

The impacts of *Hevea brasiliensis* (rubber tree) plantation on soil nutrients in Southern Nigeria

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Abstract. Ndakara OE, Ohwo O. 2022. The impacts of *Hevea brasiliensis* (rubber tree) plantation on soil nutrients in Southern Nigeria. *Nusantara Bioscience* 14: 234-239. This study investigated how *Hevea brasiliensis* (Willd. ex A.Juss.) Müll.Arg. impact on the soils within the humid rainforest ecosystem of Nigeria. The study used quasi-experimental and stratified random sampling techniques to select sampling units. Samples of soils under *H. brasiliensis* and rainforest (the control) were collected using an auger, and their laboratory analyses for total organic matter (TOM), total nitrogen (N), available phosphorus (P), exchangeable potassium (K), and pH were carried out using standard methods. Data generated were statistically analyzed using the mean, standard deviation, standard error of mean, and t-test. Findings showed that the soils under rainforest have higher nutrient properties than plantations of *H. brasiliensis*. Soil pH values were lower under rainforest than under plantations of *H. brasiliensis*. While TOM, N, and K differed significantly between rainforest and *H. brasiliensis* at a 5% confidence level, available phosphorus and pH were insignificant at a 5% confidence level. Tree species' capability to improve soil nutrition reflects its positive impact on the ecosystem. Since soil nutrients under *H. brasiliensis* are lower than soil nutrients under rainforest, efficient application of organic manure is required to improve the soil nutrient status for sustainable ecosystem functioning and management of the degraded rainforest environment.

Keywords: Agro-ecosystem, biogeochemical cycling, rubber plantation, soil nutrient quality, tree influence circle

INTRODUCTION

The rainforest has undergone increasing amounts and intensity of changes in land use, ranging from selective logging to widespread shifting cultivation agricultural practice, plantation, and intensive agriculture. This land uses impact forest soils together with the proper functioning and structure of the ecosystem (Aweto 2001; Ndakara 2012a). The alteration of land uses from the forest into non-forest requires assessment at a regional scale to adequate knowledge of how such changes affect the biogeochemical processes (Ndakara 2012b) while emphasizing the possible potentials of human-dominated landscape to sustain continued human use (Tsuji et al. 2016).

After a forested area is cleared for agriculture, plantations, or agroforestry, a series of changes occur (Phil-Eze 2010; Amiolemen et al. 2012; Ndakara and Ofuoku 2020). The most conspicuous changes are observed in vegetation compositions, structure, and soil properties (Gruba and Mulder 2015; Augusto et al. 2017; Suzuki et al. 2021). When a rainforest is converted into plantations and assemblages of single species of exotic trees, the role of the tree community in maintaining soil quality is reduced. Similarly, agroforestry practice, centered on integrating trees into farming for several beneficial purposes within the humid rainforest zone, should have exerted impacts on the soils within the rainforest environment. While it has been established that not all species of trees can return nutrient

elements to soils effectively (Aweto and Ekiugbo 1994; Londe et al. 2016; Ndakara 2016), this gap can be filled by adding rainforest trees which can return nutrients to the soil to balance the nutrient availability within the ecosystem (Ndakara 2012b).

The agroecosystems, which are fast replacing the natural rainforest ecosystem, are less diverse floristically and structurally less complex than the original rainforest (Barrios et al. 2012). Although some tree plantations seem superficially similar and alike to forest cover, they are less efficient than the rainforest in nutrient cycling and soil management (Aweto 2001; Ndakara 2012a). The problems of nutrient impoverishment under tree plantations within the rainforest ecosystem are yet to be effectively resolved (Ndakara and Ofuoku 2020). In addition, plants exert a high impact on soil properties. When a forest is converted into plantations and agroforestry, the capacity of tree cover to protect soil surfaces is affected, exposing the soil to degradation. As the agroforestry trees grow, soil deteriorations at different levels occur, and soil's physical and nutrient properties are altered (Kazumichi et al. 2018).

