FOREST BIOMASS AND CARBON CONTENT OF RUBBER-TREE PLANTATIONS IN IYANOMO RAINFOREST ECOSYSTEM, NIGERIA

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Abstract

Deforestation leads to loss of carbon stocks from terrestrial ecosystems and emission of CO_2 into the atmosphere, contributing significantly to the climate change problem. Afforestation has been advocated to augment the tree-deficit situation on the earth; but plantations of tree species that will provide both socio-economic and environmental benefits should be considered. This study, to determine whether rubber-tree plantations can provide carbon sinks for mitigating climate change, was conducted at Iyanomo where rubber-tree stands of different age levels and a reference natural forest stand were used as experimental treatments. From each of the rubber-tree stand, 1ha was marked out and sub-divided into 25 temporary plots (20 x 20 m^2 quadrants), after which 4 permanent sampling plots were randomly selected. Also, from the reference natural forest, 1 ha marked out was sub-divided into 10 temporary plots (50 x 20 m^2 quadrants) from which 4 permanent sampling plots were randomly selected to collect data including diameter at breast height (DBH) and total heights of trees. Soil samples from the natural forest and rubber-tree plantations were tested for organic carbon content, bulk density and particle size distribution. Results: organic carbon contents of soils under the rubber-tree plantations and the natural forest were not significantly different in the study area ($P > 0.05$). Total biomass carbon stock (214.2 Mg/ha) for rubber-tree plantation aged 25 years was comparable with that of the reference natural forest (212.7 Mg/ha). Conclusion: rubber-tree plantations, if well-managed on long rotation periods, can provide significant carbon sinks for mitigating climate change.

Keywords: Rubber-trees Biomass, Plantation Ecosystem, Soil Carbon

Introduction

Carbon dioxide (CO_2) is one of the principal greenhouse gases (GHG) with its concentration in the atmosphere rising, contributing largely to the global warming and climate change problem (Lal, 2004, IPCC, 2014). Climate change is irreversible change in weather factors producing visible changes in rainfall, temperature, relative humidity, with adverse effects on plant and animal health. Social impacts of climate change include impaired livelihood and migration. Global warming is attributed to a combination of natural and anthropogenic factors. Land-use and land-cover change (LULCC) including deforestation and various forms of land uses, lead to loss of carbon stocks from terrestrial ecosystems and emission of CO_2 into the atmosphere. After emissions from fossil fuel combustion and cement production, LULCC constitute the second largest source of CO_2 into the atmosphere (Prentice *et al.*, 2001; IPCC, 2007), contributing significantly to global warming, climate change and high weather variability (IPCC, 2014).

Forest conservation, reforestation and afforestation have been advocated in the Paris Accord-2015 to augment the tree-deficit situation on the earth; but plantations of tree species that will provide both socio-economic and environmental benefits should be considered. *Hevea brasiliensis* (Rubber-trees plantations) are economic forest tree crop cultivated primarily for the production of natural rubber latex which is valued for its industrial isoprene content. The plantations are been explored to harness their potential to provide carbon sink, and protect or restore soils as ecosystem services for human benefits. This study was conceptualised from the following research questions and hypothesis: (i) Can rubber-tree plantations provide significant carbon sinks in relation to mitigating climate change? (ii) Do rubber-tree plantations cause adverse changes in soil organic carbon? (iii) Null hypothesis: organic carbon contents of soils under rubber-tree plantations versus natural forest are not significantly different in the study area. Therefore, the aim of the study was to determine whether rubber-tree plantations can provide significant carbon sinks for mitigating climate change. And the specific objectives were: i) to quantify biomass carbon stock of a reference natural forest; ii) to assess biomass carbon stocks of rubber-tree plantations using an inventory-based non-destructive sampling method; and (iii) to examine the effects of rubber plantation land-use on organic carbon content and related properties of soils in the study area.

In the context of climate change mitigation and the creation of an international carbon trading scheme, the measurement of carbon in forest and agro ecosystems has become significant to the global economy, thus there is strong motivation and justification for accurate measurements of carbon in vegetal biomass and soils (IPCC, 2006; Johns, 2017). To determining whether rubber-tree plantations can provide carbon sinks, it is necessary to examine the plantations in terms of: i) vegetal biomass productivity; ii) biomass carbon stock; iii) soil organic carbon status; and iv) ecosystem carbon content of the plantations.

