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Research article

Characterizing plant biomass and soil parameters under exotic trees within rainforest environment in southern Nigeria

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Abstract: This research characterized biomass and soil parameters under exotic species of *Terminalia cattapa, Mangifera indica* and *Persea gratissima* in Southern Nigerian rainforest environment. The study area was stratified into 5 zones. In each zone, control plot measuring 30 m × 30 m and divided into 3 quadrants of 10 m × 30 m, was established from mature adjoining rainforest above 100 years, while 3 stands of each exotic species were selected. Collection of plant biomass parameters and soil samples was from 15 stands of each exotic species and control plots. Litterfall was collected daily from February 2019 to January 2020 using litter traps, heights and diameters of trees were determined using appropriate methods, while samples of soil were taken from the 0–15 cm and 15–30 cm depth using core sampler. Soil properties were analyzed by adopting standard laboratory techniques. Data analysis involved the descriptive, correlation and one-way analysis of variance (ANOVA) statistics using the SPSS 15.0 version software. Findings revealed that plant biomass and soil parameters varied significantly at 5% level of significance among the exotic and rainforest trees. Litter productions varied seasonally. Plant biomass characteristics correlated positively with soil properties. Litter production correlated with water holding capacity, total porosity, organic matter, nitrogen, phosphorus and potassium at 0.559, 0.652, 0.818, 0.805, 0.902 and 0.743 respectively for topsoil and 0.549, 0.631, 0.807, 0.801, 0.900 and 0.732 respectively for subsoil. Since the biomass parameters of the exotic trees correlated positively with soil properties, they are therefore recommended as farm trees to encourage agro-forestry practices within the rainforest environment. These agro-forestry practices prevent inorganic fertilizers' usage which is not environment friendly.

Keywords: agro-forestry; cycling of nutrients; ecosystem function; litter production; soil productivity

1. Introduction

Characterizing the biomass parameters of exotic trees and soils underneath their stands is an important pathway to understanding their importance to the productivity and sustenance of the rainforest environment. Apart from nutrient elements' exchange between soils and plants, interrelationships between plant biomass parameters and soil characteristics account for soil fertility condition and, therefore, the possibility of managing the degraded rainforest environment with fast growing exotic species of trees [1]. Despite the usefulness of exotic trees within rainforest environment, information regarding characterizing the relationships between biomass parameters and soil properties underneath their stands in Southern region of Nigeria are limited. Knowledge about trees influence on soils is essential for evaluating the functions of trees within the rainforest ecosystems and the desirability or otherwise of retaining tree plants in the ecosystems [2]. The need to ascertain how trees affect soil properties has become necessary because tree effects on soils vary with tree species compositions in question [3,4].

Plant biomass characteristics, like tree heights, account for vegetation physiognomy which represents the functional characteristics of vegetation that explain plants adaptive roles for survival in existing environment. With respect to nutrient cycling, tree height plays a functional role in the spread of tree litter. Shorter trees tend to concentrate their litter directly underneath their stands, while taller trees spread their litter before they get to the ground because of wind influence [2]. Tree litter will unquestionably lead to organic matter accumulation under and near the trees [3]. The actual nutrient enrichment will depend on nutrient contents of tree leaves and fruits before abscission. The activities of soil fauna are of great significance. Through this activity, litter and other organic materials are added to the soil thereby improving the soils' conditions [5].

Essentially, different studies have examined the relationships between trees and the soils underneath their stands in different regions of the world. In a study by Natalia et al. [6] on litter production within the tropical forest of Colombia, findings showed that monthly production of litter varied among foliar, woody material and reproductive material. Saimo et al. [7] investigated litter-fall dynamics within Brazilian tropical forest and observed that annual production of litter was higher at old-growth forest than at the intermediate forest stages, while seasonal variations of monthly litter produced was due to climatic factors related to water availability. Findings in a study conducted by Tang et al. [8] on litter production within tropical forest of Xishuangbanna in China showed that litter production within the tropical forest systems depends on tree species composition.

From the studies above, the interrelationships between plant biomass parameters and soil characteristics under their stands were not effectively ascertained because of close canopy influence of other trees within the plantations and forest ecosystem where the studies were conducted. Therefore, this study aimed at characterizing plant biomass and soil parameters under isolated exotic trees within Southern Nigerian rainforest environment. In order to achieve this, the following hypotheses were tested: (i) Measures of plant biomass characteristics vary significantly among the isolated exotic and rainforest trees. (ii) Soil characteristics vary significantly under isolated exotic and rainforest trees. (iii) There are positive relationships between plant biomass and soil parameters under the isolated exotic and rainforest trees.

