Assessment of nutrient uptake on soil properties in cocoa ecosystem in Idanre, Ondo state, Nigeria

Évaluation de l’absorption d’éléments nutritifs sur les propriétés du sol dans l’écosystème du cacao à Idanre, État d’Ondo, Nigéria

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Abstract:

Soil fertility loss as a result of annual mining of nutrient through yield harvest has been a major cause of low productivity in old cocoa plantations especially where application of chemical fertilizer is not usually practiced. This paper examines the influence of cocoa yield harvest on soil properties in cocoa ecosystem in Southwest Nigeria. Physico-chemical properties of the soil, leaf, bean, pod-husk and litter-fall in relation to their impact on soil nutrient degradation were examined with the aid of multiple regression analysis. The results show that annual harvest of cocoa beans adversely affects the soil nutrient in comparison to pod-husk and leaf, while one-way ANOVA indicates that there is no statistically significant different between the mean values of the examined variables. Aside leaching, which is negligible in cocoa ecosystem, cocoa beans and pod-husk were observed to be the main determinants of nutrient loss in old cocoa farms. Results also revealed that fresh leaf, pod-husk and cocoa bean account for an average of 2.3%, 12.3% and 41.6% of nutrient loss, respectively. To reduce the rate of soil fertility loss and complement the natural input of the litter-fall in aged cocoa farms, application of pod-husk fertilizer, seasonal relocation of cocoa pod and its spreading across the farm are highly recommended.

Résumé:

La perte de la fertilité du sol qui résulte de l’extraction des nutriments à chaque récolte est la principale cause de la diminution de la productivité dans les vieilles plantations de cacao où l’on n’utilise pas les engrais chimiques. En effet, on observe une diminution du rendement après chaque récolte. Cet article examine l’impact de la récolte du cacao sur les propriétés du sol dans un écosystème cacaoier au sud-ouest du Nigeria. Les propriétés physico-chimiques du sol, des déchets de fèves et de gousses, de la litière et leur impact sur la dégradation des nutriments du sol ont été examinées par l’analyse de régression multiple. Les résultats montrent que la récolte annuelle de fèves de cacao affecte différemment l’élément nutritif du sol par rapport à la gousse et à la feuille, tandis que l’ANOVA à sens unique indique qu’il n’y a pas de différence statistiquement significative entre les valeurs moyennes des variables examinées. Outre le lessivage, qui est négligeable dans l’écosystème cacaoier, on a remarqué que les fèves de cacao et les gousses de cacao sont les principales causes de la perte de nutriments dans les vieilles plantations de cacao. Les résultats de l’analyse ont également révélé que les feuilles fraîches, les cosses et les fèves de cacao constituent en moyenne 2,3%, 12,3% et 41,6% de la perte de nutriments, respectivement. Pour réduire le taux de perte de fertilité du sol et soutenir l’apport naturel de la litière-chute dans les vieilles cacaoïères, l’épandage de l’engrais Pod-Husk, la relocalisation saisonnière de la cosses de cacao et son étalage dans toute la ferme sont fortement recommandées.

Keywords / Mots clés

Degradation, fertility, nutrient, plantation, cocoa
Dégradation, fertilité, nutriments, plantation, cacao

INTRODUCTION

Among crops farmed in Nigeria cotton, groundnut, oil palm and cocoa made significant contributions to exports and contributed greatly to the nation’s economy. Agriculture used to be the mainstay of Nigerian economy, providing 65% of Gross Domestic Product (GDP) in the 1960s (Oluyole, 2010). Before Nigeria attained independence, agriculture was the most important sector of the economy, and accounted for more than 50% of GDP and 75% of export earnings. According to Oluyole (2010) cocoa remains the second largest foreign exchange earner. The impact of cocoa as a tree crop in the growth and development of Nigeria’s economy before and after independence cannot be undermined. Recently, Nigeria’s contribution in the world cocoa market has reduced beyond reasonable doubt due to the plantation age in consonant with loss of soil fertility via annual yield harvest. Cocoa trees are known to live for about 200 years in their natural environment, but they are more productive for about 25 years of their lifespan (ICCO, 2013). Cocoa plantation requires certain quantity of
essential nutrients for growth and yield development. Soil nutrient deterioration occurs especially in tree crop plantation when the nutrient output (yield) exceeds nutrient input (litter and fertilizer) over the years (Hertamink, 2005). Furthermore, cocoa is sensitive to some of these nutrients and their inadequacy may drastically reduce the production rate. Reduction in soil nutrient due to plantation old age without replacement via fertilizer application and annual yield harvest have been causing setback to the production of cocoa in Nigeria over the years (Aikpokpodion, 2010). In Nigeria, application of chemical fertilizer is not common despite the annual harvest that always mine the available soil nutrient via bean and pod-husk. Removal of essential plant nutrients through harvesting over long period of time without replenishment could be one of the major causes for the decline in productivity on cocoa farms (Appiah et al., 1997). The patterns of change over time for each soil property show an initial small rise followed by a drop in the level of each soil property and then a rise to a peak at above 25 years, before a continuous decline thereafter (Ekanade, 1985). In Nigeria and other tropical countries where cocoa production is highly prevalent, replacement of old plantations with hybrid cocoa varieties in many farms is yet to solve the problem of nutrient loss through annual yield harvest.