Some studies investigating the impact of cultivated plants on soils within rainforests observed that most soil nutrient properties were significantly lower under the cultivated plants than under the adjacent forest (Phil-Eze 2010; Ndakara and Ofuoku 2020). Barrios et al. (2012) observed that soil nutrient levels during cultivation within rainforest zone were depleted, with the depletion increasing with the age of cropping the land. Although numerous

studies on nutrient cycling in a rainforest (Liu et al. 2015) and fallow land (Saimo et al. 2019) are now available, little is known about the changes in nutrient cycling when fallow is in the form of tree plantations such as the plantation of *Hevea brasiliensis* (Willd. ex A.Juss.) Müll. Arg. or rubber. This knowledge gap emphasizes the necessity of studies that assess the main changes in the rainforest soil nutrient qualities when replaced with tree plantations. Although few studies have investigated this (e.g., Liu et al. 2015 in the context of erosion sites), replication is needed to enrich the variation of soil catena in a different climatic region.

In southern Nigeria, the natural rainforest has largely disappeared owing to centuries of agricultural activities, settlement development, fuel wood exploitation, and logging. These activities resulted in converting the natural rainforest ecosystem into agroecosystems and savanna landscapes (Aweto 2001). As a result, the relics now feature only as island habitats, and the timber tree species which characterize rainforests are now hardly found, while some species are extinct (Ndakara 2016). In some cases, plantations of crops that are non-indigenous to the rainforest are cultivated based on the environmental requirements of such exotic tree species. However, their implications on the rainforest soils concerning nutrient cycling and sustainable soil nutrient management must be adequately documented.

Moreover, examining the soil under exotic trees in the rainforest becomes necessary. Therefore, this research aimed to assess the ecological impacts of *H. brasiliensis* stands on soil nutrient elements in the context of rainforests in southern Nigeria. We expect the results of this study to inform whether the agroforestry practice of *H. brasiliensis* plantation in the region has implications on rainforest soil nutrient quality.

MATERIALS AND METHODS

Study area

The study was carried out in Ughelli North Local Government Area of Delta State, within the humid rainforest belt of Southern Nigeria (Figure 1). This region which covers a land area of 818 km², is geographically located at 4042'-5036' N and 5000'-6006' E. The climate is humid sub-equatorial based on the Af Koppens classification. The regional climate is influenced by two air masses: Tropical Maritime (MT) and Tropical Continental (CT). This region extends from the coast to roughly inland, and it falls within areas with an annual rainfall of 2,000-4,000 mm (which increases the rate of soil nutrient leaching), with a mean annual temperature of approximately 31.5°C (Ndakara 2012a; Ndakara and Eyefia 2021; Ukoji and Ndakara 2021).

The natural vegetation is lowland rainforest of the moist evergreen forest type, with riparian vegetation within the water-logged area. The natural vegetation covers have been highly degraded, while the landscape is now dominated by a mosaic of different stages of savanna enclaves and patches of rainforest remnants (Ndakara 2016). The soils

within this study area are mainly products of coastal deposits, which consist of well-drained sandy loam over coarse sandy clay loam subsoil thus, classified under the Alfisols, Ultisols, Oxisols, and Psalments based on the United States Department of Agriculture (USDA) classification. The soils are ideal for supporting the growth of tree plants, making it possible to grow plantations of exotic trees such as *H. brasiliensis*. As part of the agro-based economic activities, the plantations of exotic tree crops replaced the natural rainforest cover by cutting down the indigenous tree species.