To mitigate the global warming and climate change effects, one of the viable strategies is carbon sequestration in terrestrial ecosystems – particularly forest and agro-forest ecosystems (Houghton *et al.* 1998; IPCC, 2006; Brahma *et al*, 2016). Carbon sequestration (by terrestrial ecosystem) is the net removal of CO_2 from the atmosphere or the avoidance of CO_2 emissions into the atmosphere from terrestrial ecosystems (IPCC, 2000). The removal process includes the capture of CO_2 from the atmosphere by all chlorophyllus plants; the CO_2 is converted to carbon (carbon compound i.e. glucose/cellulose) via photosynthesis; and the carbon is stocked in plant biomass (trunks, branches, leaves, roots) and soil organic matter. In a forest or agro-forest ecosystem, total organic carbon is stocked (stored) in four carbon pools: i) soil organic matter (SOM); ii) above-ground biomass (AGB) including the bole, branches and foliage of living trees; iii) below-ground biomass (BGB) including the roots of living trees; and iv) necromass (dead wood, litter layer and coarse wooden debris) (Hairiah *et al.* 2001). The carbon stored in the AGB pool is typically the largest and the most directly impacted by deforestation and forest degradation (Gibbs et al, 2007); this is because AGB is usually the largest portion, constituting more than 80% of the total plant biomass in both forest and rubber plantation ecosystems (Braham *et al*., 2016).

Organic carbon (OC) is the carbon component of soil organic matter (OM) originating from biological materials. Decrease in soil OC content is one of the significant indicators for soil degradation.

There is serious concern that if OC content in soils is allowed to decrease significantly, the productive capacity of croplands will be compromised (Loveland and Webb 2003). Agricultural practices that increase organic matter/OC content in the soil provide the double benefit of improving sustainable productivity and assisting in the reduction of atmospheric greenhouse gas. The number one recommendation of the Natural Resource Conservation Service – US Department of Agriculture is to enhance soil organic carbon. Soil organic carbon (OC) mediates many of the chemical, biological and physical processes controlling soil ecosystem functioning (Quideau *et al*., 2000); hence organic carbon content is the attribute chosen as the most important indicator for soil ecosystem health and agricultural sustainability (Liu, 2006). Organic carbon is a contributor and an indicator of healthy, fertile and productive soils (Johns, 2017).

Previous studies conducted around the tropics have reported a rapid decline in soil organic carbon following deforestation and intensive cultivation; for instance, Collins *et al*. (1999) observed a decline in soil organic matter/organic carbon content in cultivated soils in comparison with adjacent forest sites. Also, McGrath *et al*. (2001) noted that soil organic carbon decreased with cropping time. However, Janzen *et al*. (1998) noted that extensive cultivation of perennial crops promoted organic carbon gains in soils. Nevertheless, much is not known about how rubber-tree plantations affect the organic carbon (and health) of soils, especially with focus on second-rotation rubber plantations; this study is expected to contribute to knowledge in that regard. By studying the forest characters of rubber-tree plantations, this study will also contribute to knowledge about the effect of rubber-tree plantations on the soil environment. The results of the study are expected to provide reliable basis for decision-making in sustainable land-use management for natural rubber production in Nigeria.

Materials and methods

Description of Study Area: The study was carried out in the rubber-tree clonal fields of the Rubber Research Institute of Nigeria, occupying land area of 2070 hectares. The study area map has a fairly rectangular shape lying within the co-ordinates of Longitudes 5º 34'E and 5º 38'E; and Latitudes 6º 08'N and 6º 11'N (figure 1). The study area is bordered by Obayantor village (northwest), Ogbekpen village (southwest), Uhie village (Northeast), and Benin Owena River Basin Development (south east). Vegetation of the area falls within the Edo-south rainforest ecosystem of Nigeria; the area is characterized by hot humid tropical climate with a dominant rainy season and three months dry season; and mean annual temperature of 23 – 26^0 C; while average relative humidity (65±5 %) is high almost throughout the year (Orimoloye *et al*., 2011). Mean annual rainfall is about 2000 mm; and the rainfall pattern is bimodal with peaks in July and September and a short rainfall break in August. The soils are mainly ultisols with 4.0 – 5.5 pH range (Waizah *et al*., 2010; Orimoloye *et al*. 2011).