2. Materials and methods

2.1. The study area

This study was carried out in Orogun region of Southern Nigeria. This region is located geographically between latitude 50 20'N and 50 36'N, and between longitude 50 30'E and 60 06'E. The natural plant cover comprises tree species of the tropical moist lowland rainforest, and has been degraded due to long-term land use. The climate falls within the humid sub-equatorial climate of Af Koppen classification, with characteristics depicting a region that has longer months of rainfall (mid March to October) than dry season (November to mid March). The annual temperature averages 31.5 ℃ with annual range of 2 ℃; while annual rainfall is between 2000 mm and 4000 mm. In line with the USDA soil classification taxonomy, the soil is of the oxisols and falls within the Sombreiro-Warri Deltaic plain types.

2.2. Samples selection and design of studies

Three commonly cultivated species of Indian almond (*Terminalia cattapa*), Avocado pear (*Persea gratissima*) and Mango (*Mangifera indica*) were selected for this study, while the rainforest tree species includes *Irvingia gaboneensis, Ceiba pentandra, Musanga cecropioides, Pentaklepta macrophylla, Milicia excelsa* and *Piptadeniastrum africanum* which featured commonly in all the control sites. The exotic trees were chosen because of their branch morphology, crown architecture, size of leaves and arrangement. The study area was stratified into 5 following the existing sub-regions (Umusu, Imodje, Emonu, Unukpo & Ogwa). The use of these 5 sub-regions was to ensure evenness in sampling as well as maintain uniqueness in ecological zone. From each sub-region, 3 stands of each species of the exotic trees were selected, making a total of 15 tree stands sampled for each isolated exotic tree species. The selection of exotic trees of ≥ 25 years of age ensured that they have not been exposed to daily sweeping and burning, while their canopies were far separated from others. In each zone, control plot measuring 30 m × 30 m and divided into 3 quadrants of 10 m × 30 m was established from mature adjoining rainforest above 100 years of age, making a total of 15 sample control sites. Therefore, 60 sample sites were established in this study.

2.3. Samples and data collection

The characteristics of tree stands investigated are those that can readily be correlated and regressed on the soil parameters, while the soil properties investigated are those that directly affect soil fertility, thereby exerting influence on soil productivity and plants growth. Therefore, data collected were on soil properties and plant biomass parameters (tree heights, tree diameter and litter production). Soil samples were collected from 0–15 cm (topsoil) and 15–30 cm (subsoil) depth in each sample site, using core sampler measuring 4" long and 3" in diameter. 120 samples of the soils were collected. The soil samples were put into labelled polythene bags and taken to laboratory for analysis on the soil-size fractions, water holding capacity, bulk density, total porosity, organic matter, phosphorus, total nitrogen and potassium. Tree heights were measured by the application of the principles of Trigonometry, using measuring tape and pegs to ascertain distances while Abney level was used to ascertain the angles projected to the top of trees. Tree diameters were ascertained by first measuring their girths at the breast height using a girthing tape, and then converted to diameter by considering the girths as circumference using $C = 2\Pi r$, and $D = 2r$; where: C = girth measurements; D = diameter; r = radius; and $\Pi = 3.142$ respectively. Litter-fall was collected daily from February 2019 to January 2020 using litter traps of 0.5 m^2 collection areas (where 4 litter bags represent $1m^2$ of the area on the ground) were set to intercept litter before they get to the ground. Litter-fall samples collected were 720 (60 samples each month). Laboratory analysis of litter-fall samples was for litter production.

2.4. Analysis of samples and data

The litter-fall samples were duly sorted into leaf, fruits, flowers and small wood litter in line with the approaches in the studies carried out by Wood, Natalia and Ngaiwi et al. [2,6,9] The litter samples were oven-dried for 24 hours at a constant temperature of 105 ℃ and weighed to ascertain the litter production using top loading electronic balance.

The soil samples were analyzed for particle size distribution, bulk density, organic carbon, water holding capacity, total porosity, nitrogen, phosphorus and potassium. The soil-size fractions were determined by adopting the hydrometer method, bulk density adopted core method, and total porosity adopted the core method using the assumed value of 2.65/cubic cm for soil particle density. Where: Porosity (%) = [1−(bulk density/particle density)] x 100.