Data collection procedure

The choice of the study area was based on the existing practice of *H. brasiliensis* plantation within the rainforest region of southern Nigeria. The quasi-experimental method was used. A stratified random sampling technique was employed to divide the study area into seven quarters in line with areas with the existing large extent of *H. brasiliensis* plantations. In each of the quarters, a plot of rubber plantation measuring 30×30 m was established, together with an adjoining rainforest of the same measurement from the same quarters, which served as study control following the studies by Aweto and Ekiugbo (1994), Ndakara (2012a), Ndakara and Ofuoku (2020). Samples of soil were collected once from both the plantation and adjacent rainforest using augers from 0-15 cm and 15-30 cm depths (Ndakara 2012a; Ndakara and Ofuoku 2020), making a total of 14 soil samples collected. The 14 soil samples obtained were based on the areas with soil, relief, and climate homogeneity where mature and undisturbed rainforest relics were found.

The samples collected were then analyzed in the laboratory for properties that directly affect soil fertility status and crop productivity to biogeochemical cycling (Ndakara 2012b). The soil properties analyzed were total organic matter (TOM), total nitrogen (N), available phosphorus (P), exchangeable potassium (K), and pH. Standard methods were adopted during the laboratory analysis exercise. The method of Walkley-Black wet oxidation was applied to determine organic carbon before conversion to TOM; Auto-analyzer was used to determine total N; available P was ascertained using a Spectrophotometer; a Flame photometer was used to determine exchangeable K; while soil pH determination was adopted the electrometric approach.

Data analysis

Data generated were further analyzed statistically using SPSS 15.0 version. The descriptive statistics were used to ascertain the mean, standard deviation, and standard error of mean values for the concentrations obtained for each nutrient element. In addition, T-test statistics were used to ascertain the variations in soil properties between topsoil and subsoil under plantations of *H. brasiliensis*, soil properties between topsoil and subsoil under adjoining rainforest, topsoil properties between adjoining rainforest and *H. brasiliensis* plantation, and subsoil properties between adjoining rainforest and *H. brasiliensis* plantation at 5% level of confidence.

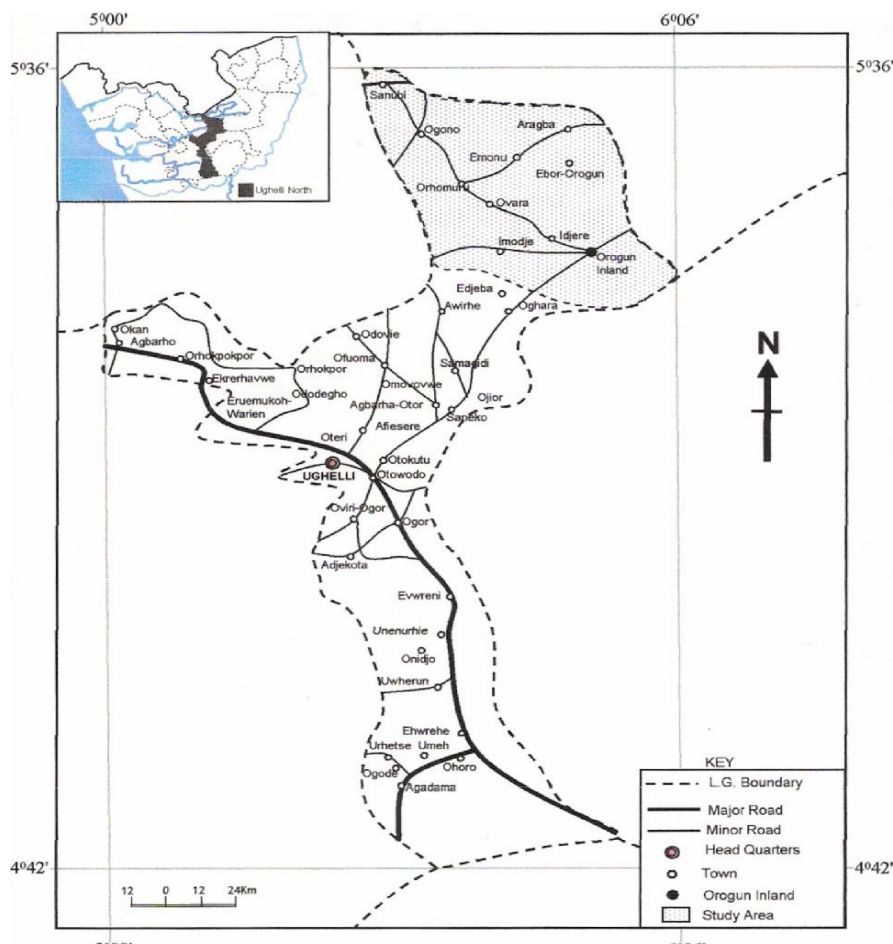


Figure 1. Map of the study area in Ughelli North Local Government Area, Delta State, Southern Nigeria

