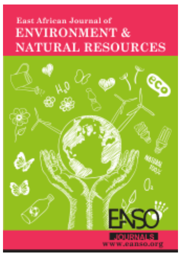

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Original Article

Soil Quality Dynamics under Isolated Stands of *Irvingia gaboneensis* (Bush Mango) and Within the Rainforest in Isoko Region, Nigeria

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ABSTRACT

This study investigated soil quality dynamics under isolated stands of *Irvingia gaboneensis* within the rainforest of Isoko South region in Nigeria. Both experimental and quasi experimental designs were adopted; while the study area was stratified into 10 from which 2 sampling sites (*I. gaboneensis* and rainforest respectively) were selected, making 20 sampling sites examined. Samples of soil were derived from topsoil (0-15 cm) and subsoil (15-30 cm) layers of soil under *I. gaboneesis* and rainforest using core sampler. Each selected site of 30 m x 30 m was divided into quadrant of 10 m x 10 m from which samples were taken. Laboratory analyses of the samples were carried out following standard procedures. All data generated were statistically analysed using descriptive and paired t-test. Results revealed that soil attributes varied under *I. gaboneensis* and rainforest. With t-value = 0.114 and P (0.9110) > 0.05, mean differences in the topsoil are not significant. For the subsoil, t-value = 0.706 with P (0.4980) > 0.05 thus, mean differences in the subsoils are not significant. Also, with t-value = 1.0250 and P (0.3320) > 0.05, mean differences between the topsoil and subsoil under *I. gaboneensis* is not significant. For the rainforest, the t-value = 1.1520 and P (0.2790) > 0.05, mean differences between the topsoil and subsoil under adjoining rainforest trees is not significant. The observed insignificant difference in properties of soils under *I. gaboneensis* and rainforest shows the capacity of *I. gaboneensis* in soil management. Therefore, its conservation should be encouraged to manage the degraded rainforest ecosystem, while their incorporation into agro-forestry farming should be encouraged.

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INTRODUCTION

Soil qualities under trees vary in response to species variation within any given ecosystem (Hermansah, Tsugiyuki & Toshiyuki, 2002; Ndakara & Ofuoku, 2020). The amount of nutrients under tree stands and how the trees impact on soil properties will therefore vary depending on the tree species in question, in addition to their distribution pattern (Pypker, Bond, Link, Marks & Unsworth, 2005). Also, different species of trees exert varying influence on physical and nutrient attributes of the rainforest soils (Muoghalu & Oakhumen, 2000; Ndakara, 2012a).

Studies have shown that all species of trees do not significantly improve soil qualities under their stands, which could possibly be as a result of the trees' interactions with the soil, in addition to level of exposure to frequent anthropogenic activities (Kazumichi et al., 2018; Ndakara & Ohwo, 2022). Indeed, the extent to which communities of trees are determined by availability of resources is central to ecosystem studies (Ndakara, 2009; Okwuokei & Ndakara, 2022). Patterns of small-scale variations in soils under individual species of trees are poorly known in rainforest due to close canopy influence, coupled with the fact that the trees are in communities (Barrios, Sileshi, Shepherd & Sinclair, 2012; Ndakara, 2012b). With the current trend in rainforest degradation owing to resource exploitation, settlement development, mineral exploitation, and other anthropogenic activities (Obi & Ndakara, 2020; Ukoji & Ndakara, 2021) it is quite necessary to examine the soils under different species of trees for the special purpose of sustainability (Ohwo & Ndakara, 2022) and effective management of the soils in rainforest ecosystem. The knowledge of which will be of immense importance in the drive for agricultural development through the incorporation of such important tree species into the agro-forestry practice, since such tree species have the capacity to enhance and improve soil under their stands (Ndakara & Ofuoku, 2020).

