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Soil-Plant Nutrient Cycling in Old Cocoa Farms in a Part of South Western Nigerian Forest Belt

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Abstract
Apart from pests and diseases, a vital issue in the early mature of cocoa crop in Nigeria is soil nutrient degradation in relation to the ageing of the farms and annual mining of nutrients via yield harvests. Indigenous production of cocoa in southwest Nigeria has been on without fertilizer applications. This is the basis for the reduction average lifespan and productive years of the plantation. The aim of this study was to quantify the rates of soil nutrient losses via cycling channels in old cocoa farm using cocoa beans, leaves, litters, and pod husks in south western Nigeria forest belt. Old cocoa farms with an average age of 55 years were selected from Idanre, where nutrients in soil cultivated to cocoa and plant variables were experimentally evaluated. Identified variables were randomly sampled and the composite samples were subjected to laboratory analysis. Results through routine laboratory techniques were subjected to descriptive analysis. Using average and percentage, the results show that inputs from litter falls account for about 29%, pod husks (24%), leaves (28%), beans (13%) and soil (6%) approximately. Soil nutrient balance equation indicates that an average of 1.32% nutrient amounts to loss via annual cycle and the order of nutrient concentrations in old cocoa ecosystem is therefore considered as litter > leaves > podhusks > beans > soil. Results also showed that nutrient cycling in old cocoa farm was high while the loss was low. The study hereby recommends land evaluation, annual relocation and seasonal spreading of pod husks across the farm for redistribution of nutrients to compliment nutrients return through litter fall instead of its usual concentrations where not useful for plant development.

Keywords: Biomass, cocoa, nutrient, degradation, litter, soil.

Introduction

All plants require essential macronutrients, secondary nutrients with micronutrients to attain their potential growth and development. In addition to water and sunlight, plants require essential mineral nutrients to complete their full life-cycles. Essential mineral nutrients can be divided into macronutrients and micronutrients depending on the amount required by the plants (Henry 1990). Nutrients are chemicals required for plant and animal growth and other life processes that are constantly recycled within the Earth's biosphere. Nutrient cycles describe the flow of nutrients in and out of stores as a result of biotic and abiotic processes which have almost perfectly balanced cycles without human interference. Imbalances in nutrient cycles may result in gradual depopulation and extinction of many plants and animal species as well as vital ecological problems such as loss of biodiversity and shortage of plants and animal's lifespan (Asmeret et al. 2006). Plants also require this supply of nutrients to be balanced, becausewhen the supply is imbalanced, interactions that occur in the soil can affect nutrient uptake causing plant growth with consequential effects on yield, quality and productivity. Impact of soil pH in cocoa ecosystem cannot be underscored because its status has synergy effects in the availability of soil nutrients. A soil pH of 5.5 or less (low) increase the concentrations of Al^{3+}, Fe^{2+}, Mn and Zn; soil pH between6.0 and 6.5 is a moderate level of pH that has normal concentrations of NO_3^-, K^+, P, Mg^{2+}, S, Cu^{2+} and B, while pH between 6.5 and 8.0 (high pH) favours high concentrations of Ca^{2+} and Mn (Roger 2008).There are many interactions that can influence the availability of nutrients in ecosystems. These need to be considered when high levels of a particular nutrient in the soil interfere with and have negative effects on the uptake of other nutrients into a growing plant. Nutrients which behave in this way are said to be antagonistic. For instance, excess of K^+ causes imbalance of Mg^{2+} and Ca^{2+}, Mg^{2+}imbalance in Mg^{2+}, P imbalances in Zn or Fe^{2+} and N causes imbalance in S or Fe^{2+}.