In cocoa ecosystem especially in tropical rainforest, fresh leaf, pod-husk, beans and soil erosion are the main channels of nutrients loss while litter-fall, stem flow and through fall are the nutrient input. Loss of nutrient in mature cocoa plantation occurs when the average inputs are less than output mainly via annual yield harvest. Studies across the tropics identified the critical value of the soil in cocoa ecosystem (Wood and Lass, 1984; Egbe et al., 1989; McKenzie, 2001). Most of the plantations in Nigeria above the age of 50 years have shortage of the main essential nutrients for further fruit development (Aikpokpodion, 2010). This causes the old plantations to be dwindling in fruit production. The aim of this study is to examine the impact of nutrient uptake on soil fertility status in cocoa ecosystem in southwest Nigeria's tropical high forest agro ecological zone. The study findings will be of agroforestry and agronomic relevance in solving soil fertility loss in the tropics, especially in perennial tree crop.

MATERIALS AND METHODS

Idanre is the largest cocoa producer in Ondo State. Idanre Local Government Area is located in the central part of Ondo State, approximately 70 06’N and 50 6’E (NGSA, 2006). It has total area coverage of 1,914km2 with estimated population of 189,476. The area based on the annual rate of cocoa production record over the years (Hertamink, 2005). Most of the plantations in Nigeria above the age of 50 years have shortage of the main essential nutrients for further fruit development (Aikpokpodion, 2010). This causes the old plantations to be dwindling in fruit production. The aim of this study is to examine the impact of nutrient uptake on soil fertility status in cocoa ecosystem in southwest Nigeria’s tropical high forest agro ecological zone. The study findings will be of agroforestry and agronomic relevance in solving soil fertility loss in the tropics, especially in perennial tree crop.

RESULTS AND DISCUSSION

Results show that the average values of physicochemical properties of the plant variables (leaf, bean, pod and litter fall) were higher when compared with that of soil (Table 1). This is an empirical indication that nutrient uptake via cocoa plant parts exceeds the available concentration in the soil, even when compared with soil’s critical limit. Litters absorbed high amount of cations except K+ in the pod husk. This may be ideal belt for the production of tree crops. Its soil is characterized by very deep and well-drained loam sandy surface, sandy clay and clay loamy subsoil. Basement complex rock is the main type of the area bedrock.

The main variables considered for this study were soil, cocoa bean, leaf, litter and pod-husk. A plot of 25m by 25m was selected in indigenous cocoa farm in Alade Idanre. Twelve soil samples were randomly selected from two different depths 0-15cm and 15-30cm considered as topsoil and subsoil, respectively. The sampling was limited to this zone due to the fact that most feeding roots of cocoa are concentrated in that depth (Wood and Lass, 1984; De Oliveira and Valle, 1990; Aikpokpodion, 2010). Soil and plant variables were subjected to laboratory routine at Step B Central Research Laboratory, Federal University of Technology, Akure.

Soil samples were air-dried, pulverized and sieved with 2.0mm sieve mesh and analyzed for particle size distribution and physicochemical parameters. Soil pH was determined potentiometrically in 0.1M calcium chloride solid to liquid solution ratio of 1:2 as per Pech (1965). Organic carbon was determined using the chromic acid digestion method (Walkley and Black, 1934). Extracts of soil samples leached with 1N ammonium acetate were used to determine the concentration of exchangeable cations, thereafter Ca, K and Mg were determined by atomic absorption and Na was determined by flame photometry.