The agro-ecosystems which are fast replacing the natural rainforest are less diverse floristically and structurally less complex than the original rainforest (Barrios, Sileshi, Shepherd & Sinclair, 2012). Although, some tree plantations which are the main components of the widespread agricultural land-use seem superficially similar and alike to forest cover they are less efficient than the rainforest in the aspect of nutrient circling and soil management (Aweto, 2001; Ndakara, 2016). Soil nutrients impoverishment problems under tree crop plantations within rainforest environment have not been effectively resolved. The capacity of tree cover to protect soil surfaces has been affected, thereby exposing the soil to degradation. As the agro-forestry trees grow, soil deteriorations at different levels occur, and in the process, essential characteristics of soils are altered (Kazumichi, et al., 2018).

Several studies have investigated properties of soils under tree stands. Fabricio, Eliana, Oscarlina, Daniel and José (2018) studied the organic matter and cation exchange capacity of tropical soil in Brazil. Ndakara and Ofuoku (2020) carried out characterization of plant biomass and the soil attributes under trees within humid lowland rainforest of Nigeria. Ndakara and Ohwo (2022) carried out an ecological assessment of how stands of *hevae brasilensis* (rubber tree) impact on rainforest soil nutrient quality. The different studies reported variation in the properties of soils under different tree species. Some of such studies carried out to investigate how cultivated plants impact on nutrient properties of soils within rainforest reported that most nutrient properties of soil were significantly

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higher under adjacent forest than under cultivated plants (Phil-Eze, 2010; Ndakara & Ofuoku, 2020). Studies by Ekanade (2003), Ndakara (2012c) have reaffirmed that all species of trees does not significantly improve soil chemical properties. The low concentrations of nutrients and organic matter in soil under cultivated trees is due possibly to frequent cultivation and burning of the vegetation prior to cultivation (Liuet al., 2015; Londe, De Sousa & Kozovits, 2016; Augusto, Achat, Jonard, Vidal & Ringeval, 2017). Findings reported in the study by Ndakara and Ohwo (2022) showed that soils under rainforest have higher nutrient properties than plantations of *H. brasilensis* thus, the study recommended efficient application of organic manure to enhance soil productivity and ecosystem functioning. Reports of findings from the research which investigated soils under *Newbouldia laevis* by Aweto and Iyanda (2003) showed a higher mean concentration of organic matter under stands of *N. laevis* than that of soil outside *N. laevis* canopy, which was attributed to the anthropogenic activity of regular burning prior to cultivation. Bulk density was lower and total porosity higher under the tree canopies. With the exception of available phosphorus, there was no marked improvement in nutrient levels of the soil under *N. laevis* canopies when compared with soils outside the canopies. A review of several studies by Kharelet al. (2019) showed that marked and significant accumulation of nutrients exist under certain species of trees like *Acacia tortilis, Faidherbia albidia, Adansonia digitata, Albizia saman,* and *Parkia biglobosa*.

The purpose of this study is to characterize the properties of soils under the stands of *Irvingia gaboneensis* and within the rainforest. This research will therefore give substance to the understanding of the extent to which *Irvingia gaboneensis* influences the soils of the rainforest environment.

Conceptual Issues

This study used the concept of "Tree Influence Circle" as framework. It emphasizes how trees exert influence on their immediate environment especially on the soils underneath their stands. The knowledge of how trees affect soil is essential for evaluating the role of trees within rainforest ecosystems and the desirability or otherwise of retaining tree plants in the ecosystems (Ndakara, 2012a). The purpose for soil properties evaluation has become necessary. As observed from the different studies on tree influence circle, how trees affect soil will vary depending on the type of tree in question (Ndakara & Ohwo, 2022). Some tree species may accumulate nutrients in their standing biomass and the rate of nutrient storage in their biomass may be higher than the rate of storage in the soil. They generally tend to immobilize nutrients faster than recycling them to the top soil (Ndakara, 2012a). Nutrients absorbed from soil by trees are mobilized in the standing biomass and then recycled back into the topsoil. Through these processes, trees help to accumulate nutrients and organic matter in soils within rainforest (Wood, Lawrence & Clark, 2006).

