than at Nko (Table 1). In the period 1993-1997, the average annual number of rainy days was 143 in Calabar and Uyo, compared with 135 at Nko. In the period 1998-2002 the number of rainy days were 137, 134, and 124 at Calabar, Uyo and Nko, respectively while between the years 2003 and 2007, there was no difference in rainfall duration across the study area. Between the years 2008-2012, Calabar received on average five more rainfall days than Uyo and thirteen more than Nko.

The intensity of rainfall from 1993 to 2007 was higher in Calabar compared to Uyo and Nko both of which were similar (Table 1). However, between 2008 and 2012, rainfall intensity in Calabar and Uyo was similar, but higher than at Nko. Calabar also recorded the highest relative humidity of 85%, followed by Nko (82%) and Uyo (81%) (Fig. 3), while the maximum ambient temperature averaged 30.8, 31.7, and 32.1ºC at Calabar, Uyo and Nko, respectively (Fig. 4). From the foregoing, the subsisting climatic conditions in the study area satisfy the recommendation of [9] for rubber cultivation.

3.2 Correlation of Latex Yield with Weather Factors

As shown in Table 2, peak latex yield of 2120.4 kg/ha was recorded in Calabar in 2006, while the least (1096.3 Kg/ha) was in 1995. On the other hand, peak yield at Uyo (1817 kg/ha) and at Nko (1568.3 kg/ha), was obtained in 2008 and 2004, respectively while the lowest yield of 986.3 kg/ha (Uyo) and 1010 kg/ha (Nko) was recorded in 1994 and 1996, respectively.

Latex yield correlated highly significantly with weather variables (P>0.05), and the multiple linear regression models obtained for Calabar, Uyo and Nko, when latex yield was regressed with annual rainfall, maximum temperature and relative humidity were as follows:

$$Y_{cal} = 0.15 - 0.69_{RF} + 0.67_{RH} + 1.01_{TMAX}$$

$$Y_{uyo} = 0.07 - 0.42_{RF} + 0.70_{RH} + 1.17_{TMAX}$$

$$Y_{nko} = 1.02 + 0.33_{RF} + 0.45_{RH} - 5.38_{TMAX}$$

Where:

Y_{cal} = latex yield in Calabar
Y_{uyo} = latex yield in Uyo
Y_{nko} = latex yield in Nko
RF =Total annual rainfall (mm)
RH = Relative humidity (%) at 0900 hour GMT
T_{MAX} = Maximum ambient temperature (ºC)

There was high negative correlation of rainfall with rubber latex yield in Calabar and Uyo, implying that rainfall is excessive in these areas, which might favour the development and prevalence of fungal diseases. An annual rainfall between 1,800 and 2,500 mm is ideal for rubber growing. With higher amounts of rainfall, leaf diseases develop easily and tapping is disrupted too often [23,4]. [24] also alluded to the disruption of tapping operations due to excessive rainfall. Farmers in these areas should adopt low density planting, cultivate clones that are resistant or tolerant to fungal diseases and adopt the use of rain guard to minimize tapping disruptions. The high negative correlation of maximum temperature with latex yield at Nko indicates that evapotranspiration rates could be high enough to cause water deficit in this area. Therefore, cultural measures that could reduce soil temperature such as mulching and cover cropping should be adopted by farmers in this area.

In all three locations, the relative humidity at 0900 hour correlated positively with latex yield, and is considered not to be a constraint to the attainment of high latex yield. According to [23], a high relative humidity prevents the latex vessels from closing, due to the high tugor pressure, and boosts the yield.