Description of Study Sites: The study was conducted in rubber-tree plantations of different ages, and a reference natural forest (Table 1). The reference natural forest represents the original vegetation of the locality. The rubber-tree plantations are second rotation plantations that were established after clear-cutting the first old rubber plantations that existed for 35 years. The oldest plantation aged 33 years had assumed the state of a secondary forest having been left to fallow since age 25 years when rubber latex yield had waned.

Data Collection

a) Measurements of Girths/DBH and Heights of Trees in Rubber-tree Plantations: Data were collected from rubber-tree stands of different ages: 4, 6, 14, 18, 25 and 33 years selected for this study (Table 2). From each of the rubber plantation stand, 1ha each was marked out for the experiment and sub-divided into 25 temporary plots (20 x 20 m^2 quadrants), after which 4 permanent sampling plots were randomly selected giving a total of 24 sampling plots for the study. For each sample plot, the following parameters were assessed: diameter at breast height (DBH) at1.3m above ground level using girth diameter tape; total height; and diameters at the base, middle and top of two mean trees. (Feldpausch *et al*, 2011). Mean plot DBH was computed, and two mean trees (having their DBH nearest to the mean plot DBH) were selected for further measurements of total heights as well as diameters at the top, middle and base of the mean trees with the aid of a Spiegel Relascope.