RESULTS AND DISCUSSION

Soil TOM (total organic matter) represents an important plant nutrient source. As mentioned earlier, the build-up of TOM is one of the significant and major changes in soils under tree stands. That is because organic matter influences the concentration and status of nutrients that accumulate under tree stands (Aweto 2001).

Table 1 presents the results of descriptive statistics for the concentrations of soil properties under plantations of *H. brasiliensis* and rainforest. In general, soils under the rainforest have higher nutrient properties than soils under the plantations of *H. brasiliensis*. That shows that the build-up of nutrients is higher under the rainforest, a vegetation community with various species, in contrast with the pure stand plantation of *H. brasiliensis*. The mean (μ), standard deviation (S2), and standard error of mean (SEM) values for the concentrations of TOM in both topsoil and subsoil are higher under the rainforest than under the *H. brasiliensis* plantation. However, the concentrations of TOM are higher in the topsoil under both rainforest and *H. brasiliensis* in the topsoil and subsoil layers, respectively, which shows that trees can accumulate TOM in the topsoil under their stands, whether in cultivated or natural habitats.

Similarly, the μ , S2, and SEM values for the N

concentrations in both topsoil and subsoil are higher under rainforest than under *H. brasiliensis*. However, the concentrations of N are higher in the topsoil under both rainforest and *H. brasiliensis* in the topsoil and subsoil layers, respectively. Higher topsoil nutrients were reported in studies by Fabricio et al. (2018), Liu et al. (2015), and Ndakara (2016). However, the SEM values for the concentrations of N under the rainforest and *H. brasiliensis* are the same, which shows that trees can accumulate more N in the topsoil under their stands than in the subsoil.

Like the other nutrient elements, the μ values for the concentrations of P in both topsoil and subsoil are higher under the rainforest than under *H. brasiliensis*. However, the concentrations of P are higher in the topsoil under both rainforest and *H. brasiliensis*. The implication of the mean concentrations is that nutrient elements are higher in the topsoil layer under trees than in the subsoil layer. The S2 and SEM values for the concentration of P in the topsoil are higher under *H. brasiliensis* than under rainforest but higher under rainforest than the *H. brasiliensis* in the subsoil layer, respectively. That shows that soil nutrients are dynamic, as shown in studies by Fabricio et al. (2018) and Ndakara and Ofuoku (2020). The mean concentration of nutrient elements may vary in proportion to its standard deviation and standard error of mean values. Trees can

accumulate more P in the topsoil under their stands than in the subsoil. The μ , S2, and SEM values for the K in both topsoil and subsoil are higher under rainforest than under *H. brasiliensis*. However, K contents are higher in the topsoil under both rainforest and *H. brasiliensis* in the topsoil and subsoil layers, respectively. The SEM values for the concentrations of K under the rainforest and *H. brasiliensis* are the same, which shows that trees can accumulate more K in the topsoil under their stands than in the subsoil. Higher K content in topsoils was reported in studies by Ndakara (2012b) and Suzuki et al. (2021).