Total nitrogen was determined by Kjedahl method and available phosphorus was determined by Bray method (Jackson, 1970). Extractable trace elements (Zn, Cu, Fe and Mn) were measured after extraction with 0.02M EDTA using atomic absorption spectrophotometer (Isaac and Korber, 1971). Laboratory results on soil chemical properties were subjected to descriptive and inferential statistics. Results were presented in table form according to the mean value of each variable. Multiple regression analysis was used to examine the contribution of each variable to the soil nutrient status while Analysis of Variance for the examination of the variability of nutrient concentration in cocoa plant variables.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Soil</th>
<th>Soil Critical Value</th>
<th>Leaf</th>
<th>Bean</th>
<th>Pod husk</th>
<th>Litter fall</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>5.81</td>
<td>6.0-6.5</td>
<td>6.47</td>
<td>5.80</td>
<td>5.84</td>
<td>6.33</td>
</tr>
<tr>
<td>OC (%)</td>
<td>2.23</td>
<td>3.0</td>
<td>5.24</td>
<td>5.50</td>
<td>5.29</td>
<td>5.06</td>
</tr>
<tr>
<td>N (%)</td>
<td>0.64</td>
<td>0.09</td>
<td>0.40</td>
<td>0.03</td>
<td>0.30</td>
<td>0.25</td>
</tr>
<tr>
<td>K (cmol/kg)</td>
<td>0.03</td>
<td>0.3</td>
<td>55.48</td>
<td>33.82</td>
<td>112.45</td>
<td>85.7</td>
</tr>
<tr>
<td>Cu (cmol/kg)</td>
<td>0.29</td>
<td>0.6</td>
<td>51.51</td>
<td>2.13</td>
<td>8.00</td>
<td>133.47</td>
</tr>
<tr>
<td>Mg (cmol/kg)</td>
<td>0.01</td>
<td>0.8</td>
<td>21.67</td>
<td>2.78</td>
<td>8.10</td>
<td>3.69</td>
</tr>
<tr>
<td>Na (cmol/kg)</td>
<td>0.01</td>
<td>0.1</td>
<td>10.82</td>
<td>3.37</td>
<td>6.38</td>
<td>6.10</td>
</tr>
<tr>
<td>P (mg/kg)</td>
<td>8.10</td>
<td>10.9</td>
<td>28.81</td>
<td>22.51</td>
<td>9.57</td>
<td>28.29</td>
</tr>
<tr>
<td>Zn (mg/kg)</td>
<td>1.34</td>
<td>1.8</td>
<td>0.50</td>
<td>0.46</td>
<td>0.49</td>
<td>0.35</td>
</tr>
<tr>
<td>Mn (mg/kg)</td>
<td>0.16</td>
<td>1.0</td>
<td>1.28</td>
<td>0.13</td>
<td>0.13</td>
<td>2.01</td>
</tr>
<tr>
<td>Fe (mg/kg)</td>
<td>1.26</td>
<td>4.5</td>
<td>0.36</td>
<td>0.27</td>
<td>0.25</td>
<td>0.20</td>
</tr>
<tr>
<td>Cu (mg/kg)</td>
<td>1.38</td>
<td>2.5</td>
<td>0.38</td>
<td>0.23</td>
<td>0.53</td>
<td>0.30</td>
</tr>
</tbody>
</table>

Source: Author’s Fieldwork and Data Analysis (2016)

Table 1: Nutrient Storage in Soil and Cocoa Plant Parts
attributed to the influence of photosynthesis and gaseous biogeochemical cycle.

Table 1 shows that the quantity of micronutrient storage in the soil exceeds bean, leaf and pod husk apart from K+ uptake in leaf, which may be as a result of immobility nature of micronutrient in the soil. The study observed that the combination of nutrient uptake by bean and pod-husk were higher than the quantity present in the leaf. It was also discovered that nutrients like organic carbon, calcium, magnesium, and potassium and all micronutrients, except zinc, were less than soil critical limit. Therefore, the rate of nutrient availability in the soil of this study area also influenced the nutrient uptake of cocoa plant parts. This corroborated with Tilmani (1978) and Sarah (1992) asserting that species from environments where soil nutrients are abundant allocate more to above ground parts, have more rapid growth rates, and have higher rates of nutrient uptake per gram of root biomass than species from low nutrient environments. Results show that K+ and P account for the most available cations in cocoa plant parts.

