Effects of Age of Rubber (*Hevea brasiliensis* Muell Arg.) Plantation on pH, Organic Carbon, Organic Matter, Nitrogen and Micronutrient Status of Ultisols in the Humid Forest Zone of Nigeria

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ABSTRACT

Micronutrients are required by plants in minute quantities. Literature on the micronutrient status of soils sustaining rubber plantations in the humid forest zone of southern Nigeria is not readily available where a study was carried out on Ultisols to examine the status of manganese (Mn), iron (Fe), Copper (Cu) and zinc (Zn) in rubber plantations aged 7, 16, 39 and 41 yr. A grid sampling method was used to collect soil samples from five quadrats of 10 m × 10 m in each of the plantation plots. For each plot, five surface (0–15 cm) soil samples were randomly collected and composited. The soil samples were analyzed for pH, organic carbon (OC), organic matter (OM), nitrogen (N), Mn, Fe, Cu and Zn. Data were analyzed using analysis of variance and Pearson's correlation. The soils were strongly acidic (pH 4.0–4.4). The OC status was rated as very low (below 2%) in all the plantation soils. In addition, the OM was rated as low under the trees at 7, 16, and 39 yr whereas, for the 41 year-old plantation, it was rated as high. The Mn and Zn contents were rated as low for the 16, 39 and 41 year-old rubber plantations, whereas they were rated as medium under the 7 year-old rubber plantation. The Mn, Fe and Cu contents varied significantly (P < 0.01 to P < 0.05) with the age of trees, while Zn did not vary (P > 0.05) among the rubber plots. The fertility rating of Fe was toxic or excessive in all the plantations and the levels of Cu were rated high. The Mn contents were rated as high, medium, medium and low in the 7, 16, 39 and 41 year-old plantations, respectively. The Fe contents were rated as high whereas the Cu contents were rated as medium. With the exception of the 7 year-old plantation, where Zn was rated as medium, the Zn contents were below the critical limits for crop production, with soils in the 16, 39 and 41 year-old rubber plantations benefitting from its application. The low values of soil pH across the rubber plantation plots did not significantly favour the increase in selected micronutrient levels in the soil. To improve the levels of micronutrients in the rubber plots, it is recommended that biomass burning should be discouraged during replanting as it strips the soil of these nutrients. The use of organo-mineral fertilizer combined with inorganic fertilizers is recommended. Care must be taken not to apply Mn in excess. A rubber-based agroforestry system, as opposed to rubber monocultures is recommended as it would improve the micronutrient levels of the soils in the plantation.

Keywords: micronutrients, rubber trees, Ultisols, Pearson’s correlation
INTRODUCTION

Rubber (*Hevea brasiliensis* Muell Arg.) is well known for its natural rubber production. The tree grows well in the tropics where there is an annual rainfall of 2,000–4,000 mm and a temperature range between 24 and 28º C. Hence, its cultivation is concentrated in the humid tropics of the world. The plant thrives best under acidic soil conditions where the pH range is 4.0–5.5 (Attoe and Amalu, 2005; Pusharajah, 2005). Large areas of planted rubber exist near Calabar, in the humid zone of Nigeria (Oku and Armon, 2006). Rubber cultivation is being promoted as a way of diversifying Nigeria’s economy. Pamol (Nigeria) Limited, a multinational company and owner of rubber plantations in Nigeria, is expanding its rubber tree plantations and systematically replacing the aged rubber tree plantations near Calabar, Nigeria where soils used for rubber plantations have been evaluated for nutritional status. However, the emphasis has been on macronutrients for the application of fertilizers based on N, P, K and Mg to obtain optimum latex yield.

Literature on the status of micronutrients for plantation soils is not available, suggesting that little or no work has been done in this direction. Micronutrients such as zinc (Zn), iron (Fe), copper (Cu), manganese (Mn) and other trace elements are necessary for plant growth in only extremely small quantities. Micronutrients have the same agronomic importance and play vital roles in the growth and development of plants; hence, they are essential for plant growth (Nazif et al., 2006; Mustapha et al., 2011). Zn is known to promote the formation of growth hormones, starch and seed development; Cu is involved in photosynthesis; Fe is important in chlorophyll formation, while Mn is known to activate a number of important enzymes and is important in photosynthesis and metabolic processes (Food and Fertility Technology Centre, 2001). The sources of micronutrients in soils are diverse and the levels of these elements (Cu, Fe, Zn and Mn) in the soil vary depending on the nature of the parent material and the pedogenic processes (Lhendup and Duxbury, 2008).