Soil acidity varied strikingly between the topsoil and subsoil, as well as between the rainforest and the plantation of *H. brasiliensis*. Within both soil layers, the μ values for the soil pH are higher under *H. brasiliensis* than under the rainforest. That implies that soils under rainforests are more acidic than those under *H. brasiliensis*. However, the S2 and SEM values for the pH contents are higher in the rainforest than in the soils under *H. brasiliensis*. Therefore, the stand of *H. brasiliensis* does not increase soil acidity within the rainforest environment. From this finding, it could be deduced that improvement in soil quality is not solely dependent on reduced acidity in the soil. Within the rainforest cover, tree species contained are numerous. Some of the tree species are more acidic than others, but the aspect of nutrients return to the soil will not be in the same direction. For instance, the lower pH content of the soils under *H. brasiliensis* than the soils under the rainforest would have meant that the soils under *H. brasiliensis* contained more nutrient elements than the soils under the rainforest. The species variant within the rainforest was earlier identified by Ndakara (2012a) to account for higher concentrations of nutrients in the native rainforest cover within the tropical environment.

The much lower nutrient contents under plantations of *H. brasiliensis* could be attributed to a factor of *H. brasiliensis* stands not being capable of improving soil nutrient elements through corresponding and adequate replacement of soil nutrient use over time. This finding is similar to results reported in studies by Phil-Eze (2010), Barrios et al. (2012), Ndakara (2012a), Liu et al. (2015), Ndakara (2016), Fabricio et al. (2018), Ndakara and Ofuoku (2020), and Suzuki et al. (2021), where soil nutrient properties were higher under native rainforest. However, the much lower nutrient properties under plantations could indicate that species of trees in the

rainforest have a higher ability to return and enhance soil nutrient properties than *H. brasiliensis*. Soil pH values are lower under rainforests than under plantations of *H. brasiliensis*. The observed variation in the soil pH values reflects equal acidity for soils under both rainforest and *H. brasiliensis*, which corroborates the findings by Ndakara (2012a) and Ndakara and Ofuoku (2020).

Table 2 presents the results of t-test statistics for the differences in soil nutrient properties between rainforests and plantations of *H. brasiliensis*. Generally, soil nutrient properties of TOM, N, and K are significantly different between rainforests and plantations of *H. brasiliensis* at the 5% confidence level. At the same time, the observed differences in mean values of available phosphorus (P) and pH are not significant. However, the t-test statistical results for the differences in the μ values of TOM content of the topsoil between the rainforest and *H. brasiliensis* are significant at the 5% level, indicating that rainforest topsoils contained more TOM than the soil under *H. brasiliensis*. While from the t-test statistical results for the differences in the μ values of TOM content of the subsoil between the rainforest and *H. brasiliensis* is significant at the 5% level, affirming that subsoils under the rainforest contained more TOM than the subsoil under *H. brasiliensis*.

Table 1. Descriptive statistics of the soil properties under *Hevea brasiliensis* plantation and rainforest

Soil properties	Statistics	Topsoil		Subsoil	
		<i>H. brasiliensis</i> plantation	Rain-forest	<i>H. brasiliensis</i> plantation	Rain-forest
TOM (%)	Mean	4.02	6.20	1.10	2.74
	SD	0.79	0.72	0.22	0.82
	SE	±0.31	±0.28	±0.09	±0.32
N (%)	Mean	0.43	0.64	0.21	0.28
	SD	0.08	0.13	0.03	0.04
	SE	±0.03	±0.05	±0.01	±0.01
P (mg/kg)	Mean	12.88	14.82	6.13	7.65
	S.D	6.03	1.94	1.29	1.72
	S.E	±2.28	±0.73	±0.49	±0.65
K (mg/kg)	Mean	56.29	114.57	18.71	31.00
	S.D	6.18	21.40	3.04	10.20
	S.E	±2.34	±8.09	±1.15	±3.86
pH	Mean	6.09	6.06	5.76	5.63
	SD	0.64	0.74	0.68	0.80
	SE	±0.24	±0.28	±0.26	±0.30

Table 2. T-test Statistical results of the differences in soil properties between *H. brasiliensis* plantation and rainforest