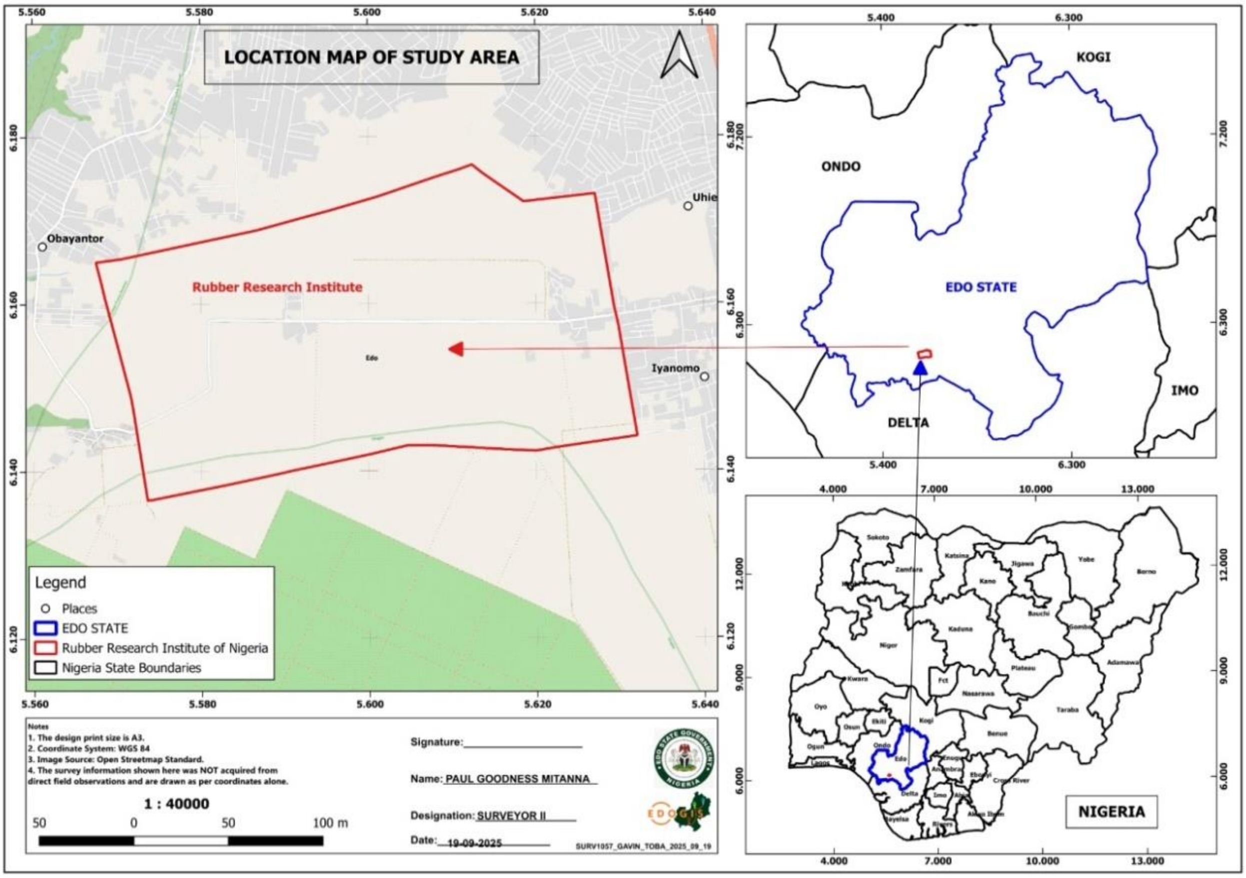

Figure 1: Location map of the study area

Table 1: Sampling site locations

S/N	*Sampling Sites*	*Longitude*	*Latitude*
1	PL-4 (Plantation Aged 4 yrs.)	Lon 6^0 9' 33.8" N	Lat. 5^0 35' 42.1" E
2	PL-6 (Plantation Aged 6yrs.)	Lon 6^0 9' 35.1" N	Lat. 5^0 35' 42.3" E
3	PL-14 (Plantation Aged 14 yrs.)	Lon 6^0 9' 27.2" N	Lat. 5^0 36' 52.1" E
4	PL-18 (Plantation Aged 18 yrs.)	Lon 60 9' 36.1" N	Lat. 5^0 35' 43.4" E
5	PL-25 (Plantation Aged 25 yrs.)	Lon 6^0 9' 25.3" N	Lat. 5^0 37' 16.2" E
6	PL-33 (Plantation Aged 33yrs.)	Lon 6^0 9' 24.6" N	Lat. 5^0 35' 41.1"E
7	RNF (Reference Natural Forest)	Lon 6^0 9' 30.2" N	Lat. 5^0 35' 27.1" E

b) Measurements of Girths/DBH and Heights of Trees in Reference Natural Forest:

50 m x 20 m was adopted as optimal sampling plot dimension for natural forests in accordance with Anitha *et al*. (2010) and Hamdan *et al.* (2013). Thus, from the reference natural forest, one-hectare area was sub-divided into 10 temporary plots (50 x 20 m^2 quadrants), after which 4 permanent sampling plots were randomly selected for measurements of heights and DBH ≥ 10 cm of individual trees.

c) Collection of Soil Samples for Analyses

Random composite sampling method was adopted using soil sampling auger to 30 cm depth of two layers: 0-15 cm and 15-30 cm (IPCC, 2003, AGDISER, 2018) in order to adequately assess the soil organic carbon (Watson *et al*., 2000; Andrew *et al.*, 2002). The soil samples were analysed in laboratory to determine organic carbon content i.e. organic carbon (OC) concentration; as well as organic matter (OM) content; pH; bulk density (BD); and sand, silt and clay contents. Soil organic carbon concentration (SOC) was determined using the wet oxidation procedure with K2Cr2O7 (Nelson and Sommers, 1982). OM was determined as OM = OC*1.724; soil pH was determined at 1:1 soil to water ratio using glass electrode digital pH meter; while soil BD was determined as the ratio of oven-dry weight of soil (Mg) to the cylinder volume (m^3) (Onyekwelu *et al*., 2006). Particle size distribution was determined by hygrometer method (Gee and Bauder, 1986).

Data Analysis

Evaluation of Growth Parameters and Biomass of Rubber-tree Stands:

Bole volumes of two mean trees per plot were calculated using the Newton's equation for estimating volumes of trees [equation 1] (Husch *et al*., 2003):

$$V = \left(\frac{\pi h}{24}\right)(D_b^2 + 4D_m^2 + D_t^2) \text{ ………….. (1)}$$

Where: D_b, D_m and D_t are diameters (cm) at the base, middle and top of the mean trees, respectively; V = volume of tree (m^3); h = total height (m).

Total volume of trees in a sample plot was determined by multiplying the mean volume of trees in the sample plot by the corresponding number of trees in that sample plot (equation 2):

$$V_T = \left(\frac{1}{2}\right)(V_1 + V_2) * n \text{ ……………… (2)}$$

Where: V_T = total tree volume per plot; n = the number of trees in the plot.