Tree influence circle as a concept has been greatly applied in studies that are focused on investigating the relationships between tree stands and the soil under their stands, or how certain species of trees impact on soils underneath their stands. Some of such studies as conducted by Aweto and Moleele (2005) applied the concept as "single-tree influence circle". These studies examined how single tree species influence and impact on the properties of soils. In some other studies as conducted by Aweto and Dikinya (2003), the concept was applied to examine the influence and impact of two or more species of trees on soil properties. Soil nutrient decline usually sets in once there is loss of biodiversity following the conversion of natural forest into monoculture plantation of trees due to a destabilization of the nutrient cycle (Ndakara, 2012b). Therefore, the emergence of isolated tree plants within community ecosystem should have exerted influence on the soil, in the course of their interactions as component parts of the ecosystem.

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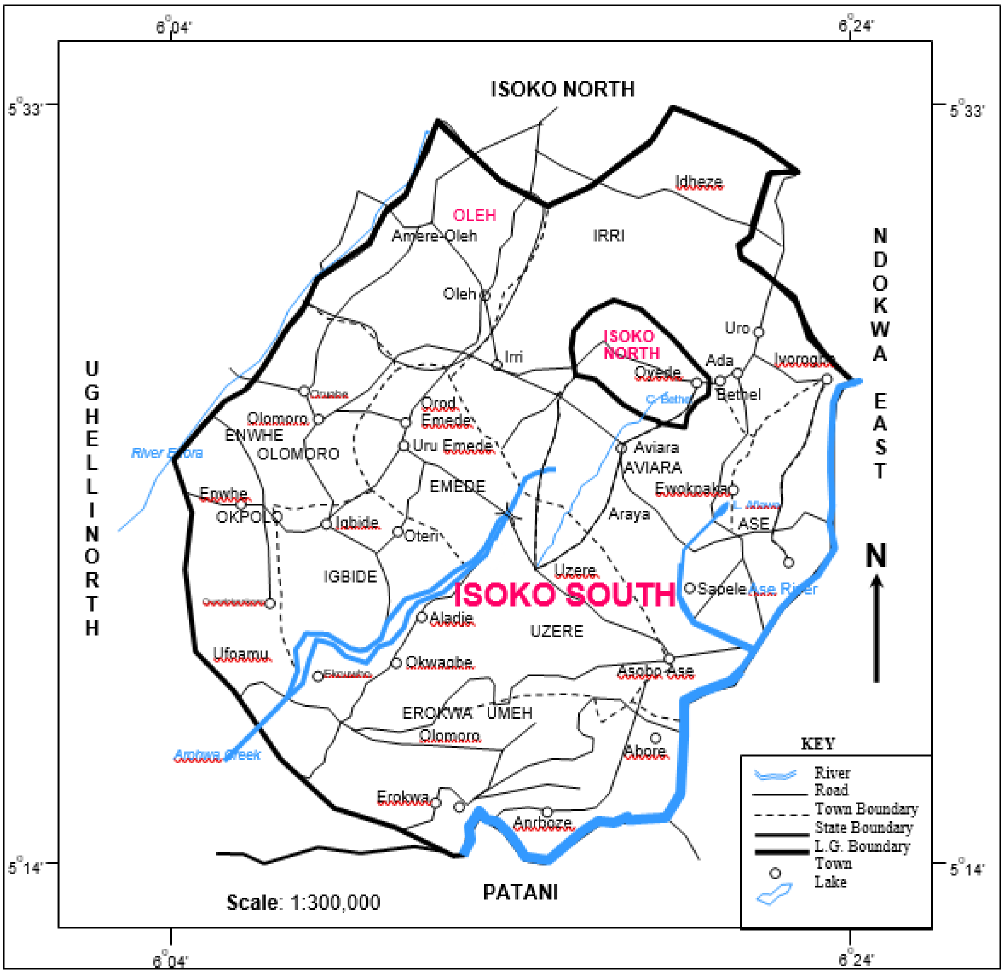
MATERIALS AND METHODS