Soil properties	Soil layer	F-value	df	T-value	Sig. 2-tailed value	Remark
TOM (%)	Topsoil	0.444	12	5.448	0.000	Significant
	Subsoil	11.843	12	5.204	0.011	Significant
N (%)	Topsoil	4.950	12	3.875	0.002	Significant
	Subsoil	0.424	12	3.784	0.003	Significant
P (mg/kg)	Topsoil	2.065	12	0.805	0.436	Not Sig.
	Subsoil	1.270	12	1.872	0.086	Not Sig.
K (mg/kg)	Topsoil	6.517	12	6.923	0.000	Significant
	Subsoil	2.760	12	3.055	0.010	Significant
pH	Topsoil	0.103	12	0.077	0.940	Not Sig.
	Subsoil	0.001	12	0.324	0.751	Not Sig.

The t-test statistical results for the differences in the μ values of N content of the topsoil between the rainforest and *H. brasiliensis* is significant at the 5% level, showing that rainforest topsoils contained more N than the soil under *H. brasiliensis*. Similarly, the t-test statistical results for the differences in the μ values of N content of the subsoil between the rainforest and *H. brasiliensis* is significant at the 5% level, emphasizing that subsoils under the rainforest contained more N than the subsoil under *H. brasiliensis*. In contrast, the t-test statistical results for the differences in the μ values of P content of the topsoil between the rainforest and *H. brasiliensis* are not significant at the 5% level, although a difference exists. Similarly, the t-test statistical results for the differences in the μ values of P content of the subsoil between the rainforest and *H. brasiliensis* are insignificant at the 5% level.

There is a significant difference in the μ values of K content of the topsoil between the rainforest and *H. brasiliensis* at the 5% confidence level, implying that rainforest topsoils contained more K than the soil under *H. brasiliensis*. In the subsoils, there are significant differences in μ values of K content under the rainforest and *H. brasiliensis* at the 5% confidence level, affirming that subsoils under the rainforest contained more K than the subsoil under *H. brasiliensis*. The t-test statistical results for the differences in the μ values of pH content of the topsoil between the rainforest and *H. brasiliensis* are not significant at the 5% level since the acidity of topsoil under rainforest is at the same range as that under *H. brasiliensis*. A similar result for soil acidity is also found in the subsoil.

As presented earlier, the higher nutrient contents under rainforest reflect a higher capability of built-up soil nutrients. Significant differences between soils under rainforest and cultivated exotic tree species were reported by Aweto and Ekiugbo (1994), Aweto (2001), Phil-Eze (2010), Ndakara (2012b), Liu et al. (2015), Fabricio et al. (2018), Ndakara and Ofuoku (2020), and Suzuki et al. (2021). The capability of trees to improve soil nutrients reflects the positive impact on the rainforest ecosystem. However, the observed insignificance in soil pH shows that stands of *H. brasiliensis* do not effectively alter the acid-base content of soils within rainforest environments.

In conclusion, this study investigated how *H. brasiliensis* plantation impacts the soils within Nigeria's humid rainforest ecosystem. Regarding the implications of cultivating *H. brasiliensis* on the functioning of the rainforest and the soils underneath, by which the plants grown on such soils could either negatively or positively impact them. The true reflection of such impact is determined and predicted by the functional contributions of plants to soils in the environment they are grown. However, the investigation of *H. brasiliensis* as a non-indigenous tree grown within a rainforest environment revealed reduced soil nutrient properties. Therefore, this study is of paramount importance to the quest to manage the degraded rainforest ecosystem effectively. The results from this research show that soils in the rainforest have higher nutrient properties than plantations of *H. brasiliensis*, except for soil pH values which were lower

under the rainforest. While TOM, N, and K differed significantly between rainforest and *H. brasiliensis* at a 5% level of confidence, available phosphorus and pH were insignificant. Since soil nutrients under *H. brasiliensis* are lower than soil nutrients under rainforest, efficient application of organic manure is required to improve the soil nutrient status for sustainable ecosystem functioning and management of the degraded rainforest environment.

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