Volume over Bark of Bole per ha (VOB/ha): stem volume of trees per hectare was calculated using (equation 3):

$\frac{\text{VOB}}{\text{ha}} = \left(\frac{1}{4}\right)(V_{T1} + V_{T2} + V_{T3} + V_{T4}) * 25$ … … … … … … (3)

Where: V_{T1}, V_{T2}, V_{T3} and V_{T4} are the total bole volume of trees in plots 1, 2, 3 and 4 respectively.

The expression, $\left(\frac{1}{4}\right)(V_{T1} + V_{T2} + V_{T3} + V_{T4}) * 25$, shows that the average total volume in the four sampling plots was multiplied by 25 as there are twenty-five (20 x 20 m^2) plots in one hectare.

Estimation of Above- and Below-ground Biomass Carbon of Rubber-tree Stands:

Aboveground biomass of individual rubber trees were estimated using [equation 4] (Oke *et al*., 2020):

AGB = V*WD*BEF … … … … … … (4)

Where: AGB = Above-ground biomass V = bole volume i.e. volume over back of bole (VOB);

WD = wood density; BEF = biomass expansion factor.

Stand level biomass of inventoried bole volume was calculated using [equation 5]

$\text{BV} = \left(\frac{\text{VOB}}{\text{ha}}\right) * \text{WD}$ … … … … … … (5)

$\rightarrow \text{BV} = \left(\frac{1}{4}\right)(V_{T1} + V_{T2} + V_{T3} + V_{T4}) * 25 * \text{WD}$ ……….. (5)

Where: *BV* = biomass of bole volume; v = bole volume.

Total above-ground biomass per hectare was determined using [equation 6] (Oke *et al*., 2020):

$\text{AGB}_{\text{Total}} = \left(\frac{\text{VOB}}{\text{ha}}\right) * \text{WD} * \text{BEF}$ …………….. (6)

$\rightarrow \text{AGB}_{\text{Total}} = \left(\frac{1}{4}\right)(V_{T1} + V_{T2} + V_{T3} + V_{T4}) * 25 * \text{WD} * \text{BEF}$ … … … … … (6)

Where: $BEF = 24.872 * DBH^2 - 0.765$ for *Hevea brasiliensis* (Hossain *et al*, 2021);

WD = wood density of *H. brasiliensis* in Nigeria [0.52 g/cm^3] (Chukwuemeka, 2016), this is the same as the pan-tropical wood density of *Hevea brasiliensis* [0.52 g/cm^3] (Yang *et al*, 2017) which is the same as the global mean wood density of *H. brasiliensis* [0.53 g/cm^3] (FAO, 2000).

Total Below-ground Biomass (BGB) was calculated using (equation 7) which is *Hevea* species-specific BGB equation of Yang *et al*. (2017)

$\text{BGB}_{\text{Total}} = 0.22 * AGB_{Total}$ ………… (7).

Estimation of Above- and Below-ground Biomass Carbon of Reference Natural Forest:

In the absence of locally developed allometric equations which involves destructive tree sampling, the pan-tropical equation of Chave *et al*. (2014) which is valid for all tropical ecosystems (Djomo, 2016), or the Africa-specific equations of Djomo *et al*. (2016) for moist forest ecosystems (equation 8) was used to estimate AGB of individual trees in the reference natural forest of this study.

Ln(M) = -2.847 + 2.145 Ln(D) + 0.627 Ln(H) … … … … … … (8)

→ M = Exp{-2.847 + 2.145*Ln(D) + 0.627*Ln(H)}

Where: M = above-ground biomass (AGB) of tree; D = DBH (diameter at breast height) trees); H = Ht. (total height of trees), →AGB = Exp{-2.847 + 2.145*Ln(DBH) + 0.627*Ln(Ht)}

Total AGB of one hectare natural forest was calculated as follows (equation 9):

$\text{AGB}_{\text{Total}} = \left(\frac{1}{4}\right)(\text{AGB}_{T1} + \text{AGB}_{T2} + \text{AGB}_{T3} + \text{AGB}_{T4}) * 10$ ………….. (9)

Where: AGB_{T1}, AGB_{T2}, AGB_{T3} and AGB_{T4} are the total AGB of all individual trees across the DBH-classes in sampling plot-1, plot-2, plot-3 and plot-4, respectively;

the expression, $\left(\frac{1}{4}\right)(\text{AGB}_{T1} + \text{AGB}_{T2} + \text{AGB}_{T3} + \text{AGB}_{T4}) * 10$ shows that the average total AGB in the four sampling plots was multiplied by 10 as there are ten (50 x 20 m^2) plots in one hectare.