In addition, there are other acknowledged factors (mostly soil properties) that influence micronutrient levels in the soil including soil organic matter, pH and clay content (White and Zasoski, 1999; Reichman, 2002; Oviasogie and Ndiokwere, 2008; Adelekan and Alawode, 2011; Aref, 2012). Soil organic matter has a significant positive effect on micronutrient levels, which perhaps underpins the importance of agricultural practices such as the planting of forest trees that minimize soil erosion and conserve soil organic matter (Aweto, 1981; Offiong and Iwara, 2012). It has also been reported that micronutrient levels in eco-regions (that is, areas of similar soils, landforms, climate and vegetation) are greatly influenced by the soil pH and the soil clay content. For example, low Zn values have been reported to occur most regularly in the mixed grasslands eco-region in southern Alberta where the soils generally have low soil organic matter and high pH (Penney, 2010).

An increase in Zn, Fe, Cu and Mn in the soil, according to Osuji and Onajake (2004), indicates that there is contamination. Bioaccumulation occurs when there is an increase in the concentration of these elements in the soil over time, compared to the natural concentration of chemicals in the environment. Micronutrients are natural components of the earth’s crust; thus they can neither be degraded nor destroyed. Micronutrient studies have been conducted in soils with different levels of anthropogenic influences such as industrial areas (Parry et al., 1981, Culbard et al. 1983; Prabu, 2009; Matini et al., 2011; Warmate et al., 2011), automobile traffic (Lagerwerff and Specht, 1970; Garcia-Miragaga 1984), mining activities (Culbard and Johnson, 2002; Osuji and Onajake, 2004), sediments of inland waters (Ihenyen, 1992; Adekola et al., 2002; Asaah and Abimbola, 2005; Olubunmi and Olorunsola, 2010) and around dumpsites/municipal
wastes (Olaniya et al., 1998; Ideriah et al., 2007; Adelekan and Abegunde, 2011; Adelekan and Alawode, 2011). In addition to scanty studies on the micronutrients of the studied soils, the trend of micronutrient status in plantations with varying ages has been little studied. Therefore, the main objective of the present study was to examine the effects of the age of a rubber plantation on the pH, organic carbon, organic matter and the availability of some micronutrients (Zn, Fe, Cu and Mn) in the soil.

MATERIALS AND METHODS

Study area

The study was carried out within the Pamol (Nigeria) Limited Rubber Estate near Calabar, Cross River State, in the humid forest zone of Nigeria in 2010. The study area is located between latitudes 05°00′N and 05°12′N and longitudes 08°15′E and 08°28′E (Ekukinam, 2010). The study area is further classified as a humid zone as its annual rainfall far exceeds 3,500 mm (Oku and Armon, 2006) when compared to high rainfall areas of Nigeria. The soils sustaining the rubber plantation are classified as Ultisols (Cross River State Ministry of Agriculture and Natural Resources, 1989; Oku and Armon, 2006). The soil is a loamy sand, characterized by weak-to-medium crumb structure, a moist, friable, (wet), nonsticky, plastic consistency, many fine-to-medium fibrous, woody roots and many interstitial pores (Attoe and Amalu, 2005). It is vulnerable to active sheet erosion following the removal of vegetation cover. The predominant vegetation in the area is secondary forest (59%) with fallows (22%) and scattered farmlands (19%). Trees found in the area include Elaeis guineensis, Funtumia elastica, Pentaclethra macrophylla, Hevea brasiliensis, Anthocleista vogelii, among others (Ekukinam, 2010).

Soil sampling

The soils were sampled under rubber plantations aged 7, 16, 39 and 41 yr. The rubber plantations were located within the same environment, less than 30 m apart; as such, they had similar soil parent materials, topography and climate. In each of the different-aged rubber plantation, five plots of 10 m × 10 m were established using a grid system of sampling. In each rubber plantation, five surface (0–15 cm) soil samples were randomly collected using a soil auger and then composited. Sampling was carried out over three days (7–9 February 2010). Prior to the establishment of rubber plantation, farmlands and secondary forest were the predominant land uses in the area, while slash and burning, as well as hoeing, occurred across the plots. Presently, with the establishment of a rubber estate in the area, slash without burning is the main cultivation practice for weed and grass control across the plots.