Nutrient cycling in rainforest ecosystem is closed and can be illustrated in terms of input and output systems (Hartemink 2005). This due to the influence of nutrient returns through litter decomposition and reabsoption, through fall, stemflow and root turnover. In the rainforest, most of the carbon and essential nutrients are locked up in the living vegetation, dead wood, and decaying leaves, but as organic materials decay, they are recycled so quickly that few nutrients ever reach the soil, leaving it nearly sterile (Dand 1999). Litterfall is a fundamental process in nutrient cycling due to its ability to transfer organic matter and mineral elements from vegetation to the soil surface. Nutrient concentrations in litter are less than nutrient concentrations in fresh leaves but the reverse may be the case when the litter from the shade trees are involved. According to Santana and Cabala-Rosand (1982), both the litter from the shade trees and cocoa make considerable contributions to the cycling of nutrients, particularly nitrogen in the plantations. Soil tests are the most common means of assessing fertility needs of crops, but plant tissue tests are especially useful for nutrient management of perennial crops (Magdoff and Van Es 2009). Nutrient concentrations in leaves serve as an index of the influence of soil fertility since all leaves have the basic functions and all use the same nutrients in photosynthesis and construction of organic materials (Robert 1996). In the Tropical High Forest Agroecological Zone of Nigeria, most of the studies on cocoa focused mainly on the soil without taking the above-ground biomass like fresh leaves, litter, fruits (beans and husks) and impacts of the grown crop into consideration. This is one of the main reasons for the inability of many studies on degradation of soil properties to proffer lasting solutions to the problem of soil fertility, especially in cocoa producing regions of the world. The aim of this study was to quantify the rates of soil nutrient degradation via cycling channels of mature cocoa farm in relation to the annual nutrient losses through cocoa beans, podhusks, leaves as well as the prominent roles of litter in the Tropical High Forest Agroecological Zone of Nigeria.

Materials and Methods

The study was carried out in Idanre Local Government Area of Ondo State, Nigeria. The area is located in the central part of the State approximately between 7° 05'N and 7° 06'N of the equator and 5°07'E and 5°13'E of the Greenwich Meridian. It has a total land area of 1,914km^2. Idanre shares boundary with Ifedore, Akure South and North in the north, Owo in the east, Edo State in the south, Odigbo, Ondo East and Ileoluji/Okeigbo in the west. Across the state, Idanre community has been the leading producer of cocoa for years.

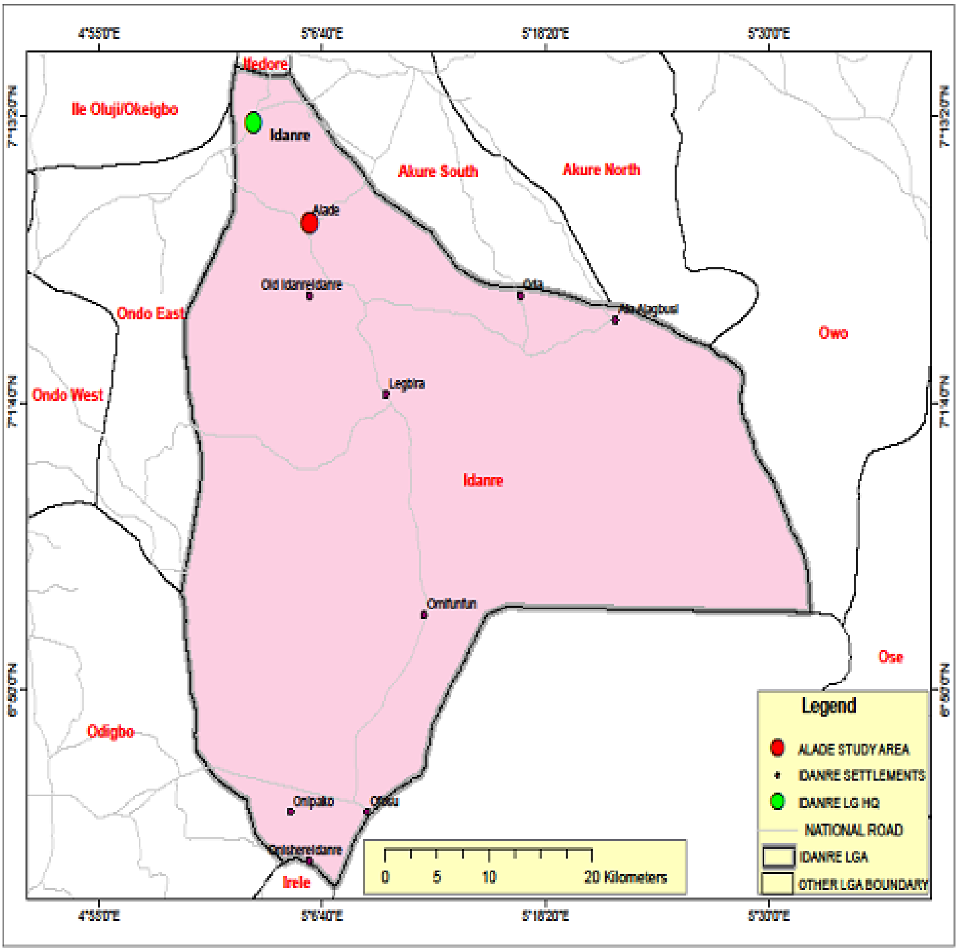

Figure 1: Idanre Local Government Area Map (Source: Mdified from Nigerian Geological Survey Agency 2006).