In water holding capacity's determination, samples were first saturated and later subjected to gravitational draining for 24 hours while they were covered with polythene bags to avoid loss of moisture through evaporation. Thereafter, the samples were weighed and oven-dried at 105 ℃ for 24 hours. The loss in weight was expressed as proportion of the oven-dried soil. Determination of soil total nitrogen was carried out by first digesting the soil with concentrated H_2SO_4, while the nitrogen content of same digest was determined with an auto-analyzer. Available phosphorus extracts were obtained by leaching the soil with Bray P-1 extracting solution, while the concentration was determined Colorimetrically with a "spectronic 20" spectrophotometer, after the colour had been developed with Murphey and Riley reagent. Soil organic carbon determination adopted the Walkley-Black wet oxidation method, while the figures obtained were multiplied by 1.724 to convert into organic matter. The exchangeable potassium concentrations were determined with a flame photometer, after leaching the sample with 1N neutral ammonium acetate.

Statistical analysis of data involved the SPSS 15.0 version. Descriptive statistics was adopted to ascertain the mean, standard deviation (SD) and coefficient of variation (CV) of the data sets. One-way ANOVA statistics was adopted to compare the mean data sets for the plant biomass parameters and the soil properties. With the one-way ANOVA test, all the means are compared simultaneously. The one-way ANOVA involves only one independent variable; while two different estimates of the population variance are made: between - group variance and the within- group variance. The Pearson's bivariate correlation technique was adopted to ascertain the levels of relationships between biomass parameters and the soil characteristics under tree stands.

3. Results

3.1. Measures of plant biomass characteristics

Litter-fall production varied with season, and among the exotic and rainforest trees. This seasonal variation of litter-fall production has been observed in studies by Oziegbe, Muoghalu, Hermansah, and Pragasan et al. [10–13] within tropical rainforest ecosystems.

Table 1. Descriptive Statistical Analysis for the plant biomass characteristics in meter per sample site.

Biomass Parameters	Statistics	*Terminalia cattapa*	*Mangifera indica*	*Persea gratissima*	Adjoining Rainforest
Tree height (m)	Mean	14.79	15.29	11.64	35.09
	S.D	1.65	1.08	0.04	0.70
	C.V (%)	11.16	7.06	3.44	2.00
Diameter (m)	Mean	0.41	0.72	0.29	0.33
	S.D	0.05	0.08	0.07	0.08
	C.V (%)	12.20	11.11	24.14	24.24
Litter production (g/m^2)	Mean	83.04	76.53	60.23	77.31
	S.D	51.87	25.58	21.27	36.35
	C.V (%)	62.46	33.43	35.32	47.02

Table 1 presents the mean, SD and CV values of tree diameter, heights, and litter production for the different exotic and rainforest trees. Trees within adjoining rainforest have the least coefficients of variation. While the tree diameters varied among the exotic and rainforest trees, highest mean value was recorded with *Mangifera indica* stands. The tree diameters were more at variant than exotic trees. Litter-fall production by *Terminalia cattapa* was highest, followed by the rainforest trees, while the variability of litter produced followed the same pattern.

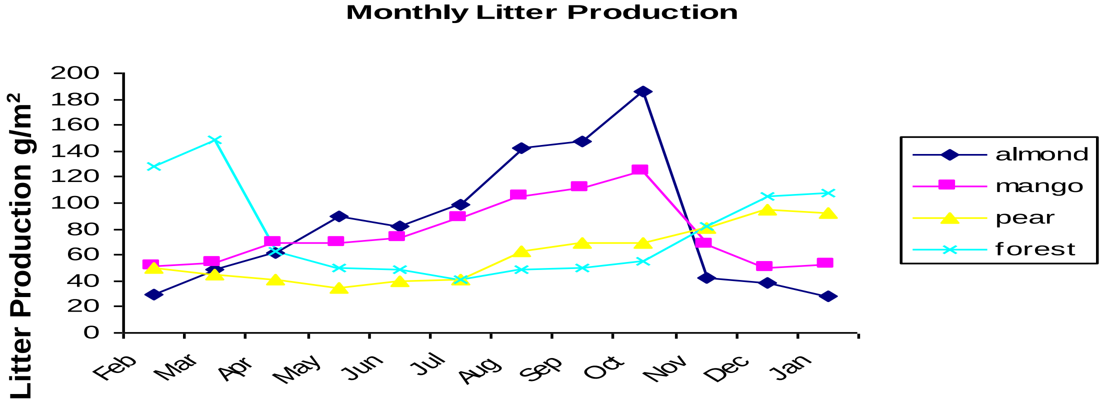
Table 2. ANOVA results for biomass Characteristics amongst exotic and rainforest trees.

Vegetation characteristics	Groups	Sum of squares	d/f	Mean square	F
Tree height	Between	5163.711	3	1721.237	1525.650
	Within	63.179	56	1.128	
	Total	5226.890	59		
Tree diameter	Between	1.683	3	0.561	113.377
	Within	0.277	56	0.005	
	Total	1.960	59		
Litter production	Between	4048.358	3	1349.453	3.85
	Within	21018.14	44	477.69	
	Total	25066.50	47		

*Note: Significant at F > critical table F (2.84) at 5% level.