Study Area

This study was carried out in Isoko South region of Delta State in southern Nigeria. The region is geographically located between latitudes $5^0$33'N and $5^0$14'N and also between longitudes $6^0$04'E and $6^0$24'E. Isoko South covers an area which is approximately 668km^{2}The terrain of this region is relatively low with some areas liable to seasonal flooding due to low height above sea level. Annual temperature ranges between 26 ^{0}C and 28 ^{0}C. Rainfall is experienced year-round, but significantly experienced in about 9-10 months of the year (Ndakara, 2009) with a little August hiatus, giving rise to double rainfall maxima in July and September (Ndakara & Ohwo, 2023). The annual rainfall ranges between 2000 mm and 4000 mm; with relative humidity of between 55% and 90% depending on the hour of the day and season of the year (Efe & Ndakara, 2010). The study area is located within the humid tropical rainforest belt, which is evergreen forest with riparian forest covers. The rainforest consists of three canopies of trees (upper, middle, and lower layers) respectively. The mature forest is well-developed physiognomically with three identifiable tree layers. The soils are orderly classified under oxisols, alfisol and psalments following the United States Department of Agriculture (U.S.D.A.) soil classification taxonomy (Ndakara, 2012a). They have the attributes of soils in the lowland rainforest ecosystems of the tropical region. The Psalments dominates the areas liable to seasonal flooding. The seasonal returns of nutrients by dead plants after flooding supports soil quality maintenance thus, makes psalments important in supporting effective growth and production of riparian trees within the region.

Figure 1: Map of Isoko South local government area



Source: Ministry of Lands, Survey & Urban Development, Asaba, (2022)

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Data Collection Procedures

This study adopted both experimental and quasi experimental design approaches. This design was appropriate to this study where mature rainforest covers were examined as control sites to under-study the isolated stands of *Irvingia gaboneesis* being the experimental sites. The sampling technique used was the stratified random approach. The region was stratified into 10 strata (Olomoro, Enwhe, Emede, Igbide, Erowha, Oleh, Okpolo, Irri, Uzere and Aviara) from which an experimental and control sites were selected. Therefore, from each stratum, 2 sampling sites were randomly selected making 20 sampling sites, 10 experimental sites and 10 control sites respectively. Following the design adopted in the study by Ndakara and Ofuoku (2020) Quarters were chosen because they all fall within the same ecological zone featuring similar moist lowland rainforest characteristics; presence of isolated stands of *Irvingia gaboneesis* that satisfied the conditions of being selected; and presence of mature adjoining rainforest that satisfied the conditions of being used as control sites. The selection of experimental sites was because isolated stands of *Irvingia gaboneesis* are not influenced by litterfall from other tree species (Ndakara, 2012b). On the other hand, the selection of control sites was based on reason that no stand of *Irvingia gaboneensis* was contained in the measured plots chosen as sites within the adjoining mature rainforest in the quarter.

The tree species that featured commonly in the selected rainforest sites were the *Terminalia superba*, *Ricinodendron heudelotii*, *Ceiba pentandra*, *Pentaklepta macrophylla*, *Antiaris toxicaria*, *Piptadenastrium africanum* and *Triplochiton scleroxylon*. In all 40 samples of soil were collected for the study using core sampler, from the topsoil (0-15 cm) and subsoil (15-30 cm) layers under stands of *Irvingia gaboneesis* and rainforests, from adopted quadrants 10m x 10m which were derived from selected sites measuring 30 m x 30 m. The samples of soils were analysed in the laboratory for particle size distribution (PSD), bulk density (BD), total porosity (TP), water holding capacity (WHC), exchangeable potassium (K), total nitrogen (N), available phosphorus (P), and total organic carbon (TOC). The hydrometer method was used in the analysis of PSD; BD was determined by the core method (Blake, 1965); TP was determined by the core method, where;