Total below-ground biomass (BGB) for the natural forest was calculated using [equation 10] (IPCC, 2006)

$$BGB_{Total} = 0.25 * AGB_{Total} \; \dots \dots \; \dots (10)$$

Carbon Stocked and CO_2 Sequestered in Biomass of Rubber Trees per hectare:

These were calculated using equations 11 and 12 respectively (IPCC 2006):

Carbon stock in biomass = $0.5 * (AGB_{total} + BGB_{total}) \; \dots \dots \dots \dots \dots (11)$

Where: AGB_{total} = total above-ground biomass; BGB_{total} = total below-ground biomass.

CO_2 sequestered in biomass = $\left(\frac{44}{12}\right) * 0.5 * (AGB_{total} + BGB_{total}) \; \dots \dots \dots \dots (12)$

Where: 44 = molecular mass of CO_2; while 12 = atomic number of carbon (C).

Statistical Data Analyses: Two-way analysis of variance (ANOVA) was used to examine presence of significant differences in organic carbon contents and related properties of soil across the treatments. Where significant differences were present, mean separation was carried out using the Fisher's Least Significant Difference (LSD).

Results and discussion

Can rubber-tree plantations provide carbon sink for mitigating climate change? This was the central question around which the research study was conceptualized. Thus, the aim of the study was to assess carbon sequestration potential of rubber-tree plantations by evaluating their biomass carbon stocks as well as examining land-use effects of the plantations on soil organic carbon in the study area so as to determining whether rubber-tree plantations as a land-use type can offer significant carbon sink for mitigating climate change.

Biomass and Carbon Stock of Reference Natural Forest

Table 2 shows the results of the biomass carbon stock of the reference natural forest. The total number of trees per hectare estimated was 260. These were trees with DBH up to 10 cm and above. The lowest and highest mean DBH recorded were 12 cm and 89.3 cm respectively, resulting to average DBH of 46.9 cm for the entire sampling plots. Tree heights ranged between 12.4 m and 40.3 m with an average height of 27 m across the entire forest area. Above-ground biomass (AGB) ranged from 3.8 to 72.1 Mg/ha across the DBH classes with an average of 37.8 Mg/ha; while below-ground biomass ranged from 0.95 to 15.78 Mg/ha with an average of 9.45 Mg/ha. Above-ground biomass (AGB) of the reference natural forest amounted to 340.4 Mg/ha which is equal with 341 Mg/ha reported by Brown *et al*. (1989) for a tropical rainforest in Cameroon. Muller (1982) also obtained an AGB of 330 Mg/ha for a tropical broad-leaved forest of eastern USA. The above-ground carbon stock of the reference natural forest in this study amounted to 170.2 Mg/ha; this value is greater than 163.5 Mg/ha for a primary natural forest in Congo reported by Sebastian *et al*. (2015). However, Glenday (2006) reported higher value of 200 Mg/ha for tropical rainforests in Kenya. Total biomass carbon stock (AGB-carbon plus BGB-carbon) amounted to 212.7 Mg/ha compared to the total biomass carbon stock in tropical forests (269.0 Mg/ha) reported by Brown and Lugo (1982) which is probably the highest biomass carbon stock capability among all types of vegetation covers (Keith *et al*., 2009). The differences observed in biomass and carbon stocks of this study compared to the others cited is normally attributed to environmental variations (Rajput *et al*., 2017; Daba and Soromessa, 2018); it could also be attributed to method of estimation employed (Vashum and Jayakumar, 2012; Valbuena *et al*., 2016).

Table 2: Summary of DBH, Heights of trees; and Biomass Carbon Stock of Reference Natural Forest