Laboratory analysis

The soils were air dried and passed through a 2 mm sieve. Sieved samples were used to determine: organic carbon by the Walkley-Black method (Walkley and Black, 1934), after which each value obtained was multiplied by 1.724 (Aweto 1981) to obtain organic matter; total nitrogen by the Kjeldahl method (Bremner and Mulvaney 1982), while pH values were determined using a glass electrode digital pH meter (pH model WPHI Waterproof; Dwyer Instruments Inc.; Michigan City, IL, USA) with a soil to water ratio of 1:2.5. The available fractions of Zn, Cu, Fe and Mn were extracted with 0.1 m HCl solution (Osiname et al., 1973) and determined using an atomic absorption spectrometer (model 210-211; Dwyer Instruments Inc.; Michigan City, IL, USA). The micronutrient fertility rating limits given by Esu (1991) and also reported by Mustapha et al., (2011) were employed; For Zn, values less than 0.8, from 0.81 to 2.0 and greater than 2.0 mg kg⁻¹ were rated low, medium and high, respectively, while for Cu, the same fertility category ratings were defined by values less than 0.2, between 0.21...
and 2.0 and greater than 2.0 mg.kg\(^{-1}\), respectively. Fe was regarded as low if the value was less than 2.5 mg.kg\(^{-1}\), medium if the value was between 2.51 and 5.0 mg.kg\(^{-1}\) and high if the value was greater than 5.0 mg.kg\(^{-1}\), while Mn was low if the value was less than 1.0 mg.kg\(^{-1}\), medium if the value was between 1.1 and 5.0 mg.kg\(^{-1}\) and high if the value was greater than 5.0 mg.kg\(^{-1}\).

**Data analysis**

The data were analyzed using a one-way analysis of variance at the 1% and 5% probability levels to determine if there were highly significant or significant variations, respectively, in the levels of chemical properties and micronutrients among the different ages of the rubber plantations. Pearson’s correlation was also used to determine the nature of association between pH, organic matter and the measured micronutrients.

**RESULTS AND DISCUSSION**

**Chemical properties of soils**

**Soil pH, organic content, organic matter and nitrogen**

Data on the pH, organic carbon (OC), organic matter (OM) and nitrogen (N) are presented in Table 1. The soils of the area were rated as acidic (pH 4.0–5.0) with a pH range of 4.06 to 4.44 (Table 1). The acidic nature of soil is typical of Ultisols (Lal, 1987) due to the high rainfall which is sufficient to leach basic cations, especially calcium, from the surface horizons of the soils (Paudel and Sah 2003; Foth 2006). However, these pH values are within the desirable range (pH 4.3–4.6) recorded for soils growing rubber worldwide (Chan et al., 1975; Attoe and Amalu, 2005). However, the pH values varied significantly among the soils of the rubber plantations (Table 1). Considering the pH values, it can be inferred that a significant amount of exchangeable Al\(^{3+}\) exists in the soils. Also, the soils are deficient in Ca and Mg, thus, lime should be applied. Soil pH has a major influence on the availability of micronutrients in the soil, as micronutrients decrease with increasing soil pH (Adelekan and Alawode, 2011; Aref, 2012).

The OC status of the soils was rated as low (below 2%) in all the plantation soils (Chude et al., 2011). The organic matter (OM) content of the soils under rubber trees aged 7, 16 and 39 yr was rated as low (below 2.0%) (Chude et al., 2011), whereas for 41 year-old stand, OM was rated as high (above 3.0%). This increase in OM could be attributed to the accumulation of litter fall over a long period, providing evidence of an OM increase between the ages of 39 and 41 years. The low OM content in the 7 and 16 year-old rubber plantations could be attributed to insufficient tree canopy cover with less litter fall, which means the litter is unable to adequately reduce the direct impact of raindrops and suppress runoff which in turn results in the loss of plant nutrients. Nitrogen in the soil followed a similar trend as OC.

In spite of the increase in total nitrogen (TN) with the age of the rubber plantation, the content of TN did not vary (\(P > 0.05\)) among soils in the rubber plantations (Table 1). In addition, the