Porosity (%) = (1 – (Bulk density / Particle density) × 100;

Soil WHC was determined by saturating and gravitational draining for 24 hours with zero evaporation followed by oven-drying for 24 hours at 105 ºC; Exchangeable K was determined with a flame photometer; N was determined with auto-analyzer after digesting soil samples with H_2SO_4; available P extracts were obtained by leaching the soil with Bray P – 1 extracting solution of 0.025N HCl + 0.03N NH_4F, while the concentrations were determined with spectrophotometer. TOC was determined by the Walkley-Black wet oxidation method. The figures obtained for TOC were converted into total organic matter (TOM) values. The descriptive statistics were used to determine the mean and graphical representation of the data sets. The student's t-test was used to ascertain the difference between the: properties of soils under stands of *Irvingia gaboneensis* and control rainforest trees; and topsoil and subsoil properties unde the stands of *Irvingia gaboneensis* and control rainforest trees.

RESULTS AND DISCUSSION

Soil Properties under Stands of *Irvingia gaboneensis* and Rainforest Trees

The properties of soils varied between the stands of *Irvingia gaboneensis* and the adjoining rainforest trees. These soil properties examined are those that account for the functional interrelationships between soil and trees in rainforest ecosystem. The extent to which the concentrations deviate from the ascertained concentrations within any mature native rainforest shows the capacity of such tree species in the bid for management of the soils in rainforest environment (Ndakara, 2012b).

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Table 1: Topsoil Parameters under Stands of *Irvingia gaboneensis* and Rainforest Trees

Soil Properties	Mean Concentrations and Values	
	***I. gaboneensis* Sites**	**Rainforest Sites**
Total Nitrogen (%)	0.65	0.74
Available Phosphorus (mg/kg)	15.08	15.35
Total Organic Matter (%)	5.27	5.86
Exchangeable Potassium (mg/kg)	111.9	102.5
Bulk Density (g/ cm^3)	1.08	0.97
Total Porosity (%)	60.38	65.42
Water Holding Capacity (%)	55.27	60.98
Sand Fraction (%)	69.82	70.37
Silt Fraction (%)	19.33	17.95
Clay Fraction (%)	10.87	10.98

Source: Field work, 2023

Table 1 presents the concentrations and values of the topsoil parameters under stands of *Irvingia gaboneensis* and adjoining rainforest trees. The mean values show that soil properties varied between the stands of *Irvingia gaboneensis* and the adjoining rainforest trees. Within the topsoils, total nitrogen (0.74%), available phosphorus (15.35 mg/kg), total organic matter (5.86%), bulk density (0.97 g/ cm3), porosity (65.42%), water holding capacity (60.98%), sand (70.37%) and clay (10.98%) were higher under the adjoining rainforest trees; while exchangeable potassium (111.9 g/ cm3) and silt (19.33%) were higher under the stands of *Irvingia gaboneensis* respectively. The results show that the mean values of chemical and physical properties of topsoils are higher under adjoining rainforest than that of the stands of *Irvingia gaboneensis*. These findings are in line with the findings reported in the studies by Ndakara (2012a), Ndakara and Ofuoku (2020). The findings could be attributed to the combined impact of tree species in community of rainforest which made it often difficult to isolate the direct contribution of specific species of tree within the community to the rainforest (Ndakara, 2012c).