The climate of the state is of the lowland tropical rain forest type, with distinct wet and dry seasons. The rainy season normally starts from March to October with double maxima rainfall in June/July and slight dry season between November and March. In the south, it rains throughout the year with mean annual rainfall exceeding 2000 mm, but the three months of November - January may be relatively dry. The study area has a mean monthly temperature of 27°C with range of 2°C, while mean relative humidity is over 70%. However, in the northern part of the state, the mean monthly temperature and its range are about 30°C and 6°C, respectively. The vegetation of the study area is classified as rainforest agro-ecological zone, an ideal belt for the production of tree crops. Soil across the state is characterized by very deep and well-drained; loam sandy surface, sandy clay and clay loamy subsoil (Afolayan 2016). The geology of the state is of sedimentary rocks in the south and basement complex rocks in the north.

This study was carried out in October 2015. Data collected for this study were related to the soil and plant sampling techniques. A 55 years old indigenous cocoa farm was purposively selected for study. A plot of 25 m by 25 m quadrat was demarcated in three settlements and twelve (12) soil samples were randomly taken with soil auger from soil depths of 0-15cm and

15-30cm considered as topsoil and subsoil, respectively. The sampling was limited to this area due to the fact that most of the feeding roots of cocoa are concentrated in that depth (Aikpokpodion 2010). Twelve (12) samples from each depth were bulked together to form a composite sample. Composite samples were taken to the laboratory for physico-chemical analyses. Soil particles were air-dried, mixed up together, sieved with a 2.0mm sieve and analyzed using routine laboratory techniques at Step-B Central Research Laboratory, Federal University of Technology, Akure.

Soil samples were analyzed for particle sizes and compositions using the hydrometer method (Bouyoucos 1926). Soil pH was determined potentiometrically in 0.01M calcium chloride solution ratio of 1:2.5 according to Thomas (1996). The soil organic matter content was derived by first determining soil organic carbon through Walkley Black dichromate methods and then converted to organic matter by multiplying by a factor of 1.724 (Nelson and Sommers 1982). After digestion of soil sample with 5ml of nitric acid (HNO_3) exchangeable cations which included calcium (Ca^{2+}), potassium (K^+), magnesium (Mg^{2+}) and sodium (Na^+) were determined with the aid of Atomic Absorption Spectrophotometer (AAS). Total nitrogen (N) was extracted with Bray-P solution according to Kjedahl Method (Bremner and Mulvaney 1982). Extractable trace elements (Zn, Cu^{2+}, Fe^{2+} and Mn) were digested and measured after extraction with 0.1 N HCl and the filtrate read with the aid of Atomic Absorption Spectrophotometer according to the Association of Official Analytical Chemists (1990). To examine the nutrients storage capacity in cocoa farm components, average values of the considered variables were to descriptive statistics.

In each of the selected plots, cocoa plant variables considered as outputs (fresh leaves, cocoa beans and podhusks) and input (litterfall) were randomly taken. Twelve (12) samples from each plot were bulked together to form a composite sample. Fresh leaves, litter and podhusks were air-dried and pulverized before chemical analysis while cocoa beans were fermented for five (5) days and sun-dried followed by grounding to powder before chemical analysis according to Aikpokpodion (2010). Plant samples were ashed with Murphy furnace at 500 °C for 5 hours, cooled, dissolved with 5 mL of 0.4 N HCl and leached to 100 mL with distilled water. The filtrates were determined for the Cu^{2+}, Zn, Mn and Fe^{2+} contents. Quantities of Na^+ and K^+ were determined by flame photometry, Ca^{2+} and Mg^{2+} by AAS; P by colorimetry, and N by the Kjeldahl distillation method (Isaac and Kerber 1971).