S/N	DBH Class (cm)	No. of trees	Mean DBH (cm)	Mean Ht. (m)	Mean AGB (kg/ha)	Total AGB (kg/ha)	Total AGB (Mg/ha)	Total BGB (Mg/ha)	$_{AG}$-C (Mg/ha)	Biomass C stock (Mg/ha)
1	10 – 14	65	12.0	12.4	58.5	3,800.5	3.80	0.95	1.9	2.4
2	15 – 19	43	16.6	15.6	134.2	5,771.9	5.8	1.45	2.9	3.6
3	20 – 29	45	25.7	19.1	389.0	17,504.8	17.5	4.38	8.7	10.9
4	30 – 39	32	35.5	28.1	995.9	31,868.8	31.9	7.95	15.9	19.9
5	40 – 49	20	45.6	27.2	1661.9	33,238.0	33.2	8.30	16.6	20.8
6	50 – 59	23	55.4	30.4	2712.9	62396.7	62.4	15.60	31.2	39.0
7	60 – 69	15	66.0	33.8	4218.1	63,271.5	63.3	15.83	31.7	39.6
8	70 – 79	10	76.0	36.0	5939.0	59,389.0	59.4	14.85	29.7	37.12
9	≥ 80	7	89.3	40.3	9016.0	63,112.0	63.1	15.78	31.6	39.5
Mean	–	–	46.9	27.0	–	–	37.8	9.45	18.9	23.6
Total	–	260	–	–	–	340,353.2	340.4	85.09	170.2	212.7

Note: AGB (above-ground biomass); BGB (below-ground biomass);
$_{AG}$-C (above-ground Carbon stock); Mg/ha (mega-gram/hectare = tons/ha) = 1000 kg/ha

Biomass and Carbon Stocks of the Rubber Plantations

Table 3 shows the results of total biomass and carbon stocks estimates per hectare of the rubber-tree plantations aged 4 to 33 years. Total biomass carbon stock increased from 12.7 to 220.3 Mg/ha between the youngest plantation aged 4 years and oldest plantation aged 33 years, respectively. From the age of 25 years, biomass carbon stock (C stock) of the rubber plantation was already equal with that of the reference natural forest. For instance, the biomass C stock in rubber-tree plantation aged 25 years was 214.2 Mg/ha which was equal with the biomass C stock (212.7 Mg/ha) of the reference natural forest in the study area (Table 3). This is in consonance with Sethuraj *et al*. (1996) who noted that biomass C stock of rubber plantation may exceed that of virgin forest or at least equal with it. Aboveground plus belowground biomass carbon stocks (total biomass carbon stock) are the key carbon pools in the study of forest carbon because they provide insight to carbon sink/sequestration potential of the forest ecosystem (Ibrahim *et al.* 2018; Aghimien, 2019). In this study, total biomass carbon stock of the rubber plantation at age 33 years was 220.3 Mg C/ha, while at age 25 years it was 214.2 Mg C/ha (Table 4); this showed that the area under matured rubber plantations falls within the category of high carbon density area (158-408 Mg/ha) as classified by Ravilious *et al.* (2010).

Table 3: Summary of biomass production and carbon stock of rubber-tree plantations

Land-use	Mean DBH (cm)	Mean Ht. (m)	Bole Volume (m^3/ha)	BV (Mg/ha)	BEF	AGB (Mg/ha)	BGB (Mg/ha)	Total Biomass C stock (Mg/ha)	CO_2 Equivalent (Mg/ha)
PL-4	8.0	6.0	9.4	4.9	4.28	20.8	4.6	12.7	46.6
PL-6	10.4	8.0	28.1	14.7	4.10	60.7	13.4	37.1	136.0
PL-14	20.8	14.1	126.6	65.8	2.55	160.9	35.4	98.2	360.1
PL-18	28.5	19.6	201.1	104.5	1.80	200.4	44.1	122.3	448.4
PL-25	32.1	23.2	385.9	200.7	1.75	351.2	77.3	214.2	785.6
PL-33	33.6	23.5	411.0	213.7	1.69	361.2	79.5	220.3	808.0
RNF	-	-	-	-	-	340.4	85.1	212.7	780.0

Note: PL-4 (Plantation aged 4 year); PL-33 (Plantation aged 33 years);
RNF (Reference natural forest); AGB (above-ground biomass); BGB (below-ground biomass);

Effects of Rubber Plantation Land-use on Soil Organic Carbon in the Study Area

Organic matter (OM) content under the reference natural forest (3.75%) was similar with 3.87% and 3.53% under the older rubber plantations aged 25 and 33 years, respectively (Table 4). Although, the youngest rubber plantation aged 4 years had a slightly lower OM content (3.22%) probably due to current cultivation/intercrop of the young rubber tree with arable crops until canopy closure. However, soil organic matter/carbon tended to be regained under the plantations at older ages; this is as a result of the increasing vegetal biomass and litter-fall produced by the plantations as they get older (Onyekwelu *et al*., 2006). This is in consonance with Trouve *et al*. (1994) who found a progressive increase in organic matter under *Eucalyptus spp.* plantations in Congo Democratic Republic, just as Gay *et al*. (2021) noted soil quality gradually improving from the immature stage of rubber plantations to the mature phase. It was also observed by Kimmins (2004) that forest plantations managed on long rotations have the ability of regaining soil organic matter and nutrients to their original levels.