Table 2 presents the multiple regression result of the relationship between soil nutrient loss and cocoa output of cocoa plantations. This model indicates that cocoa bean and pod-husk are significant determinants of soil nutrient loss in cocoa plantations. Therefore, it can be deduced that the nutrient return from the dead tree parts to the soil depends on the quantity of nutrient extracted from the soil via plant roots. The results from this study show that the magnitude of nutrient concentration in aboveground cocoa plant parts ranges from fresh leaf to cocoa bean. Thus, the serial order of nutrient distribution in cocoa plant parts is expressed as bean > pod-husk > leaf. Cocoa plant parts account for 80% of nutrient variance in cocoa ecosystem. Among the examined cocoa plant variables, the highest variable with side effect on soil fertility in mature cocoa plantation is cocoa bean, annually removed through yield harvest. Regression analysis results also show the rate of nutrients annually removed via harvest in sequential order of 41.6% (bean), 12.3% (pod-husk) and 2.3% (leaf) of what plant parts uptake from the soil under mature cocoa plantation (Table 2).

Model of nutrient uptake in cocoa plant parts

\[ y = 1.063 - 0.023 \text{ (Leaf)} + 0.416 \text{ (Bean)} - 0.123 \text{ (Pod-husk)} \]

\[ R^2 = 0.80; \text{ S.E} = 1.27 \]

Apart from synergistic interaction of nutrients in the soil, fresh leaf, bean and pod husk development are the main variables that determine the state of nutrient in mature cocoa farm especially in tropical rainforest. Cross examination of the variation within the examined plant variables through the analysis of variance (Table 3) indicates that there is no statistically significant different between the mean values of the examined variables.

Table 3: Analysis of Variance on Cocoa Plant Variables

<table>
<thead>
<tr>
<th>Model</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>61.637</td>
<td>3</td>
<td>20.546</td>
<td>12.661</td>
<td>0.001</td>
</tr>
<tr>
<td>Residual</td>
<td>14.605</td>
<td>9</td>
<td>1.623</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>76.242</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Author’s Data Analysis (2015)

Table 3: Analysis of Variance on Cocoa Plant Variables

The study also shows that cocoa bean and pod-husk are the main determinants of nutrient loss from the cocoa ecosystem because their values (0.416 and 0.123) are greater than significant value P<0.05 in cocoa producing community under this study. This implies that the contribution of cocoa bean and pod-husk in soil nutrient loss is statistical significant compared to the negligible impact of the fresh leaf (Table 2). Nutrient concentration in fresh leaf is an indication of soil fertility. Nutrient concentration in leaves serves as an index of the influence of soil fertility since all leaves have the basic function and all use the same nutrients in photosynthesis and construction of organic material (Robert, 1996). Difference in result may also be linked to special location of the sampling points in the farm. Thus, the impact of rainfall directly influenced soil properties. Sandy loamy soil in Idanre is another considerable factor for soil variability. Also, changes in soil chemical properties under perennial crops were found to be different. The changes in soil chemical properties may reflect the decrease in nutrient stocks of the soil, but it also reflects immobilization of nutrients in the biomass (Hartemink, 2003).

CONCLUSION AND RECOMMENDATIONS

In cocoa ecosystem, nutrient uptake is the function of the quantity of nutrient available in the soil. The age, soil, climate and location of the study area directly influence the soil fertility. Results from this study revealed that nutrient uptake by cocoa bean and pod-husk were the main determinants of soil fertility status in mature cocoa ecosystem. Both bean and pod-husk account for approximately 30% of the nutrient uptake from the soil, while the rest accounts for the nutrient immobilization, stocked in plant parts. There is negligible impact of leaching in cocoa plantations. Soil fertility status may also be related to the quantity and quality of nutrient storage in cocoa bean and its pod husk. Results show that nutrient storage in plant biomass exceeds the soil concentration. To avoid deterioration of soil nutrient with respect to annual yield harvest and plantation lifespan, especially in old cocoa plantation, periodic evaluation of soil properties, seasonal relocation and spreading of pod husk across the plantation are required. Alternatively, annual application of the processed pod husk fertilizer to augment the impact of litter-fall is recommended.

REFERENCES


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