Table 2 presents the ANOVA results for biomass characteristics among exotic and rainforest trees. Differences in the tree heights, diameter and litter productions within the exotic and rainforest cover are significant at 5% level of confidence. Therefore, the hypothesis which states that "measures of tree biomass characteristics vary significantly among the isolated exotic and rainforest trees" was accepted.

Litter-fall produced by the exotic rainforest varies seasonally and, obviously, with the phonological changes that occurred among all the tree species. While litter production by *Mangifera indica* and *Terminalia cattapa* was higher between July and October, *Persea gratissima* produced a higher litter between August and January and rainforest produced the highest litter between the months of November and March (Figure 1).



Figgure 1. Seasonality and Variations of Litter Production**.**

3.2. Measures of soil characteristics

Soil characteristics vary under the exotic and rainforest trees, and between the topsoil and subsoil under tree stands.

Tables 3 and 4 respectively present the mean, SD and CV values of topsoil and subsoil characteristics respectively, under the exotic and rainforest trees. The mean values of total porosity under adjoining rainforest for the topsoils and subsoils are more than those under exotic trees, while total porosity varied most under *Mangifera indica*. The lowest mean total porosity value observed under the stands of *Persea gratissima* indicates a lower biomass parameter than the *Mangifera indica* and *Terminalia cattapa* trees which are also exotic tree species. While the mean value of soils' bulk density is higher under exotic trees, CV is higher under the rainforest.

Sand is the predominant soil fraction in the two soil layers, accounting for about 70% by weight of mineral fragments in the soil, while the concentrations of silt and clay is less than 30% of the inorganic fractions of both soil layers. Silt proportion is lowest under rainforest and highest under the *Persea gratissima*. In contrast with the percentage composition in subsoil, silt proportion reduced with increase in depth of soil profile. However, the lowest proportion was observed under rainforest and the highest under *Mangifera indica* tree stands. Highest mean value within the topsoil was observed under *Indian almond*, while the lowest was under *Mangifera indica* stands. In contrast with the subsoil, the highest mean value was observed under rainforest, while the lowest was under *Mangifera indica* tree stands. Generally, clay composition in subsoil is higher than in the topsoils.

Table 3. Descriptive statistical analysis for the topsoil characteristics under the exotic and rainforest trees.

Soil Properties	Statistics	*Persea gratissima*	*Mangifera indica*	*Terminalia cattapa*	Adjoining Rainforest
Total Porosity (%)	Mean	55.15	59.44	57.79	63.81
	S.D	2.45	4.06	2.88	3.48
	C.V (%)	4.44	6.83	4.98	5.45
Bulk Density(g/cm^3	Mean	0.91	0.92	0.96	0.84
	S.D	0.10	0.11	0.07	0.14
	C.V (%)	10.99	11.96	7.29	16.67
Water holding capacity (%)	Mean	52.97	55.00	56.18	60.69
	S.D	1.71	2.66	2.55	3.02
	C.V (%)	3.23	4.84	4.54	4.98
Sand content (%)	Mean	72.36	69.48	72.60	74.04
	S.D	2.43	1.62	1.77	2.19
	C.V (%)	3.36	2.33	2.44	2.96
Silt content (%)	Mean	16.67	19.70	14.54	13.47
	S.D	2.43	1.57	1.17	0.98
	C.V (%)	14.58	7.97	8.05	7.28
Clay content (%)	Mean	10.98	10.82	12.86	12.49
	S.D	0.72	0.37	2.63	1.26
	C.V (%)	6.56	3.42	20.45	10.09
Organic Matter (%)	Mean	4.06	5.20	5.00	6.33
	S.D	0.76	0.49	0.31	0.59
	C.V (%)	18.72	9.42	6.20	9.32
Total Nitrogen (%)	Mean	0.45	0.48	0.53	0.59
	S.D	0.07	0.05	0.05	0.12
	C.V (%)	15.56	10.42	9.43	20.34
Available Phosphorus (mg/kg)	Mean	11.76	12.09	13.87	14.86
	S.D	4.26	2.62	1.93	1.82
	C.V (%)	36.25	21.67	13.92	12.25
Exchangeable Potassium (mg/kg)	Mean	60.73	61.73	116.47	57.80
	S.D	4.43	5.69	26.69	5.67
	C.V (%)	7.30	9.22	22.92	9.81

Total nitrogen and organic matter contents are higher under rainforest than exotic trees; while their concentrations are generally higher in topsoils than in the subsoils. Available phosphorus content in topsoil is highest under rainforest, and lowest under *Persea gratissima*; while available phosphorus content in subsoil is highest under *Terminalia cattapa*, and lowest under *Persea gratissima*. In contrast, available phosphorus is higher within the topsoils than the subsoils in the entire sample sites. The concentrations of exchangeable potassium are higher within the topsoil than the subsoil. However, from the topsoil, exchangeable potassium is highest under *Terminalia cattapa*, and lowest under the rainforest.