Results and Discussion

Average nutrient storage in cocoa components

Soil-plant interrelations are dynamic and subject to all inputs (fertilizers, pollutants, and soil chemistry) and losses (erosion, leaching, and harvesting). Ability of cocoa plant outputs to store nutrients exceeds the available soil nutrients in cocoa ecosystem (Table 1). Soil particle analysis results were 38.80–48.80% sand, 20% silt and 31.20–51.80%; hence, they indicate topsoil is sandy loam and subsoil is clay loam. In cocoa farm, annual harvesting of the yields removes nutrients from the soil. In this study, the main variables considered as outputs are fresh leaves, podhusk and cocoa beans; and litter as input. The soil pH ranged from 5.80 to 6.47, an indication of slight acidic soil. This however, falls below 6.0–6.5 reported to be normal for tree crops like cocoa, coffee, cashew and kola (Opeke 1987). Potasium content of the soil ranged from 0.02 to 0.03 cmo1/kg and for the plant parameters and it was between 8.57 cmo1/kg in the litter to 112.45 cmo1/kg in the podhusk. K^+ values were within the critical level of 0.03 cmo1/kg required for cocoa cultivation in the soil. Soil has the least Ca^{2+} content that ranged from 0.18 cmo1/kg in the subsoil to 133.47 cmo1/kg in the litter. Magnesium contents hads 0.01 cmo1/kg in the soil and ranged between 2.78–21.67 cmo1/kg in plant parameters. Zinc ranged between 1.21–1.32 cmo1/kg in the soil and between 0.36–0.50 mg/kg in the plants.

These values were below the soil critical C^{2+} and Mg^{2+} level of 3 cmo1/kg and 1.2 cm01/kg soil required by calcium and magnesium as reported by Iloyanomon and Ogunlade (2011). Manganese ranged between 0.13 and 2.01 mg/kg in the plant parameters and remained as 0.14 mg/kg in the soil. Iron content in the soil ranged between 1.29 mg/kg and between 0.20–0.36 mg/kg in the plants. Soil copper ranged between 1.28–1.50 mg/kg and 0.23–0.53 mg/kg in the plants. Soil nitrogen and organic carbon content were higher in the soil than cocoa components, it ranged between 0.63% – 0.71% and 0.23– 0.40% in the plants. While the findings from this study show high concentration of micronutrients in the soil and macronutrients were found higher in the cocoa components when compared.

Table 1: Average values of nutrients storage in cocoa components

Properties	Topsoil	Subsoil	Leaves	Beans	Podhusks	Litter
pH	5.86	5.82	6.47	5.80	5.84	6.35
K^+ (cmo1/kg)	0.03	0.02	55.48	33.82	112.45	8.57
Ca^{2+} (cmo1/kg)	0.26	0.18	51.51	2.13	8.00	133.47
Mg^{2+} (cmo1/kg)	0.01	0.01	21.67	2.78	8.10	3.69
Na^+ (cmo1/kg)	0.01	0.01	10.82	3.35	6.38	6.18
Sub-total	**0.31**	**0.22**	**139.48**	**42.08**	**134.93**	**151.91**
P (mg/kg)	5.91	5.91	28.81	22.51	9.57	28.29
Zn (mg/kg)	1.32	1.21	0.50	0.40	0.49	0.36
Mn (mg/kg)	0.14	0.14	1.28	0.13	0.13	2.01
Fe^{2+} (mg/kg)	1.29	1.39	0.36	0.27	0.25	0.20
Cu^{2+} (mg/kg)	1.28	1.50	0.38	0.23	0.53	0.30
Sub-total	**9.94**	**10.15**	**31.33**	**23.82**	**10.97**	**31.16**
OM (%)	3.69	2.31	9.00	9.61	9.11	8.71
OC (%)	2.31	1.34	5.24	5.50	5.29	5.06
N (%)	0.63	0.71	0.40	0.32	0.30	0.23
Sub-total	**6.63**	**4.36**	**14.9**	**15.17**	**14.70**	**14.0**
Grand total	**22.74**	**20.55**	**191.92**	**86.85**	**166.44**	**203.42**
Percent (%)	3.29	2.97	27.74	12.55	24.05	29.40
Sand (%)	48.80	28.80				
Silt (%)	20.00	20.00				
Clay (%)	31.20	51.80				
Textural class	Sandy loam	Clayloam				

Source: Author's Analytical Data (2016).