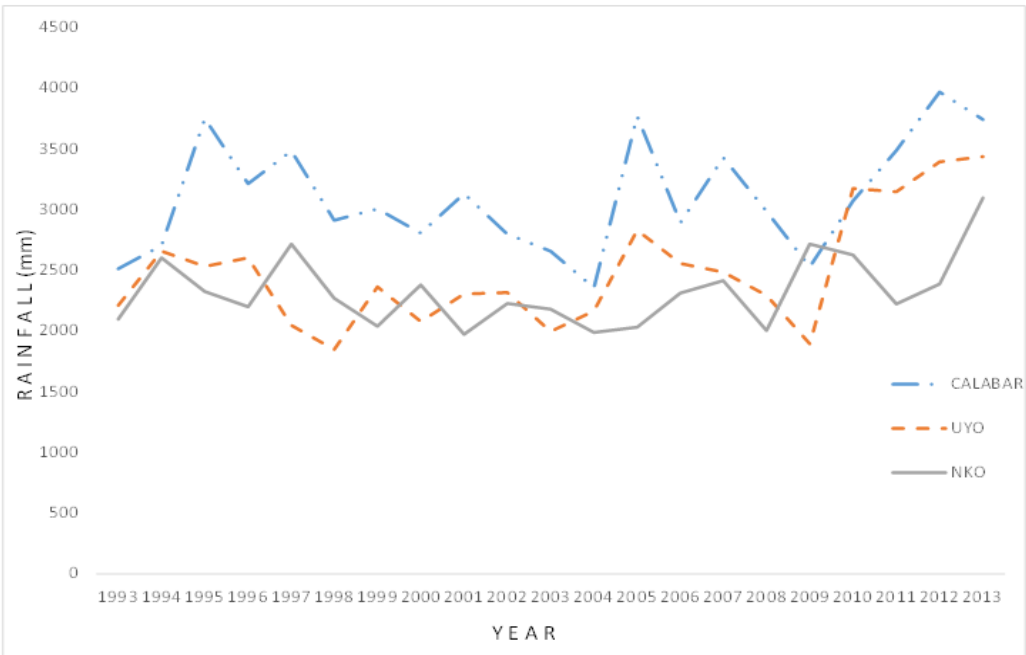

Fig. 2. Total annual rainfall (mm) received at different study locations from 1993 to 2013

Table 1. Five-year running average of rainfall duration and intensity for Calabar, Uyo, and Nko for the period 1993-2012

Rainfall	1993-1997	1998-2002	2003-2007	2008-2012
Duration (days)				
Calabar	143	137	138	144
Uyo	143	134	140	139
Nko	130	124	130	131
SD	0.30	0.21	0.11	0.20
CV (%)	9.0	6.7	4.9	6.0
Intensity				
Calabar	19.82	18.69	17.86	19.96
Uyo	15.74	14.26	16.52	19.93
Nko	15.58	14.63	14.82	16.92
SD	1.02	0.83	0.96	0.70
CV (%)	8.8	6.8	5.5	5.8

CV= Coefficient of variability

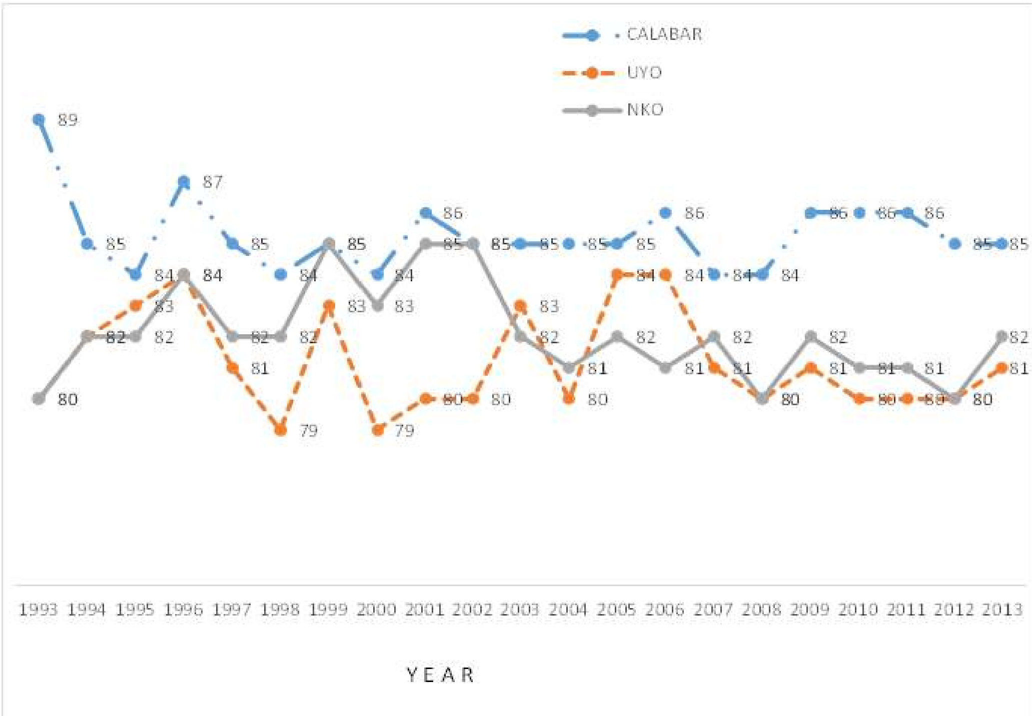

Fig. 3. Average annual relative humidity (%) at Calabar, Uyo and Nko from 1993 to 2013

Thus, while the critical range of climatic and environmental conditions required for the growth of members of the genus *Hevea* are known [9, 25, 26], the specific optimal set of these variables vary from one location to another, and may be subject to the law of limiting factors. [11] who worked with seven local and three exotic clones in Calabar also reported significant variation for latex yield and weather factors.