Table 4. Descriptive Statistical Analysis for the mean values of subsoil characteristics under the exotic and rainforest trees.

Soil Properties	Statistics	*Persea gratissima*	*Mangifera indica*	*Terminalia cattapa*	Adjoining Rainforest
Total Porosity (%)	Mean	65.52	65.42	63.44	68.49
	S.D	3.66	4.14	2.56	5.24
	C.V (%)	5.59	6.33	4.04	7.65
Bulk Density (g/cm^3)	Mean	1.19	1.08	1.12	0.96
	S.D	0.07	0.11	0.08	0.09
	C.V (%)	5.88	10.19	7.14	9.38
Water Holding Capacity (%)	Mean	57.00	57.39	57.77	64.94
	S.D	2.95	2.67	2.32	2.50
	C.V (%)	5.18	4.65	4.02	3.85
Sand content (%)	Mean	71.16	69.42	71.43	70.03
	S.D	1.62	2.37	0.38	1.66
	C.V (%)	2.28	3.41	0.53	2.37
Silt content (%)	Mean	11.89	13.36	13.34	11.03
	S.D	0.62	1.49	2.32	0.82
	C.V (%)	5.22	11.15	17.39	7.43
Clay content (%)	Mean	16.49	17.56	15.23	18.95
	S.D	2.13	2.09	2.32	2.45
	C.V (%)	12.92	11.90	15.23	12.93
Organic Matter (%)	Mean	1.02	2.05	1.93	2.89
	S.D	0.31	0.38	0.25	0.64
	C.V (%)	30.39	18.54	12.95	22.15
Total Nitrogen (%)	Mean	0.19	0.20	0.23	0.27
	S.D	0.05	0.03	0.03	0.04
	C.V (%)	26.32	15.00	13.04	14.82
Available Phosphorus (mg/kg)	Mean	6.22	6.79	7.61	7.58
	S.D	1.16	1.15	0.71	2.07
	C.V (%)	18.65	16.94	9.33	27.31
Exchangeable Potassium (mg/kg)	Mean	18.20	16.40	19.60	29.40
	S.D	2.48	2.39	3.00	11.01
	C.V (%)	13.63	14.57	15.31	37.45

Tables 5 and 6 present the ANOVA results for topsoil and subsoil characteristics respectively, under the exotic and rainforest trees. Significant differences exist between soil characteristics under the exotic and rainforest tree stands which are significant at 5% confidence levels for all soil properties in the two soil layers. Therefore, the hypothesis which states that "soil characteristics vary significantly under the isolated exotic and rainforest trees" is accepted.

Table 5. ANOVA results for the differences in topsoil characteristics under *Persea gratissima*, *Mangifera indica, Terminalia cattapa* and the Adjoining Rainforest.

Soil parameters	Groups	Sum of squares	d/f	Mean square	F
Porosity	Between	594.853	3	198.273	18.486
	Within	600.619	56	100.715	
	Total	1195.472	59		
Bulk density	Between	0.416	3	0.149	18.456
	Within	0.421	56	0.008	
	Total	0.837	59		
Water holding capacity	Between	479.722	3	159.808	24.932
	Within	359.151	56	6.413	
	Total	838.873	59		
Sand	Between	163.828	3	54.510	13.270
	Within	230.445	56	4.115	
	Total	394.273	59		
Silt	Between	338.982	3	112.996	42.294
	Within	149.607	56	2.672	
	Total	488.589	59		
Clay	Between	48.403	3	16.144	7.070
	Within	127.784	56	2.283	
	Total	176.187	59		
Organic matter	Between	38.857	3	12.962	41.717
	Within	17.386	56	0.310	
	Total	56.243	59		
Total nitrogen	Between	0.175	3	0.059	9.340
	Within	0.348	56	0.006	
	Total	0.523	59		
Available phosphorus	Between	97.008	3	32.336	4.044
	Within	447.684	56	7.994	
	Total	544.692	59		
Exchangeable	Between	35882.982	3	11960.984	60.072
Potassium	Within	11150.000	56	199.107	
	Total	47032.982	59		

* Note: Significant at F > critical table F (2.84) at 5% levels.