Figure 2: Mean concentrations and values of topsoil parameters under stands of *Irvingia gaboneensis* and adjoining rainforest trees

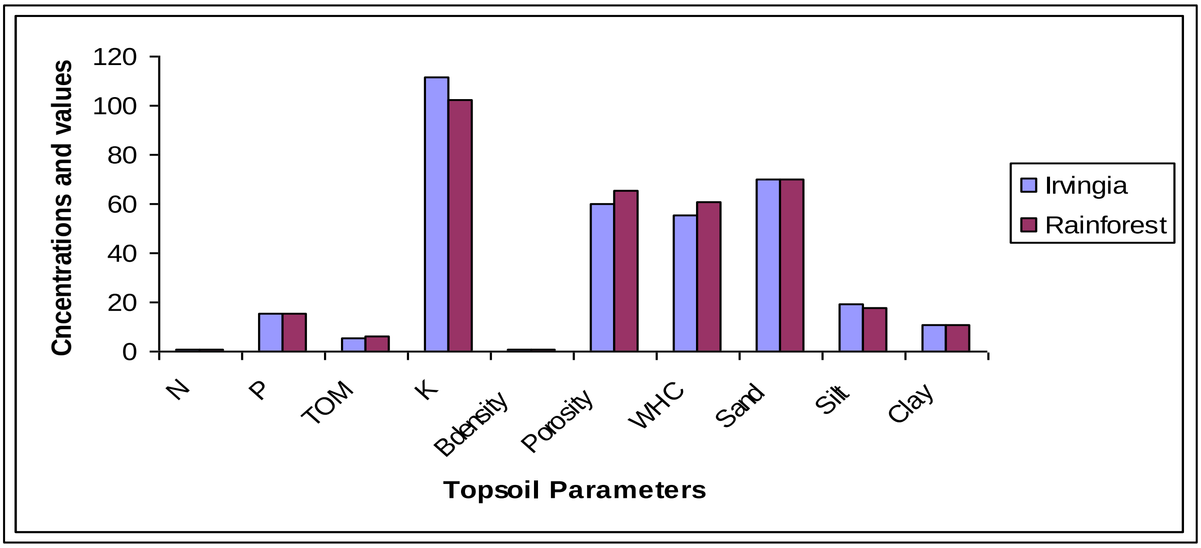

Figure 2 shows the mean contents and values of the topsoil properties under the stands of *Irvingia gaboneensis* and the adjoining rainforest trees. The topsoils, total nitrogen (0.74%), available phosphorus (15.35 mg/kg), total organic matter (5.86%), bulk density (0.97 g/ cm3), porosity (65.42%), water holding capacity (60.98%), sand (70.37%) and clay (10.98%) were higher under

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the adjoining rainforest trees; while exchangeable potassium (111.9 g/ cm3) and silt (19.33%) were higher under the stands of *Irvingia gaboneensis* respectively. For both stands of *Irvingia gaboneensis* and rainforest trees, potassium concentrations (111.9 mg/kg, 102.5 mg/kg) respectively were highest. These findings corroborate findings reported in studies by Ndakara (2012a), Ndakara and Ofuoku (2020).

Table 2: Subsoil Parameters under Stands of *Irvingia gaboneensis* and rainforest trees

Soil Properties	Mean Concentrations and Values	
	***Irvingia gaboneensis* Sites**	**Rainforest Sites**
Total Nitrogen (%)	0.30	0.35
Available Phosphorus (mg/kg)	8.33	8.51
Total Organic Matter (%)	4.71	2.83
Exchangeable Potassium (mg/kg)	29.50	31.70
Bulk Density (g/ cm^3)	0.87	0.82
Total Porosity (%)	62.07	67.96
Water Holding Capacity (%)	57.57	55.97
Sand Fraction (%)	69.45	70.04
Silt Fraction (%)	13.20	12.37
Clay Fraction (%)	18.48	18.89