3.3 Relationship between the Physico-chemical Properties of the Soils with Latex Yield

Soil pH was 4.5, 5.8, and 4.6 in Calabar, Nko, and Uyo rubber plantations respectively, and falls within the critical range of 4.0 to 6.6 recommended for rubber growing soils [26], while the texture of the soil was sandy clay loam at Nko, and sandy loam at both Calabar and Uyo (Table 3). The bulk density of all sampled soils was higher than the critical value of 1.8g/cm^3 showing that they would not offer mechanical impedance to root penetration, but total nitrogen content was low in the Calabar and Uyo soils, and medium at Nko, while the effective cation exchange capacity (ECEC) was low across all plantations. Although, the organic carbon content of the soils was low, similar to reports by [27], the percentage base saturation was high which is indicative of their potential high fertility status if measures are taken to alleviate the acidity. The high sand fraction in the soil in Calabar and Uyo may be attributed to the nature of their parent material, and the low pH and ECEC to excessive rainfall that caused the leaching of basic cations beyond the rooting zone, leaving behind the acid-forming H^+ and Al^{3+} ions.

The effect of soil pH on plant growth is partly through its effects on root functions and on soil properties and availability of nutrients. Liming the soils in Calabar and Uyo with such materials as dolomite to raise the pH of the soil can improve the nutrition of the plants. However, while it may not be necessary to lime the Nko soil, it is imperative to avoid the use of acid-forming fertilizers, and measures to increase the organic matter content of the soil should be adopted. Given the significant positive correlation between latex yield and soil pH, bulk density, ECEC, base saturation, and exchangeable bases (Table 4), latex yield could be increased by raising the value of these soil properties.

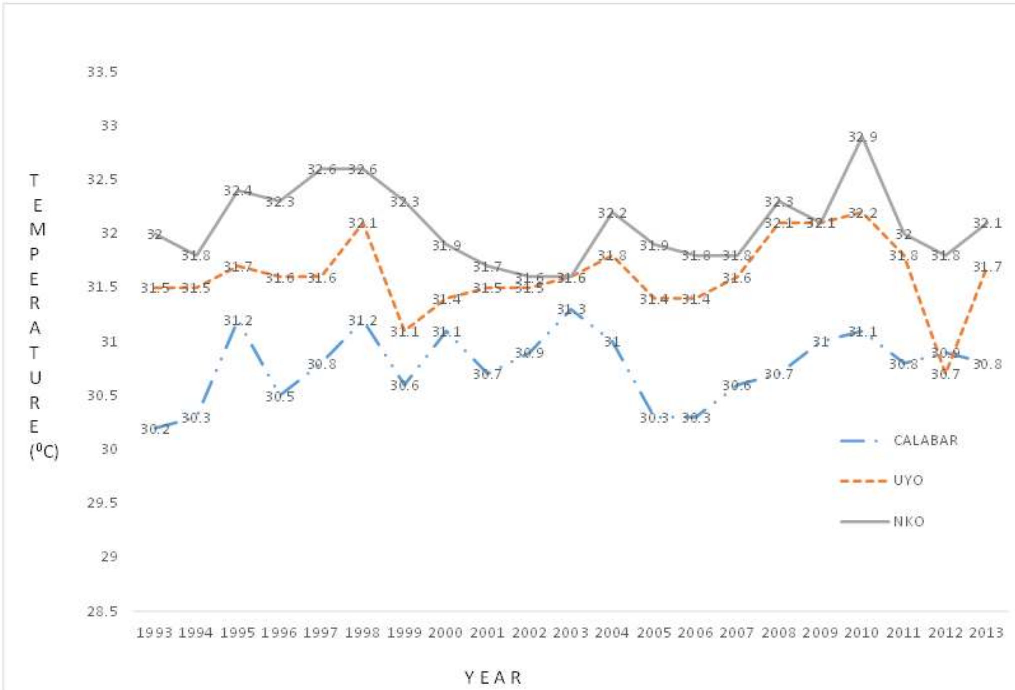

Fig. 4. Mean annual maximum temperature (^{O}C) at Calabar, Uyo and Nko from 1993 to 2013

Table 2. Latex yield (Kg/ha) and five-year running averages in Calabar, Uyo and Nko Rubber plantations from 1993 to 2012