3.3. Interrelationships between the biomass parameters of plants and properties of soils under their stands

Biomass parameters correlated positively with soil properties under the exotic and rainforest trees.

Table 6. ANOVA results for the differences in subsoil characteristics under *Persea gratissima*, *Mangifera indica, Terminalia cattapa* and the Adjoining Rainforest.

Soil parameters	Groups	Sum of squares	d/f	Mean square	F
Porosity	Between	194.741	3	64.924	4.024
	Within	903.441	56	16.133	
	Total	1098.182	59		
Bulk density	Between	0.121	3	0.040	3.559
	Within	0.631	56	0.011	
	Total	0.752	59		
Water holding capacity	Between	645.953	3	215.328	31.417
	Within	383.795	56	6.853	
	Total	1029.747	59		
Sand	Between	40.615	3	13.549	4.855
	Within	156.155	56	2.788	
	Total	196.770	59		
Silt	Between	59.209	3	19.737	9.154
	Within	120.857	56	2.158	
	Total	180.066	59		
Clay	Between	112.247	3	37.426	7.380
	Within	283.915	56	5.070	
	Total	396.162	59		
Organic matter	Between	26.240	3	8.748	48.592
	Within	10.081	56	0.181	
	Total	36.321	59		
Total nitrogen	Between	0.063	3	0.021	12.240
	Within	0.094	56	0.003	
	Total	0.157	59		
Available phosphorus	Between	20.227	3	6.740	3.625
	Within	104.151	56	1.862	
	Total	124.378	59		
Exchangeable Potassium	Between	1522.201	3	507.401	14.285
	Within	1989.201	56	35.521	
	Total	3511.402	59		

*Note: Significant at F > critical table F (2.84) at 5% levels.

Table 7 shows the correlation results between tree biomass and soil parameters under *Terminalia catappa*. Significant correlations at the 5% level were observed between diameter of trees and topsoil properties (water holding capacity and silt fractions) as well as between litter-fall production and topsoil properties (water holding capacity, organic matter, total porosity, phosphorus, total nitrogen, and potassium). Within the subsoil, significant correlations at 5% level were observed between heights of trees and soil characteristics (silt and clay fractions); diameter and water holding capacity; as well as litter-fall production and properties of soil (water holding capacity, organic matter, total porosity, phosphorus, total nitrogen and potassium). The observed correlations between litter-fall production and properties of soil are similar for both soil layers under *Terminalia catappa*.

Table 7. Pearson's correlations between biomass parameters and soil characteristics under *Terminalia catappa.*

Soil properties	Topsoil under *Terminalia catappa*			Subsoil under *Terminalia catappa*		
	Tree height	DBH	Litter production	Tree height	DBH	Litter production
Sand	0.134	−0.344	−0.149	−0.106	−.023	−0.138
Silt	−0.058	−0.436*	0.379	−0.445*	0.120	0.262
Clay	−0.064	0.426	−0.312	0.462*	−0.116	−0.311
Water holding capacity	0.000	−0.535*	0.559*	−0.186	−0.524*	0.549*
Total porosity	0.119	−0.203	0.652*	0.119	−0.086	0.631*
Bulk density	−0.118	0.203	0.151	0.068	0.209	0.141
Organic matter	−0.127	−0.020	0.818*	0.220	−0.002	0.807*
Nitrogen	−0.028	−0.284	0.805*	−0.125	−0.045	0.801*
Phosphorus	0.242	0.126	0.902*	0.306	0.265	0.900*
Potassium	−0.320	−0.206	0.743*	−0.382	−0.328	0.732*

*Note: Significant at 5% levels.

Table 8. Pearson's correlations between biomass parameters of plants and properties of soil under *Mangifera indica*.

Soil Properties	Topsoil under *Mangifera indica*			Subsoil under *Mangifera indica*		
	Tree Height	DBH	Litter production	Tree height	DBH	Litter production
Sand	−0.391	−0.088	−0.224	−0.043	−0.091	−0.202
Silt	0.351	0.064	0.368	−0.112	−0.208	0.351
Clay	0.215	0.112	−0.221	−0.106	−0.002	−0.211
Water holding capacity	0.274	−0.281	0.654*	0.342	−0.386	0.630*
Porosity	0.119	−0.085	0.472*	−0.001	−0.038	0.461*
Bulk density	−0.117	0.089	0.008	−0.022	0.055	0.007
Organic matter	0.326	−0.068	0.799*	0.182	−0.294	0.794*
Nitrogen	0.126	−0.116	0.856*	−0.021	−0.075	0.840*
Phosphorus	−0.110	−0.091	0.897*	−0.003	−0.041	0.882*
Potassium	0.241	0.323	0.876*	−0.184	−0.097	0.866*

*Note: Significant at 5% levels.