Soil nutrient balances in cocoa ecosystem are the functions of the inputs (litter and fertilizers) and outputs (yields and timber harvests, erosion, and leaching). In this study, yield harvests and litter were considered with assumption that the impacts of fresh leaves are negligible.The results show that litterfall accounts for about 29.40% of the nutrient inputs, cocoa podhusks (24.06%), cocoa beans (12.55%), and soilas the nutrient pool (6.26%). Fruits are considered as part of biomass but appear separately on the chart for the recognition of its impacts in nutrient storage capacity (Figure 2).

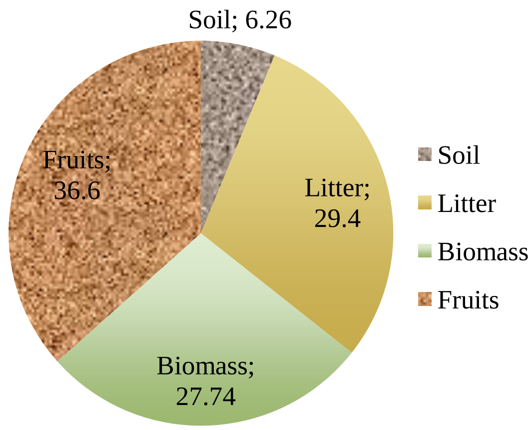

Figure 2: Model of nutrient storage in cocoa ecosystem (Source: Author's analytical data 2016).

Also, separate illustration indicates that biomass is made up of 67.5%, litter 32.4% and soil 0.01% of macronutrients cations (K^+, Ca^{2+}, Mg^{2+}, and Na^+), and micronutrients (Zn, Mn, Fe^{2+}, and Cu^{2+}) are composed of 32%, 17.6% and 50.4% of biomass, litter and soil, respectively. The results show a clear disparity in the nutrient storage of each compartment. This is in line with the findings of Ipinmoroti and Ogeh (2014) that observed a great difference in the soil and leaf nutrient contents between the old and new plantation in Edo State, Nigeria. About 64.7% of carbon is stocked in biomass, 0.5% in litter and 14.8% in the soil; the situation that may be attributed to soil quality content. Nijmeijer et al. (2019) reported that the annual increase in soil organic carbon concentrations of A-cAFS was lower in soil with low clay contents (10-15%) than in soils with higher clay contents (20-25%). Similarly, biomass, litter and soil are made up of 60.3%, 28% and 11.7% of phosphorus. In summary, the increasing order of nutrient concentrations in old cocoa ecosystem can therefore be summarized as: biomass> litter > soil against the order given by Gersmehl (1976) as: litter > biomass >soil in mere tropical rainforest (Table 2).

Table 2: Percentage (%) nutrient stocked in cocoa ecosystem

	Biomass	Litter	Soil
Cations	67.5	32.4	0.01
Micro-nutrients	32.0	17.6	50.4
Carbon	64.7	20.5	14.8
Phosphorus	60.3	28.0	11.7

Source: Author's analytical Data (2018)

Nutrients are said to be low when the plants are growing and fruiting although this situation is preponderance during the fruiting period. Cocoa absorbs a large quantity of nutrients mainly from the soil for its development. Conversely, availability of soil nutrients may be recorded in a contrary season. Nutrient storage in litter as inputs exceeds the individual plant variables considered as outputs in the cocoa ecosystem. This may be the main reason why cocoa plantations remain productive for many decades without chemical fertilizer applications. Fresh leaves may not be really considered as a channel of nutrient losses because they return as litter and serve as indications of soil fertility. Contributions of fresh leaves to soil fertility losses in cocoa ecosystem are negligible, less than 1.5% (Afolayan 2016). Loss of nutrient occurs when the average inputs are less than outputs, mainly via annual yield harvests because soil erosion is negligible in mature cocoa plantation (Ajibade and Afolayan 2014). Higher concentrations of nutrients in litter above that of fresh leaves are attributed to the impacts of litter from the shade trees.Studies on the assessments of soil fertility are common and are usually limited to the soil nutrient status. However, the impacts of plant variables need to be considered because not all nutrients stocked in plant parts return via litter due to their immobility in plants. Some nutrients are mobile in soil but immobile in plants.