Table 4: Organic carbon content and related properties of soils under rubber plantations and natural forest

Soil Depth	Land-use	OC (%)	OM (%)	BD (g/cm^3)	Sand (%)	Clay (%)	Silt (%)
0-15 cm	PL4	1.87	3.22	1.24	80.85	16.60	2.55
	PL14	2.04	3.51	1.22	80.22	17.04	2.74
	PL25	2.25	3.87	1.19	81.05	15.67	3.28
	PL33	2.05	3.53	1.21	82.30	14.54	3.16
	RNF	2.17	3.75	1.14	75.64	17.15	7.21
	SE of Mean	*0.16*	*0.28*	*0.03*	*3.80*	*3.43*	*4.11*
15-30 cm	PL4	1.22	2.11	1.17	81.22	14.88	3.90
	PL14	1.53	2.64	1.19	84.20	13.66	2.14
	PL25	1.55	2.68	1.25	79.31	19.58	1.11
	PL33	1.75	3.02	1.11	81.01	16.53	2.43
	RNF	1.78	3.07	1.21	79.79	16.34	3.87
	SE of Mean	*0.21*	*0.38*	*0.03*	*7.47*	*3.50*	*5.48*

Note: PL4 (Plantation aged 4); …; PL33 (Plantation aged 33 years); RNF (Reference natural forest); OC (Organic Carbon content); OM (organic matter content), SE (standard error)

Organic carbon content and related properties of top-soils (0-30 cm depths) under rubber plantations were similar with those of the reference natural forest. Analyses of variance (ANOVA) showed that the organic carbon, organic matter, sand, silt and clay contents as well as the bulk density of soils under the rubber-tree plantations were not significantly different from those under the reference natural forest in the study area ($P > 0.05$). Thus, the null hypothesis was accepted (that organic carbon contents of soils under rubber-tree plantations and natural forest are not significantly different in the study area). While this does not represent an avowed claim of confirmation of the null hypothesis, it means that at least there is not enough evidence to reject the null hypothesis. Karthikakuttyamma *et al*. (1997) reported that soils under rubber plantations did not show significant difference in texture from those in adjacent virgin forests. Generally, previous studies reported that land-use practices affected several soil properties such as soil organic matter/organic carbon content; for instance Collins *et al*. (1999) observed a decline in soil organic matter concentration in cultivated soils in comparison with adjacent forest sites. Soil disturbances (tillage, mixing and inversion) constitute the primary process by which organic matter is destabilised, mineralized and emitted into the atmosphere as CO_2. Nevertheless, rubber-tree plantations with generous vegetation cover will likely have their organic matter content protected from carbon mineralization.

Conclusion

This study was conducted to determine whether rubber-tree plantations can provide carbon sinks for mitigating climate change. From the results, it was concluded that organic carbon content of soils under the rubber plantations were similar with those under the reference natural forest; thus, soil organic carbon was not adversely affected by rubber-tree plantations in our study area. Secondly, biomass carbon content in rubber-tree plantations is comparable to the biomass carbon content in some tropical forest ecosystems including the reference natural forest in our study area; this is because the rubber-tree species is very productive with more than 80% of biomass carbon stored in the aboveground portion. Therefore, rubber-tree plantations can provide significant carbon sink for mitigating climate change provided the plantations are well managed on long rotation periods.

Recommendations

Rubber plantations should be managed on long rotation period up to 30 years as it has been noted that forest plantations managed on long rotations have the ability of regaining soil organic carbon to their original levels. As forest tree crop, rubber-tree plantations in Nigeria can become important forest resource providing national carbon sink for climate change mitigation. The rubber tree (*Hevea brasiliensis*) is a versatile species because in addition to its industrial and socio-economic value, it can provide environmental and climate regulatory services for human benefit; rubber-tree plantations are thus recommended for reforestation and afforestation on marginal lands, and for restoration of degraded lands in Nigeria.

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