<table>
<thead>
<tr>
<th>Soil property</th>
<th>Age of rubber trees in plantation (years)</th>
<th>F-values</th>
<th>P-values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7</td>
<td>16</td>
<td>39</td>
</tr>
<tr>
<td>pH(1:2.5 soil:water)</td>
<td>4.44±0.12</td>
<td>4.06±0.02</td>
<td>4.24±0.02</td>
</tr>
<tr>
<td>Organic carbon (%)</td>
<td>1.14±0.26</td>
<td>1.04±0.19</td>
<td>1.16±0.07</td>
</tr>
<tr>
<td>Organic matter (%)</td>
<td>1.97±0.44</td>
<td>1.79±0.33</td>
<td>1.99±0.13</td>
</tr>
<tr>
<td>Total nitrogen (%)</td>
<td>0.28±0.06</td>
<td>0.25±0.05</td>
<td>0.25±0.02</td>
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</tbody>
</table>
increase in OM and TN in the 39 and 41 year-old plantations could be attributed to the mature rubber trees with their large biomass which not only afforded adequate ground cover, but also acted as a huge reservoir of nutrients, thereby preventing the nutrients from being leached away from the soil beneath it. Such trends in OM and TN, according to Aweto (1981), may be attributed to the increase in soil and cover tree size. The thick vegetation helps in reducing the direct impact of raindrops on the soil, and as a result of infiltration, reduced the loss of soil nutrient through runoff (Aweto and Dikinya 2003). The increasing trends of OM and TN in the studied plantation soils collaborated earlier, similar studies (Geetha and Balagopalan 2009; Yasin et al., 2010).

**Manganese**

Manganese levels ranged from 0.94 to 5.38 mg.kg⁻¹ (Table 2). The level of available Mn in the rubber plantation soils varied significantly with the highest value of 5.38 mg.kg⁻¹ recorded in the 7 year-old plot, while the lowest mean value of 0.94 mg.kg⁻¹ was obtained in the 41 year-old plot. Mn levels were rated as high (above 5.0), medium (between 2.32 and 5.0), medium (between 1.1 and 5.0) and low (below 1.0 mg.kg⁻¹) under the 7, 16, 39 and 41 year-old plantation, respectively. Manganese is necessary in photosynthesis, nitrogen metabolism and to form other compounds required for plant metabolism. Similar results have been reported of widespread Mn deficiency in some areas of Asia where rubber trees are grown (Pushparajah et al., 1983), whose authors recommended that the deficiency could be corrected by the application of MnSO₄ at 100 g.tree⁻¹ or 45 kg.ha⁻¹. According to Matini et al., (2011), soil acidity induces the dissolution of heavy metals.

**Iron**

Table 2 shows the Fe levels in the soils studied, which, according to the ratings by Northwest Agricultural Consultants (2003), were toxic or excessive (above 50 mg.kg⁻¹). Iron is one of the most abundant elements in the earth’s crust with variable oxidation states of +2 and +3 (Fe²⁺ and Fe³⁺). Fe has been found to occur at high concentrations in Nigerian soils (Adefemi et al., 2007). Its level in the soil is attributed to rainfall and runoff which induces soil acidity and Fe deficiency is unlikely in such soils, as Fe is known to be soluble under relatively acidic and reducing conditions (Cheswotrth, 1991; Mustapha et al., 2011). The Fe contents in the soils tended to decrease with the age of the rubber plantation, with high and low mean values of 93.98 and 62.80 mg.kg⁻¹ obtained in the 7 year-old and 41 year-old rubber plots, respectively. Where both the Fe and Mn levels in a soil are high, the formation of complexes could result which could lead to serious drainage and infiltration problems (Mustapha et al., 2011).

**Copper**

The levels of copper in the soils (Table 2) placed Cu in the medium fertility rating class (between 0.21 and 2.0 mg.kg⁻¹) according to

<table>
<thead>
<tr>
<th>Micronutrient</th>
<th>Age of rubber trees in plantation (years)</th>
<th>F-values</th>
<th>P-values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7</td>
<td>16</td>
<td>39</td>
</tr>
<tr>
<td>Manganese</td>
<td>5.38±0.95</td>
<td>2.32±0.57</td>
<td>1.18±0.08</td>
</tr>
<tr>
<td>Iron</td>
<td>93.98±1.55</td>
<td>90.66±9.25</td>
<td>69.24±3.68</td>
</tr>
<tr>
<td>Copper</td>
<td>0.74±0.08</td>
<td>1.26±0.06</td>
<td>0.93±0.14</td>
</tr>
<tr>
<td>Zinc</td>
<td>1.47±0.37</td>
<td>0.59±0.08</td>
<td>0.74±0.06</td>
</tr>
</tbody>
</table>
Consequently, no supplementary Cu application is required. Also, the Cu levels in the rubber plots increased from age 7 to 16 yr and decreased thereafter. Copper is an essential micronutrient required for plant growth and is normally found in soils in only trace amounts (McLaren, 2003). Cu levels varied across the rubber plots, with the highest Cu level obtained in the 16 year-old rubber plantation, while the lowest level was in the 41 year-old plantation with mean values of 1.26 and 0.64 mg.kg$^{-1}$, respectively. Cu is often primarily found bound to the organic matter fraction in the soil; soil organic matter can be the most important soil factor in determining Cu bioavailability (Del Castilho et al., 1993).