Table 8 presents correlation analysis results between plant biomass parameters and properties of the soil under Mangifera indica. Significant correlations at the 5% levels were observed between litter-fall production and topsoil properties (water holding capacity, total porosity, phosphorus, organic matter, total nitrogen and potassium). While within the subsoil, significant correlations at the 5% levels were also observed between litter-fall production and properties of the soil (water holding capacity, total porosity, potassium, organic matter, total nitrogen and phosphorus). The observed correlations between soil properties and litter-fall production were similar in both soil layers under *Mangifera indica*.

Table 9. Pearson's correlations between biomass parameters of plants and properties of soil under *Persea gratissima*.

Soil Properties	Topsoil under *Persea gratissima*			Subsoil under *Persea gratissima*		
	Tree height	DBH	Litter production	Tree height	DBH	Litter production
Sand	0.478*	0.251	−0.182	0.198	0.143	−0.162
Silt	−0.281	−0.206	0.291	−0.601*	−0.086	0.281
Clay	−0.665*	−0.153	−0.082	−0.060	−0.025	−0.072
Water holding capacity	0.111	0.139	0.729*	0.306	−0.132	0.709*
Porosity	0.072	0.250	0.746*	−0.263	0.155	0.735*
Bulk density	0.070	−0.251	0.157	0.269	0.260	0.140
Organic matter	0.011	0.284	0.756*	−0.126	−0.445*	0.741*
Nitrogen	0.044	−0.007	0.812*	0.238	−0.202	0.800*
Phosphorus	−0.217	0.478*	0.898*	0.168	0.409	0.872*
Potassium	0.108	0.005	0.649*	−0.165	0.053	0.641*

*Note: Significant at 5% levels.

Table 9 shows the correlation results between biomass parameters of plants and properties of the soil under *Persea gratissima*. Significant correlations at the 5% levels were observed between the height of trees and topsoil properties (sand and clay fractions), tree diameters and topsoil phosphorus content, and litter-fall production with topsoil properties (water holding capacity, total porosity, organic matter, phosphorus, total nitrogen and potassium). Within the subsoil, significant correlations at the 5% levels were also observed between tree heights and silt fraction, diameters and soil organic matter, litter-fall production and soil characteristics (water holding capacity, total porosity, organic matter, potassium, total nitrogen and phosphorus). The observed correlations between soil properties and litter-fall production were similar in both soil layers under *Persea gratissima*.

Table 10. Pearson's correlations between plant biomass parameters and properties of soil under adjoining rainforest.

Soil Properties	Adjoining rainforest Topsoil			Adjoining rainforest Subsoil		
	Tree height	DBH	Litter production	Tree height	DBH	Litter production
Sand	0.041	−0.241	−0.339	−0.099	−0.553*	−0.139
Silt	−0.176	0.350	0.380	0.137	−0.600*	0.360
Clay	0.066	0.148	−0.317	0.021	0.577*	−0.317
Water holding capacity	0.511*	−0.228	0.845*	0.552*	−0.090	0.805*
Porosity	−0.241	−0.058	0.829*	−0.175	−0.149	0.719*
Bulk density	0.238	0.058	0.238	0.175	0.150	0.235
Organic matter	0.069	−0.205	0.898*	0.000	−0.273	0.768*
Nitrogen	−0.144	−0.055	0.848*	−0.076	−0.074	0.741*
Phosphorus	0.547*	0.069	0.905*	0.592*	−0.341	0.805*
Potassium	−0.221	−0.121	0.897*	−0.320	0.247	0.867*

*Note: Significant at 5% levels.

Table 10 presents correlation analysis results between plant biomass parameters and soil characteristics under adjoining rainforest. Significant correlations at 5% levels were observed between water holding capacity content of topsoil and tree heights, litter-fall production and topsoil properties (water holding capacity, phosphorus, total porosity, organic matter, potassium and total nitrogen). Within the subsoil, significant correlations at the 5% levels were also observed between the soil properties (water holding capacity and available phosphorus) and tree height, soil parameters (sand, silt and clay fractions) and tree diameters, litter-fall production and soil parameters (water holding capacity, phosphorus, total porosity, total nitrogen, organic matter and potassium). The observed correlations between litter-fall production and soil parameters were similar in both soil layers under adjoining rainforest.