Source: Field work, 2023

Table 2 presents the concentrations and values of the topsoil parameters under stands of *Irvingia gaboneensis* and adjoining rainforest trees. The mean values show that soil properties varied between the stands of *Irvingia gaboneensis* and the adjoining rainforest trees. Within the subsoils, total nitrogen (0.35%), available phosphorus (8.51 mg/kg), exchangeable potassium (31.70 g/ cm3), porosity (67.96%), sand (70.04%) and clay (18.89%) were higher under the adjoining rainforest trees; while total organic matter (4.71%), bulk density (0.87 g/ cm3), water holding capacity (57.57%) and silt (13.20%) were higher under the stands of *Irvingia gaboneensis* respectively. The results show that the mean values of the properties of subsoils are higher under adjoining rainforest than that of the stands of *Irvingia gaboneensis*. The findings here are similar to the findings reported in the studies by Ndakara (2012a), Ndakara and Ofuoku (2020). This could also be attributed to the combined impact of different species of trees in rainforest community which made it often difficult to isolate the direct contribution of each species of trees within the community to the rainforest as reported in a study by (Ndakara, 2012a).

Figure 3: Mean concentrations and values of subsoil parameters under stands of *Irvingia gaboneensis* and adjoining rainforest trees

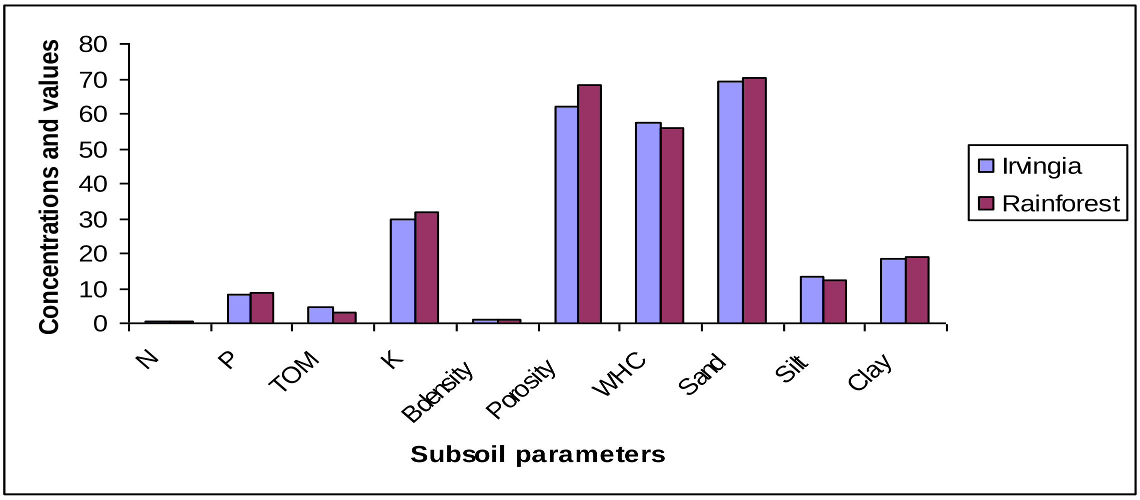

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Figure 3 shows the mean contents and values of soil parameters under the stands of *Irvingia gaboneensis* and the adjoining rainforest trees. The subsoils total nitrogen (0.35%), available phosphorus (8.51 mg/kg), exchangeable potassium (31.70 g/ cm3), porosity (67.96%), sand (70.04%) and clay (18.89%) were higher under the adjoining rainforest trees; while total organic matter (4.71%), bulk density (0.87 g/ cm3), water holding capacity (57.57%) and silt (13.20%) were higher under the stands of *Irvingia gaboneensis* respectively. For both stands of *Irvingia gaboneensis* and rainforest trees, sand content (70.04%, 69.45%) respectively were highest. The results corroborate the results presented in the studies by Ndakara (2012a), Ndakara and Ofuoku (2020).

Student's t-test statistical technique was used to test the difference between properties of soils under stands of *Irvingia gaboneensis* and the rainforest trees at 0.05 level of confidence.