Year	Calabar	Uyo	Nko
1993	1265.9	1119.4	1203.4
1994	1137.4	986.3	1068.5
1995	1096.3	1021.5	1036.5
1996	1243.6	1026.0	1010.0
1997	1338.0	1033.6	1040.0
Mean	1216.24	1037.36	1071.68
1998	1565.4	1069.1	1023.0
1999	1588.0	1214.8	1119.3
2000	1594.6	1166.3	1133.8
2001	2010.0	1316.0	1218.4
2002	2089.4	1422.0	1226.0
Mean	1769.48	1237.64	1144.1
2003	2116.4	1518.4	1423.0
2004	2028.0	1326.0	1568.3
2005	2000.9	1633.0	1454.3
2006	2120.4	1763.0	1506.2
2007	2012.0	1522.3	1516.0
Mean	2055.54	1552.54	1493.56
2008	2051.6	1817.0	1528.3
2009	1984.0	1616.3	1493.6
2010	1922.4	1530.4	1500.0
2011	1834.0	1316.5	1300.0
2012	1827.9	1121.9	1093.9
Mean	1923.98	1480.42	1382.16

Table 3. Physical and chemical properties of soil at the study locations

Parameter	Calabar	Nko	Uyo	Standard deviation	Coefficient of variability (CV) (%)
Sand (%)	78.40	22.64	76.78	6.86	22.07
Silt (%)	19.40	22.64	6.98	0.88	16.39
Clay (%)	0.81	31.68	16.24	0.07	45.11
Textural class	SL	SCL	SL	-	-
pH	4.5	5.8	4.6	0.03	12.35
Bulk density (g/cm)	1.3	1.6	1.4	1.02	10.48
Organic carbon (%)	1.18	1.15	1.06	0.41	9.63
Total Nitrogen (%)	0.10	0.15	0.08	0.01	24.0
Available P (mg/kg)	30.02	38.16	35.14	5.40	19.27
Exchangeable bases (cmol/kg)					
Ca^{2+}	2.38	3.50	2.30	1.90	11.66
Mg^{2+}	1.16	2.29	1.23	0.45	30.59
K^{+}	0.17	0.17	0.19	0.03	5.43
Na^{+}	0.09	0.11	0.09	0.06	6.14
Exchange acidity	1.25	1.33	1.30	0.03	10.82
ECEC (meq/100g)	5.66	7.98	7.02	3.53	21.82
Base saturation (%)	68.42	79.19	70.91	5.05	15.88

SL = sandy loam, SCL = sandy clay loam, CV: < 15 % (least variable); 15-35 % (moderately variable); > 35 % (highly variable) (Wilding, 1985)

Table 4. Correlation coefficient (r) of the relationship between rubber latex yield and soil physico-chemical properties

Soil property	Calabar	Nko	Uyo
Sand	-0.192^{ns}	0.095^{ns}	-0.125^{ns}
Silt	0.032^{ns}	0.019^{ns}	0.024^{ns}
Clay	0.353^{ns}	0.790^{*}	0.403^{ns}
pH	0.69^{*}	0.73^{*}	0.65^{*}
Bulk density	0.526^{*}	0.703^{*}	0.566*
Organic carbon	0.633^{*}	0.572^{*}	0.654^{*}
Total nitrogen	0.606^{*}	0.872^{*}	0.774^{*}
Available P	0.065^{ns}	0.058^{ns}	0.060^{ns}
Exchangeable bases			
Ca^{2+}	0.658^{*}	0.946^{*}	0.773^{*}
Mg^{2+}	0.772^{*}	0.930*	0.852^{*}
K^{+}	0.901^{*}	0.971^{*}	0.894^{*}
Na^{+}	0.011^{ns}	0.020^{ns}	0.016^{ns}
Exchange acidity	0.322^{ns}	0.405^{ns}	0.459^{ns}
ECEC	0.767^{*}	0.911^{*}	0.798^{*}
Base saturation (%)	0.492^{*}	0.666^{*}	0.523^{*}

**= significant at 5 % probability level, ns = not significant*

Based on [28] classification scheme for identifying the extent of variability for soil properties based on their coefficient of variability (CV), the sand (CV= 22.07) and silt (CV= 16.39) fractions were moderately variable, while the clay (CV = 45.11) fraction was highly variable (Table 3 above). On the contrary, the variability in soil pH, organic carbon, bulk density, Ca, K, Na and exchange acidity was low, while that of Mg, ECEC, and base saturation was moderate.

4. CONCLUSION

The cultivation of natural rubber is an important socio-economic activity in the Niger Delta region on Nigeria, and considering the differences in soil fertility and weather factors in the area, efforts to increase rubber production in the country would require the adoption of location-specific recommended agronomic practices. The acid sandy loam and sandy clay loamy soils of the area can sustain commercial rubber production, but measures to ameliorate acidity including liming with dolomite and planting clones that are tolerant to the prevalent fungal diseases, together with the use of rain guard in areas experiencing excessive rainfall, should be adopted.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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