Soil nutrient index in cocoa ecosystem

The relevant channels of nutrient cycling in cocoa ecosystem are considered to be the soil, litterfall, cocoa pods (beans and podhusks) and leaves. Analysis of Soil Nutrient Budget in old cocoa ecosystem computed from Table 1 can be expressed as follows:

$$\mathbf{SNI = (S + L) – (P + B)}$$

where: S is nutrient storage in soil, L is the nutrient storage in litter, P indicates nutrients in podhusks and B means nutrient concentrations in cocoa beans. Applications of the above equation into the results in this study were used to generate the Soil Nutrient Index (SNI). Ideally, soil nutrient index is a function of the available nutrients in the soil, litter, fruits (pods and beans), leaves and natural losses via erosion and leaching in mature cocoa ecosystem. However, soil erosion actions in mature cocoa ecosystem are negligible when compared with the losses from yields or harvests.

$$SNI = f\,(S + L) – (P + B) \pm Lf + E + LE;$$

where: Lf is nutrient concentrations in leaves, E is the effect of soil erosion and LE is the loss of nutrients through leaching (Equation 1). Due to this, four main factors; soil, litter, beans and podhusks were considered in this study.

SNI = (S + L) – (P + B)-----------equation 1

SNI = (43.29 + 203.43) - (166.44 + 86.85)----equation 2

SNI = 246.72–253.29-------------equation 3

SNI = -6.57 (1.32%)--------------equation 4

Results from this equation indicate that average nutrient losses via cycling were approximately 1.32% annually from the nutrient pool, which was almost of the same quantity with average soil storage capacity. Incorporation of negligible impacts of fresh leaves reduced the value from 1.32 to 0.95% annually. The higher the soil nutrients index the higher the rate of nutrient loss and vice versa. Therefore, if the average productive lifespan of cocoa is considered tobe 25 years according to ICCO (2013), about 33% of nutrients must have been lost at the end of the life cycle due to yield harvests. This creates nutrient imbalances in cocoa ecosystem provided the inefficiency of other nutrient output channels (erosion and leaching) are minimal. Results from this study indicate low soil nutrient degradation due to the replenishment impacts of litter (from cocoa and shaded trees). This has been the main reason for the long lifespan of cocoa in its suitable environment, precisely the tropical rainforest. Cocoa trees have been known to live for about 200 years in their natural environment, but they are more productive for about 25 years of their life span (ICCO 2013). This is contrary to the findings of Ayanlaja (1983) that attributed declining productivity of most cocoa plantations in Nigeria after 10 years to an inadequate site selection of many farms. Results from equation 4 imply that cocoa farms may require fertilizer applications after the productive period of 25 years. However, with regard to the considered farm, about 72.60% of the nutrients were lost due to the annual harvests despite the roles of the litter. This supports reason provided by Ekanade (2011) that once the tropical rainforest is removed, soil properties, especially the chemical properties deteriorate with time. Descriptive evaluations of the inputs and outputs of the nutrients indicate that there will be less than 27% of the available nutrients for the subsequent utilization for yield production in the next 21 years if not augmented with fertilizer applications. From this analysis, it is empirically assumed that cocoa farms may remain productive for about 75 years in the ideal tropical high forest agroecological zone of Nigeria without fertilizer applications.

Conclusion and Recommendations

Cycling of nutrients in old cocoa farms is the function of outputs and inputs. Aside biomass and soil, litterfall is one of the prominent inputs and channels of nutrient cycling in cocoa farm. This study indicates that mean nutrient storage in litterfall is greater than in soil and with magnitude order of nutrient storage can be considered as biomass > litter> soil in mature cocoa farm. The exchange of nutrients between soil and plant variables in cocoa farm is sequentially reflected demand and supply concept, the higher the the nutrients in plant components the lower the concentrations of such nutrients in the soil and vice versa. Therefore, to elongate the lifespan of cocoa farms and reduce the annual nutrient loss through cycling channels, seasonal relocation and spreading of the accumulated podhusk deposit sites across the farm for nutrient redistribution are recommended. It was observed that this practice will go a long way in redistribution of the nutrient across the farmland, complement litterfall impacts and reduce the nutrient losses in cocoa ecosystem. Also, There is a need for periodic soil fertility evaluation, especially after productive period of 25 years. Also, the impacts of tree parts such as bark, branch, bole (stem) and root on nutrient storage capacity can be further investigated.

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