**Zinc**

The status of Zn in the studied soils is presented in Table 2. The Zn status under the 7 year-old rubber plantation was rated in the medium soil fertility class (between 1.0 and 2.0 mg.kg$^{-1}$) whereas soils in the 16, 39, and 41 year-old rubber plantations were ranked as low fertility (between 0.4 and 0.8 mg.kg$^{-1}$) according to Esu (1991) and Northwest Agricultural Consultants (2003). The low content of Zn could be attributed to the sandy nature of the soil; the low OM content as well as the low pH of the studied soil did not favour increases in the Zn level in the soil and Del Castilho et al., (1993) and Reichman (2002) reported that the amount of organic matter found in soils also affects the bioavailability of Zn. Fotovat et al. (1997) reported that while Zn readily forms complexes with organic matter, it does not compete for these sites as much as Cu and other more prevalent cations such as Ca$^{2+}$. Hence, organic matter, while important, does not tend to be as important a factor as pH in determining Zn bioavailability (Reichman, 2002).

**Correlation matrix between pH, organic matter and studied micronutrients**

The Pearson’s correlation matrix (Table 3) indicates that the pH levels (4.06–4.44) had high, positive but nonsignificant associations with Mn and Zn (0.79 and 0.81, respectively, $P > 0.05$), while the pH levels in relation to Fe and Cu were low and nonsignificant (0.43 and -0.39, respectively, $P > 0.05$). These results implied that the present levels of pH in the soils do not significantly favour an increase in Mn, Zn, Fe and Cu. The present pH levels brought about a corresponding increase in the Mn, Zn and Fe contents in the studied soils, though it was not significant, whereas the pH levels resulted in a reduction of Cu in the studied soils. These relationships confirmed the findings of Lindsay (1979) and Aref (2012) that the solubility of micronutrients decreases a thousandfold for each unit increase in the range of soil pH 4–9. Moreover, the content of OM (1.79–3.24) negatively and nonsignificantly correlated with Mn (-0.47, $P > 0.05$), Fe (-0.74, $P > 0.05$), Cu (-0.71, $P > 0.05$) and Zn (-0.26, $P > 0.05$). The content of OM substantially reduced the levels of Fe and Cu, but had a moderate, adverse effect on Mn and

<table>
<thead>
<tr>
<th>Parameter</th>
<th>pH</th>
<th>OM</th>
<th>Mn</th>
<th>Fe</th>
<th>Cu</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OM</td>
<td>-0.37$^+$</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mn</td>
<td>0.79$^+$</td>
<td>-0.47$^+$</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fe</td>
<td>0.43$^+$</td>
<td>-0.74$^+$</td>
<td>0.84$^+$</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cu</td>
<td>-0.39$^+$</td>
<td>-0.71$^+$</td>
<td>-0.10$^+$</td>
<td>0.45$^+$</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Zn</td>
<td>0.81$^+$</td>
<td>-0.26$^+$</td>
<td>0.97$^*$</td>
<td>0.70$^+$</td>
<td>-0.32$^+$</td>
<td>1</td>
</tr>
</tbody>
</table>

*Correlation is significant at the 5% alpha level (2-tailed).

*C* Correlation is not significant at 5% alpha level (2-tailed).
These results corroborated the findings of Aref (2012) that micronutrient deficiencies are greatest in soils with a low organic matter content and pH levels above 7.0. Indeed, Table 3 further reveals that the proportion of pH and OM have nonsignificant and low (positive and negative) associations with the selected micronutrients. These nonsignificant and low associations among the parameters show that the elements may not have been influenced by similar biotic, chemical and climatic factors. Nevertheless, Zn and Mn showed a high and significant correlation ($0.97, P < 0.05$), which implies the elements may probably have been influenced by similar factors (Adelekan and Alawode, 2011).

**CONCLUSION**

The study revealed there were low levels of organic matter and pH across the rubber plantations indicating a low level of native soil fertility. The level of Fe in the soils indicated that the plantation soils are iron rich. Fertilizer that contains manganese should only be applied based on soil test recommendations, as a blanket application may lead to toxic or excessive levels. With the Fe levels already rated as excessive, Fe and Mn will form complexes such as plinthites leading to a hard pan formation thus restricting infiltration and drainage. Organo-mineral fertilizer which is rich in organic matter should be combined with inorganic fertilizers. Also a rubber-based agroforestry system as opposed to rubber monocultures would be an excellent option and is recommended, as it would improve the fertility of the soils in the plantations.

**ACKNOWLEDGEMENTS**

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