4. Discussion

Generally, findings regarding relationships between soil properties and biomass parameters of plants suggest that the greater the biomass of standing plant, as evidenced in the larger sizes of trees, the higher the soil nutrient status. This relationship is to be expected because in nutrient cycling, tree plants depend on soil nutrient for their growth and development, while plants return nutrient elements to soil in the process [7]. Biomass parameters like tree diameter correlated positively and significantly with soil properties. This indicates that the biomass parameters enhance the capacity of trees to regenerate soil fertility as they develop.

Measures of the biomass characteristics varied among the exotic and adjoining rainforest trees. Trees of the exotic species are shorter than adjoining rainforest trees. However, among the exotic trees, tree heights also varied. Taller tree stands spread their litter-fall outside their canopies due to height. The implication of litter-fall farther away from tree stands may reduce nutrient returns under some tree stands because litter-fall contributes to organic matter concentrations in soil. Organic matter does not only influence nutrient concentrations accumulated under tree stands but also soil physical attributes such as porosity, water holding capacity and soil crumb structure which have a direct bearing on soil fertility level [14]. The much lower litter production observed in the stands of *Persea gratissima* could be due to tree size together with their crown architecture, while the close canopy influence in rainforest cover may have enhanced litter production under the forest cover. The seasonal pattern of litter-fall production within the rainforest shows that higher litter is produced within dry season months. This pattern reveals close similarity with that observed in studies by Muoghalu and Ngaiwi et al. [2,11] It could, therefore, be deduced that the seasonal trends in litterfall production between *T. cattapa* and *M. indica* stands are similar, while litter production by *P. gratissima* and rainforest are also similar. Although rainforest produced higher litter than *P. gratisima*, the pattern of litter-fall production is quite similar throughout the year.

Measures of soil characteristics varied under the exotic and adjoining rainforest trees. The higher bulk density under exotic trees was expected given that it can be easily modified by the presence of plants [15]. As the exotic trees develop, bulk density tends to decrease with increasing maturity because plant roots open up the soil, making it less compact. Soils under adjoining rainforest have higher water holding capacity than those under exotic tree stands. This is because shade cast on soil by tree crown supports its capacity to hold water. Thus, water holding capacity was lowest under stands of *P. gratissima* which obviously have the smallest tree crown area among the species of exotic trees. The soils are texturally similar under the tree stands, except in a few cases where differences were observed. This is so because soil size fractions do not change since plants are not capable of modifying inorganic components of the soil proportions. Therefore, cultivated tree crops like these exotic trees did not change the textural composition of soils underneath their stands as they developed with time. However, despite the textural homogeneity, some variations exist between the sites belonging to different species of trees. *T. cattapa* trees, for instance, tend to have more clay in topsoil underneath their stands than the other exotic trees, but have the lowest clay than the other exotic trees in subsoils. As expected, some variations observed in nutrients levels as well as soil water holding capacity may be attributed partly to differences in soil clay fractions. Higher concentrations of total nitrogen and organic matter were observed in soils under rainforest than exotic trees. As pointed out earlier, organic matter build-up is an important change that takes place in soils under rainforest [16], while the total nitrogen pattern is as expected since organic matter stores nitrogen in soils [17]. No appreciable build-up of total nitrogen was observed in the subsoils under the exotic trees and those of the rainforests. Therefore, it emphasizes that total nitrogen accumulation under tree stands is confined to topsoil like organic matter. The pattern of variation shown is adjoining rainforest > *T. cattapa* > *M. indica* > *P. gratissima.*

There are positive relationships between plant biomass parameters and soil parameters as opined by Kazumichi et al. [1]. The levels of the interrelationships appeared similar between the exotic trees and rainforest, thus indicating that in nutrient cycling, biomass parameters of exotic and rainforest trees contribute to soil nutrient status [18]. However, litter production had higher correlation with soil properties than other biomass parameters of the exotic and rainforest trees. This has implications on soil nutrient characteristics underneath stands of trees as observed in a study by Ngaiwi et al. [2].

5. Conclusion and recommendation

Findings in this research showed that biomass characteristics vary among the exotic and rainforest trees. Although stands of *T. cattapa and M. indica* trees maintain about the same range in height, trees within the rainforest are taller, with higher litter production. Litter productions varied seasonally, and have been attributed to variations in the phonological changes which occur in the different species of trees. Soil characteristics under tree stands vary among the exotic and rainforest trees. Plant biomass parameters are positively related with soil properties under the exotic and rainforest trees.

Since the biomass parameters of the exotic trees correlated positively with soil properties, they are therefore recommended as farm trees to encourage agro-forestry practices among arable crop farmers in the rainforest environment. These agro-forestry practices prevent inorganic fertilizers' use because they are not environmentally friendly.

Conflict of interest

All authors declare that there is no conflict of interest in this paper.

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