Table 3: Paired Samples T-Test Output for the Differences between the Soil Properties under Stands of *Irvingia gaboneensis* and the Rainforest Trees

Soil Profile	Paired Samples	Paired S.E.M	Paired Differences (95% CI) Lower	Upper	t-value	df	P-value
Topsoil	*I. gaboneensis* Rainforest	1.2859	3.0558	2.7618	0.114	9	0.9110
Subsoil	*I. gaboneensis* Rainforest	0.7025	2.0851	1.0931	0.706	9	0.4980

Table 3 presents the paired t-test outputs for the differences between properties of soils under stands of *Irvingia gaboneensis* and adjoining rainforest trees. The t-value is 0.114 and P-value of 0.9110 > 0.05; mean differences in the topsoils are not statistically significant. For the subsoil, t-value is 0.706, with p-value of 0.4980 > 0.05, mean differences in the subsoils are not statistically significant at 0.05 confidence level. This implies that although the parameters of soils varied between stands of *Irvingia gaboneensis* and adjoining rainforest trees, the mean differences were not significant. The insignificant difference observed could be attributed to *Irvingia gaboneensis* being an indigenous rainforest tree species like the adjoining rainforest tree species examined within the communities, as such, soil under its stands will be similar in concentrations and characteristics.

Differences between the Topsoil and Subsoil Properties under the Stands of *Irvingia gaboneensis* and Rainforest Trees.

Soil properties under the stands of *Irvingia gaboneensis* and the adjoining rainforest trees vary between the topsoil and subsoils. The mean contents of topsoil parameters were higher than those of the subsoils for both the stands of *Irvingia gaboneensis* and the adjoining rainforest trees. Statistical test regarding the differences in concentrations of soil parameters between the stands of *Irvingia gaboneensis* and the adjoining rainforest trees were carried out and presented below.

Student's t-test statistical technique was used to test the difference between topsoil and subsoil properties under the stands of *Irvingia gaboneensis* and the adjoining rainforest at 0.05 level of confidence.

Table 4: Paired Samples T-Test Output for the Differences between the topsoil and subsoil properties under the stands of *Irvingia gaboneensis* and the rainforest trees

Sites	Paired Samples	Paired S.E.M	Paired Differences (95% CI Lower	Upper	t-value	df	P-value
I. gaboneensis	Topsoil Subsoil	8.3094	10.2802	27.3142	1.0250	9	0.3320
Rainforest	Topsoil Subsoil	7.0922	7.8758	24.2118	1.1520	9	0.2790

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Table 4 presents the paired t-test outputs for the differences between the topsoil and subsoil properties under the stands of *Irvingia gaboneensis* and adjoining rainforest trees. The t-value = 1.0250 and P(0.3320) > 0.05, mean differences between the topsoil and subsoil under *Irvingia gaboneensis* is not statistically significant. For the rainforest, the t-value = 1.1520 and P(0.2790) > 0.05, mean differences between the topsoil and subsoil under adjoining rainforest trees is not statistically significant at the 0.05 level of confidence. Although the properties of soils varied between the two soil layers, their differences were not significant.

CONCLUSION AND RECOMMENDATION

This study characterised properties of soils under isolated stands of *Irvingia gaboneensis* in the rainforest of Isoko South region of Nigeria. Both experimental and quasi experimental designs were adopted; while the region was stratified into 10 from which 2 sampling sites (*Irvingia gaboneensis* and rainforest respectively) were selected, making 20 sampling sites. Results of statistical tests showed that properties of soils varied under *Irvingia gaboneensis* and rainforest. However, statistical analysis using student t-test revealed that significant difference did not exist between properties of soils under *Irvingia gaboneensis* and rainforest; also, significant difference did not exist in properties of soils between the two soil layers under *I. gaboneensis* and the rainforest thus, reaffirming the capacity of rainforest in the storage of chemical elements in humus within the 30 cm layer of soil profile. Therefore, conservation of *I. gaboneensis* should be encouraged for the purpose of managing the rainforest ecosystem, while their incorporation into agro-forestry farming should be encouraged.

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